National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment for Devils Postpile National Monument

Natural Resource Report NPS/DEPO/NRR—2014/889

ON THE COVER
Soda Springs Meadow
Photograph courtesy of Devils Postpile National Monument

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Publisher's Note: Some or all of the work done for this project preceded the revised guidance issued for this project series in 2009/2010. See Prologue (p. xvii) for more information

Executive Summary

This Natural Resource Condition Assessment for Devils Postpile National Monument (DEPO) seeks to summarize the current conditions of a selected set of natural resources within the boundaries of the monument using information available up through 2009 or 2010. DEPO is a relatively small NPS unit located high on the western slope of the Sierra Nevada near the range crest in a subalpine valley with significant volcanic, hydrologic, and geomorphic history. As one of the four units of the Sierra Nevada network (SIEN), it protects a variety of physical and biological resources that have both local and regional value.

A modified subset of Sierra Nevada Network Inventory and Monitoring program Vital Signs was used as the initial structure to determine a set of resources for which an assessment of current conditions would be made. Using DEPO staff input, available spatial and non-spatial datasets, published and unpublished research, and expert opinion, each selected resource indicator is evaluated for its current condition, and potential trends in condition. In addition, primary identified exiting stressors or potential threats that either are or are likely to impact the resource are identified and discussed.

Overall, much is unknown about the status of natural resources within DEPO, making it difficult to assess current conditions. However, in most cases there were enough data and information, even if limited qualitative information and research from outside the unit, to make a determination as to likely condition. Compared to/with other national parks and protected lands close to larger urban areas, the resources of DEPO are in good condition. However, due to many significant extant systemic and local stressors, most resources are impacted to some degree, and information suggests that many resources are in a poorer condition than first meets the eye. In many cases, recent actions have already improved resource condition, though information currently is insufficient to determine the absolute effect of those actions on resource condition.

Physical resources are currently being degraded to a certain extent by pollution, changing climate, and more local scale human impacts. Recent local evidence and regional evidence confirm the presence of pollutants in air and water. While the concentrations of many pollutants are below levels to cause ecological damage, some are not. Visibility degradation (from particulate matter) is a concern in the area due to transport from exogenous sources. Although some scattered water quality testing in the recent past found pollutants or nutrients either absent or at very low levels, many pollutants and pathogens have not yet been targeted. Other regional evidence suggests that at least some pollutants and nutrients may be affecting local air and water quality. Significant data have been used to document a rise in minimum temperatures across the region. This warming has likely driven changes in the amounts and especially timing of surface water flows, and may be starting to impact the amount of snowpack in and around DEPO, thus affecting systems and species that depend on snowmelt. Precipitation amounts in the area have been variable, but appear to be within historic ranges.

Biological resources are being affected by changes in the physical resources in the area that have been documented or are suspected, as well as by systemic and local stressors. Some stressors are

significant and persistent. Several recent surveys have documented the presence of many plant and animal species, but beyond that, little is known about the current status or health of the local or even regional populations of those species. We can infer from research and data collected in other parts of the Sierra Nevada that systemic stressors, particularly climate change, may have driven a few species locally extinct around DEPO, but local information either contradicts those findings or data and information is insufficient to confirm this. An extant, though currently small threat, is the presence of nonnative plants that may become a larger problem in the future under a warming climate. Exceptions to the generally sparse nature of the biological information are bats and birds. Recent bat surveys and assessments have confirmed the presence of many species that are likely being impacted by several stressors and threats. While the absolute abundances of bird species have been estimated through a monument-wide survey protocol, the relatively short time period of data collection makes it difficult to assess the conditions of local populations at this time. Regional evidence suggests many bird species have been in decline, though most species that use DEPO as habitat appear to be doing well at this time.

The forests and woodlands in DEPO are still in state of transition and succession following the 1992 Rainbow fire that affected most of the monument. This fire followed an extensive period of fire exclusion. A changing climate may also have contributed to the nature and severity of that fire and the successional processes that follow. Forests and woodlands that remained unburned are likely still in an altered state. A resumption of the natural fire history in DEPO through management efforts would be beneficial to the forests and woodlands, and the species that use them as habitat.

Recent evidence has documented a significant degradation of the natural soundscapes in the monument, with both local (particularly buses) and exogenous sources (particularly airplanes) responsible. In the meso-scale landscape context, DEPO sits within a matrix of mostly protected federal lands including Wilderness areas and National Forests that offer continuous habitat and a buffer around the monument. Mammoth Mountain Ski Area and the Town of Mammoth Lakes, in relatively close proximity to DEPO, are the exception to this general rule, and the activities and operations in these areas may be impacting resources in the monument.

In general, the condition of the natural resources of DEPO is good, with several significant local and regional stressors and threats that have either begun to impact these resources, or that likely will impact them based on regional evidence. We offer suggested recommendations to fill in data and information gaps that will begin to shed more light on the status and trends of natural resources of DEPO. Many steps have already been recently taken to fill those gaps.

Acknowledgments

We would like to thank the NPS Water Resources Division and the Pacific West Region Natural Resources Division for guidance and assistance on this project, in particular from J. Albright and M. Davis. Thank you to Yosemite National Park Resources Management and Science (RMS) Division for their support of this project. The report would not have been possible without all the help in locating data and reports, and providing relevant information and significant background material from DEPO staff, in particular from D. Dulen, H. Alpert, M. Adrian, and D. Scott. Extensive input was solicited from many NPS staff in the Yosemite RMS Division and Yosemite USGS field station and their time and effort was greatly appreciated. We also thank all the named and anonymous reviewers who kindly reviewed earlier versions of this report: DEPO staff of H. Alpert, D. Scott, M. Adrian, and D. Dulen; NPS staff H. Werner, T. Newberger, S. Veszu, G. Stock, J. Roche, L. Tarnay, M. Denn, C. Johnson, L. Mutch, L. Kirn, D. Graber, W. Van Liew, and C. Sydoriak; USGS staff P. Moore, J. van Wagtendonk, and W. Hildreth; and, other independent reviewers including J. Holmquist, S. Moss, R. Burnett, and colleagues from Point Reyes Bird Observatory and Conservation Science, R. Siegel, A. Bytnerowicz, M. Dettinger, D. Cayan, C. Millar, S. Burak, and R. Perloff. We also are grateful to volunteers A. McGinley and K. Centanni who contributed many hours to helping track down information and literature.

Prologue

Publisher's Note: This was one of several projects used to demonstrate a variety of study approaches and reporting products for a new series of natural resource condition assessments in national park units. Projects such as this one, undertaken during initial development phases for the new series, contributed to revised project standards and guidelines issued in 2009 and 2010 (applicable to projects started in 2009 or later years). Some or all of the work done for this project preceded those revisions. Consequently, aspects of this project's study approach and some report format and/or content details may not be consistent with the revised guidance, and may differ in comparison to what is found in more recently published reports from this series.

Abbreviations

Abbreviation	Full name
DEPO	Devils Postpile National Monument
FWS	Fish and Wildlife Service
GAP	Gap Analysis Program
I&M	Inventory and Monitoring Program
KICA	Kings Canyon National Park
MFSJ	Middle Fork San Joaquin
NPS	National Park Service
SEKI	Sequoia and Kings Canyon National Parks
SEQU	Sequoia National Park
SIEN	Sierra Nevada Network (Inventory and Monitoring Program)
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WACAP	Western Airborne Contaminants Assessments Program
YOSE	Yosemite National Park

Publisher's Note: Some or all of the work done for this project preceded the revised guidance issued for this project series in 2009/2010. See Prologue (p. xvii) for more information

CHAPTER 1. Natural Resource Condition Assessment Background

The Natural Resource Condition Assessment (NRCA) evaluates and reports current conditions for a subset of natural resources and resource indicators in a national park. The assessment reports on the strength and direction of trends, identifies critical data gaps, and presents the general level of confidence for final assessments. The indicators used for evaluation are selected by the authors of the assessment and are based upon on a park's primary natural resources. Selection of indicators is highly dependent upon the status of park-level resource stewardship planning and science in the park (particularly whether or not priority indicators have already been selected for that park) and availability of quality data, reports, published research, and subject matter expertise.

The NRCA presents a relatively new approach to assessing and reporting on park resource conditions. It is meant to complement, but not replace, traditional issue- and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

1. Are multi-disciplinary in scope[1]
2. Employ hierarchical indicator frameworks[2]
3. Identify or develop logical reference conditions/values to compare current data against[3],[4]
4. Emphasize spatial evaluation of conditions and GIS (maps) products[5]
5. Summarize key findings by park areas[6]
6. Follow national NRCA guidelines and standards for study design and reporting products

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[1] However, the breadth of natural resources (and number/type of indicators) evaluated will vary between parks.
[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures of conditions for indicators and condition reporting by broader topics and park areas.
[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of reference conditions.
[4] Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g. ecological thresholds or management "triggers").
[5] As possible and appropriate, NRCAs describe condition gradients or differences across the park for important natural resources and study indicators through a set of GIS layers and map products.
[6] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall conditions, existing/emerging resource issues, and suggest future studies and management activities that could help protect or restore park resources.

Although the primary objective of the NRCA is to report current condition relative to reference conditions, the NRCA also discusses trends for any study indicators with supporting data. Factors known to influence resource condition are the core of discussion. These can include past activities and condition reporting, which provide historical context for understanding current condition. Present-day condition influences (threats and stressors) are interpreted at park, watershed, and/or landscape scales. The NRCA does not report on condition status for land areas beyond the park boundaries, conduct cause/effect analysis of threats and stressors, nor suggest management strategy and treatment options.

Credibility for study findings derives from the data, methods, and reference values used in the project work – are they appropriate for the stated purpose and adequately documented? For each study indicator where current condition or trend is reported, it is important to identify critical data gaps and describe level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject matter experts at critical points during the project timeline is also important to: 1) assist selection of study indicators; 2) recommend study data sets, methods, and reference conditions and values to use; and 3) provide a multi-disciplinary review of draft study findings and products.

The NRCA complements the more rigorous natural resource support programs in the park service, such as the NPS Inventory and Monitoring Program. For example, the NRCA can provide current condition estimates and help establish reference conditions or baseline values for the park's "vital signs" monitoring indicators. It can also bring in new data to help evaluate current conditions for those same vital signs. In some cases, NPS Inventory and Monitoring datasets are incorporated into NRCA analyses.

An in-depth analysis of climate change impacts on natural resources is not a priority objective for the NRCA. However, the condition analyses and datasets should provide useful information for subsequent climate change studies and resource management planning.

The NRCA does not establish management targets. Decisions about management targets must be made through sanctioned park planning and management processes. The NRCA does provide science-based information that will help park managers with ongoing, longer term efforts to describe and quantify desired conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[7] and help parks report to government accountability measures.[8]

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[7] NRCAs are an especially useful lead-in to working on a park Resource Stewardship Strategy (RSS) but study scope can be tailored to also work well as a post-RSS project.

[8] While accountability reporting measures are subject to change, the spatial and reference-based condition data provide d by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

Due to the modest funding, relatively quick timeframe for completion and reliance on existing data and information, the NRCA is not intended to be an exhaustive study. Assessment methods typically involve an informal synthesis of existing data from multiple and diverse sources at a level of rigor and sophistication that reflects the level of present data for each resource or indicator that is evaluated. Statistically repeatable analysis should be conducted where the underlying data and methods support it. A successful NRCA delivers science-based information that is credible and has practical uses for a variety of park policy, planning and partnership activities.

National project standards and guidelines apply to all NRCA projects but particulars of the study can be adjusted to meet individual park needs. This flexibility accommodates the diversity of resources and primary management/interpretive themes among parks, as well as varied knowledge and available data. The specialized indicators, datasets, and analysis methods that are a good fit for one park may not be as relevant for use at another park. Park managers, NPS science support staff and project investigators should coordinate, within the sideboards of the national guidance, to develop assessment details to fit a given park's situation.

Over many years, the NPS plans to fund a NRCA project for each of the 270 parks served by the NPS Inventory and Monitoring Program. Additional NRCA Program information can be found at the website developed by the NPS Water Resources Division at: *http://www.nature.nps.gov/water/NRCondition_Assessment_Program/Index.cfm.*

CHAPTER 2. Resources Setting

2.1 Park and Landscape Setting

Devils Postpile National Monument and the Reds Meadow Valley are located on the western slope of the Sierra Nevada within the upper reaches of the Middle Fork San Joaquin River watershed. The monument is located high in the mountains and close to the Sierra Nevada crest. The monument encompasses 323.6 hectares (800 acres[9]), 673 of these acres (84%) is designated Wilderness (Ansel Adams Wilderness). [Recent corrections to the monument boundary and new evaluations of the Wilderness boundary resulted in different monument size and percent Wilderness than have been reported previously.] The designated Wilderness within the monument includes all land to the west of the Middle Fork of the San Joaquin River and all land to the east of the Middle Fork of the San Joaquin River that are south of the point at which this river flows back into the monument (just south of the intersection with Boundary Creek) (Fig. 2.1). Within the northeastern portion of the monument, all land east of the river is non-Wilderness. The monument is surrounded on all sides by the Inyo National Forest, most of which is designated Wilderness. Non-Wilderness areas lie north and east of the monument, encompassing Reds Meadow Campground and Reds Meadow Resort and Pack Station to the east, and seven campgrounds to the north. The access road from Minaret Vista to Reds Meadow Valley and the monument lies within non-Wilderness. There is one campground within the monument in the northeast corner, consisting of 21 individual camp sites (see Fig 2.1).

[9] When the monument was created, it was designed to be rectangular with an area of 800 acres. However, the only official survey of the monument calculated the area to be approximately 798 acres. While this number is the current official area, a future survey should rectify this error and correct the official area to 800 acres.

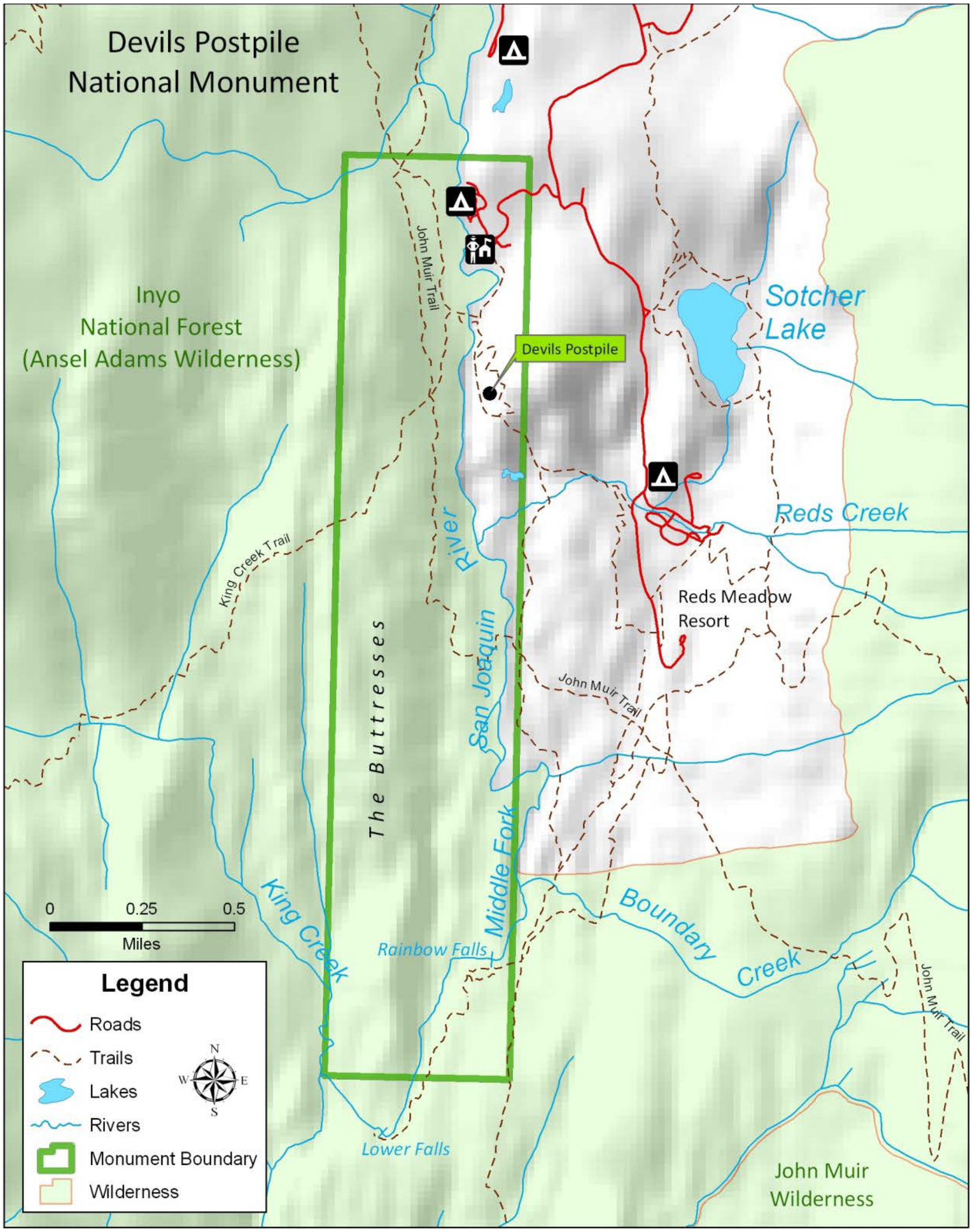

Figure 2.1. Devils Postpile National Monument with associated Wilderness, Reds Meadow area, and campgrounds.

2.1.1 Park Resource Setting – the Sierra Nevada

Devils Postpile National Monument is located in the Sierra Nevada, the highest and most continuous mountain range in California. It is the smallest of four national park units in the Sierra Nevada Network. The border of its closest neighbor, Yosemite National Park, is 11 miles (18 km) to the northwest. Approximately 70 miles (113 km) to the south are Sequoia and Kings Canyon National

Parks (Figure 2.2). These four parks comprise the Sierra Nevada Network parks (SIEN), as designated by the NPS Inventory and Monitoring program.

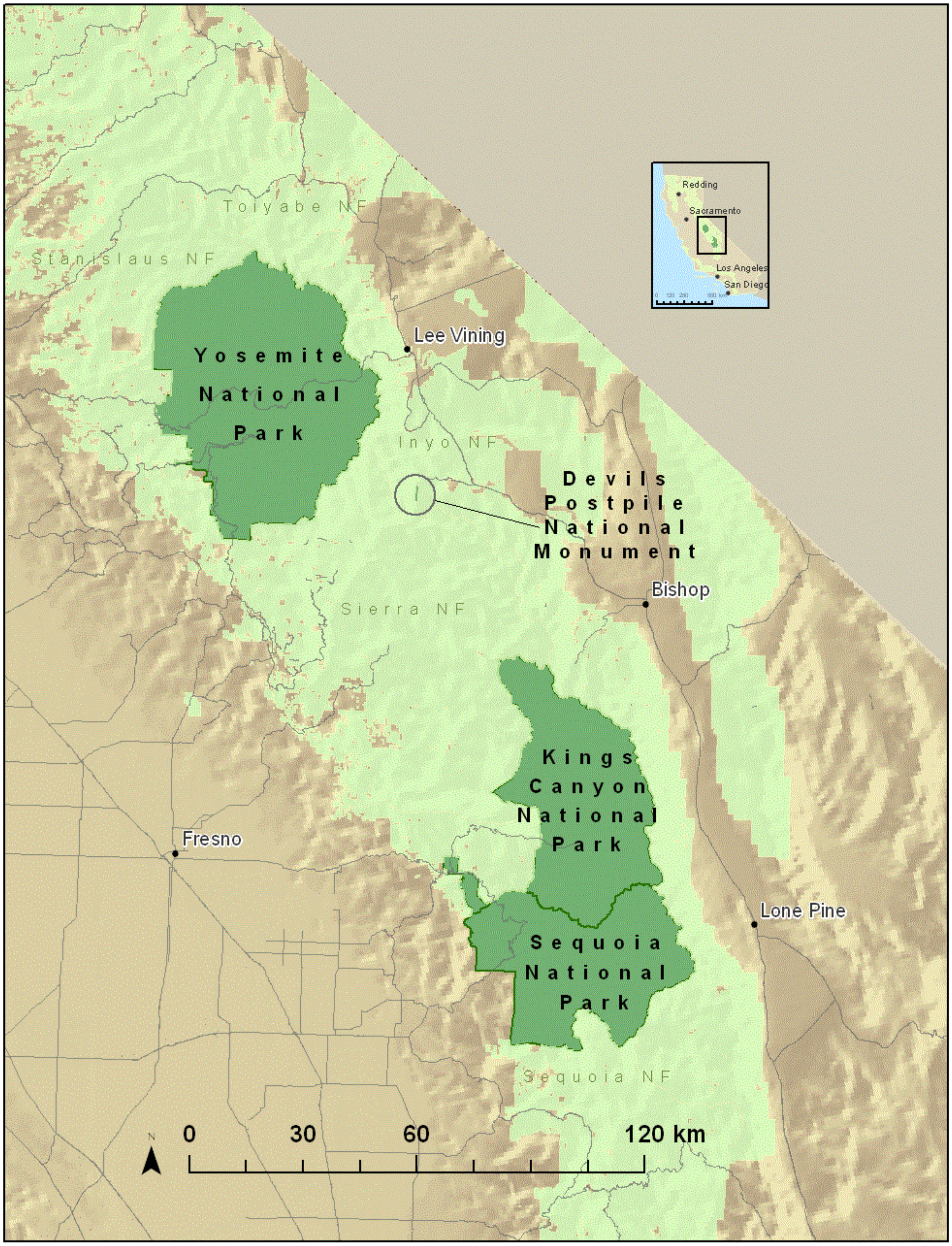

Figure 2.2. Location of DEPO within the Sierra Nevada Network parks.

The Sierra Nevada stretches 692 kilometers (430 miles) north to south, is as wide as 113 km (70 miles) east to west, and cover a total area of over 75,000 square kilometers (29,000 sq. miles). The mountain range is situated along the eastern edge of California and is bounded by the agriculturally important Central Valley on the west and the Great Basin on the east. Elevation ranges from near sea level on the western slope to 4,418 m (14,494 ft) at the top of Mount Whitney, the highest mountain in the contiguous United States.

The Sierra Nevada is an asymmetric tilt-block mountain range that is part of a near-continuous belt of plutonic rocks called the Sierra Nevada batholith. The Sierra Nevada batholith formed during magmatic intrusions 200 to 85 million years ago and extends from the Mojave Desert to northwestern Nevada (Bateman et al., 1963). It is characterized by fairly uniform intrusive granitic bedrock and remnants of older rocks that were in place before the more recent granites (Bateman et al., 1963; Huber, 1987; Bateman, 1992). Tectonic uplift was thought to have begun about 25 million years ago, though new evidence suggests that uplift began as early as 60 – 70 million years ago (Cassel et al., 2009). It was also generally thought that the mountains lifted and tilted westward so that the range became asymmetric, with a gently-sloped elevation gradient on the west and a very steep gradient on the east. However, Cassel et al. (2009) conclude that approximately 30 million years ago, at least the northern Sierra Nevada had a steep western slope gradient with similar elevations to today. Over time, stream gradient and power increased as the mountains lifted, causing waterways to incise and form steep-sided river canyons.

About one million years ago, several glacial episodes began to shape the landscape, beginning with the Sherwin glacial period and ending with the Tioga glaciation. In each glacial period, lower temperatures resulted in large accumulations of snow and ice across the higher elevations, leading to the formation and movement of glaciers. The glaciers and ice sheets eventually created the cirques, U-shaped valleys, and river canyons of the Sierra Nevada. The last glacial period peaked 15,000-20,000 years ago, and was followed by a significant warm period that probably eliminated all glaciers and ice fields in the Sierra Nevada. Post-Pleistocene cool periods (e.g. Little Ice Age) saw the rebirth of some small glaciers and ice fields, some of which remain at high elevations, such as the Lyell and Maclure glaciers in Yosemite National Park (Huber, 1987). The major glacial periods were followed by interglacial warm periods when glaciers and ice sheets largely or completely disappeared.

Due to the relatively recent glaciations, Sierra Nevada soils are generally poorly developed, rocky, and generally low in fertility, the exceptions being deep soils in some basins and canyon bottoms where soils can be quite deep. Soil depth generally decreases with increasing elevation and is thinnest in areas where past heavy glaciations were most persistent. The soils in river basins of the Sierra Nevada have a high proportion of glacial tills left behind in lateral or recessional moraines. Glacial tills are usually composed of granite from high elevations (Mutch et al., 2008a) though in some areas, metamorphic and volcanic rocks can make significant contributions. Unlike most of the Sierra Nevada, the river and stream valleys within DEPO have glacial deposits that contain a greater diversity of rock type; an abundance of volcanic, metamorphic, and granitic bedrock occur within the watershed (Huber & Eckhardt, 2001).

Regions of low to middle elevation in the Sierra Nevada have a Mediterranean climate, with hot, dry summers and cool, wet winters. High elevations are classified as a Boreal climate, where average daily air temperature is less than -3 degrees Celsius (26.6 degrees Fahrenheit) in the coldest month. Strong temperature gradients exist generally along the elevation gradient as well as from south to north along the Sierra Nevada (Mutch et al., 2008a). Depending on air humidity, air temperature can be expected to decrease by 5-10 degrees Celsius for every 1,000 m (2.7 - 5.5 degrees Fahrenheit per 1,000 ft) increase in altitude with a mean near the lower end of this range, though precise gradients depend upon local factors such as topography, wind speed, wind direction, water vapor content, insolation rates, and vegetation type (Stephenson, 1988). At very small local scales, the lapse rate can be negative at night, such that canyon bottoms are cooler at night than slopes above them (e.g. Lundquist & Cayan, 2007). Precipitation on the west slope varies from 50 to 200 cm (20 to 79 in) per year, with amounts generally increasing with elevation. Above 2,100 m (6,900 ft), about half the annual precipitation falls as snow (Stephenson, 1988). Precipitation rates are much lower east of the crest, but still increase with altitude and latitude.

Devils Postpile National Monument is at the northeastern corner of the Upper San Joaquin Watershed (Fig 2.3), which drains 424,535 hectares (1,049,048 acres) of the western Sierra Nevada into the San Joaquin River that flows into the Central Valley. The monument is within the headwaters of the Middle Fork of the San Joaquin River, a sub-basin that drains 20,132 hectares (49,748 acres).

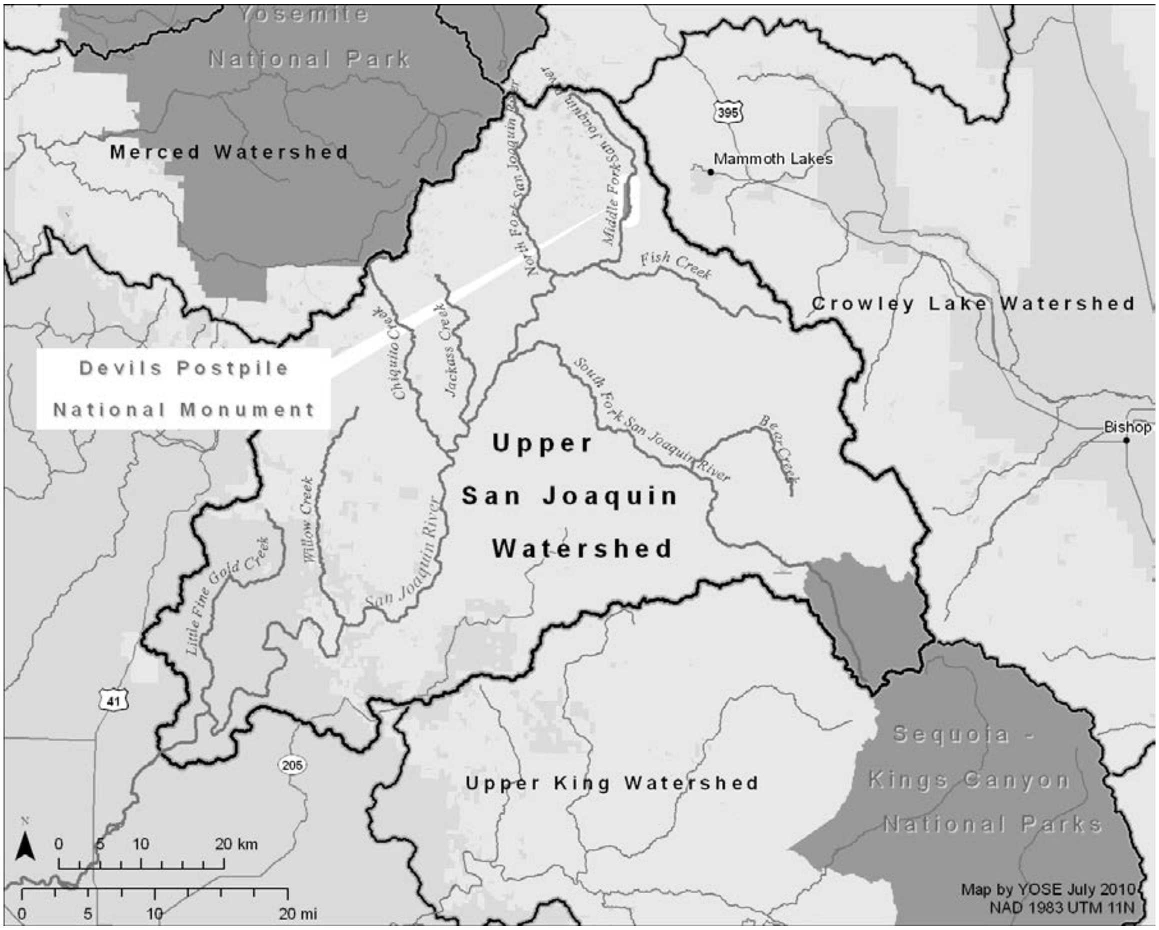

Figure 2.3. Location of DEPO within the Upper San Joaquin watershed

Hydrologic resources are among the most important natural resources in the Sierra Nevada; these include rivers, streams, lakes, seeps, wet meadows, waterfalls, hot springs, mineral springs, and karst springs (Mutch et al., 2008a). These hydrological systems support aquatic communities that account for 21% of vertebrate taxa and 17% of plant taxa in the Sierra Nevada Ecosystem Project boundary (SNEP, 1996c). Due to the strongly seasonal nature of precipitation, temperature, and water availability in the Sierra Nevada, water resources also play a key role in the distribution and health of terrestrial ecosystems of the mountains and of those downstream. Located in the foothills of the mountains, a series of reservoirs are used to collect runoff for agricultural irrigation, household use, hydroelectricity, recreation, and tourism. The California State Water Resource Control Board (WRCB) and nine Regional Water Quality Control Boards protect these resources and are responsible for developing basin plans that outline use designations, water quality objectives, and implementation programs. The many uses of freshwater provide an estimated $1.3 billion (60%) of the annual revenue generated by natural resources in the Sierra Nevada (SNEP, 1996d).

Though the Sierra Nevada Ecosystem Project considered water quality to be excellent throughout the Sierra Nevada (though with local exceptions), extensive water management practices have significantly altered hydrological processes across the landscape while land uses such as logging, development, grazing, and mining have degraded local geomorphic conditions and hydrologic processes (Kattelmann, 1996). In addition, the SNEP report on water resources (SNEP, 1996d) highlighted riparian and aquatic systems as the most altered and impaired habitats in the Sierra Nevada. Hydrologic modifications and impacts as well as degraded water quality are of greatest concern downstream of the Sierra Nevada national parks. The SIEN parks protect some of the least altered aquatic systems in the Sierra Nevada (with some notable exceptions), but are still subject to many of the same impacts affecting aquatic resources throughout the region. These include dams and diversions, altered fire regimes, atmospheric deposition of pollutants, changing climate, introduction of nonnative plant and animal species, and local anthropogenic disturbances.

Plant and animal diversity in the Sierra Nevada is high relative to other parts of the United States due to a wide diversity of habitats, low levels of habitat fragmentation, relatively recent settlement by Euro-Americans, and extensive governmental protection. The region supports more than 3,500 species of vascular plants, which is half of all found in the state of California, and over 400 species of vertebrates, including 65% of California's bird and mammal species and 50% of its amphibian species (Graber, 1996; Mutch et al., 2008a). Over four hundred plant species and 13 vertebrate species are endemic to the Sierra Nevada (SNEP, 1996b). The high species diversity is largely due to the complexity of habitats created from large elevational and climatic gradients. Five distinct vegetation zones are identified along the western slope. From lowest to highest in elevation,they are oak woodland/chaparral, lower montane, upper montane, subalpine, and alpine. Vegetation on the eastern slope is alpine and sparse forest at high elevation, mixed conifer and montane forests and woodlands below this, and then blending into semi-arid desert plateau shrublands of the Great Basin at its base.

The Sierra Nevada has a long history of human occupation. Native American peoples have occupied or passed through the area for at least the last 7,500 years. In the mid-19th century, the Native American population is thought to have been 90,000 to 100,000 people (Anderson & Moratto, 1996). Following a long history of Native American use and activity in the Sierra Nevada, Euro-Americans began a period of rapid settlement from 1848 to 1860 when gold and other minerals were discovered. After this time, their movement into the area was more gradual. In recent decades, there has been a rapid increase in human populations in the Sierra Nevada foothills. By 1990, the population of the Sierra Nevada was 650,000 people, most of which was focused near major highways on the western slope and was projected to reach 1.5 million to 2.4 million by 2040 (SNEP, 1996f).

2.1.2 Park Setting and Important Resources

Devils Postpile National Monument is located within the upper montane and subalpine zones of the western slope of the Sierra Nevada Mountains in eastern Madera County, California. The monument is located near the boundary between east and west slopes of the Sierra Nevada. Its boundary forms a narrow rectangle running north to south. Elevation ranges from 2,200 to 2,500 meters (7,200 to 8,200 feet). The Town of Mammoth Lakes and Mammoth Mountain Ski Area are located less than 10 kilometers (6 miles) to the east (Figure 2.4)

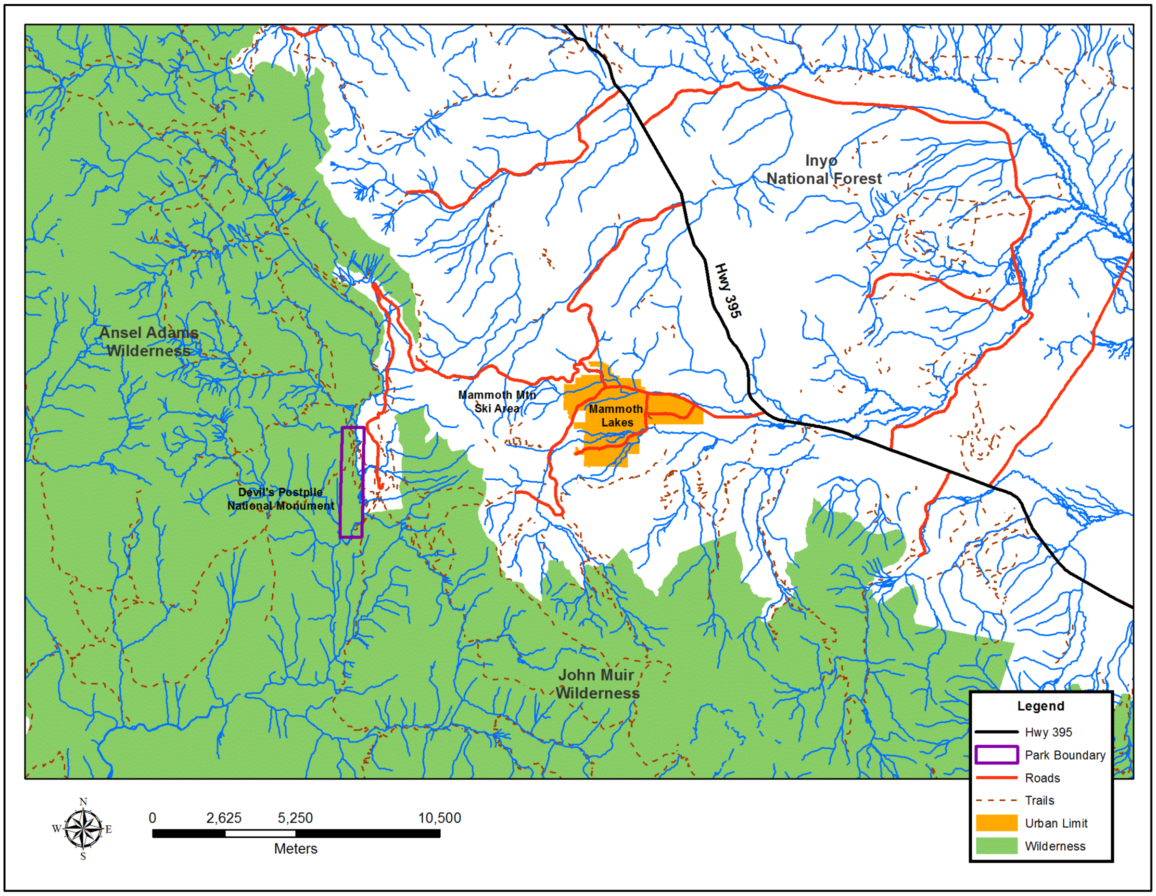

Figure 2.4. Location of Devils Postpile National Monument in relation to Mammoth Mountain Ski Area and the Town of Mammoth Lakes.

The monument is located within the Middle Fork of the San Joaquin River canyon that has a complex geologic makeup including granitic intrusions, and past volcanic activity and periods of glaciation. This canyon provides habitat for a variety of migrating species such as deer and birds. A large number of species occur there or use habitats within the monument. As of 2010, 378 native plant species, 128 bird species, 149 invertebrate taxa, and 33-37 mammal species (including 13 species of bats) use the monument as habitat for at least part of the year. [Note: a range is provided for mammals since there is variability among sources.] Since the monument lies at the bottom of a montane-to-subalpine valley, this results in a temperature regime different from the slopes above it, with nighttime air temperatures that are generally cooler and daytime temperatures that are generally warmer than upland areas in the immediate surrounding area. There is interest in exploring the effects of meso- and micro-scale temperature regimes on species and processes in the valley.

The monument has only one paved road, an access road that begins from XXX Rd outside the monument and extends 386 meters (0.24 miles) within the monument and leads to the headquarters, visitor center, and two small unpaved parking lots. Access to the rest of the monument is provided by eight kilometers (five miles) of unpaved trails and two pedestrian trail bridges crossing the Middle Fork of the San Joaquin River. The monument contains one campground with 21 campsites and an administration area with five small rustic wood-frame cabins, three tent cabins, one maintenance building, an employee facility, a cache for emergency and search and rescue supplies, and three other storage units.

The peak season of visitation for the monument is mid-June through Labor Day weekend. Heavy snows limit access and force closure by automobile access to the monument in winter. Visitor services cease after October 31, or when the road to the monument is closed due to snow and ice after October 15. The road typically re-opens and visitor services resume in late May or early June, though winters with exceptionally high snowfall have pushed opening day into late June. Private vehicle use is regulated during most of the summer season when mandatory shuttle service brings visitors in and out of the monument. During the 2004 to 2007 period, average summer use was 143,868 visitors per year, with a daily average of 2,000 during peak season. The average length of stay for day use is 4-5 hours and for overnight use is 2.5 days. The monument is used as an access point for backcountry hikers heading for the Pacific Crest Trail and the John Muir Trail, as well as for approximately 1,500 equestrians, most of these commercial day trips to Rainbow Falls from the Reds Meadow Pack Station (Mutch et al., 2008a). The number of visitors accessing the monument during the cold winter months is probably less than one hundred per year, though winter use has been increasing in recent years (Mutch et al., 2008a). Legal winter access is by backcountry skiing or snowshoeing, though snowmobiles that are allowed in adjacent Reds Meadow Valley occasionally trespass into the monument.

Fundamental Resources and Values

The NPS recognizes the monument’s purpose to protect and preserve the significant and fundamental resources and values (FRVs) of the monument for scientific value, public interest, and inspiration. The FRVs were developed as part of the monument’s first General Management Plan (GMP) process that included input from the neighboring Inyo National Forest. An interdisciplinary and interagency team of federal employees developed the Foundation Plan within which they articulated these FRVs specific to natural resources as: (1) distinct landscape features; (2) the Upper Middle Fork of the San Joaquin River (corridor); (3) biological diversity that is a component of a larger ecosystem; (4) wilderness character; and, (5) opportunities for science and learning (NPS, 2009).

Distinct Landscape Features

The outstanding character of the monument is its unique landscape of geomorphic features shaped by volcanism and ice. The Postpile, Rainbow Falls, granitic domes, and other geologic features provide excellent evidence of the natural processes of volcanism, glaciations, hydrology, and the mountain building forces of plate tectonics.

The main geologic feature for which the monument is named, the Devils Postpile, is one of the world’s finest examples of columnar jointing. This feature is an exposed outcrop of 8-18 meter (25-59 foot) high basalt columns that were formed by lava that flowed down the river valley approximately 76,000-82,000 years ago (Mahood et al., 2010; W. Hildreth, pers. comm.), became blocked by a natural dam and formed a 122 meter (400 foot) deep lava lake. As the homogeneous lava cooled uniformly from all sides, it fractured along hexagonal joints that created tall, hexagonal columns that were later lifted by tectonics, eroded by weathering, and polished by glacial ice over 20,000 years ago (Huber & Eckhardt, 2001). The work of glaciers created the polished surface and dome shape of the top of the columns. The Devils Postpile is an outstanding formation among the world's other exposed columnar rocks. In one location, the exposed basalt columns create a wall 18 m (59 ft) high of tall vertical posts resembling a pipe organ. This formation may have earned its name "Devils Postpile" from sheepherders in the late 1800s who had named the formation "Devil's Woodpile" as the handiwork of the devil (Solomons, 1894). Natural processes of weathering and earthquakes have caused some columns to slowly break away and crumble, forming a pile of rubble at the base.

Volcanism is still active in the region, with most activity occurring to the east of Devils Postpile in Long Valley (Huber & Eckhardt, 2001). Eruptions in this area over the past 5,000 years have been episodic with long periods of no activity. Evidence of nearby volcanic activity can be seen all over the monument, which is covered almost completely by pumice from post-glacial eruptions in the Mono and Inyo Craters of the Long Valley Caldera Complex. Soils throughout the monument are thin and have high concentrations of volcanic ash and pumice, leaving many areas mostly barren with some litter (Mutch et al., 2008a). Soil formation is slow due to sparse vegetation, insufficient moisture, and steep slopes.

Unlike other waterfalls in the Sierra Nevada that were created through glacial forces, Rainbow Falls is the result of differential weathering of volcanic rock layers. This 31 meter (101 feet) high waterfall falls over an upper layer of more resistant rock overlaying a more erodible layer below. The harder rock layer above is being undercut as the weaker layer beneath it erodes away more rapidly. In the process, the waterfall has migrated upstream approximately 152 meters (500 feet) since it was first created, yet it is believed to have retained its original height.

Other prominent landscape features include a meandering reach of the Middle Fork of the San Joaquin River, an outcropping of older basalt called The Buttresses, and a large granite dome near Soda Springs Meadow locally known as One-tenth dome.

Middle Fork of the San Joaquin River (corridor)

The dominant geomorphic process (and important resource) acting today is the hydrological force of the Middle Fork of the San Joaquin (MFSJ) River and its tributaries (Mutch et al., 2008a). This river flows within the monument from north to south near the eastern boundary. In the northern portion of the monument, it meanders through meadows, then begins to descend more rapidly in the southern portion that includes scattered pools, quickly flowing rapids, cascades, and waterfalls. The San Joaquin River is one of California's seven primary rivers and supplies a critical water source for the state (California Department of Water Resources, 2009). It is part of the Sacramento-San Joaquin River watershed, which is under jurisdiction of California's Central Valley Regional Water Quality Control Board. The headwaters of the MFSJ River are located in the area of the Ritter Range and Thousand Island Lake, located 14 km (8.7 miles) upstream, north and west of Devils Postpile. Three primary creeks drain into the river in and near to the monument: King Creek, Boundary Creek, and Reds Creek. Reds Creek flows from Sotcher Lake and Reds Meadow, entering the MFSJ River in a small waterfall.

The MFSJ River is free-flowing through and upstream from the monument. The fundamental resources of the river system include the mineral springs, wetlands, waterfalls, aquatic communities, riparian areas, and associated habitats and terrestrial communities of the corridor that are all sustained by the naturally functioning river that is supplied by relatively unpolluted surface and ground water. The greater San Joaquin River and its tributaries ecologically link the monument to areas up and downstream. The main river corridor is thought to provide a natural migration corridor for animals and birds.

Biological Diversity that is a Component of a Larger Ecosystem

Principal vegetation of the monument is upper montane and subalpine forests dominated by red fir (*Abies magnifica*) and lodgepole pine (*Pinus contorta* ssp *murrayana*), with small pockets of other conifer and broadleaf trees. Basalt and andesite upland slopes typically support open woodlands of Jeffrey pine (*Pinus jeffreyi*) and white fir (*Abies concolor*) due to high rates of water percolation and a low water table. Riparian zones support populations of black cottonwood (*Populus balsamifera* ssp *trichocarpa*), mountain alder (*Alnus incana* ssp *tenufolia*), willows (*Salix* spp.), and quaking aspen (*Populus tremuloides*).

Biodiversity in the monument is high in spite of its small size. This may in part be due to its location near the boundary of two important and vegetationally distinct biological regions: the Sierra Nevada and the Great Basin. The relatively high proportion of wetlands in the monument (compared to other Sierra Nevada parks) probably also contributes significantly to the diversity. A vascular plant inventory of the monument in 2001 documented 371 native plant taxa (Arnett & Haultain, 2005). A total of 162-179 vertebrate species have been recorded in the monument through several surveys (Siegel, et al., 2004; Pierson & Rainey, 2002; Werner 2004; Richardson & Moss, 2010) and other independent reports. The most frequently observed vertebrates are birds and small diurnal mammals. Few reptiles and only one amphibian species are known to use the monument. The close proximity of relatively low passes (Mammoth Pass and Minaret Vista) at the upper end of this corridor and near the monument may contribute to local biodiversity.

The fact that it is narrow and straddles the MFSJ River, the monument does contain a relatively large proportion of meadows and other wetlands (compared to YOSE and SEKI) that are associated with this river corridor. Wetlands are known to be highly productive systems with substantial biodiversity (USEPA, 2001). Many of the wetland areas in DEPO are also known to be important feeding areas for bird and bat species (see Chapter 4).

Wilderness Character

Monument visitors can experience varied geologic features, montane and subalpine conifer forests and woodlands, riparian zones, meadows and other wetlands, and a diversity of species. The monument lies within a much larger protected area that includes the Ansel Adams and John Muir Wilderness areas that together form the second largest contiguous designated Wilderness in the lower 48 states. This area provides extensive recreational opportunities within a large roadless area.

Opportunities to experience natural soundscapes, dark night skies, and unspoiled natural vistas contribute to the overall character of the monument and surrounding Wilderness. Visitors are provided opportunities for natural area experiences in a setting that emphasizes the enjoyment of natural sights and sounds.

Opportunities for Scientific Discovery and Learning
The Presidential Proclamation that established Devils Postpile a National Monument in 1911 described its value as offering important opportunities for scientific study and shared learning about past, present, and future natural conditions and connected physical processes. Scientific interpretation has been a major theme in the monument's management history.

The monument has a long history of science and interpretation. Early on in the 1930s, the NPS emphasized the monument's significance as a place to interpret the geology of the Sierra Nevada using local geologic resources as examples. Today the monument is encouraging the participation of children, Native Americans, students, scientists, gateway communities, and the general public in interpretation, education, science, and stewardship. The monument has strived to be at the forefront in developing strong interagency and institutional scientific partnerships that have resulted in progress toward creating useful adaptive strategies for responding to threats, and that have provided opportunities for teaching and engaging students, communities, and the public.

2.2 Resource Stewardship Context

Devils Postpile National Monument has a varied administrative and managerial history due partly to the relatively small size of the monument, its isolation from other parks, and the fact that it is surrounded by national forests. For the first 23 years of its existence, the monument was managed onsite by one or two U.S. Forest Rangers. In 1933, the National Park Reorganization Act transferred all National Monuments to the National Park Service.

Beginning in 1934, Yosemite National Park assumed general administrative and management duties for Devils Postpile National Monument. During World War II, an arrangement was made with the U.S. Forest Service such that Yosemite would retain administrative responsibility but Inyo National Forest would take over onsite management duties. However, by 1947, the Park Service considered also transferring administrative oversight to the Forest Service. In 1952, an intensive review recognized the scientific value of the monument and all duties were returned to Yosemite National Park. For the next twenty years, Yosemite's administrators attempted to provide funds and manpower to manage and interpret the resources of this small and relatively inaccessible park unit. Onsite managers made the most of this situation and did their best to protect and interpret natural resources with minimal staffing and budgets (Johnson & Palmer, 2010).

In the earlier years, monument staff developed relationships with the Forest Service and its permit operator at nearby Reds Meadow Pack Station to facilitate and accommodate increased visitation. However, NPS presence at the monument and within the Mammoth region remained weak even as visitation continued to grow. The inability of the NPS to administer to the needs of the monument and to address potential threats became clear during the 1960s and early 1970s when a trans-Sierran highway was proposed that would have skirted the northern monument boundary. In response to this perceived threat, a coalition of recreational enthusiasts in the Mammoth Lakes area and local conservationists led the fight to block the proposed highway. In 1972, this group overcame the powerful pro-development interests in the Central Valley and convinced President Nixon to officially halt the road project by executive order. In the 1980s, their efforts also lead to the designation of the Ansel Adams Wilderness which included much of the monument. The Wilderness designation also served to close the gap in Forest Service land through which the proposed highway would have passed and prevented ski resort development on the southern slope of Mammoth Mountain. While some NPS officials were skeptical of the proposed highway and other regional development proposals, the NPS mostly stayed away from these battles while other interested parties stepped in (Johnson & Palmer, 2010).

On January 1, 1972, administrative responsibilities were transferred from Yosemite to Sequoia and Kings Canyon National Parks (SEKI). After this time, the monument was administered by and received technical support from SEKI. Management and supervision of the monument was the responsibility of the monument supervisory ranger, who reported to the SEKI superintendent (Johnson & Palmer, 2010).

In 1979, monument officials worked with staff from the Inyo National Forest and the Mammoth Mountain Ski Area to fund and operate a mandatory shuttle bus that would transport visitors from the resort to the monument and Reds Meadow and back to alleviate automobile impacts to the area (Johnson & Palmer, 2010).

In 2006, superintendents of DEPO and SEKI requested a management operations review. The review determined that their partnership propagated operational inefficiencies in both park units. The decision was made to transfer management oversight of the monument to the Deputy Regional Director, Administration and Facility Management, Pacific West Region. This decision also recognized the need for sustained involvement in DEPO operations by Yosemite, SEKI, and Mojave Network parks. Agreements were made to establish continuity and sustainability regardless of changes in staff or park management. To date, the following agreements are in place:

1. Yosemite National Park for law enforcement support
2. NPS Mojave Network for maintenance support
3. Yosemite National Park (Anthropology Branch of Resources Management and Science Division) for management assistance and technical support, especially to assist with compliance to Section 106 of the Advisory Council on Historic Preservation and National Historic Preservation Act
4. Sequoia and Kings Canyon National Parks for support with environmental compliance, fire, general administration, and human resources (draft agreements), as well as for support for the curatorial program and administration of the research permitting process.

The monument also receives support from SIEN Inventory and Monitoring staff as well as natural resource staff from Sequoia and Kings Canyon National Parks, and on occasion Yosemite National Park.

Similar to other natural resource programs in the National Park Service, the monument benefited greatly from the establishment of the Natural Resource Challenge and the Inventory and Monitoring Program. The monument has developed productive partnerships with the U.S. Geological Survey, USDA Forest Service Pacific Southwest Research Station, Inyo National Forest, and several academic institutions in order to conduct important monument-specific research in support of a natural resource program.

In 2010, base and project funding contributed to the development of a natural resources program at the monument, consisting of a part-time GS-9 Ecologist, two seasonal GS-7 Biological Science Technicians, and a climate change intern. However, in the next year, budget limitations severely constrained this program. The monument has a proposal in place for additional base funding to support the natural resource program, and approval is anticipated for fiscal years 2012-2014. Acceptance of this proposal would provide funding for additional natural resource staff, including a permanent GS-11 Supervisory Ecologist for program management, a permanent GS-9 Hydrologist (subject to furlough), and additional seasonal technicians. Under this proposal, staff would be shared with Manzanar National Historic Site to provide operational efficiencies. If funded, the proposal would support high priority natural resources work in the monument such as groundwater issues, degraded river habitat, and feasibility studies for the Wild and Scenic River designation.

Currently the Superintendent is one of three Superintendents on the Board of Directors of the SIEN Inventory and Monitoring program and a participant on the national Steering Committee for Climate Change.

2.2.1 Enabling Legislation

From 1890 to 1905, the area that is Devils Postpile National Monument was part of Yosemite National Park. When the boundary of Yosemite was re-drawn in 1905, the area of the park was greatly reduced. Primarily in response to increased pressure from mining companies, the area of the monument was removed from Yosemite and became part of the Sierra Forest Reserve, managed by the newly formed U.S. Forest Service.

Soon after, the U.S. Forest Service received an application for a permit to build a dam on the Middle Fork of the San Joaquin River at the site of Devils Postpile. The intent was to blast the Postpile formation to create a rock fill dam that could be used to support local mining operations. Walter Huber, District Engineer for the U.S. Forest Service, regarded the proposal as “wanton destruction of scenery” and enlisted the support of District Forester F.E. Olmsted and University of California Professor Joseph N. LeConte to evaluate the situation with the hope of denying the permit.

On December 5, 1910, the Sierra Club drafted an influential letter to U.S. President Howard Taft, the Secretary of the Interior, and the Secretary of Agriculture in Washington D.C. Among the list of authors were the prominent figures of John Muir, Joseph N. LeConte, and Secretary of the Sierra

Club William Colby. The letter requested that the Devils Postpile and nearby Rainbow Falls be protected due to their scientific and scenic values. It strongly recommended that President Taft declare this area a National Monument, thereby exercising the power given to U.S. Presidents by the American Antiquities Act of 1906 to preserve unique natural and cultural resources of historic, scientific, or scenic value.

Their efforts, along with the support of the U.S. Forest Service, resulted in Presidential Proclamation No. 1166 signed by President Howard Taft. The enabling legislation of July 6, 1911 established the monument “for scientific interest and public enjoyment” to be administered by the newly established U.S. Forest Service. The proclamation transferred several tracts of land (approximately 324 ha (800 acres)) around the Postpile formation and Rainbow falls from the Sierra National Forest to the newly established national monument. It required that both U.S. Forest Service and National Monument protections remain effective, but that National Monument protections take precedence. All activities that interfere with its preservation and protection were deemed unlawful.

The National Park Service was created by the National Park Service Organic Act on August 25, 1916, to manage lands that had been entrusted to the federal government as national parks. The decision to create the National Park Service was influenced by the construction of O’Shaughnessy Dam in Yosemite National Park, which flooded Hetch Hetchy Valley. The loss of the battle to preserve Hetch Hetchy Valley created impetus for instituting a strong government body to oversee management of the treasured national parks.

In June of 1933, President Franklin Delano Roosevelt signed Executive Order 6166 to transfer responsibilities of administration and management of national monuments to the National Park Service.

Public lands designated as Wilderness are part of the National Wilderness Preservation System, a federal reserve of undeveloped and roadless land kept for the purpose of preserving the natural state, as described in the 1964 Wilderness Act. These lands are managed by the Department or agency having previous jurisdiction. As part of the Wilderness Act of 1964, the 44,313 ha (109,500 acre) Minarets Wilderness was created by enlarging and renaming the Mount Dana-Minarets Primitive Area. Later, this Wilderness area was incorporated into the 93,698 ha (231,533 acre) Ansel Adams Wilderness, which was established in Devils Postpile and the Inyo National Forest on September 28, 1984, when the U.S. Congress passed the California Wilderness Act. The Ansel Adams Wilderness includes just over 84% of the monument (272 of the 324 total hectares (673 of the 800 acres).

2.2.2 Resource Stewardship Planning

Federal law and National Park Service policies require that park managers understand the status and trends of resources under protection in order to administer effective resource management policy. Stewardship roles of the National Park Service have shifted in the years since its establishment in 1916, moving more toward conservation and preservation of the resources under its care. Each park is expected to develop a General Management Plan (GMP) that details park significance, fundamental resources and values, guiding principles of management and policy, and long-term management goals. A GMP provides guidance for managers to meet the demands of resource protection and visitor access that is placed upon national parks. It must be consistent with the general purpose and significance of the park and all enabling legislation.

There are several current plans that apply to resource stewardship of DEPO. The Natural Resources Management Guideline (National Park Service, 1991) outlines general resources management goals and strategies. Several other plans outline knowledge of local resources and strategies for stewardship practices, including the Natural Resources Management Statement for Devils Postpile National Monument (National Park Service, 1982), the Natural Resources Management Plan for Sequoia and Kings Canyon and Devils Postpile (National Park Service, 1974), and the Fire and Fuels Management Plan for Devils Postpile National Monument (National Park Service, 2005).

The Natural Resources Management Statement describes the natural resources of the monument and summarizes management objectives, accomplishments, and general needs (NPS, 1982). The earlier Natural Resources Management Plan for Sequoia and Kings Canyon National Parks and Devils Postpile National Monument describes the information known at the time about vegetation, fire management, wildlife species, fishery management, meadow restoration, and human use of the Wilderness areas (NPS, 1974). The Fire and Fuels Management Plan for Devils Postpile National Monument (NPS, 2005) outlines fire management objectives and the ways that the monument can meet the needs of resource management and firefighter and public safety. These documents provide guidance to managers of the monument and are meant to be used in cooperation with the GMP, which is currently under development (in 2010).

Devils Postpile began the process of developing its first GMP in 2009, which included the articulation of preliminary alternatives and draft affected environment sections. The GMP will serve as the primary planning document for the monument for the next 15-20 years. The GMP planning area also includes the upstream watershed of the MFSJ River in cooperation with the Inyo National Forest. The first phase of the GMP included completing a Foundation Statement in February 2009 (NPS, 2009), which articulated the monument's purpose, significance, fundamental resources and values, and primary interpretive themes.

From the draft Foundation Plan written for the GMP, the monument's purpose reads:

"Devils Postpile National Monument preserves and protects the glacially exposed columns of the Devils Postpile, the scenic Rainbow Falls, and the wilderness landscape of the upper Middle Fork San Joaquin River in the Sierra Nevada for scientific value, public interest, and inspiration." (NPS, 2009)

The GMP planning team is an interdisciplinary and interagency group with subject matter experts from Devils Postpile National Monument, Sequoia and Kings Canyon National Parks, Yosemite National Park, the NPS Pacific West Regional office, the Inyo National Forest, as well as federal scientists from other USFS offices, the USGS, and the NPS. A scientific technical committee (STC) of interagency scientists will review the GMP to ensure the best available science is integrated into the planning process. The STC will provide feedback and advice on scientific issues, including consultation on scientific assumptions, recommendations for specific topics and alternatives, and review for scientific consistency and accuracy.

The GMP team developed the Fundamental Resources and Values (FRVs) relating to natural resources and presented them to stakeholders and the general public during scoping sessions and through publication of a newsletter in the summer of 2009. The FRVs are meant to guide future resource protection and management and planning efforts.

Other plans currently under development for DEPO include a water quality and quantity monitoring plan, and data and records management plans. In the future, DEPO expects to develop a resource stewardship strategy and adaptation plan as well as a climate change adaptation plan.

DEPO will continue to collaborate with the Inyo National Forest on resource management plans and strategies appropriate for the MFSJ River watershed. DEPO will also continue to work with partners to develop an adaptive learning framework, and use new information to adaptively manage a range of resource issues. Monument staff hopes to help identify information needs shared by partners, and methods to efficiently share knowledge and learning that will inform planning documents and decision making. Additionally, DEPO management will seek to collaborate with other NPS units, national forests, and other federal and state agencies in the region. These collaborations can also be extended to partner organizations and gateway communities.

2.2.3 Resource Stewardship Science

The National Parks Omnibus Management Act of 1998 established a structure by which the National Park Service can effectively support internal and external research that will inform stewardship and preservation of physical and biological resources. It also initiated the Inventory and Monitoring (I&M) program for all parks, so that conditions, changes, and long-term trends in park resources can be identified for current and future generations. The I&M program for the Sierra Nevada Network of parks (SIEN) includes Yosemite, Devils Postpile, Sequoia, and Kings Canyon National Parks. Its primary functions are to collect information about the current condition and trends of park ecosystems that can be used to advise and assess the success of resource management practices (Mutch et al., 2008a). In 2010, six monitoring protocols and associated “vital signs” were selected and prioritized for protocol development and implementation by the SIEN I&M program: birds, lakes, high-elevation forests, rivers and streams, wetland ecological integrity, and weather and climate (Table 2.1). In DEPO, all protocols except lakes and high-elevation forest dynamics are scheduled for implementation.

Table 2.1. SIEN I&M monitoring protocols and associated vital signs slated for development and implementation. Those in bold are scheduled to be implemented in DEPO.

Monitoring Protocol	Associated Vital Sign
Weather and Climate	**Weather, climate, snowpack**
Wetlands Ecological Integrity	**Plant communities, macroinvertebrates, water dynamics**
Lakes	Water chemistry, amphibians
Rivers and Streams	**Surface water dynamics, water chemistry (limited)**
Birds	**Birds**
High-elevation Forest Dynamics	Forest dynamics (whitebark and foxtail pines)

Although the I&M program has identified scientific vital signs that will be monitored within the SIEN parks, they do not address all stewardship science needs. Therefore, the monument is looking for ways to address monitoring gaps. In doing so, DEPO will continue to develop its "Science for Parks/Parks for Science" program that uses partnerships with other agencies and institutions to learn from and apply science to meet management needs, such as research on the effects of climate change on local resources. Those involved in the partnerships between management and scientists realize that all research may not address immediate management needs, but it all will contribute to the general goal of providing research opportunities to develop knowledge that will likely inform future management.

By way of facilitating this scientific discovery within DEPO, managers are reaching out to potential researchers and partners by identifying priority research needs, developing funding and grant proposals, and working with partners and researchers to gather and share current information such as past and present trends and drivers of climate change.

2.3 Park Resource Management Issues

Devils Postpile National Monument is home to a variety of natural resources that currently are or will be impacted or threatened by local, regional, and global stressors. The five primary stressors identified for Sierra Nevada ecosystems are (1) rapid anthropogenic climate change, (2) altered fire regimes, (3) nonnative invasive species, (4) air pollution, and (5) habitat loss and fragmentation. All five of these stressors have been recognized in or nearby DEPO and have been the focus of research and/or mitigation efforts.

Specific resource management issues identified for the monument by management and resources staff include: 1) need for improved general knowledge of monument and watershed ecology and biology and how they are being affected by stressors (ecological inventory and monitoring); 2) understanding and preservation of the hydrologic resources and processes; 3) understanding of physical process within and surrounding the monument; 4) understanding of meadow and other wetland habitats and how they are and may be impacted by stressors; 5) understanding local effects of and vulnerabilities to climate change; 6) management of existing and potential future nonnative invaders; 7) protection of natural soundscapes and nightsky; 8) protection of valuable geologic resources; 9) understanding and managing for natural fire regimes; 10) understanding and mitigating air pollution; and, 11) direct and indirect human impacts. Each of these issues is further discussed next.

2.3.1 Ecological Inventory and Monitoring

Although many biological inventories have targeted the monument in the last decade, DEPO management sees a need for a more comprehensive understanding of the biology and ecology of the monument and the larger watershed. This and other information about hydrology and geomorphology are needed to develop conservation strategies that strive to understand the nature and extent of the effects of threats and stressors.

2.3.2 Hydrologic Resources and Processes

DEPO resource managers are concerned about maintaining the naturally functioning hydrologic processes and the clean surface and ground water systems of the monument and beyond. These systems help to support meadow and riparian areas as well as other hydrologic and geologic features such as Rainbow Falls and mineral springs. Management would like to address how changing climate and others stressors may affect stream temperatures, peak and low flow discharges, and stream channel disturbance regimes, and how these physical changes will translate into impacts on native species and their habitats.

The SIEN I&M program is monitoring weather and climate, and surface hydrology in DEPO. Monitoring of the Soda Springs Meadow in the monument may be continued. DEPO management hopes that these efforts will provide sustained data collection and analysis well into the future. This monitoring combined with other targeted research and monitoring will allow managers to assess how the entire Middle Fork of the San Joaquin River watershed is responding to climate change and other stressors.

The monument is unique among Sierra Nevada Network parks in that it does not contain the headwaters of its major waterway. Upstream of the monument, the Middle Fork of the San Joaquin begins and passes through land managed by the Inyo National Forest, where riparian community protection is less strict than that of the monument. For this reason, water quality and the health of aquatic communities in the monument are partially under the control of management practices of the Inyo National Forest. Therefore, knowledge about the integrity of the waterway within and upstream from the monument is vital to developing informed management policy in both agencies.

The monument has begun water quantity and quality monitoring that is directed by a plan to be completed in 2012 or 2013. This plan will include data collection and analysis methods, indicators, and standards for evaluating results. It is unknown whether ground and surface water use by the Town of Mammoth Lakes and by the Mammoth Mountain resort has any impact on the surface or groundwater resources of the monument. No research has been conducted to establish if there is a connection between the neighboring watersheds. However, the continuation of current monitoring of groundwater and surface water flows is an important management goal of the monument in order to assess any vulnerability as well as to develop mitigation strategies that may be needed.

2.3.3 Physical Processes

DEPO management would like to better understand the current nature of natural and disturbance processes in the monument, including hydrologic, fire, and others. In addition, management is concerned about impacts and consequences of regional climate change and the micro- and meso-scale climate regime of the valley where DEPO is located.

2.3.4 Wetland Habitats

Meadows and other wetlands provide habitat for a diverse assemblage of plants and animals that play an important role in the productivity and biodiversity of the monument. The recent wetlands inventory and assessment will be leveraged to develop a management strategy to address several threats to these systems. Wetlands depend upon surface and groundwater systems that provide seasonal inundation in summer and relatively high ground water levels year-round. The integrity of the hydrologic regime that has sustained wetland areas in the monument may be vulnerable to shifting snowfall and snowmelt patterns in the Sierra Nevada. Wetland areas may also be threatened by over-use, specifically by human social trailing and associated soil compaction that reduces infiltration and damages sensitive meadow species. Nonnative invasive plants have been found in some monument meadows, but further inventory and monitoring of this threat is needed. In addition, management would like to further understand the extent and drivers of conifer recruitment into monument meadows. General understanding of local meadow ecology and the role of pollinators is also a management concern. Soda Springs Meadow, the largest meadow in the monument, is identified as an important resource that has undergone at least some degradation due to its location next to the day-use area. Information is needed to address potential changes in size, vegetation structure, and hydrology of the monument's wetlands due to direct human impacts and other stressors.

2.3.5 Climate Change and Local Effects

Understanding the effects of projected climatic changes on the ecosystems of the monument is critical to developing policy that protects at-risk natural resources. Extensive research has been conducted in the Sierra Nevada at large and the Sierra Nevada Network parks, but little has been done to examine the vulnerabilities within the monument. A major challenge of the resource managers at DEPO and partner organizations is to fill this knowledge gap by assessing the condition of specific resources and developing standardized monitoring programs to assess changes driven by changing climate. The monument has identified high-resolution climate monitoring as a research priority. This includes research into micro- and meso-scale weather and climatic patterns and how these may be buffered by or accelerated by changing climate.

The scientific technical team for the monument will be addressing how to answer questions of how climate change will affect species and their habitats, and how migratory corridors may be enhanced or degraded by a changing climate. Research will inform adaptive management strategies to address the effects of climate change and will be transferable to other locations with similar issues and needs. Conservation strategies will include vulnerability assessments and scenario planning. Vulnerability of an ecological system is a function of the natural variation to which a system has been exposed, the magnitude of the current change, the sensitivity to that change, the capacity to respond to the change, and the amount of exposure to that change (Gallopín, 2006; IPCC, 2007a).

In recognition of the importance and impact of a rapidly changing climate on parks and resources under NPS stewardship, the NPS Director established the Climate Change Response Program under the Natural Resource Stewardship and Science Directorate in 2007 (NPS, 2010a). This Directorate is responsible for directing an interdisciplinary approach to dealing with climate change. Many past and existing NPS planning processes assumed that climate and natural disturbance regimes are static, and that ecosystems are expected to respond as they have during past climate fluctuations. These assumptions are no longer valid. The NPS is addressing this need for change, in part through development of a NPS-wide climate change response strategy that identifies goals for science, adaptation, mitigation, and communication (NPS, 2010a).

2.3.6 Nonnative and Invasive Species

Biological surveys over the past decade have identified a small number of nonnative species in the monument: 11 plant, five vertebrate, and one invertebrate species. Efforts to survey and control nonnative plants began in 2002 and have been successful in substantially reducing the total area impacted and numbers of invasive plant species. However, persistent populations and the risk of new introductions, as well as changing climate, may facilitate the future spread of invasive species within the monument.

All officially documented nonnative vertebrate species in DEPO are introduced trout. Although no stocking within DEPO has occurred since 1971, stocking continues in USFS lands upstream from the monument and fish travel downstream into DEPO. Since the monument does not control the headwaters of its primary waterway, it could not manage fish populations without full support from Inyo National Forest. Monument management is also concerned with the prevention of new introductions of potentially damaging invasive aquatic invertebrates, such as the New Zealand mud snail (*Potamopyrgus antipodarum*) which is currently in the Owens River just to the east of Mammoth Lakes, and the quagga mussel (*Dreissena bugensis*) which is in the Lake Mead area and in southern California.

2.3.7 Natural Soundscapes and Nightsky

Although some soundscape baseline data were recently collected, more inventories are necessary to document the current conditions of the natural and human-caused noise environment in the monument. In addition, nightsky baseline data and a formalization of nightsky values are required. Scientific information gaps will need to be identified and filled to address these issues.

2.3.8 Geologic Resources

Although the monument recently established qualitative repeat photography monitoring of the Postpile formation, quantitative monitoring would be needed to identify and monitor visitor use impacts to this and other important geologic resources. A more formal assessment and monitoring plan will aid visitor use management.

2.3.9 Fire Regimes

Over a century of fire suppression (or exclusion) in the monument and surrounding forests has contributed to significant ecological changes, including but not limited to increased tree density in forests and a shift to more shade-tolerant species (Stephenson, 1994). In 1992, 82% of the monument burned in the Rainbow fire; it burned hot in some areas because fuel loads were high in and around the monument. As a result, the tree mortality rate was high in these high severity patches. Because of that fire, today fuel loads are light in most of the monument area and fire risk is now relatively low, but strong regeneration in some areas has increased fuel loads. Some fuels reduction has occurred in the developed area of the monument that did not burn in 1992, and several efforts to reduce fire hazards have been completed with coordination of the Mammoth Lakes Fire Department (NPS, 2005). Due to the small size of the monument, fire regimes within the monument are largely determined by fire management practices outside its boundaries in the Inyo National Forest. For the monument, management of fire and fuels will continue to be a primary natural resource concern.

2.3.10 Air Pollution

Air pollution is a pervasive and chronic problem in most areas of the Sierra Nevada. Down slope from the monument, pollutant levels are very high, are responsible for obscured views, and have damaged sensitive vegetation. Since the concentrations of air pollutants that are transported from the Central Valley of California and beyond to the west generally decrease with distance from source, air quality of the monument is protected by its relative isolation and high elevation. However, recent air quality data collected from DEPO indicate that concentrations of certain pollutants are higher than expected and similar to concentrations found much further west and lower in elevation (Bytnerowicz et al., 2010), and this is probably facilitated by enhanced direct transport up the San Joaquin River canyon. In addition, exposure to ozone at night may be greater in the DEPO area than in the Central Valley due to differences in atmospheric chemistry between the two locations. An important resource management objective is to further investigate the air quality in the monument and implement air quality monitoring to determine the true magnitude of air pollution concerns over long time periods.

2.3.11 Direct & Indirect Human Impacts

Sport fishing is a very popular recreational activity in the monument, and anecdotal evidence suggests this activity negatively impacts riparian vegetation and riverbank integrity. Streambank restoration projects in the monument have mitigated effects in some highly impacted areas. In the summer of 2009, a Visitor Use Assessment (Pettebone et al., 2010) initiated long-term monitoring of visitor use patterns (including social trails) in Soda Springs Meadow and nearby MFSJ River stream banks. The assessment collects data on streambank integrity, vegetation structure and composition, and water quality that will be integral to successful management.

There are management concerns about potential future expansion and increasing demands of operation of Mammoth Mountain resort in nearby Mammoth Lakes that may result in increased air traffic, air pollution, and groundwater extraction. In turn, natural resources at the monument might be affected. Effective monitoring of potentially impacted resources will support any agreements between DEPO and Mammoth Mountain resort and the Town of Mammoth Lakes.

CHAPTER 3. Study Approach

3.1 Preliminary Scoping

3.1.1 Park Input

This NRCA was completed in cooperation between the primary authors at Yosemite National Park and staff at Devils Postpile National Monument. After an initial meeting in Yosemite in the summer of 2009 to discuss concerns and issues, the authors visited the monument in September of 2009 to coordinate with monument staff and collect copies of reports, articles, and data relevant to the assessment. After the initial draft was completed in February of 2010, subsequent discussion and review helped the NRCA to better fit with the development of the monument's General Management Plan. A second draft was presented to monument staff in the summer of 2010 and review comments incorporated. A third draft was sent out for further review in early 2011.

3.1.2 Other NPS Input

Primary project guidance for the NRCA came from Jeff Albright of the NPS Water Resources Division, the project lead and contact person for all NRCA projects. Jeff managed several NRCA pilot projects and developed process guidelines and protocols to assist Yosemite staff with this NRCA. Additional guidance came from Marsha Davis, Geologist for the NPS Pacific West Region.

Sequoia and Kings Canyon National Parks began work on their NRCA in the summer of 2009. A small number of resource assessments funded through the SEKI NRCA process that were also seen as important for all SIEN parks were expanded to include all park units in the network. Some of these assessments were completed in time to be incorporated into this final report.

Much research conducted within the Devils Postpile region was conducted by NPS staff at Sequoia and Kings Canyon or by independent institutions and researchers under the direction of the NPS SIEN Inventory and Monitoring Program. Whenever possible, these researchers and institutions were contacted directly in order to explain the goals of the NRCA and to request data, and project reports or peer-reviewed publications generated from the research.

3.2 Reporting Areas

3.2.1 Ecological Reporting Units

Natural resource conditions were reported by indicator for the park unit as a whole. Due to the small size of Devils Postpile National Monument and its limited infrastructure, no ecological reporting units were deemed necessary. Instead, the monument was considered as one reporting unit. However, if data supported it, resource conditions were reported by named areas within the monument.

3.2.2 Management / Thematic Overlays

When applicable and supported by the available data, natural resource conditions are summarized by the two primary land stewardship designations: Wilderness and non-Wilderness that includes high-use areas in the monument. Resource conditions may differ between these because monument facilities, infrastructure, and visitor use are concentrated in the 14% of the monument that is non-Wilderness. Most of the visitation is limited to the northeastern corner of the monument near to the campground, parking lot, and visitor center, and within the non-Wilderness portion along trails leading to the Postpile, though there is significant visitation to Rainbow Falls in the south in designated Wilderness. Designated Wilderness covers all land to the west of the Middle Fork of the San Joaquin River, totaling 86% of park unit area, and it receives a disproportionately small amount of use.

3.3 Resources and Indicators

3.3.1 Assessment Frameworks Used in the Study

This study utilizes the NPS Ecological Monitoring Framework developed by the NPS Inventory and Monitoring Program (Fancy et al., 2009) to assess condition by primary resource. This framework outlines a 3-tiered hierarchy that divides ecological resources into six categories, each of which is divided into second and third-level categories. This framework was built to be applicable to any national park in the United States. For the case of Devils Postpile in particular, the third level of the general framework was replaced by the vital signs identified by the NPS SIEN Inventory and Monitoring Program and the network parks (Mutch et al., 2008a). The vital signs were selected to be relevant to the SIEN parks and can be adapted to the I&M. All but two vital signs – cave biota and cave/karst processes - were used as potential indicators to assess the condition of natural resources for Devils Postpile National Monument. From the list of potential indicators, the available data and information reduced this list to the final set of indicators chosen. Some indicators were added where relevant data existed and/or were needed to reflect the current knowledge base.

3.3.2 Candidate Study Resources and Indicators

Assessment structure, resource categories, and resource condition indicators were chosen by using the NPS Ecological Monitoring Framework as the assessment foundation. Level 3 in this framework is intended to be used as an indicator set for assessment, but the indicator set provided is not specific to the needs of DEPO. Therefore, vital signs selected by the Inventory and Monitoring Program for the Sierra Nevada Network of parks were substituted for the level 3 category in the framework. The final indicator set presented in Table 3.1 represents a combination of vital signs, NPS Ecological Monitoring Framework indicators, and additional indicators chosen to meet needs of DEPO through input from monument staff.

Table 3.1. Study resources and indicators used in the condition assessment. (* indicates that the indicator is a SIEN Inventory and Monitoring vital sign).

Resource Category	Resource Condition Indicator
Air and Climate	**Air quality**
	Ozone *
	Atmospheric deposition (nutrients)*
	Particulate matter*
	Airborne contaminants*
	Visibility*
	Weather and Climate*
Geology and Soils	**Geologic Features**
	Stream channel morphology*
Water	**Surface water dynamics***
	Ground water dynamics
	Snowpack*
	Water quality*
Biological Integrity	**Major Plant Communities***
	Native Plants
	Nonnative & Invasive Plants*
	Wetlands
	Forests & Woodlands
	Macro-invertebrates*
	Birds*
	Mammals
	Bats*
	Amphibians*
Landscapes (Ecosystem Patterns and Processes)	**Soundscapes***
	Landscape Dynamics*
	Fire Regimes*

3.4 Reference Conditions/Reference Values Used in this Study

The fundamental reference condition used in this study was the natural condition of each resource. A combination of historical data and expert knowledge was used to determine natural condition of indicators or indicator groups as they existed prior to Eurasian settlement in the 18th and 19th centuries. Certainly, it is difficult to establish reference conditions as past ambient conditions were in constant flux as climates changed. We qualify that our reference conditions are those conditions representative of the period after the last glacial episode.

Although Native American populations altered the natural landscape, the extent to which they did so is somewhat beyond historical knowledge. In most cases, their impacts on natural systems have not been found to have disrupted or degraded the condition of the landscape and/or ecosystem processes. However, research has concluded that native tribes used fire extensively as a management tool that at least in some cases altered ecosystems and communities significantly during their occupation of the area. Therefore, unless otherwise stated, the reference conditions used in this study incorporate the influences of native populations into reference or natural condition.

In addition, all relevant legal and regulatory standards were used. Governmental agencies or organizations such as the US EPA and California EPA offer health and environmental quality standards for clean air and water that were used to determine both reference and current conditions. The NPS Air Resources Division provided reference condition standards and threshold values for some criteria air pollutants by which air quality could be qualified for NRCA projects.

The degree to which a certain indicator deviates from its reference condition was determined by compiling all known data for that resource. Where specific threshold values of good to poor condition were not available, judgments were made based upon expert knowledge of the resource within the study area, behavior of the resource, and critical need for attention. Examples of information that would be used to determine condition include number of exotic and/or invasive species in an area combined with their invasive nature; number or percent of state or federal listed species; observed visitor impacts that have changed condition over time; primary habitat area and fragmentation; change in meadow area; and, change in forest health or stand density.

3.5 Study Methodologies

Assessment of resource condition in this study employed a process that started with a wide review of internal reports (management plans, technical reports, project summaries, etc.) and external publications (journal articles, project reports, theses), and miscellaneous sources that included websites, legal documents, and regulatory information. The goal was to make the assessment of each chosen indicator to be comprehensive and – in addition to providing a condition assessment – to expand the collection of resource data available to resource managers at Devils Postpile National Monument.

After relevant literature, data, and expert judgements were compiled, an attempt was made to highlight the best available information and data relating directly to the current condition of each natural resource indicator. In addition, great effort was expended to highlight study results that reflected change in condition, such as trend analyses and ecosystem response. Rate and magnitude of change was impossible to quantify in most cases due to lack of consistent and historical data. In most cases, research included one-time surveys or short term assessments of targeted biological communities or physical resources. Long term data and monitoring in DEPO are exceptions at this point in time. Where data and information are lacking, we used proxy data and information from other sites in the Sierra Nevada (if available) that are directly applicable to resources in DEPO. In addition, this report offers known knowledge gaps and recommendations to fill those gaps.

Definitions of reference conditions and standards were quantified whenever possible, or qualified if not, and a comparison made between them and each observed condition. Unfortunately, these specific quantitative values were not commonly found. In most cases a qualitative judgment was made about the condition of the resource and the justification is included in the resource summary. For most, if not all indicators we examined, local data and literature were limited and as such it would have been easy to classify current conditions as unknown. However, we felt that doing this would not be beneficial. Instead, we used whatever limited information was at hand, however sparse it was, and supplemented this with information from other locations (particularly the Sierra Nevada) that had clear relevance to DEPO resources, and used these to assign a qualitative condition class. The confidence with which that class is applied should be readily apparent by the amount of information available. In many cases, the sparse local knowledge and equivocal regional information would result in a relatively low confidence in condition assignment. As new information becomes available, those condition classes can be adjusted. Current condition of resources was assessed relative to reference conditions and assigned to a qualitative class defined as one of the following:

Poor: relative to stated reference conditions, the indicator is experiencing significant negative alterations from one or more stressors and is well beyond those reference conditions as a result.

Fair: relative to stated reference conditions, the indicator is experiencing moderate to mild negative alterations from one or more stressors and is currently moderately beyond those reference conditions as a result.

Good: relative to stated reference conditions, the indicator is experiencing only minor negative alterations from one or more stressors and is currently in a state only marginally beyond those reference conditions as a result.

Excellent: relative to stated reference conditions, the indicator is not experiencing any significant negative alterations from any stressors and is in a state consistent with the reference conditions.

Unknown: not enough information exists locally or elsewhere to make a determination on indicator condition.

In addition to the general review of available data and published and unpublished research to assess conditions, this NRCA also attempted to critically assess the strength and utility of research and monitoring projects directed at resources. If research or monitoring methods were inadequate to support conclusions made or the stated goals, or if conclusions of the research or monitoring were not supported by the data, then we offer a critical assessment of the inadequacies of the methods or lack of support for the conclusions, and we may also recommend that the scope and methods of the research or monitoring be modified to improve their value to applied resource management.

CHAPTER 4. Natural Resource Conditions

4.1 Regional Landscape Context

Devils Postpile National Monument lies within the California Floristic Province (CFP) that covers most of the state of California to the west of the drier Great Basin and Desert biogeographic regions. This province abuts the drier regions at the mountain range crests that include the Sierra Nevada, Tehachapi Mountains, Cascade Ranges, and the southern California Transverse Ranges. The CFP has been named a global biodiversity hotspot by Conservation International due to its high rates of endemism and the relatively threatened state of remaining habitats. For example, 61% of the plant species are endemic and 54% of the amphibian species are endemic to the CFP. The high rate of floristic endemism is due to the area's varied topography and climate zones as well as varied geology and soils. The Sierra Nevada sub region of the CFP is considered by Conservation International to have exceptionally high plant endemism. The CFP is also the largest avian breeding ground in the United States (Conservation International, 2010).

The monument also lies within the Sierra Nevada ecoregion as defined by the Jepson Manual for Higher Plants of California (Hickman, 1993; Davis & Stoms, 1996). Ecoregions for California were developed for the Jepson Manual and were defined by natural features including broadly defined vegetation types as well as geologic, topographic, and climatic variation. The closest ecoregion boundary to DEPO is just to the east at the Sierra Nevada crest, not far from the monument, where it transitions from the Sierra Nevada region into the East of Sierra Nevada region that is characterized by a different climate and vegetation community.

While California, the CFP, and the Sierra Nevada ecoregion are known for high biodiversity, pressures from a large and rapidly expanding human population have made the state one of the four most ecologically degraded areas in the country (Conservation International, 2010). However, much of the Sierra Nevada still remains unimpacted by high use development and land use conversion. Within this relatively well protected Sierra Nevada ecoregion lies Devils Postpile National Monument, home to a variety of natural resources. However, several global, regional, and local threats and stressors may endanger the condition of natural resources in the monument.

4.2 Threats and Stressors

Stressors are factors for which there is direct evidence that it has affected a specific resource while threats are factors for which local evidence is lacking but which is suspected to have the potential to affect resources. Each of the factors (stressor or threat) identified will be examined in terms of its current known effect or potential effect on targeted natural resources such as rare plant species, wildlife species, or stream flow. For each resource, the threat or stressor will be assessed in terms of its current or potential level. Levels for each threat or stressor are rated as follows:

Existing problem - Strong evidence exists from the past 10-20 years that the stressor has negatively affected the target.

Potential problem - Expert opinion suggests that the threat is probably negatively affecting the target, though little or no evidence is available to document the effect.

Past problem – The stressor was known to exert a negative pressure on the resource in the past; however evidence has recently (past 10-20 years) been found that the problem no longer affects the resource. (If the data do not strongly support a reversal of effects, then this designation should not be used.)

Unlikely problem - Evidence suggests that the resource is not negatively affected by the threat or stressor.

Unknown problem -- No evidence exists to support or dismiss negative effects of the threat or stressor on the target resource.

The spatial extent of each threat or stressor for a particular resource will be defined as follows:

Global: Affects all or much of the globe or region and therefore will have a pervasive effect on resources throughout the monument. These threats and stressors are systemic in nature.

Local: Is localized in extent and therefore only affects a portion of the resource within the monument.

The strength of available information or data is rated for each stressor or threat acting upon each indicator using a qualitative level: Strong, Moderate, Weak, None.

Major systemic stressors that pose a threat to Sierra Nevada Network ecosystems, species, and natural processes have been identified by the SIEN I&M. For an in-depth discussion of these primary stressors and their documented and potential impacts to the Sierra Nevada, see Mutch et al. (2008a). In this research, stressors are defined as physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive level (Barrett et al., 1976) and are capable of causing significant changes to natural systems. The five primary and significant threats[10] to the Sierra Nevada are:

1. Climate change (rapid and anthropogenically driven)
2. Altered fire regimes
3. Nonnative invasive species

[10] These are the top five threats. Many others have been identified.

4. Air pollution

5. Habitat fragmentation and human use

Each stressor does not act in isolation; two or more stressors often interact to create a synergistically greater impact than if acting alone. For example, the effects of rapid climate change on ecosystem function are especially pervasive and impactful due to an exacerbation of other stressors (Figure 4.1).

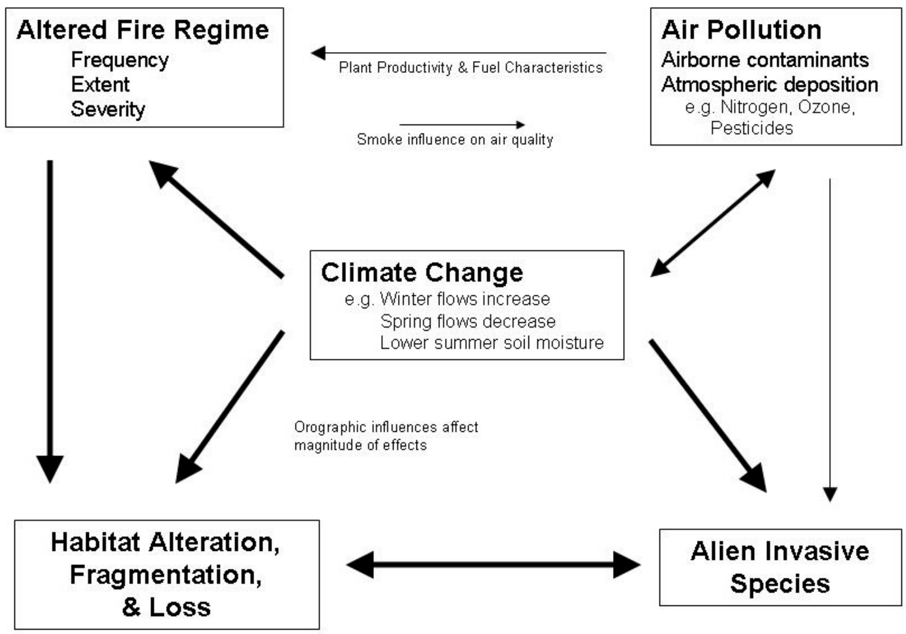

Figure 4.1. Sierra Nevada stressors and associative or synergistic effects [from Mutch et al., 2008a]

Following is a discussion of these five major systemic stressors impacting Sierra Nevada ecosystems and thus also likely to be impacting resources within DEPO. This discussion is meant to lay a foundation of their general understanding in the region. The local links and effects of these stressors to DEPO resources as quantified by research and monitoring in or near the monument are discussed later in the resource briefs section.

4.2.1 Climate Change

Global climate is naturally in flux, and there has been a documented rapid rise in observed global temperatures in the past 50-100 years (Miller, 2003; IPCC, 2007b), though the rate and magnitude may not be unprecedented. Recent documented trends in global temperatures have been linked to anthropogenic greenhouse gas emissions and have gained much attention. Relative to other greenhouse gas changes, CO_2 concentrations have been increasing over at least the last 20,000 years. However, since approximately 1750, the atmospheric concentration of CO_2 has increased by 31% (IPCC 2007a). In the recent past, sources of CO_2 have primarily been anthropogenic, with an estimated 75% of the increase due to fossil fuel burning and the remaining 25% due predominantly to land-use change, especially deforestation (IPCC, 2001a; IPCC, 2001b; IPCC, 2007a; IPCC, 2007b).

However, during times of active volcanism, these events can be significant contributors to atmospheric CO_2.

Spring temperatures in the western United States have already warmed by 1 to 2 °C (1.8 – 3.6 °F) in the last century (Cayan et al., 2001) and the Sierra Nevada has warmed by 0.5 to 1.5 °C (0.9 – 2.7 °F) (Mote et al., 2005). These changes are generally greater than the global average of 0.8 °C (1.4 °F). Recent model simulations of climate change project that by the years 2050 to 2100, average annual temperature in the Sierra Nevada could increase by as much as 3.8 °C (6.8 °F) (Snyder et al., 2002). Snyder et al. (2002) also estimate that warming of this magnitude would roughly translate to an average upward elevation shift of species' climate niches of 800 meters (2,600 feet) in response to that warming. The greatest projected change is an increase in average May temperatures, which could rise by as much as 9 °C (16.2 °F) by the end of this century (Snyder et al., 2002). In addition, temperatures are expected to increase more at higher elevations in the Sierra Nevada (Cayan et al., 2007).

Projections of the impact of regional warming on the western U.S. and the Sierra Nevada are cause for concern. Even a moderate projected warming of 2.5 °C (4.5 °F) would be expected to significantly alter precipitation amounts and patterns, snowpack, and stream flow in the Sierra Nevada. The most significant effects would be an earlier seasonal snowmelt and therefore reduced base flow in late summer (IPCC 2007a), a smaller snowpack volume at middle elevations (Knowles & Cayan, 2001), and a prolonged summer drought. An increase in winter and spring flood events is also likely (Dettinger et al., 2004a, 2004b).

Some of the predicted responses of regional warming have so far been borne out in significant physical changes. Over the past 50 years, mountain snowpack in the western states has been melting earlier in the spring, leaving diminished snow cover and reduced summer and fall hydrologic reserves (Stewart et al., 2004; Mote et al., 2005; Regonda et al., 2005; Stewart et al., 2005). In many western streams, peak flows are arriving nearly three weeks earlier than in the mid-20th century (Cayan et al., 2001; Dettinger, 2005a). In addition, the fall/winter rainy season is trending toward a slightly later start that could result in longer and drier summers (Dettinger, 2005a).

Climate in California over the next 100 years is predicted to become hotter and Sierra Nevada snowpack is predicted to shrink significantly by the year 2100, leaving ecosystems with a greater water deficit during the seasonal summer drought (Cayan et al, 2007). A conservative climate model predicts a 30 –70% reduction in seasonal snowpack while another predicts a 73 – 90% reduction by the end of this century (Hayhoe et al., 2004). In the Sierra Nevada, there has already been a dramatic documented retreat in the size and volume of glaciers over the last century (Basagic, 2008).

High elevation habitats and their associated species could be particularly vulnerable to climate change. Based on assumptions of species responses to increases in temperature, Hayhoe et al. (2004) used climate models to predict that alpine and subalpine forests could experience a reduction in extent of 50% to 90% by the year 2100. As climate warms, entire plant communities will likely not shift in unison, but rather each species will respond differently, resulting in new species associations and communities. This could pose challenges to the wildlife species currently associated with existing plant communities.

A warming climate may already be impacting vegetation in the Sierra Nevada. Tree demography research in coniferous forests of Yosemite and Sequoia National Parks indicates that tree mortality has increased significantly over a 22-year period (1983-2004) (van Mantgem & Stephenson, 2007). The rate of mortality of pines (*Pinus spp.*) and firs (*Abies spp.*) within old growth stands across an elevation gradient doubled over the 22-year monitoring period. Mortality primarily occurred in the smaller tree size classes. Over the period of study, precipitation was unchanged but temperatures gradually increased, raising the overall drought index. Tree mortality rates were best predicted by soil water deficits. An increasing trend in the mortality of young pines and firs may be evidence of climate change effects. Although the immediate cause for the increase in mortality has been attributed to increased water stress, pathogens, and pests (due to a decrease in soil moisture), the ultimate cause is thought to be the changing climate (van Mantgem & Stephenson, 2007). Thorne et al. (2008) found that while some tree and shrub species expanded their ranges in the Sierra Nevada, others contracted their ranges since the early 1930s, with the change thought to be at least partially explained by changing climate.

As vegetation shifts and changes in response to warming and a potential increase in fire frequency and severity, so might the animals that depend on that vegetation. In the Sierra Nevada, recent changes in the response of plants and the behavior of animals have been observed, and could be attributed to changing climate. The timing of seasonal activities like bud-break, flowering, migrations, nesting, and hatching are happening earlier globally (Root et al., 2003) and in the western U.S. (Cayan et al., 2001). Range-shifts in butterflies have been observed northward and upward in elevation along the Pacific coast (Crozier, 2003) and upward in elevation in the Sierra Nevada (Forister et al., 2010). Upward elevational range shifts have also been observed in migratory birds and small mammals in the Sierra Nevada (Moritz et al., 2008; Moritz et al., 2011). Response of species to climate change will likely be complex and variable and may be counter-intuitive in some cases.

If the summer dry season lengthens as a result of regional warming, vegetation would be further stressed and significant changes in vegetation structure and distribution would occur. Drier summers would probably lead to further increases in area burned and fire severity. This increase would likely be driven by a contemporaneous increase in lightning strikes (Price & Rind, 1991), combined with an accumulation of dry fuels. The response of fire to a changing climate is complex and is potentially exacerbated by decades of fire suppression. However, predictions are for an increase in area burned and fire severity in the future under a warmer climate (Liu et al., 2010; Pechony & Shindell, 2010).

From the paleoecological evidence, it is known that fire frequency increases during hotter, drier periods, resulting in a shift to different species assemblages (Anderson, 1990; Anderson, 1994; Anderson & Smith, 1997), and to more fire tolerant species and more open forest canopies (Clark, 1990; Veblen et al., 1999). Wildfire frequency and area burned have already increased dramatically in the U.S. in recent decades, and these changes have been linked to a warmer and drier climate (Westerling et al., 2006). This increase in burned area in the western U.S. has occurred even though more governmental support has been given to fight fires (in cases where infrastructure or human lives are threatened). A decrease in spring snowpack in Yosemite National Park during the period 1984 through 2005 had an inverse and exponential association with an increase in the number of lightning-ignited fires (Lutz et al. 2009b). The authors apply a snowpack forecast model to conclude that given current warming scenarios, the number of lightning-ignited fires will increase 19.1% and the annual area that burns at high severity will increase by 21.9% by the middle of the 21st century.

As discussed earlier, climate change is also likely to lead to changes in other stressors of the Sierra Nevada, potentially resulting in even greater negative impacts. Besides increasing fire frequency, a warmer and drier climate is likely to result in increased production of some atmospheric pollutants, and a potential increase in the distribution and abundance of some nonnative invasive species (IPCC 2007a).

4.2.2 Altered Fire Regimes

Today, lightning-ignited wildland fires are relatively common in the Sierra Nevada where summer drought and occasional summer thunderstorms have created a natural regime of seasonal fires to which plant and vegetation communities have adapted (McKelvey et al., 1996; Skinner & Chang, 1996; SNEP, 1996a). However, the frequency of fires varies substantially by elevation and vegetation type. As regional climate has changed in the past, the frequency of fires has also changed, with drier and hotter periods having a higher overall fire frequency (see citations above). Before the time of Euro-American settlement, Native American populations practiced burning as a tool for shifting and managing the plant communities for their benefit (Reynolds, 1959; Anderson, 2005). This management practice certainly varied in space and time, with burning likely concentrated around population centers and along travel routes. Native American management using fire within the Sierra Nevada ecosystems was pervasive, though likely discontinuous in space and time, until the last half of the 19th century when fire suppression policies were enforced. The extent to which Native Americans used fire is a subject of much debate, with some arguing that their influence across North America has been exaggerated, especially at the landscape level (e.g. Barrett et al., 2005). Fire suppression lasted until approximately 1970 in the Sierra Nevada National Parks, though there is not much direct evidence in the historical record that much suppression occurred around DEPO, at least in the early part of the federal land management period (C. Johnson, pers comm.).

Until the 1960s, most federal resource agencies failed to recognize fire as a critical component of local forest ecosystems and followed a policy of complete fire suppression. This resulted in a profound change to forest, shrubland, and grassland dominated ecosystems in the Sierra Nevada that had adapted to centuries of periodic burning. Policy change was slow to follow, but by the 1980s and 1990s the objectives of fire management teams in the Sierra Nevada were to mitigate the negative effects of fire suppression and to reintroduce or maintain near-natural fire regimes. Since that time, extensive research has been completed to better understand the role of natural fire regimes and to assess the negative effects of extended fire suppression. This research has included a better understanding of pre-suppression fire return intervals for major vegetation communities in the Sierra Nevada (Swetnam et al.,1992; Swetnam, 1993; Skinner & Chang, 1996; Caprio & Graber, 2000; Caprio & Lineback, 2002; Caprio et al., 2002; Van Wagtendonk et al., 2002; Mallek et al., 2013).

Fire suppression has been linked to a multitude of changes to Sierra Nevada ecosystems. Tree densities in forests have become greater and the relative abundance of shade-tolerant species has increased (Parsons & DeBenedetti, 1979). While these changes have been attributed to fire exclusion, variations in climate may also have played a role. Reproduction (regeneration) of Giant Sequoias in the absence of fire had been severely curtailed or even stopped (Stephenson, 1994), while the positive reproductive response of the sequoias to prescribed burning has highlighted their dependence on fire (Kilgore & Biswell, 1971; Harvey et al., 1980). Forests became (and some areas still are) dominated by intermediate-aged stands with few young stands (Bonnicksen & Stone, 1978; Vankat & Major, 1978; Bonnicksen & Stone, 1982; Stephenson, 1987). Fire suppression resulted in a dramatic accumulation of surface fuels (van Wagtendonk, 1985; Agee et al., 1978), and in increasing numbers and densities of small and medium sized trees that has created ladder fuels which can carry fire up into the top canopy (Kilgore & Sando, 1975; Parsons & DeBenedetti, 1979).

Ecological changes that may be related to both fire suppression and changing climate were recently noted in Yosemite National Park. Lutz et al. (2009a) documented a 24% decline in large diameter trees in Yosemite from the 1930s to the 1990s. Declines were greatest in subalpine and upper montane forests. Overall densities of large-diameter trees decreased for 11 species and increased for three species, and the composition of large diameter trees in forests dominated by ponderosa pine (*Pinus ponderosa*) and incense cedar (*Calocedrus decurrens*) varied with fire history. In test plots that had burned at least once since 1936, ponderosa pine dominated the largest size classes while in unburned plots, white fir (*Abies concolor*), incense cedar, and canyon live oak (*Quercus chrysolepis*) dominated the largest size classes. The preferred explanation for the counterintuitive decline in large-diameter trees is that higher overall tree densities from fire suppression and changing climate have increased tree mortality through elevated water stress (Lutz et al., 2009a). Conclusions from other research is that higher than normal tree densities arising from fire suppression or climatic changes increases the susceptibility of large diameter trees to pest and pathogen attack, contributing to higher mortality (Sherman & Warren, 1988; Rizzo & Slaughter, 2001; Millar et al., 2007).

In addition to vegetation changes, research has documented the physical and biogeochemical effects of fire exclusion in fire-adapted systems. These include, among others, a reduction in some nutrients in streams and lakes since runoff after fire increases input of nutrients significantly (Williams & Melack, 1997; Hauer & Spencer, 1998). Annual stream flow volumes were found to increase in the years following a prescribed burn in SEKI, indicating that lack of fire may reduce long-term stream flows (Moore, 2000).

Although the long history of fire exclusion is still apparent across the Sierra Nevada, recent evidence points to a significant increase in area burned and fire size in the last several decades (Miller et al., 2009), perhaps in response to a warming climate.

4.2.3 Nonnative Invasive Species

Plants

As of January 2010, DEPO had documented 11 nonnative plant species while YOSE had 168 and SEKI had 193 (National Park Service, 2010b). Of these, most are not invasive, but the small percentage that are can have significant impacts. While all invasive plant species are exotic (nonnative), not all exotic species are invasive. In California, there are more than 1,000 nonnative resident plant species, of which only about 6% are considered invasive (Hickman 1993). A species is only considered invasive if it has the ability to rapidly expand its range and significantly disrupt native biota and processes (Richardson et al., 2000). A small percentage of nonnative species either are by nature or at some point become “invasive.” Invasive plants are nonnative species that vigorously reproduce and spread over long distances, with the potential to affect a wide area in a short time period (Richardson et al., 2000). Most exotic species found in the Sierra Nevada parks are not invasive, but those that are invasive are currently locally abundant in the region. Examples include velvet grass (*Holcus lanatus*), Himalayan blackberry (*Rubus discolor*), cheatgrass (*Bromus tectorum*), and bull thistle (*Cirsium vulgare*).

Due to their ability to substantially alter native plant systems and outcompete native plants, exotic (especially invasive) plant species have become one of the leading causes of ecosystem degradation throughout the world (Mooney & Drake, 1984; Drake et al., 1989; Vitousek et al., 1996; Mack et al., 2000). Documented impacts of alien species to ecosystems include changes to species composition, physiognomic structure, and diversity, and disruptions to natural process including disturbance regimes (Mack & D'Antonio, 1998) and hydrology, soil erosion, and decomposition (MacDonald et al., 1988). Many exotics currently threaten native species within the Sierra Nevada and threaten to alter natural fire and hydrologic regimes (MacDonald et al., 1988; Gerlach et al., 2003).

California and the Sierra Nevada foothills are home to an abundance of nonnative plants that have been introduced both deliberately and inadvertently. Much of California’s grasslands are dominated by Eurasian grasses introduced accidently during colonization. In an examination of Sierra Nevada foothill grasslands, Parsons and Stohlgren (1989) found that nonnative (and likely invasive) species comprised 99% of total herbaceous biomass. If climate continues to warm, we might expect that these nonnative species will move further upslope and endanger resources of DEPO if they respond more to changes in temperature. However, meso- and micro-scale climate will influence and determine actual plant movements around DEPO and these movements may be as predicted or not.

Nonnative species are often found in areas that experience repeated disturbance such as roadsides and trails (Tyser & Worley, 1992; Forman et al., 2003; Frakes, 2005, Potito & Beatty, 2005), construction areas, and others. In general, there is an established link between the magnitude of disturbance in an area and the frequency of nonnative species (Mooney & Drake, 1984; Alpert et al., 2000; Mack et al., 2000). In protected areas like national parks, nonnative species are most likely found in areas of repeated disturbance including campgrounds, residential areas, pack stations, trails, and picnic areas (MacDonald et al., 1988; Cowie & Werner, 1993). Exotic species are often early colonizers of these recently or repeatedly disturbed zones within protected areas because seeds or propagules of alien plants are transported to these locations via humans, pets, pack stock, vehicles, and construction equipment (Schmida & Ellner, 1983; Hodkinson & Thompson, 1997). Another location that experiences considerable repeated human and natural disturbance and thus is likely to have nonnative species present are river and stream banks and corridors (DeFerrari & Naiman, 1994).

Using fire as a management tool has been somewhat effective at reducing the abundance of targeted nonnative species (DiTomaso et al., 1999; DiTomaso et al., 2001; DiTomaso et al., 2006) because re-establishing a natural fire regime reduces the incidence of high-severity fires and promotes establishment of native trees and shrubs. However, others have found that burning of certain grassland systems may actually enhance or facilitate further invasions by nonnative species (Hobbs & Huenneke, 1992; Maret & Wilson, 2000; Crawford et al., 2001). Reintroduction of fire into forest-dominated systems may promote the establishment of invasive herbaceous species by creating canopy openings and exposed ground in areas of high fire severity (Keeley, 2001). In turn, the presence of some invasive plants can actually lead to an increase in fire frequency (Keeley, 2001).

Animals

According to the NPSpecies database (now part of IRMA), as of January 2010, six nonnative invasive vertebrate species have been documented in SEKI (four fish, one amphibian, and one bird), eight in YOSE (six fish, one amphibian, and one bird), and five in DEPO (four fish and one bird) (National Park Service, 2010b). If non-invasive species are included, the numbers for each park are much higher. Most of the invasive species are of concern to management because they negatively impact native wildlife populations and ecosystems. For example, the widespread introduction of brown, rainbow, and brook trout into naturally fish-free high elevation lakes and streams of Yosemite, Sequoia, and Kings Canyon has been linked to the decline of the native Sierra Nevada mountain yellow-legged frog (*Rana muscosa* and *Rana sierrae*). Removal of the fish from some high-elevation lakes resulted in the expansion of these native frog populations (Knapp et al., 2007). Some have concluded that introduced fish species are a leading factor in the declines of native amphibian species in the Sierra Nevada, including an estimated 95% decline of the Sierra Nevada mountain yellow-legged frog in Yosemite (Bradford, 1989; Bradford et al., 1993; Knapp & Matthews, 2000; Knapp et al., 2001; Rachowicz & Vredenburg, 2004; Knapp, 2005; Rachowicz et al., 2006), a native species that is a candidate for federal listing as endangered.

Other nonnative species have impacted native species in at least some of the SIEN parks. For example, bullfrogs that were introduced from the eastern United States and have locally extirpated red-legged frogs and probably also contributed to the local extirpation of foothill yellow-legged frogs in many locations across the Sierra Nevada (Jennings, 1996). Hlowever, chytrid fungus and other factors may have also played a role in the case of foothill yellow-legged frogs, though no evidence supports this. Though bull frogs are not currently threatening the higher elevation Sierra Nevada, a warmer climate could change that. Another example is the brown-headed cowbird that is a native to North America and has expanded its range westward in recent decades into parts of the Sierra Nevada. It is considered an invasive species due to its rapid range expansion and association with human settlements and disturbance. It is known to parasitize nests of native bird species in the Sierra

Nevada, though its impact was thought not to be significant in the late-1990s (Halterman & Laymon 1999; Halterman & Laymon, 2000).

4.2.4 Air Pollution

While the population of California has increased dramatically in the last 20 years, the emissions of some air pollutants have decreased by as much as 57%. Today, the entire state meets national and state air quality standards for human health for all pollutants with the exception of ozone and particulate matter (Cox et al., 2009). Throughout the state, local emissions and air quality vary greatly, with coastal areas generally better than inland valleys.

Air quality in remote areas of California is among the best in the United States, especially in the northern Sierra Nevada and Cascades (Sullivan et al., 2001) but southern air basins on the western slope of the Sierra Nevada are subject to some of the worst air quality in the United States (Peterson & Arbaugh, 1992; Cahill et al., 1996; Bytnerowicz et al., 2002), particularly during summer months. Prevailing eastward winds carry airborne pollutants from the densely populated San Francisco Bay Area and primarily agricultural San Joaquin Valley (Lin & Jao, 1995) to mountains and deserts to the south and east (Sullivan et al., 2001). Weather conditions in California are relatively stable with dominant high pressure systems and strong inversions in valley areas, creating conditions that are conducive to accumulation of pollutants (Peterson & Arbaugh, 1992). Emissions come mostly from motor vehicles, fossil-fuel power plants, agricultural activities, cleaning and surface coatings, and solvent evaporation (Sullivan et al., 2001).

Primary sources of air pollution in California are the densely populated south coast, San Francisco Bay Area, and San Joaquin Valley. The San Joaquin Valley, directly west of Sierra Nevada Network parks, had the worst ozone air pollution in the United States from 1999 to 2004 (Hunsaker et al., 2007). The San Joaquin Valley is a trap for air pollutants because eastward winds that enter at the San Francisco Bay and central California coast are forced southward by the orographic barrier of the Sierra Nevada, then form an eddy at the southern end of the San Joaquin Valley (Lin & Jao, 1995) where they are trapped by the Tehachapi Mountains and transverse ranges (to the south) and the Coastal Mountain Range (to the west). Airborne pollutants move into the Southern Sierra Nevada air basins when the air mass warms and rises, usually on a diurnal cycle and especially in summer when daily temperatures are high. Transport of pollutants to specific regions of the Sierra Nevada is largely dependent upon local air flow patterns and proximity to source areas (Sullivan et al., 2001) while the types of pollutants transported depend mostly upon the types of activities in urban, industrial, and agricultural source areas.

Poor air quality presents a public health and ecological hazard. Airborne pollutants adversely affect ecological function by altering the chemical and biological composition of vegetation, soil, surface water, and ground water (Hunsaker et al., 2007). Pollutants of greatest concern are oxides of nitrogen and sulfur, surface ozone (and the precursors to ozone), ammonia, and particulate matter. Other damaging pollutants are nitrogen, phosphorous, and organophosphates as contaminants of the commonly used pesticides and herbicides. Ozone and particulate matter threaten public health, visibility, and vegetation. Nitrogen and sulfur deposition threaten the healthy function of aquatic and terrestrial systems but are not believed to be a public health hazard (Sullivan et al., 2001). Loss of visibility due to haze is also a concern, especially in scenic areas where visual range (for western parks) has decreased from 225 km (140 mi) to 56-145 km (35-90 mi) (US EPA http://www.epa.gov/visibility/what.html).

Surface ozone is the primary constituent of smog and is the most damaging of the common air pollutants. It is formed by a chemical reaction between oxides of nitrogen and volatile organic compounds in the presence of sunlight (USEPA www.epa.gov/air/ozonepollution). Precursors to ozone are found in motor vehicle exhaust, industrial emissions, gasoline vapors, chemical solvents, and some natural sources. Surface ozone concentrations in the San Francisco Bay Area declined from the early 1980s to 1997, but remained the same in the San Joaquin Valley over the same time period (Sullivan et al., 2001).

Ambient ozone concentrations in some areas of California are high enough to cause reduced vigor in sensitive conifer species (Peterson & Arbaugh, 1992). Chronic ozone pollution may lead to shifts in forest structure and composition (Kohut, 2007). An assessment of the potential risk of ozone exposure and damage to vegetation determined that all four SIEN parks have a high level of vulnerability (Kohut, 2007), and foliar damage due to ozone exposure has already been documented in Yosemite, Sequoia, and Kings Canyon National Parks (Sullivan et al., 2001) as well as other southern California forests (Takemoto et al., 2001). Studies on the effect of ozone on pine and sequoia seedlings show that high levels of ozone will alter their genetic composition, increase vulnerability to fatal insect attacks, increase death rates, and decrease recruitment rates (Miller, 1973; Miller, 1996; Ferrell, 1996).

Wet and dry deposition of nitrogen and sulfur oxides can negatively impact aquatic and terrestrial ecosystems even at very low concentrations, particularly for sensitive organisms or communities such as lichens and aquatic phytoplankton (Fenn et al., 2003a). Surface waters of the SIEN parks are some of the most acid-sensitive in the world due to low buffering capacity caused by steep slopes, thin soils, deep winter snowpack, and high resistance of the bedrock to weathering (Sullivan et al., 2001). Even moderate amounts of nitrogen and sulfur deposition can lead to chronic or episodic acidification. Although recent evidence found significant deposition of nitrogen and sulfur in SIEN parks, the levels are believed to be too low to cause ecological damage (Landers et al., 2008). Atmospheric sulfur concentrations have been very low in California since the early 1980s, making deposition rates too low to pose a significant ecological problem (Sullivan et al., 2001).

Temporarily high or chronically high levels of nitrogen deposition can result in ecological changes, including but not limited to: shifting species dominance relationships of lichen communities and/or changing overall abundances (Nash & Sigal, 1999); favoring nonnative invasive plants, increasing the relative abundance of exotics (Allen et al., 1998) and thereby decreasing the diversity of native plant communities (Vitousek et al., 1997); increasing the invasibility of grasslands (Huenneke et al., 1990; Maron & Jefferies, 1999); causing eutrophication of lakes with resultant changes in abundance of plankton communities (Baron et al., 2000); enhancing tree growth via fertilization (Kenk & Fischer, 1988; Tamm, 1989); and, damaging plant tissues and reducing plant health, leading to increased mortality rates (van Dijk & Reolofs, 1988; Aber, 1992). Acidification of freshwater through deposition of nitrogen oxides has been hypothesized as a factor in the observed amphibian declines, but no evidence currently exists to support this (Sullivan, 2001), and field research has concluded that it is not a factor in the declines (Bradford et al., 1994).

Particulate matter (PM) is comprised of extremely small particulate and liquid aerosols. PM may include airborne inorganic ions (such as nitrates, ammonia, and sulfates), organic compounds, metals, and soil or dust particles. The US EPA considers particles smaller than 10 micrometers in diameter to be potentially toxic because these are small enough to enter the respiratory systems of humans and animals, potentially resulting in serious health risk. Particulates are separated into two primary categories based upon their size: coarse particles are between 2.5 and 10 micrometers in diameter (PM10) and are often found near roadways and dusty areas, and fine particles smaller than 2.5 micrometers (PM2.5) that are found in smog, fire smoke, and haze. Although atmospheric particulates present risk to public health and ecological function, atmospheric concentrations have been declining in all air basins in California since the early 1980s (Sullivan et al., 2001).

Visibility impairment is caused by particulates in the atmosphere that absorb and scatter sunlight. The result is referred to as “haze,” and occurs naturally from sources like windblown dust and smoke from wildfires. However, most haze is caused by anthropogenic air pollution. Loss of visibility due to haze has been recorded in all NPS monitoring sites in California (Sullivan et al., 2001). Whereas sulfates and nitrates contribute most to haze in most areas of California, organics contribute to the majority of haze in the Sierra Nevada (Sullivan et al., 2001), probably due to extensive agricultural practices and use of fertilizers in the Central Valley.

The pesticides that are responsible for much of the haze in the southern San Joaquin Valley are being transported to high elevations in the Sierra Nevada where they are accumulating in plant tissues (Landers et al., 2008). These pesticides are known to impact wildlife (Sparling et al., 2001a), though the exact nature of impacts to native vegetation is uncertain.

4.2.5 Habitat Fragmentation and Human Use

While Devils Postpile National Monument is small, it is surrounded by Wilderness and U.S. Forest Service land (Inyo National Forest) and is thus protected from extensive forest fragmentation resulting from urbanization near its borders. The Inyo National Forest experienced moderate logging for lumber throughout the 20th century until the mid-1990s when the emphasis changed to restoration through stand thinning and fuels reduction. The timber harvested from these operations supports local demand for fuel wood. Though extensive logging and habitat fragmentation is not occurring in the area around DEPO, in habitats further away in the Sierra Nevada foothills to the west of the monument where most land is privately owned, population growth has been rapid and is forecast to continue at a brisk pace (Hickey et al., 2005). Habitat loss and fragmentation on these private lands will reduce overall habitat in the Sierra Nevada Bioregion, which could have an adverse effect on some resources within the monument such as resident bird species birds that utilize these lower elevations seasonally.

The impact of habitat fragmentation includes loss of habitat, degradation of remaining habitat, and loss of connectivity between habitat patches. Response of a particular species to habitat fragmentation depends upon the species in question, the magnitude and type of loss, and the extent and spatial arrangement of converted areas and extant habitat patches. Ecological theory and modeling have predicted grave consequences of habitat fragmentation for various species, and to some extent empirical evidence supports this prediction, although the evidence can be complex and quite variable.

Results of habitat fragmentation are difficult to interpret because it is usually measured at the patch scale rather than at the landscape scale, and fragmentation is often measured in ways that do not distinguish between habitat loss and habitat fragmentation (Fahrig, 2003). Besides the obvious though complex negative impacts to the vegetation being lost and fragmented (Hobbs & Yates, 2003; Bruna et al., 2009), the wildlife that depend on that vegetation are equally affected. Empirical studies from the wildlife perspective do strongly suggest that habitat loss has large negative effects on biodiversity (Findlay & Houlahan, 1997; Wettstein & Schmid, 1999, Gurd et al., 2001), population abundance and distribution (Hargis et al., 1999; Best et al., 2001; Guthery et al., 2001), and genetic diversity (Gibbs, 2001). Donovan & Flather (2002) found that species in global decline are more likely to occur in areas with high amounts of habitat loss compared to species that are stable or increasing. Habitat loss has been found to also negatively impact breeding success in grouse (Kurki et al., 2000) and dispersal success in damselflies (Pither & Taylor, 1998). However, Fahrig (2003) reviewed the literature and found that fragmentation of habitat has much weaker effects on biodiversity and is just as likely to be positive (McGarigal & McComb, 1995; Belisle et al., 2001) as negative (Rosenberg et al., 1999; Trzcinski et al., 1999).

Many animal groups have been found to be negatively affected by land conversion (habitat loss) and resulting habitat fragmentation, including amphibians (Stuart et al., 2004), birds (Andren, 1994), reptiles (Gibbons et al., 2000), and invertebrates (Didham et al., 1996). In California, the precipitous decline of the California red-legged frog (*Rana draytonii*) has been directly linked to habitat loss and fragmentation, though the exact causation is unknown and other factors are likely at work (Davidson et al., 2001). Other species have seen precipitous declines in numbers, such as the willow flycatcher (*Empidonax trailii*), Yosemite toad, (*Bufo canorus*) and Sierra Nevada yellow-legged frog (*Rana sierrae*). These losses and declines are at least partly due to habitat loss on public and private lands in the Sierra Nevada ecoregion (Graber, 1996). Habitat loss and fragmentation is particularly serious for foothill species where land conversion continues outside of protected lands and also for species that migrate up and down slope.

In addition to habitat loss and fragmentation, intensive use of the landscape and habitats within has also had a host of negative impacts on native ecosystems and individual species through physical and biological effects. Livestock grazing continues to be practiced within national forests of the Sierra Nevada, especially along the western slope, even though it has been shown to greatly impact ecosystems such as meadows and riparian areas, water quality, and species diversity (Allen-Diaz et al., 1999). Although little is known about the historical abundance of some species such as the wolverine, fisher, bats, and some owl species, their apparent declines based on limited presence data have been attributed to changes in forest structure on national forests due primarily to livestock grazing and timber harvest (Graber, 1996). In response to grazing impacts, the Inyo National Forest currently manages grazing allotments in a manner that is designed to maintain or enhance vegetation condition, and grazing permits are modified as necessary to protect rare species or important habitat types. Domestic sheep grazing on non-park public land in the Sierra Nevada is suspected to have played a major role (through transfer of disease) in the local extirpation of some herds of Sierra Nevada bighorn sheep (*Ovis canadensis californianus*) beginning around 1870, and was thought to be the greatest disease threat to the restoration of native sheep (Wehausen, 2003). However, since the late 1990s, the Inyo National Forest has cooperated with state and federal wildlife agencies to identify domestic sheep grazing allotments that pose a high level of risk to Sierra Nevada bighorn sheep. Currently, all sheep allotments in the Inyo that are classified as high risk have been closed or placed in non-use status.

4.3 Natural Resource Indicator Condition Briefs

4.3.1 Air and Climate

Air Quality

Air quality in Devils Postpile National Monument and surrounding forests of the Sierra Nevada is heavily influenced by proximity to the densely populated urban areas and large-scale agriculture of the San Joaquin Valley and San Francisco Bay Area. The San Joaquin Valley, directly west of Sierra Nevada Network parks, had the worst ozone air pollution in the United States from 1999 to 2004 (Hunsaker, 2007). Prevailing eastward winds carry airborne pollutants (Lin & Jao, 1995) to relatively isolated and rural mountains of the Sierra Nevada (Sullivan et al., 2001). As a result, southern air basins on the western slope of the Sierra Nevada (i.e. the San Joaquin Valley Air District) are subject to some of the worst air quality in the United States (Peterson & Arbaugh, 1992; Cahill et al., 1996).

DEPO is located along the northeastern edge of Madera County which is part of the San Joaquin Valley Air District. Madera County exceeded 1-hour and 8-hour state and federal ozone standards many times each year during the period 1979 - 2009 (California Air Resources Board website) based on monitoring data from a station in the city of Madera. The San Joaquin Valley Air District exceeded state and national standards for PM2.5 in all years of record (1999 – 2009) and exceed PM10 national standards in most years and state standards in all years of record (1988 – 2009).

Of the six criteria pollutants identified by the U.S. EPA, those of primary concern in the region around the monument are: (1) elevated levels of ambient ozone (O_3), a pollutant that, due to its high oxidative nature, is very damaging to living cells; and, (2) nitrogen dioxide (NO_2), which contributes to nitrogen deposition and interrupts the natural ecological balance in aquatic and terrestrial systems by enhancing plant and algal growth. Visibility can also be a primary concern, since pollutants that create haze will diminish views and impact the visitor experience in DEPO. Here we focus on several air constituents or parameters of concern for DEPO: visibility (affected by particulate matter), ozone, nutrients (nitrogen and sulfur), pesticides, and mercury.

Visibility (particulate matter)

Though there is no visibility dataavailable from DEPO, data from nearby areas in the Sierra Nevada can be used as proxies to estimate conditions in the monument. The IMPROVE network had an air sampling station at Turtleback dome in YOSE and one at the Ash Mountain headquarters site in Sequoia National Park (SEQU). Both sites collected data from 1994 through 2003. For both the SEQU and YOSE sites, there were no improving or degrading trends in haze over the period of record. For the worst 20% of days, the coefficient for total light extinction from aerosols ranged from 69/mm to 123/mm at SEQU and from 35/mm to 69/mm at YOSE (Causes of Haze website: http://www.coha.dri.edu/). These values indicate that haze is worse in these parks than most other western national parks. These two sites give an indication of the amount of haze that may be present at DEPO. Haze is measured as the extinction or attenuation of light through the air due to scattering and absorption by particulates and aerosols.

More recently, an air quality condition assessment by the NPS Air Resources Division (ARD) estimated visibility in each national park in the continental United States using data from all available air quality monitoring sites (NPS, 2009). Estimates were derived from spatial interpolations made between monitoring stations during the years 2003 - 2007. Interpolated values were used to establish acceptable thresholds for each pollutant measured and assign an air quality condition to each park. Interpolated estimates of visibility, ozone, and nitrogen and sulfur wet deposition for DEPO are shown in Table 4.1. The adjusted conditions reflect the estimated parameter relative to established standards that were based on all national parks. Visibility is measured in deciviews (dv), a haze index based on the magnitude of light extinction over distance (as the haze index increases, visibility decreases). A statistical measure of visibility, called Group 50, represents the 40^{th} to 60^{th} percentile of observations. To assess condition for each park, Group 50 values for natural conditions ("Grpnat 50" in table 4.1) were estimated and compared to observed Group 50 visibility ("Grp 50" in table 4.1), and the mean annual difference value was used. For DEPO, the ARD estimated that the haze measure was over 5 points higher than that expected in natural conditions and thus concluded that loss of visibility due to haze was a significant concern.

Table 4.1. Air quality estimates made by National Park Service Air Resources Division for DEPO for the years 2003 to 2007.

	Ozone (ppb) Mean annual 4th highest 8-hr	**Wet Deposition (kg/ha/yr)**		**Visibility (dv) Mean annual (Grp 50 – Grpnat 50)**
		Nitrate	**Sulfate**	
Value Estimated by NPS ARD	82.43	2.49	0.72	5.16
Condition (adjusted)	Significant Concern	Significant Concern	Moderate Concern	Significant Concern

Ozone

Maximum concentrations of ground-level ozone tend to decrease with increased elevation in the Sierra Nevada (Sullivan et al., 2001; Bytnerowicz et al., 2004; Hunsaker et al., 2007) because high elevations are generally farther from source areas (a dilution effect) (Hunsaker et al., 2007). However, its residence time increases with altitude such that average 24-hour exposure to ozone typically increases with elevation. At higher altitudes farther from urban areas concentrations remain elevated at night due to a lack of nitric oxide (NO) which acts to scrub (titrate) ozone out of the air. In urban areas, the titration of ozone by NO during the cool hours of the night is common, but not in remote air sheds due to very limited supply of NO (Bytnerowicz et al., 1987; Lioy et al., 1987; Bytnerowicz et al., 2000). A long residence time of ozone allows it to remain active longer than it would at low elevations, providing greater opportunity to damage humans, wildlife, and vegetation (Vogler, 1982; Bytnerowicz et al., 1987; Lioy et al., 1987; Bytnerowicz et al., 2002).

A recent empirical assessment of some air constituents within the monument was conducted during the summers of 2007 and 2008 (Bytnerowicz et al., 2010). Measurements were taken from the meadow adjacent to the Visitor Center and the Middle Fork of the San Joaquin River. A passive sampler measured concentrations of nitrogenous compounds (NO, NO_2, NH_3, and HNO_3) and ozone as 2-week averages, and an active ultraviolet absorption monitor measured hourly concentrations of ozone. This monitoring measuredlevels of these pollutants that were higher than expected, especially ammonia (NH_3) and ozone.

Ozone concentrations observed in the monument in 2007 and 2008 were at levels that are considered unhealthy for visitors and staff, and may be harmful to local flora (especially Jeffrey pine) (Bytnerowicz et al., 2010). Eight-hour mean ozone concentrations exceeded California air quality standards on five consecutive monitoring days in 2007 and four in 2008. Federal standards were exceeded once in 2007 and twice in 2008 (Table 4.2). The seasonal peak for 8-hour concentrations occurred in mid-to-late June both years, while hourly concentrations peaked in July and August with hourly peaks above 80 ppb. Hourly ozone concentrations showed a more pronounced diurnal cycle than expected, showing highest concentrations in the afternoon (1700 to 1800 hours) and lowest just before dawn (0500 hours) during both years (Bytnerowicz et al., 2010).

Table 4.2. Results of air quality monitoring for ozone at DEPO in 2007 and 2008.

	Hourly [O_3]		**8-hour [O_3]**	
Year	**Maximum Observed (ppb)**	**Days >80 ppb**	**Days >75 ppb (US EPA standard)**	**Days >70 ppb (Cal EPA standard)**
2007	86	5	1	5
2008	100	7	2	4

Earlier, Bytnerowicz et al. (2004) measured atmospheric ozone and nitric acid concentrations in air and examined pine needles for signs of ozone damage along a transect running through the San Joaquin River drainage from the foothills up to just upstream of the monument during the summer and fall of 2002. They found that average ozone concentrations over a two week period did not decrease significantly with distance from the San Joaquin Valley, suggesting efficient long-distance transport from this source area. While ozone generally ranged between 50 and 100 ppb (with spikes up to 130 – 180 ppb) at each station along the transect, foliar damage to Ponderosa and Jeffrey pines generally decreased with elevation. For reference, typical background ozone concentrations are 50 to 60 ppb in the northern hemisphere and mid-latitudes (Hunsaker et al., 2007).

A recent air quality condition assessment by the NPS Air Resources Division estimated concentrations of ozone in the air of DEPO during the years 2003 - 2007 (NPS ARD, 2009).

Estimates for the monument were derived from spatial interpolations made between monitoring stations across the region. The estimated levels of ozone for mean fourth highest 8-hour concentrations were high – 82.4 ppb – and similar to those documented by Bytnerowicz et al (2010) (Table 4.1).

Levels of ozone in the Sierra Nevada were modeled for the summer of 1999 using data from 89 monitoring stations across the region (Fraczek et al., 2003). Results of this study show that 2-week long average ozone concentrations were highest in the foothills of the southwestern Sierra Nevada and lowest at high altitudes in the northern Sierra. Localized areas of very high ozone concentration on the east side of the Sierra could indicate long-range transport from the San Joaquin Valley or Los Angeles Basin. One local anomaly, seen intermittently throughout the year, was high localized ozone concentrations that stretched from the lower San Joaquin River Valley to Mammoth Lakes. It was especially high in June, July, and September. DEPO lies within this high concentration corridor. It is possible that the high modeled ozone was due to a pattern of air flow from the San Joaquin Valley through the San Joaquin River Valley and over Mammoth Pass, which is at 2,800 meters (~9,200 ft), 200 meters (~650 ft) lower than what is generally assumed to be the upper limit of ozone transport. Both Mammoth Pass and nearby Minaret Vista are low points along the Sierra Nevada crest where air flow from west to east is enhanced (Figure 4.2).

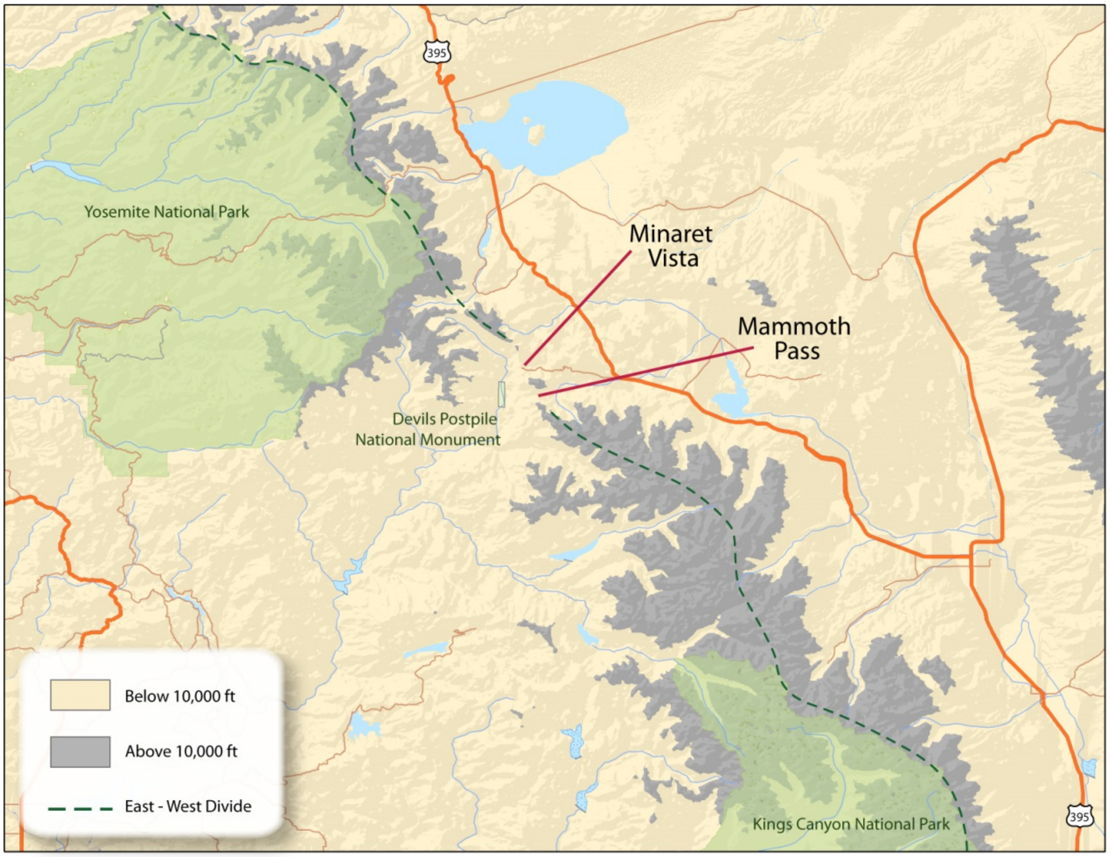

Figure 4.2. Both Minaret Vista and Mammoth Pass to the east of Devils Postpile form a low point in the southern Sierra Nevada where west to east air flow is enhanced.

We can conclude from the empirical monitoring and the modeled data that concentrations of ozone at DEPO are relatively high, at least seasonally, and high enough to damage sensitive plants such as Jeffrey pine, and thus potentially harmful to humans and wildlife. The empirical evidence supports the modeled data for ozone. Both sources indicate that ozone levels are a significant concern.

Nutrients (Nitrogen, Sulfur)
Nitrogen and Sulfur, the two macronutrients in question, can primarily impact species and ecosystems in two ways. In some forms, these nutrients act to fertilize systems when supplied in excess while in other forms they can acidify systems. Nitrogen in fertilizers (such as ammonium nitrate, NH_4NO_3) applied to enhance plant growth, is potentially a major concern for some national parks, wilderness, and other protected natural areas. Fertilizers and pesticides applied to farmland throughout the San Joaquin Valley volatilize and are transported to the Sierra Nevada (Zabik & Seiber, 1993) where they settle into sensitive aquatic and terrestrial ecological systems. During and immediately after rain events in the warmer months, transported and deposited pollutants cause lakes and streams of the Sierra Nevada to experience temporary acidification (Stohlgren & Parsons, 1987). High-elevation aquatic ecosystems in the Sierra Nevada are particularly sensitive to atmospheric deposition because the waters are oligotrophic, with a low buffering capacity such that small nutrient additions have large effects (Peterson et al., 1992).

The Western Airborne Contaminant Assessment Project (WACAP) examined the potential ecological consequences of the observed levels of nitrogen and sulfur in lichen and conifer needles within many national parks (Landers et al., 2008). Although DEPO was not included in the assessment, lichen samples indicated enhanced nitrogen and sulfur availability at all elevations sampled in SEKI. In addition, air was sampled at the lower elevation IMPROVE sites at Turtleback dome in YOSE and at Ash Mountain in SEQU during the period 1998 – 2004. These air samples had concentrations of ammonium nitrate (NH_4NO_3) of 2.25 ug/m^3 in SEQU and 0.5 ug/m^3 in YOSE. Concentrations of ammonium sulfate ($(NH_4)_2SO_4$) were 2.0 ug/m^3 in SEQU and 1.0 ug/m^3 in YOSE. The concentration of ammonium nitrate at the SEQU site was much greater than any other park studied. Both IMPROVE sites also recorded a significant increase in the extinction of light due to nitrate over the period from 1994 through 2004, indicating an increase in the availability of nitrogen from regional sources, which are likely from fertilizers (Landers et al., 2008). The extinction of light due to ammonium nitrate in SEQU was higher than any of the other parks in the western U.S. Ammonium nitrate light extinction at YOSE was much less than at SEQU and moderate compared to the other western parks. These two sample sites in SEQU and YOSE are much lower in elevation than DEPO.

Recently in 2007 and 2008, air was monitored in DEPO for nitrogen air constituents. Of those measured, ammonia (NH_3) concentrations were the highest overall in both sample years (Bytnerowicz et al., 2010). In 2008, ammonia comprised 43% of all inorganic reactive nitrogen sampled, followed by nitric oxide (NO) at 39%, nitrogen dioxide (NO_2) at 13%, and nitric acid (HNO_3) at 3%. The unexpectedly high ammonia concentrations could be explained by transport from the San Joaquin Valley, regional wildfires, or locally from vehicles (Bytnerowicz et al., 2010). Nitric oxide concentrations were also much higher than expected. The ratio of $NO:NO_2$ was high (2.4), indicating a low rate of oxidation and a prevalence of local emission sources. Nitrogen dioxide and nitric acid concentrations were low and typical, well within the range of expected ambient levels for remote locations in the Sierra Nevada (Miller & Walsh, 1991; Johnson et al., 1997).

Fenn et al. (2010) estimated nitrogen deposition loads across California from various sources and compiled known critical loads of nitrogen from the literature. A critical load is the level of exposure to nitrogen above which plants or communities begin to show signs of significant harmful effects. Although their estimates show that most of the high Sierra Nevada does not receive nitrogen inputs above critical loads for plant species or communities, a small area including DEPO does appear to experience nitrogen deposition rates high enough to impact sensitive lichen species (3.1 – 5.2 kilograms/hectare/year) (Fenn et al., 2010).

The WACAP study determined background levels of nitrogen and sulfur in lichens from other remote public lands in western North America (Landers et al., 2008). The upper limit of the levels found in these remote sites provides background levels to which we can compare levels found in areas around DEPO. These upper limits are: nitrogen = 10,940-17,520 ppm; sulfur = 901-1,558 ppm. Lichens tested from across a broad elevation gradient in both YOSE and SEKI showed evidence of enhanced sulfur and nitrogen deposition. The average of the lichen samples from SEKI was above the background level upper limit for sulfur and within the background range for nitrogen. At YOSE, nitrogen in lichen was slightly below this background level (sulfur was not measured in YOSE). It should be noted that even remote sites from western North America are receiving some regional and long-range transport of sulfur and nitrogen.

Using data from the 2003 to 2007 period, the NPS Air Resources Division estimated and assessed the condition of air quality in DEPO based on several constituents (NPS ARD, 2009). Although rated significant concern by the NPS ARD (Table 4.1), the estimated levels of nitrogen deposition at the high elevations around DEPO do not appear to be sufficiently high to cause major physiological damage to vegetation, although the nitrogen cycle at lower elevation is being altered (Fenn et al., 2003c).

The limited local and regional empirical evidence for nitrogen appears to support the modeled data that collectively indicate that some atmospheric nitrogen compounds that can fall in wet and dry deposition are high enough to be of concern, but may not be at levels that would significantly alter ecosystems in the high elevation Sierra Nevada. Evidence from SEKI indicates that concentrations of sulfur may also be a concern in the DEPO area, though not as much of a concern as nitrogen.

Pesticides and other Airborne Contaminants

The WACAP project investigated contaminant concentrations in western national parks from 2003 to 2006 (Landers et al., 2008; Landers et al., 2010). Primary airborne contaminants of concern were semi-volatile organic compounds (SOCs) and heavy metals. SOCs were separated into four groups: (1) current-use pesticides; (2) historic-use pesticides; (3) industrial and urban-use compounds; and, (4) combustion byproducts. These constituents were evaluated in eight core parks and 12 secondary parks. Devils Postpile was not included in the study but the nearby parks of Sequoia and Kings Canyon National Parks (primary park) and Yosemite National Park (secondary park) were included, and some concerns for the region are highlighted in these conclusions. Data were collected in 2003 and 2004 in SEKI and in 2005 in YOSE.

The contaminants in question become airborne and are transported away from source areas and into the parks of the Sierra Nevada. The WACAP study chose seven ecosystem components from which to determine levels of contamination in the parks: air, snow, water, sediment, lichen, conifer needles, and fish. Measurements of contamination in snow give a very direct indication of wet deposition rate and quantity. Measurements in lake water demonstrate cumulative effects of physical and chemical processes in the watershed. Lake bed sediments indicate historical patterns of deposition. Levels of contamination in vegetation (such as conifer needles) demonstrate an accumulation of contaminants by direct uptake from the ecosystem (via air, water, and soil) that are incorporated into biomass. Variations in levels of contamination are used to determine spatial gradients of contamination. Measurements of contaminants in the bodies of fish are used to determine danger to consumers and the impact of contaminants on aquatic systems.

Results of the WACAP study show that in the region of Yosemite and Sequoia and Kings Canyon, the contaminants of greatest concern are SOCs, particularly current-use pesticides. All constituents were sampled at two sites in Sequoia National Park (Emerald Lake at 2,810 meters (9,219 ft) and Pear Lake at 2,908 meters (9,541 ft)) in the northwestern portion of the park. SOCs in conifer needles and lichens were sampled more extensively, including 11 sites in SEKI (ranging from 427 meters to 2,911 meters (1,400 – 9,550 ft)), and five sites in YOSE (ranging from 661 meters to 3,048 meters (2,170 – 10,000 ft)). SOCs were also sampled by passive air samplers at four sites in SEKI (ranging from 658 meters up to 2,816 meters (2,160 – 9,240 ft), and one site in YOSE (3,048 meters (10,000 ft)).

Samples of air, vegetation, sediments, and snow from the SEKI sites had among the highest concentrations for current-use and historic-use pesticides compared to samples taken from all other parks in the study. Air samples taken from SEKI recorded the largest number of individual SOCs for all parks, and concentrations of SOCs were among the highest of all parks studied. SOC concentrations in vegetation were highest in SEKI, YOSE, and the Rocky Mountain region. In these parks, levels of DDT and dieldrin (historic-use pesticides) in fish were higher than those found in similar alpine regions of Europe and are therefore of moderate concern. SOCs, mercury, and nutrient levels were in the medium to high range in vegetation compared to all parks in the study. Fluxes of some current-use and historic-use pesticides into sediments at the two SEKI lakes were either the highest or second highest of all parks studied.

In Yosemite, the five sites sampled along the Merced River corridor showed mixed results compared to the other parks. Air sampled at the highest elevation site had concentrations of most SOCs above the median level for all parks. Vegetation sampled at all five sites showed relatively high concentrations of current-use pesticides, moderate levels of historic-use pesticides, relatively high levels of PCBs, and moderate levels of combustion byproducts, compared to all other parks studied. Concentrations of SOCs were high in lichen and increased dramatically with altitude. Therefore, the presence of SOCs in air, water, and vegetation is a definite concern for natural resources and visitors in DEPO.

The WACAP study concludes that there is a strong correlation between current-use pesticide concentrations in samples and percent cropland within 150 km (93.2 mi) of the study site (Hageman et al., 2006; Landers et al., 2008). A buffer applied to the monument shows that a great deal of source area in the San Joaquin Valley is within this distance (Figure 4.3). Also correlated with agricultural intensity within this buffer zone were number of current-use pesticides in lichens and conifer needles, DDT (banned in the U.S. in 1972) in conifer needles, and PAHs (polycyclic aromatic hydrocarbons --common organic pollutants found in processed fossil fuels) in lichens. Concentrations of many pesticides increased with elevation while levels of PAHs decreased with elevation. When parks examined in the WACAP study are compared to similar alpine regions of Europe, results show that current-use pesticide levels in WACAP parks were 2-9 times lower, but concentrations of the flame retardant PBDE were about three times higher.

Figure 4.3. DEPO within the southern Sierra Nevada and adjacent San Joaquin Valley. A great deal of agricultural source area in the San Joaquin Valley is within 150 kilometers (93.2 miles) of the monument.

The fact that concentrations of contaminants in samples taken from SEKI and YOSE were relatively high, and that SOCs increased with altitude strongly suggests that deposition of these contaminants at DEPO is also relatively high compared to other protected areas of the western U.S. This suggests that concentrations of SOCs in air, surface water, vegetation, snow, and sediments in DEPO are likely elevated and higher that would be suggested by its remote location.

The likely source of SOCs found in SEKI and YOSE are probably the same sources for DEPO, though the exact nature and magnitude of this transport and deposition to DEPO is unknown. Deposition of SOCs onto DEPO could be great due to highly efficient transport of air contaminants through the large and wide canyon of the San Joaquin River (L. Tarnay, pers. comm.). However, transport of contaminants to the monument may be less than what has been measured in the other SIEN parks since it is further away from the Central Valley source area than most observation sites in YOSE and SEKI, and may be somewhat protected by a high ridge of mountains to the west that may block or slow airborne transport.

Mercury

The WACAP study also determined background levels of Mercury (Hg) in lichens from remote public lands in western North America (Landers et al., 2008). The upper limit of the levels found in these remote sites provides a background level to which we can compare levels found in areas around DEPO. These upper limits for mercury are: 0.41-0.72 ppm. Mercury concentrations were low in snow and are of only moderate concern in fish at sites in SEKI. Concentrations found in SEKI were greater than those found in wilderness areas in Canada but much less than parks in the Midwest and northern U.S. states. For mercury in fish, levels from the two SEKI lakes were in the range of 41 – 213 ng/g wet weight for the entire body. This is well below the level of known toxicity for fish (Niimi & Kissoon, 1994). Concentrations of mercury in lichen, snow, fish, and sediments at the SEKI sites were moderate compared to other parks, and at levels low enough to not be a concern. Since relatively low levels of mercury were found in nearby SEKI, mercury contamination is probably not of concern for DEPO resources.

Air Quality – Current Condition Summary

Reference conditions would be air free of abnormally high concentrations of pollutants that have been identified in standards, and found in air samples or in other end targets of atmospheric transport (water, fish, vegetation) from remote locations in the western U.S. Limited local data as well as expanded regional data suggests that overall, the condition of these selected air resources in DEPO are relatively poor compared to a background reference condition of very low levels of pollutants that are generated only periodically by local fires. From evidence within DEPO, nearby, and from other SIEN parks, we know or suspect that air quality is generally poorer than would be expected by its relative isolation. Air quality is fair to good, though of course still relatively good compared to highly impacted areas.

Air Quality – Threats & Stressors

Climate Change

A warming climate in the region is expected to negatively impact air quality as hotter temperatures in the San Joaquin Valley are predicted to lead to the creation of more ozone and smog (Luers et al., 2006). Hotter temperatures and more pollution and pollution byproducts would mean more exposure to the Sierra Nevada.

Air pollution

Airborne pollutants of all kinds discussed here will continue to threaten air quality in DEPO as long as the sources of contaminants (e.g., local vehicle sources moving in and out of the monument and distant urban areas in the San Joaquin Valley and San Francisco Bay Area of California) persist. In addition, long-range sources of metals such as mercury coming from Asia that use coal for energy generation are likely to increase in the future. The types and amounts of airborne contaminants produced at these regional and distant sources will be affected most by population change (likely growth) and transportation technologies and infrastructure. Mitigation by the monument is limited to restricting local sources of pollution and monitoring effects of transported pollution, so as to influence policy change at large.

<u>Weather and Climate</u>

The climate of the region is characterized as Mediterranean but portions of the SIEN parks are generally cooler and wetter at the higher altitudes. Due to its location, DEPO has a climate that is more typically boreal (also called microthermal), with cold, snowy winters and warm, mostly dry summers. Winter temperatures are cold with mean daily temperatures below 0 °C (32 °F). Summer days are warm but nights are cool. Skies are usually clear and the humidity is usually low. Local winds tend to be directed along the north-south axis of the Upper Middle Fork of the San Joaquin River.

Short and long-term climate patterns are affected by several cyclical oscillations ranging from years to millennia that are driven by different mechanisms (Millar et al., 2006). At the shortest time scales, there are a number of large spatial scale climate and atmospheric circulation patterns. Noteworthy amongst these are the Pacific Decadal Oscillation (PDO), the El Nino/Southern Oscillation (ENSO), and the Madden Julian Oscillation (MJO), which are associated with cool season precipitation patterns in the region. The complex interaction of these three phenomena, as well as potential influences from anthropogenic climate warming and the other very long-term climate fluctuations, translate into a moderately to highly variable inter-annual climate for the area (Edwards & Redmond, 2011). Temperatures tend to be more consistent year to year while annual total precipitation can be highly variable. The drivers of the circulation patterns that can significantly affect precipitation are rooted, partially, in Pacific air-sea interactions, but are not completely understood. Recent research has investigated their interactions and flooding in the Sierra Nevada and Northern California Coast Ranges (Gershunov et al., 1999; Gershunov et al., 2000; Ralph et al., 2006; Neiman et al., 2008). The southwestern monsoon can affect weather around DEPO, with localized and sometimes heavy rainfall during the June to September period.

DEPO is located on the west slope of the Sierra Nevada but near the Sierra crest. Due to orographic uplift of winds on the west slope, precipitation from winter cyclonic storms generally increases with elevation, though topographic setting has a strong influence on precipitation at any given elevation (Edwards & Redmond, 2011). In many cases, the highest precipitation areas are not the highest elevations.

There is no long-term (~60 yrs or more) climate data for the monument and so an assessment of trends over a long time period and determination of long-term averages is not possible. Sources of short-term weather data from within the monument are available but limited. There is one active weather station in the monument, located in Soda Springs Meadow. It was installed in August of 2005 by a cooperative effort between Devils Postpile National Monument, National Park Service Sierra Nevada Network Inventory and Monitoring, Sequoia and Kings Canyon National Parks, California Department of Water Resources, Scripps Institution of Oceanography, California Energy Commission's Public Interest Energy Research (PIER) program, and U.S. Geological Survey. The station has dual sensors and data loggers that measure hourly precipitation, air temperature, barometric pressure, relative humidity, wind speed, wind direction, solar radiation, irradiance, and reflected irradiance (Balmat & Scott, 2010). Data summaries since 2006 for air temperature variables are presented in Table 4.3. Large gaps in precipitation data collection since 2006 preclude summarizing that data here. Temperature data collection has also been somewhat inconsistent at this automated site and monthly temperature means and precipitation amounts do not provide long-term averages as they only represent three to five years of data.

Table 4.3. Temperature summaries for the DEPO weather station, 2006 – 2009. Temperature in degrees Fahrenheit.

Month	Mean Temperature	Mean minimum Temp	Mean maximum Temp
Jan	26.7	13.2	44.9
Feb	28.6	16.2	45.1
Mar	33.5	18.7	52.0
Apr	35.9	22.2	53.1
May	43.8	29.3	60.7
Jun	50.9	33.4	68.1
Jul	58.7	38.8	78.4
Aug	54.8	35.0	75.3
Sep	50.0	31.0	72.6
Oct	40.7	28.3	59.7
Nov	34.6	22.4	53.6
Dec	25.9	13.4	44.1
Annual mean	40.3	25.2	59.0

A Remote Automated Weather Station (RAWS) provided daily air temperature, precipitation, humidity, solar radiation, wind direction, and wind speed for the years 1993-2004. It was located near the housing area northeast of Soda Springs Meadow. Summary data for temperature and precipitation from the 12 year period of operation are presented in Table 4.4. While the time of record of this station is too short to adequately determine long-term averages or trends, the data do provide recent statistics for temperature and precipitation. However, the precipitation data may be suspect since the gage may not have been heated and even if so may not have done well with snow. In addition, anecdotal evidence suggests pine needles often clogged the gage, leading to inaccurate data at times (Balmat & Scott, 2010). While monthly mean temperatures from this dataset are fairly consistent inter-annually, there is great variability in precipitation. For example, rainfall equivalent amounts in the wettest month of the year, January, varied from one-quarter inch up to over 28 inches. This is likely at least partially due to problems mentioned above, but these records may also reflect the high degree of month-to-month and year-year variability that is known to have occurred in the region. That is, there are extremely dry and extremely wet months, both intra- and inter-annually.

Table 4.4. Summary of climate data from the DEPO RAWS station that was active from 1993 through 2004. Temperatures in degrees Fahrenheit. Precipitation in inches.

Month	Mean Temp	Mean minimum Temp	Mean maximum Temp	Precipitation (in)
Jan	26.9	16.8	42.0	8.3
Feb	27.1	15.5	43.0	6.7
Mar	32.3	20.1	49.7	2.8
Apr	35.1	23.5	51.1	2.7
May	42.9	29.0	60.7	1.5
Jun	46.7	30.9	64.5	0.6
Jul	52.1	35.1	71.1	0.3
Aug	50.2	33.1	70.1	0.2
Sep	50.1	33.2	71.0	0.9
Oct	40.9	26.6	61.2	1.6
Nov	28.4	18.2	43.7	4.6
Dec	24.2	14.8	38.3	5.7
Annual Mean	38.1	24.7	55.5	Total: 35.9

Independent of the automated weather station observations, an archive of daily ranger logs kept by rangers on duty at the monument contains daily observations of weather from 1972 to 2003. Weather observations include (but do not consistently record) daily high and low air temperatures, air temperature at the time of observation, precipitation amounts, and miscellaneous weather comments (Balmat & Scott, 2010). These data were insufficient for construction of longer-term averages or trends.

Besides the decommissioned RAWS station and newly established weather station in DEPO, microclimate temperate data in and around DEPO has been collected by USGS and USFS investigators. This effort aims to characterize the small-scale diurnal elevational variability in temperature within and outside the monument. Small automated temperature loggers were set out in late 2008 along several elevational transects across and outside of the monument for one year (Balmat & Scott, 2010). Data gathering has continued and is of interest to DEPO management and researchers. An analysis of this raw data collected so far has not been published at this time, but understanding the spatial and temporal temperature regimes and gradients within and near the monument and the effect of these processes on hydrology and species are a current management priority.

Sources of weather data near to the monument could provide useful information that can be used to loosely assess long-term patterns at the monument (Table 4.5). However, there is a relative dearth of high quality weather station data in close proximity to the monument and the Town of Mammoth Lakes (Edwards & Redmond, 2011). A review of the data available from the stations close to DEPO found that little consistent long-term data are available. Some stations were discontinued, some lack precipitation or temperature data, and/or data collection was inconsistent over the period of record for the station. This makes it difficult to use these stations as proxies for DEPO climate conditions and trends.

Table 4.5. Climate recording stations in and near DEPO evaluated for use in assessing climate conditions.

Station ID	Name/location	Period of Record	Period of Precip Data	Period of Temp Data	Notes
DEPO	DPO	2006-present	2006-present	2006-present	Temporally limited
CDPP	DEPO	1993-2004	1993-2004	1993-2004	Temporally limited
MMS	Mammoth Pass (LADWP[1])	1948-1976			Data not available
MHP	Mammoth Pass (USBR[2])	1989 – present	1989 – present	2005 – present	Much missing data
MMS	Mammoth Lakes	1993-present	1993-present	1993-present	Temporally limited
CUES	Mammoth Mountain Ski Resort	Mid-1980s - present	None	1982 – present	Temporally limited
Gem Lake	Gem Lake	1924-2004	1924-2004	1924-1950	Inconsistent data collection
Ellery Lake	Ellery Lake	1931-present	1931-present	1931-1949	Missing some yrs precip data

[1] Los Angeles Department of Water and Power

[2] United States Bureau of Reclamation

A cooperative weather station just below Gem Lake (near June Lake) has climate records that go back to 1924. While there has been consistent data collected on total monthly precipitation and most years recorded maximum snow depth, temperature data was only recorded through 1950. As Balmat and Scott (2010) note, the precipitation data from the Gem Lake site could potentially be used as a proxy for relative long-term changes and patterns. However, a comparison of total annual precipitation over the short time period that the DEPO RAWS station and the Gem Lake station overlap (1993 – 2004) shows that the correlation of precipitation between them is very low (correlation coefficient = 0.06), and so this station may not be a good proxy for precipitation amounts and trends at DEPO. However, due to potential problems with the RAWS rain gage (noted above), precipitation measurements in snow may not have been accurate. Therefore, the measurements from the Gem Lake site may prove to be an accurate proxy dataset for longer term precipitation trends for DEPO.

A nearby station with a relatively long historical period of record was located at Mammoth Pass from 1948 until 1976, and operated by the Los Angeles Department of Water and Power. Unfortunately, data from this station were not available at the time of this writing. Another weather station was placed at Mammoth Pass in 1989 and has been collecting daily precipitation data since. However, a close examination of these data reveals many days missing data in the years up to 1998. After this time, the data are also suspect with many consecutive days during normally wet months with no recorded precipitation and when the DPO station did record precipitation. This dataset therefore is not useful as a proxy for temperature trends for DEPO.

A dataset appropriate for climate trend analysis for the Sierra Nevada Network would require at least 60 years of well-documented, consistent, and complete data (Edwards & Redmond, 2011). Therefore, records from Devils Postpile and nearby are insufficient to determine historical trends. Though beyond the scope of this assessment, available records from the region could be used, perhaps in hybrid fashion, to create a composite historic climate record that could prove useful for assessing the climate trends in DEPO. Sierra Nevada Network parks have substantial climate monitoring infrastructure that is managed through cooperation of several agencies and universities, some of which are benchmark stations that maintain high quality data with periods of record that extend 100 years or more (Davey et al., 2007; Edwards & Redmond, 2011). For the purpose of this NRCA, data from regional climate models and weather stations located outside the monument that have long-term records were used to estimate long-term climate trends in the monument.

While local climate at any given location and elevation is subject to local influences such as topography, wind patterns, and vegetation, examining regional trends can be useful for more synoptic changes that are probably also affecting DEPO. Using data from the network of weather stations in and around the SIEN parks and PRISM (Parameter Regression on Independent Slopes Model) modeling, rainfall amounts and temperatures were modeled over the Sierra Nevada national parks for the period 1961 - 1990 (Davey et al., 2007). The modeling included records from 45 active and inactive weather stations from within 40 km (25 mi) of DEPO.

Due to the rain shadow effects from the Ritter Range and Clarke Range to the west of DEPO, PRISM modeled mean annual precipitation from1961 through 1990 at the monument is relatively low compared to similar elevations in the other SIEN parks, between 600 and 800 mm (23.6 – 31.5 inches) annually (Davey et al., 2007). The decommissioned RAWS stationrecorded an average of 911 mm (35.9 inches) annually over the period of its record, so the PRISM modeling substantially underestimates the precipitation at DEPO. Furthermore, an informal comparison of data from the new automated weather station with the interpolated PRISM data found the interpolated data to be inaccurate for the local scale around DEPO. Edwards and Redmond (2011) examined all weather station records around the SIEN and compiled data since 1895, then summarized by county. They found that precipitation amounts for Madera County (and all other counties) that include the SIEN parks have not trended up or down since 1895 (Edwards & Redmond, 2011). In contrast, Millar et al., (2004) found that a composite of weather station precipitation data in the central and southern Sierra Nevada showed an increase in rainfall between the 1910-1920 decade and the 1990-2000 decade. However, there is considerable variability within this time period, and the trend may be disproportionally affected by anomalies near the end points, and so precipitation trends may not be statistically significant over the entire length of record.

Although examinations of precipitation over the entire Sierra Nevada or all of California have shown no trends in annual precipitation amounts over the last 100 years, the intensity and frequency of large one day precipitation events have been trending upward (Western Regional Climate Center, unpublished data).

In contrast to trends in precipitation, since 1895 the mean annual temperatures around DEPO and the other SIEN network parks have increased substantially, especially over the last approximately four decades, with the steady increase beginning in the early to mid-1970s and accelerating in the late 1980s (Edwards & Redmond, 2011). However, it is cautioned that at least some of this observed warming may be due to discontinuities in temperature records at individual weather stations that are caused by station relocations (Davey et al., 2007). The mean temperature increase has been largely or entirely driven by a dramatic rise in mean minimum temperatures, while mean maximum temperatures have remained steady (Edwards & Redmond, 2011). For Madera County, a linear trend fit to the composite of weather station data (1895 – 2010) indicates an increase in annual mean temperatures of approximately 1.0 °C (1.8 °F), while mean minimum temperatures have increased 2.0 C (3.6 F). These findings were echoed by Millar et al. (2004) in their examination of climate trends and subalpine conifer growth patterns at high elevations in the central and southern Sierra Nevada from the area near Dunderberg peak south to San Joaquin Mountain. They found that a composite record of temperature from 1910 until 2000 recorded an increase in minimum monthly temperatures of 3.7° C (6.7 °F). Since Millar et al. (2004) focused on higher elevation sites, this indicates that higher elevations have experienced more warming than lower elevations. Indeed, a recent reanalysis of free atmosphere temperature data from 1958 to 2007 indicates that there has been a trend of increasing temperatures over the Sierra Nevada. During this period, temperatures have increased more in spring and early summer (0.2 – 0.6 °C/decade (0.36 – 1.08 °F/decade)) than in winter and fall (Edwards & Redmond, 2011). Higher altitudes have experienced the most increase during the March to July period. In general, higher mountain elevations are expected to warm faster than lower elevations (Cayan et al., 2007).

Results from other research indicate similar trends of increasing temperature for the western U.S. over recent decades (NAST, 2001), and especially the mountain regions, with associated changes to precipitation patterns, snowfall, and timing and duration of spring snowmelt (Cayan et al., 2001; Westerling et al., 2003; Hamlet et al., 2005; Regonda et al., 2005; Stewart et al., 2005; Knowles et al., 2006; Mote, 2006; Knowles et al., 2007).

Weather and Climate – Current Condition Summary

Reference conditions would be a record of inter-annually variable though stable long-term averages of precipitation and temperature, with no significant trends in these measures that could be associated with greenhouse gas emissions or other stressors. Though long-term data are absent from the monument, observations from weather stations throughout the Sierra Nevada, and especially those within the SIEN parks, show that the climate within the monument has been variable over the past 50-100 years. There have been no or slight increases in precipitation, but modest to large increases in temperature, especially daily minimum temperatures. However, due to local topography and microclimate, the trend in DEPO may be more or less than that found in the larger region around the SIEN parks and more widely across the Sierra Nevada. Cold air subsidence at night may occur frequently at DEPO, creating a temperature and climate regime that may not be in step with the larger region. Regional data suggests the condition of weather and longer term climate are split, with precipitation demonstrating good to excellent conditions while temperatures have demonstrated only fair conditions.

Weather and Climate – Threats & Stressors

Climate Change

Bonfils et al. (2008) modeled the natural variability in temperature variables across the mountain ranges of the western U.S. and compared these to the record of observations. They concluded that natural variability is insufficient to explain the recent observed warming trends in winter and spring temperature. Instead, the trends are consistent with climate simulations that include the combined effects of greenhouse gases and aerosols. In a similar effort, Barnett et al. (2008) modeled hydrology in the mountainous western U.S. driven by general circulation models (GCM) (aka global climate models). The results of these GCM runs show that 35% to 60% of the magnitude of the trends in river runoff timing, winter air temperature, and snow water equivalent (SWE) between 1950 and 1999 are anthropogenic in origin (greenhouse gases and aerosols). Most areas demonstrated a projected decrease in the ratio of SWE to winter precipitation, with the exception of the southern half of the Sierra Nevada that showed a slight increase. All areas showed a projected increase in minimum winter temperatures and an earlier arrival of spring runoff.

Climate models project warming in California of 1.5 to 4.5 °C (2.7 to 8.0 °F) by the year 2100, with temperature increasing more in summer than in winter (Cayan et al., 2007), and with significant associated changes to Sierra Nevada hydrology (Hayhoe et al., 2004). For the Sierra Nevada, temperatures are projected to rise 2.5 °C (4.5 °F) on average by the end of this century (Dettinger et al., 2004; Dettinger, 2005b). Increases in temperature are expected to occur throughout the year, though not equally in each season (Cayan et al., 2007).

In response to anthropogenic climate change in California, annual precipitation rates are not expected to change significantly (Cayan et al., 2007). Climate models vary in their projection of precipitation changes in California and the southwestern U.S. over the next century, from slight decreases to moderate increases (Kim et al., 2002; Snyder et al., 2002; Dettinger, 2005b).

Taking the projected changes in precipitation and temperature and resulting changes in evapotranspiration from the array of climate models used in the IPCC assessment of 2007, Seager et al. (2007) determined that most models indicated a drier climate for the southwestern U.S. through the end of the century. As temperature increases, the rate of evapotranspiration will increase, potentially negating any increases in precipitation.

Increasing temperatures will also raise the snow level. Andrews (2010) found a decreasing trend in snowfall in the Sierra Nevada around the SIEN parks for elevations below approximately 2,591 meters (8,500 feet) over the past 60 years. Similar trends of decreased snowfall accumulations at medium and lower elevations (Mote et al., 2005) as well a declining trend in the proportion of precipitation falling as snow (Knowles et al., 2006) across the western U.S. support these findings. These same trends will likely continue if climate continues to warm regionally, bringing more of the total precipitation to DEPO as rain versus snow.

4.3.2 Geology

Geological Features – Natural Forms and Processes

The distinct geologic features identified by staff and partners of Devils Postpile National Monument are the Postpile, Rainbow Falls, granitic domes, and other evidence of volcanism and glaciations at many locations within the monument. A recent comprehensive inventory of the geologic resources of the monument detailed these resources, threats to their integrity, and the history of their formation (Graham, 2009). To be expected, the overall condition of these features is very good, though both natural and human threats exist. Exposed geologic features were formed at various times in the past and include the relatively recent Postpile column formation (~76,000-82,000 years ago), other volcanic rocks, and Cretaceous intrusive igneous rocks.

The geology of DEPO was mapped by Huber and Rinehart (1965) when they mapped the entire Devils Postpile USGS 15 minute quadrangle. In this quadrangle, they mapped dozens of unique geologic units including surficial deposits, volcanic rocks, granitic rocks, metamorphic rocks, and metasedimentary rocks. Later, Clow and Collum (1986) more accurately mapped the volcanic rocks within and around the monument. Then Bailey (1989) produced an updated geologic map of a larger area that included DEPO. Currently, the geologic makeup of the area around DEPO is in revision, with Wes Hildreth, USGS research geologist, currently engaged in a project to obtain improved estimates of the age of individual volcanic flows. The NPS Geologic Resources Division is planning to produce a digital version of the map being produced by W. Hildreth when it is completed, and will also complete revisions to the NPS geologic resources inventory report for DEPO as needed. The data presented here are a combination of Clow and Collum (1986), Huber and Reinhart (1965) and Wes Hildreth (pers. comm.) based on the Bailey (1989) map (Table 4.6, Figure 4.4). The rocks inside the monument are dominated by Cretaceous age granites and basalts, with minor portions of andesite, alluvium, and other surficial deposits. Outside of the monument there are substantial amounts of Reds Meadow tuff, dacite from Mammoth Pass, and basalt of Red Cones. The upcoming revisions to the geologic map by W. Hildreth will likely revise and provide more detail regarding the geologic units.

Table 4.6. Geologic units of DEPO and the percentage of the monument that they cover, listed in descending order by aerial coverage.

Symbol	Geologic unit (from Huber & Rinehart)	% coverage
Kgr	Cretaceous granite	45.3
Qbb	Basalt of the Buttresses	21.8
Qbd	Basalt of Devils Postpile	14.8
Qrr	Rhyodacite of Rainbow Falls	12.4
Qal	Alluvium	2.6
Qam	Andesite of Mammoth Pass	2.1
Qsu	Undifferentiated surficial deposits	0.94

Table 4.6. Geologic units of DEPO and the percentage of the monument that they cover, listed in descending order by aerial coverage (continued).

Symbol	Geologic unit (from Huber & Rinehart)	% coverage
Qbl	Basalt of Lost Camp	0.08

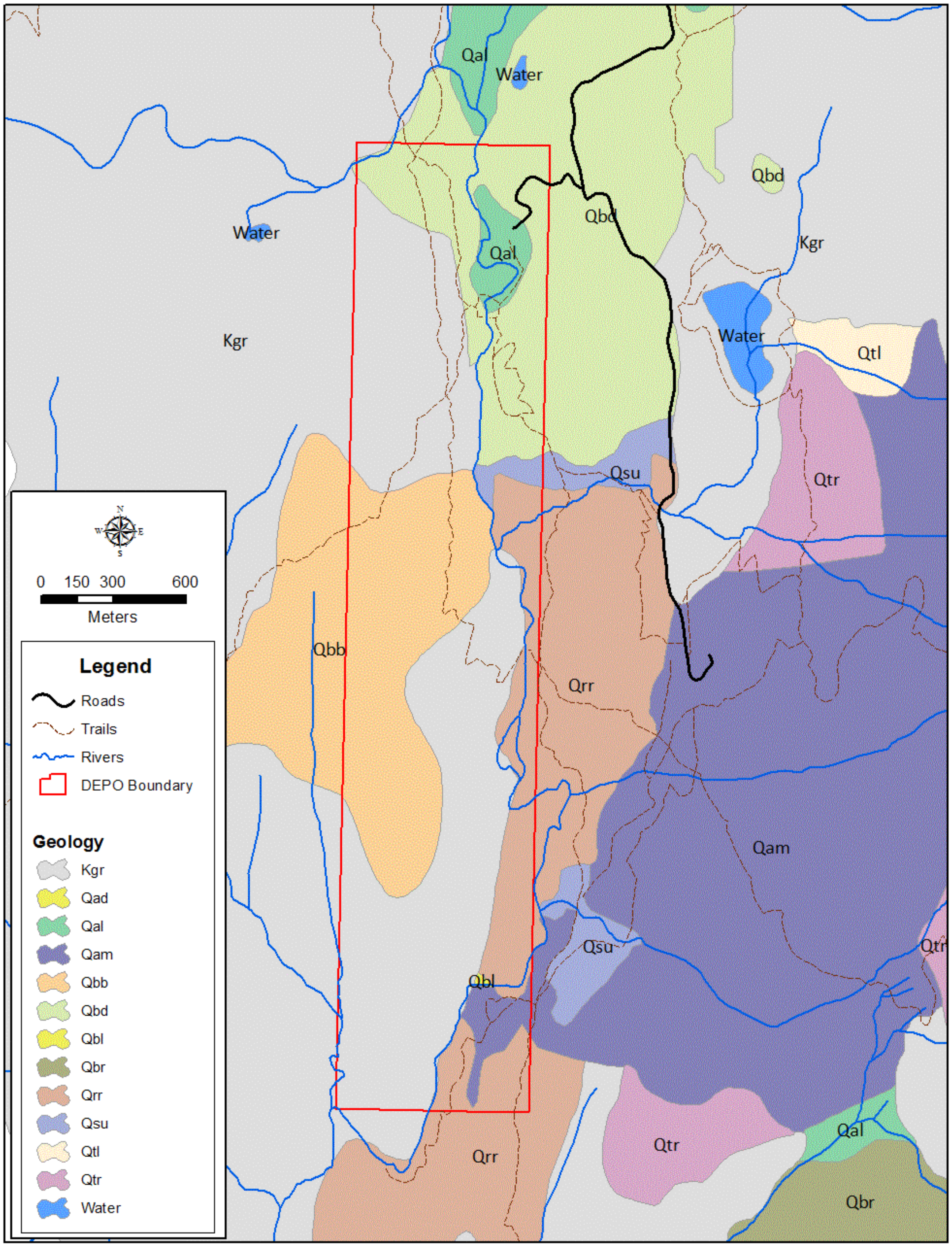

Figure 4.4. Geology of Devils Postpile National Monument and surrounding area. Compiled from several sources: Clow and Collum (1986); Huber and Rinehart (1965); and, W. Hildreth, written communication.

Devils Postpile columns

These 12-18 meter (39 – 59 ft) tall columns are subject to several natural forces that have and will continue to cause them to fall and break apart. These include earthquakes which are relatively common in the Mammoth Lakes area, and the natural erosive forces of water and the freeze-thaw process. The glacial polish on the top of the columns is also under threat by both illegal rock collecting and the natural weathering processes (Graham, 2009).

At Devils Postpile National Monument, visitors are free to explore the monument but are encouraged to do so safely and to stay on designated trails. The trail system currently in place is sufficient to allow visitors to view the Postpile columns from below and to walk on them from above. Due to safety concerns, visitors are prohibited from climbing on the columns or walking on the talus field below.

Glacial features

During the most recent glacial period, ending approximately 12,000 – 16,000 years ago, large glaciers flowed down the upper San Joaquin River valley, scouring the landscape as they moved. Evidence of this glacial action still exists – from the polished tops of the basalt columns to the large glacial erratics across the landscape, many of which are metamorphic rock transported down from north of the monument. Anecdotal evidence suggests that some natural texture (especially glacial polish) on the top of the Postpile has been worn smooth, presumably by foot traffic, though there is no monitoring data to confirm this. SIEN Inventory and Monitoring identifies the need to preserve the areas that have been less affected (Mutch et al., 2008a). Recently, some repeat photography of the column tops has been used to qualitatively assess conditions and changes over time, but no quantitative data exist at this time.

Rainbow Falls

Formed by the undercutting of less erosion-resistant rock below a harder rock layer, Rainbow Falls drops 31 meters (102 ft). Over time, the rock layer over which the water falls crumbles away as it loses support from the underlying rock. It is estimated that due to this natural erosive process, the falls have slowly migrated upstream approximately 152 meters (500 ft) from where it started (Huber & Eckhardt, 2001). According to monument staff, visitor use near the falls provides some evidence of wear from foot traffic but overall condition is still very good.

The Buttresses

The buttresses are composed of a stacked series of basaltic lava flows emanating from sources upstream about 2.8 million years ago. Over time, they have been substantially eroded by repeated glaciations. They are not known to be degraded by visitor use or other processes or stressors within the monument.

Geologic Features – Natural Forms and Processes – Current Condition Summary

Reference conditions would be natural geologic features and associated process that exist or are operating unimpaired by human influences. With very minor exceptions of direct impacts to geologic features, the conditions of geologic resources in DEPO are in excellent condition.

Geologic Features – Natural Forms and Processes – Threats & Stressors

Visitor use

Staff at Devils Postpile National Monument have identified visitor use as the primary threat to the integrity of the geologic features. The features are not likely to be altered greatly by visitor use alone, but foot traffic has probably altered glacial polish on the tops of the Postpile in some locations, and may have similar effects elsewhere in the monument. A maintained trail and some social trails have been rerouted in an attempt to protect some areas of glacial polish on the postpile. Further management efforts may be taken to preserve the subtler features like glacial polish; these features help tell the story of geologic history in the region and should be considered an important component of natural forms and processes. There is a need to identify reference conditions for the glacial polish with which to compare and monitor visitor impacts.

Climate Change

Indirectly, changing climate may affect the rates of weathering processes that are slowly eroding rock surfaces and accelerating the collapse of postpile columns and other features. Changes in temperature and precipitation amounts and patterns will affect the freeze-thaw process and the degree of water erosion on geologic features.

Pollution

There is potential for nitric and sulfuric acids that result from the deposition of NO_x and SO_x from regional sources to degrade rock surfaces. However, while the deposition of nitrogen and sulfur within the monument is a likelihood, the levels of acid in solution that result are likely very low and pose no immediate threat to the surface geology.

Stream Channel Morphology

Investigations within the monument have included descriptions of channel morphology and assessments of riverbank condition in sensitive areas. A restoration project contributed to river bank rehabilitation of apparent human-caused damage both within and nearby the monument. However, there has been no comprehensive assessment of stream channel morphology within the monument as of 2009, either in the main river channel or in its tributaries. Therefore we cannot make a comprehensive assessment of stream bank conditions or channel morphology in their current or recent state across the monument. Despite this lack of information, here we summarize research and monitoring within the monument that can be used to qualitatively assess current conditions.

Rowan et al. (1996) collected data and made observations of amphibian and trout habitats in the Middle Fork of the San Joaquin (MFSJ) River and its tributaries in the mid-1990s. In their recommendations, they note that there was apparent soil compaction and stream bank instability along the banks of the MFSJ River near the ranger station due to high visitor use activity. In 2002 and 2003, restoration of severely eroded river banks of the MFSJ River occurred in the area adjacent to the campground, day use area, and heavily used area in Soda Springs Meadow. Next to the day use area, approximately 30 meters (100 feet) of riverbank were restored. Again in 2004, another 9 meter (30 foot) section of riverbank just to the north of the campground was also restored with native plants. No current empirical data exists on the success of these restoration projects. However, photographs have been taken since 2002 of the restored areas and they apparently visually support the success of the restoration.

In the summer of 2009, a rapid assessment of stream bank condition was conducted for the approximately 4 km (2.5 mi) stretch of the MFSJ River directly upstream of the monument that flows by the three main U.S. Forest Service campgrounds in the area. The rapid assessment used an index called the RCI (Riverbank Condition Index) that takes into account riverbank morphology, substrate type, vegetation, and erosion. Although no report was provided, digital GIS files indicate the river reaches and their condition index. The range of RCI values is 1 to 4, with 1 indicating very good condition. Approximately 80% of the river channel surveyed ranked 1to 2, indicating a generally healthy condition. Problem areas that ranked 3 to 4 constituted less than 10% of total channel length and were found along short reaches of the river nearest to trails, parking lots, and campgrounds. Specifically, the most degraded reaches of river can be found near Soda Springs, Minaret Fall, and Pumice Flat Campgrounds. These assessments indicate that sections of the MFSJ River within the monument near the campground and other high use areas may be similarly affected.

A long-term assessment and monitoring of stream bank condition in the monument began in the summer of 2009 as part of the Visitor Use Assessment (Pettebone et al., 2010), a project that uses standardized data collection procedures to monitor visitor use impacts on stream bank integrity and riparian communities. The study collected data for a 100 meter (328 ft) stretch of river bank adjacent to Soda Springs Meadow just south of the visitor center. This is the only reach of the MFSJ River channel in the monument that is composed of deposited alluvium instead of the more common bedrock and unconsolidated material. Alluvial channels are characteristic of low-lying meadow river reaches and are more vulnerable to the degrading effects of concentrated visitor use and trampling. Three riverbank vegetation plots and three cross-channel transects were established, and the 2009 data will be used as a baseline to determine extent and direction of future changes. Two vegetation plots span the eastern bank and include a 30 meter (98 foot) section that was previously rehabilitated, while the third plot is on the western bank. Since the objective of the Visitor Use Assessment is to monitor changes in condition and only one year of data has been collected and examined (2010 data not yet available), no conclusions about overall condition of this reach of the river have been made. However, with qualitative observations made, the authors concluded that most of the stream bank area surveyed was in good condition except for an access point on the eastern bank near the picnic/day use area (Pettebone et al., 2010).

Stream Channel Morphology – Current Condition Summary

Reference conditions for stream channels in DEPO would be physical conditions representing a healthy system. Components of a healthy stream system include a stream channel with natural stability and a profile that contains pools, riffles, meander bends, and well-established, often vegetated banks. Bank vegetation is often used as an indicator of healthy steam channel morphology on relatively short time scales because mature communities of abundant and diverse riparian vegetation can only develop where stream channels have been stable. However, on longer time scales, stream channels are in flux, moving in response to episodic events like large floods. If the upland geomorphology allows, an active floodplain should be adjacent to the stream such that it is able to overflow its banks during high flows. Channel widening, eroded banks, channel incision, increased silt and clay on channel bottom, and encroachment of upland shrub species are all indications of a degraded stream system. The continued collection of riverbank vegetation and stream channel morphology will shed light on changing conditions. Although restoration has improved stream bnak condition within Soda Springs Meadow, visitor foot traffic could continue to impact the conditions here and elsewhre. Considering minor to moderate impacts in the Soda Springs Meadow area and near the campground and Visitor Center, we conclude that the stream channel and associated river banks are in good condition, though continued monitoring is necessary.

Stream Channel Morphology – Threats & Stressors

Visitor Use

Riverbank erosion can occur beyond natural rates due to human activities (Kondolf et al., 1996). Recreational use of the river and riparian zones has impacted the stream channel and banks in small areas, and restoration projects have attempted to restore these areas. Pettebone et al. (2010) describe the first season of an anticipated longer-term monitoring of stream channel morphology.

Climate Change

Expected changes in the frequency and severity of flooding events with a warming climate can impact stream channel morphology by increasing bank erosion and altering episodes of sediment input into the rivers and streams.

4.3.3 Water

Surface water resources within the monument include flowing rivers, waterfalls, springs, and small ponds and collectively they are a principal attraction to visitors. The primary waterway in Devils Postpile National Monument is the MFSJ River which was designated a Wild Trout River by the California Department of Fish and Game in 1995. In addition, in 1991 the MFSJ River, from the junction of the North Fork up to its headwaters (conclusive of the length with the monument), was determined eligible for recreational designation in the Wild and Scenic River System (USDA Forest Service, 1991). No final determination has yet been made. The primary tributaries near the monument are King Creek, Reds Creek, Boundary Creek, and Minaret Creek (Figure 4.5). The MFSJ River flows in a southerly direction through the monument and joins the north and south forks of the San Joaquin River downriver where the San Joaquin River then flows southeast into the San Joaquin Valley and then north through the valley to the San Francisco Bay. Other significant surface water resources in the monument are Sag Pond, Rainbow Falls, and Soda Springs. Surface water resources near the monument include Reds Lake, Johnston Lake, Starkweather Lake, Sotcher Lake, and Reds Meadow Springs (Mutch et al., 2008b Appendix D). There are many small meadows and other wetlands that are supported by the water resources of the monument (National Park Service, 1998), the sum of which constitute 7.5% of the monument area (Denn & Shorrock, 2009).

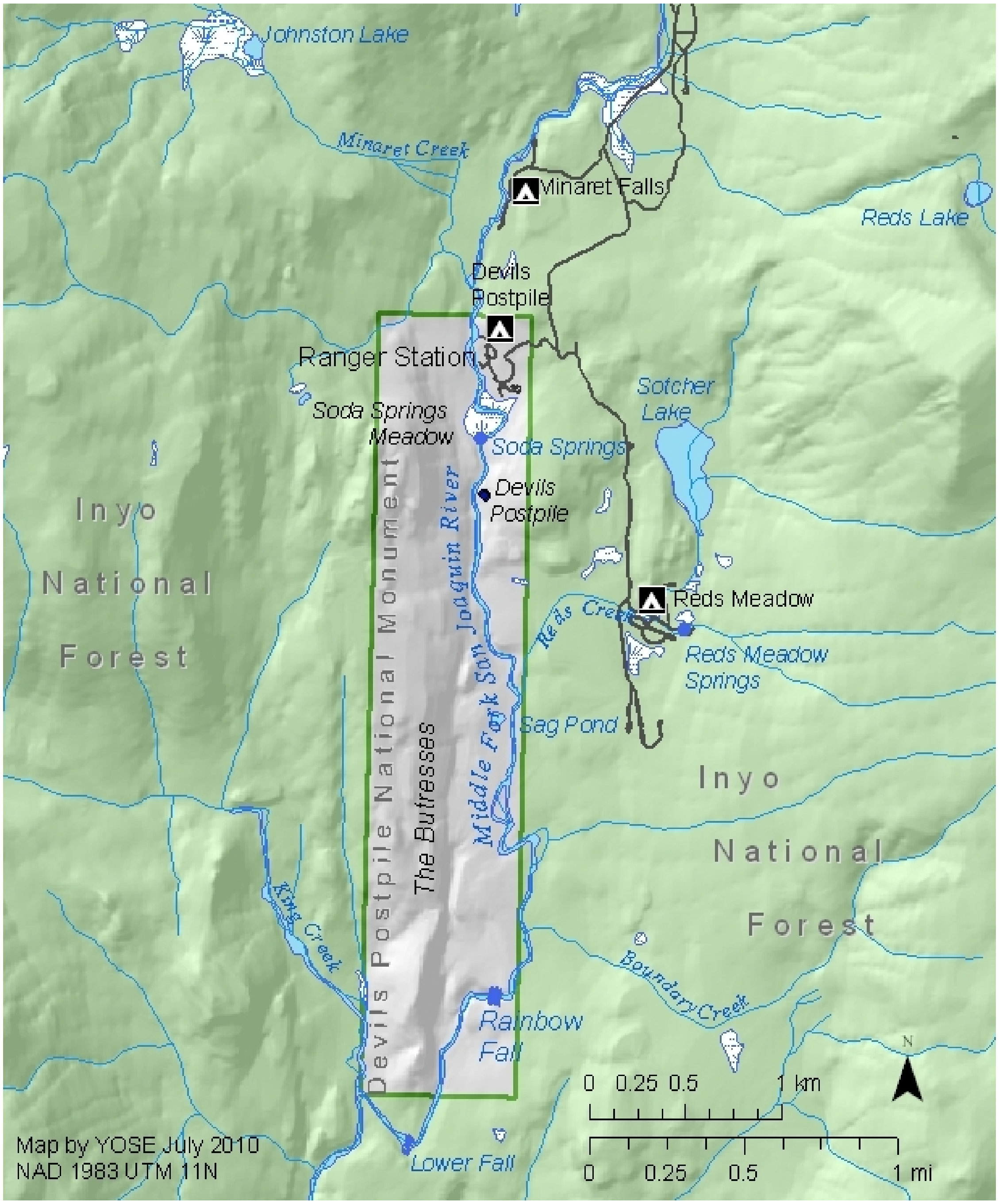

Figure 4.5. Surface water resources in and around DEPO.

The monument does not contain the headwaters of its surface streams. The headwaters of the MFSJ River are in the area of Thousand Island Lake, located 14.1 km (8.75 mi) upstream from the monument at an elevation of 2,998 m (9,834 ft) in the Ansel Adams Wilderness of the Inyo National Forest. From Thousand Island Lake, the river flows south through a steeply-sloped glacial canyon and crosses the northern boundary of DEPO (Mutch et al., 2008b, App D). The total length of the river from its entrance at the northern monument boundary to its exit at the southern monument boundary (including the small portion that flows outside) is 6.0 km (3.7 mi). The total area of the watershed that drains to and through the monument is 131.5 km^2 (32,495 acres, 50.8 mi^2) (Rowan et al., 1996).

Surface Water Dynamics

Surface waters in Devils Postpile National Monument follow a natural hydrologic regime. Quantification of surface hydrology reference conditions is difficult because long-term monitoring of stream discharge, as well as floodplain and inundation perimeters has not been conducted in or upstream from the monument. Long-term river flow data do exist from downstream gaging stations, but even the best period of record at Miller's Crossing is discontinuous and too far downstream to be wholly representative of hydrology in the monument. However, this dataset is the best proxy for surface flow data and trends for the watershed containing DEPO. All other stations further downstream on the MFSJ River are limited in usefulness because they are downstream of large reservoirs (e.g. Mammoth Pool Reservoir) and so are considered to represent impaired rather than natural flows.

There are some stream flow data from the monument, though they are limited and very recent. A permanent staff gage that was installed in 1994 near the Postpile formation (Mutch et al., 2008b, Appendix D), and a stage-discharge relationship was established based on flow estimates from a suitable site 1.2 km (0.7 miles) upstream from the staff gage (Rowan et al., 1996). Park rangers manually recorded stage height from the staff gage during the summer months for a number of years, but this was eventually discontinued sometime in the early 2000s. Since these data are limited to summers and were not consistently recorded, they are of limited utility. In late 2004, a stream flow sensor was installed by Scripps Institution of Oceanography in the MFSJ River within the monument upstream from the campground. In 2009, a permanent automated gage was installed downstream of this location. Due to high year-to-year variability in precipitation and flows, these short term datasets are of limited use for characterizing the status of surface water flows in the monument. Data from the stream flow sensors were not available for this report.

The automated gage was installed in the fall of 2009 through a cooperative effort between the U.S. Geological Survey and the National Park Service. It is located on the MFSJ River at the northern edge of the monument. It provides provisional stage height and discharge data at 15-minute intervals and transmits them remotely. These provisional data are available on the USGS National Water Information System website under the name "MF San Joaquin NR Mammoth Lakes CA." Daily mean discharges are published annually by the U.S. Geological Survey in their Annual Data Reports. In time, these discharge data will provide important information about the hydrologic regime in the monument. The Sierra Nevada Inventory & Monitoring Program is developing a rivers and streams monitoring protocol that will monitor surface water dynamics (Skancke et al., in draft). The MFSJ River is included as a monitoring site and will be monitored in collaboration with DEPO and the U.S. Geological Survey. Conditions at this time, however, would have to be based on a long-term assessment that is only available outside the monument.

The longest period of record for the MFSJ River comes from a retired gage on the San Joaquin River at Miller's Crossing, at 1,393 meters (4,570 feet) elevation, 15 km (9.3 mi) downstream from the monument and several kilometers below the confluence of the Middle Fork and the North Fork (but above the confluence with the South Fork). Miller's Crossing was active from 1921 to 1928 and again from 1952 to 1991, representing 47 years of data. Total annual flow fluctuates dramatically inter-annually, but there is no statistically significant trend in total flow over the period of record (Figure 4. 6). A linear regression of the flow volume data points has an R-squared of 0.01 and a type I error of 0.50. Without data since 1991 we cannot conclude with any confidence that the lack of trend has continued up to today.

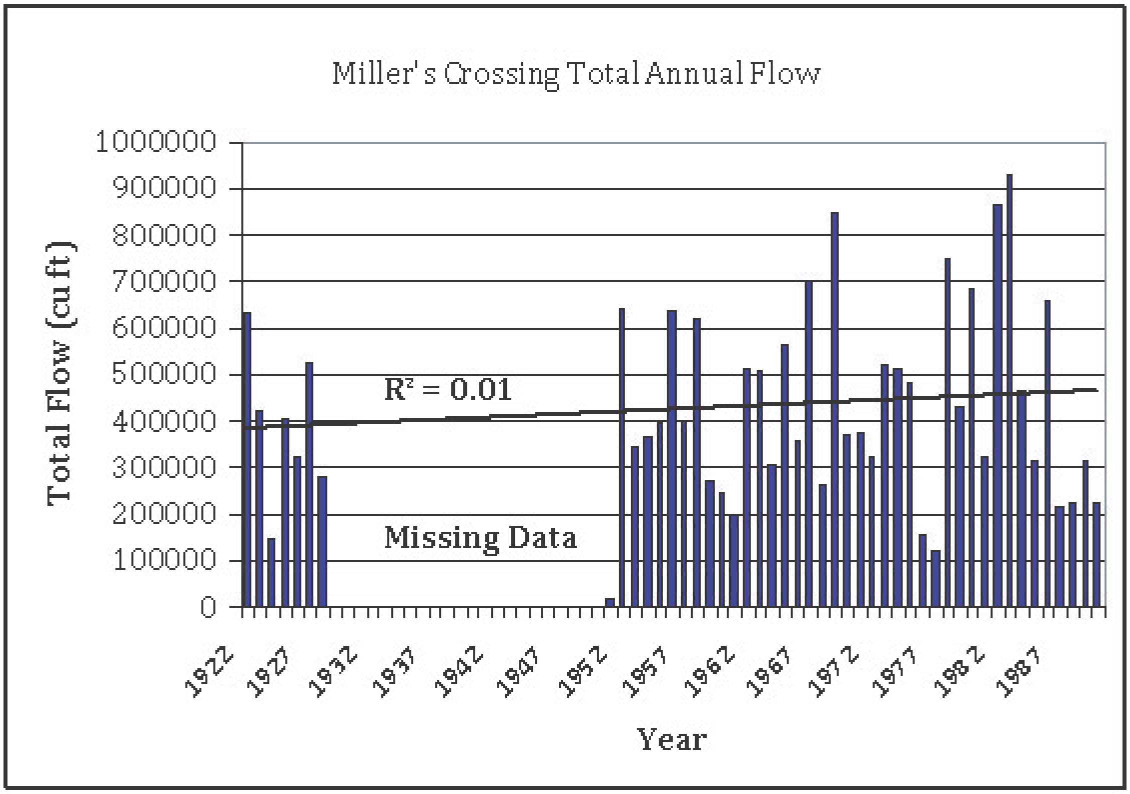

Figure 4.6. Annual discharge at Miller's Crossing 1922 – 1991. Linear trend line: $R^2 = 0.01$ ($p < 0.50$).

An analysis of stream flow data for the Sierra Nevada Network parks was recently finished (Andrews, 2012). Andrews analyzed trends in surface water flows at 20 gages with the longest period of record of essentially unimpaired flow within and around the SIEN parks. The gage at Miller's Crossing was included in this analysis. Using records at each gage, Andrews calculated three common metrics of the temporality of spring snowmelt and runoff: 1) the proportion of water year flow that occurs during the months of April through July to total water year flow (aka spring runoff amount); 2) the number of days from the start of the water year (Oct 1) to the center of mass of the surface flow (aka center of mass); and, 3) the number of days from January 1 to the beginning of spring melt runoff (aka spring runoff time). All three metrics are commonly used in the assessment of trends in surface hydrology in response to changing climate (e.g. Dettinger & Cayan, 1995; Cayan et al., 2001; Regonda et al., 2005).

In general, Andrews found only a few trends in these three metrics over the 20 gage stations that are statistically significant (at $p < 0.05$) using least-squares regression (Andrews, 2012). This includes the Miller's Crossing data which show no temporal trends in any of the three metrics. However, the spring runoff amount metric at this station has been trending down and does have a low p value ($p = 0.16$), and so certainly suggests that there may be a shift to less annual runoff during the April through July period for the watershed above this gage. The conclusions drawn from a shift to lower amounts of runoff during the typical spring and early summer runoff period are that a warming climate is generating earlier snowmelt runoff, and perhaps more rainfall runoff in the late winter period prior to April, and that less snow is accumulating above the gages. The reason why Miller's Crossing and so many gages in the Sierra are not showing statistically significant trends in the three metrics is that, as Andrews and others have found, while snowfall is decreasing at middle and low elevations, it is increasing at higher elevations. The increase at high elevations so far seems to be sufficient to offset the reduction at lower elevations, so that surface flows measured in the middle and lower altitudes are not changing much or at all. Nevertheless, Andrews (2012) does conclude that despite the lack of consistent statistical significance, there is a pattern of decreasing spring snowmelt amount on the western slope of the Sierra Nevada.

Andrews (2012) also analyzed magnitudes and trends of short period (3 – 14 days) high and low surface water flows for the same 20 gaging stations. For example, a 14-day high flow for a given year would be expressed as the maximum magnitude of flow exceeded over a 14 consecutive day period and the calendar date the 14-day period began. Overall, Andrews found no trends in the magnitude and timing of both high and low flows for the 20 gages across the SIEN, including Miller's Crossing. Many gages did express some weak trends in timing of low winter and summer flows, with some indicating earlier onset and some indicating later onset. At the Miller's Crossing gage, there were no statistically significant (at $p<0.05$) trends in magnitudes and timing of high flows or summer low flows. One exception in the flow analysis was a weak but non-significant trend of increasing magnitude of short-period winter low flows. A likely explanation for this trend is that the contemporaneous trend of increasing minimum temperatures over the last 30-40 years is driving the increase in wintertime flows.

Peterson et al. (2008) examined flow data from Miller's Crossing and 23 other Sierra Nevada gaging stations. Using only data from 1952 through 1990 at Miller's Crossing, they found that the timing of peak flow (maximum daily stream discharge) progressed 22.5 days earlier from 1952 to 1990 while the magnitude of that peak discharge declined slightly. Most (19) gaging stations in the Sierra Nevada examined by Peterson et al. demonstrated similar advances in the timing of peak flow. However, in contrast with Miller's Crossing, most (19) stations showed an increase in peak flow.

Currently, we can conclude that the surface water flows in DEPO are much as they have been for the last approximately 90 years. However, there may be a small trend toward earlier spring runoff and decreased late spring and summer runoff due to regional climate warming and associated changes in precipitation patterns. However, the findings of Peterson et al. (2008) indicate a large shift toward earlier spring snowmelt, though only through 1990. A dramatic documented rise in regional minimum temperatures is likely driving these weak trends and shifts, though higher snowfall at elevations above ~2,590 m (8,500 ft) are somewhat alleviating the effect of the rise in temperature on the magnitude and timing of surface flows. In future years, the automated stream gage in DEPO will be used to more accurately determine conditions and trends within the monument.

Surface Water Dynamics – Current Condition Summary
Reference conditions for surface water dynamics would be a long-term record of variable though steady longer-term averages of the measures of flow volumes and timing of flow events that have not been influenced by direct human actions or indirectly by greenhouse gas emissions and associated warming. While total annual flows based on proxy data indicate mostly only small changes over long periods, findings of the research so far suggest and even provs that the timing of flows has changed in the southern Sierra Nevada. Although no local data confirms these patterns, we can infer that it is likely happening in DEPO as well. Therefore, the current status of surface water dynamics may be expressing the influences of a rapidly changing climate that appear to be altering the timing and duration of snowmelt, peak flows, and low flows. We conclude that the current conditions of surface water dynamics are fair to good.

Surface Water Dynamics – Threats & Stressors

Climate change
Research has already documented that spring snowmelt and runoff are occurring 1-3 weeks earlier in the Sierra Nevada and these changes have been linked to a changing climate (Stewart et al., 2005; Peterson et al., 2008). However, Maurer et al. (2007) found that observed trends in the center timing (CT) of stream flow in four large watersheds in the Sierra Nevada were not beyond the natural variability of the watersheds and so the observed trends could not be positively attributed to external (anthropogenic) factors.

Although there is variation in the model projections of precipitation amounts through the end of this century, it appears that amounts would not change much, though increasing temperatures could make the climate dryer overall (Seager et al., 2007; Cayan et al., 2010). With no significant changes to precipitation amounts, it has been speculated that there will be no significant changes in total annual surface runoff as well (Dettinger & Cayan, 1995; Dettinger et al., 2004), though anticipated increased in evapotranspiration could very well reduce flows (Null et al., 2010). Regardless, temporal patterns of runoff are expected to change. A projected increase of 2.5 °C (4.5 °F) by the end of this century could translate into significantly earlier snowmelt runoff, reduced summer water flows, and reduced soil moistures (Dettinger et al., 2004; Stewart et al., 2004, 2005; Dettinger, 2005a), an increase in winter and spring flooding events (Dettinger et al., 2004), and an overall shift to more annual runoff occurring during winter (Miller, 2003). An increase in 2 - 4 °C (3.6 - 7.2 °F) by the end of the century is expected to bring longer and more severe droughts in the southwest (Cayan et al., 2010) resulting in reduced surface flows.

Maurer et al. (2007) examined the potential effects of changing climate on the hydrology of four Sierra Nevada basins, including one to the north and one to the south of the San Joaquin. Using a hydrologic model, they predict that river flows will increase during the December – April period, and decrease during the May – October period for high elevation basins. The model predicts that the combined effects of changes in temperature, precipitation, and snow water equivalent could result in the earlier arrival of half the annual flow volume by as much as 36 days by the end of the century. In addition, Null et al. (2010) used a rainfall-runoff model to determine changes in the timing and magnitude of rivers flows in 15 west slope Sierra Nevada watersheds with increases in air temperature of 2.0, 4.0, and 6.0 °C (3.6, 7.2, 10.8 °F) in order to understand each basin's sensitivity to warming. Unimpaired base flow was established from the 1981 - 2001 period. They modeled changes in mean annual flow (MAF), center of timing (CT), and low flow duration (LFD). The San Joaquin watershed (includes DEPO) was one of the least sensitive to reductions in MAF, though warming scenarios did reduce flows for each incremental increase of temperature. In contrast, this watershed was one of the most sensitive to shifts to earlier CT – from two weeks earlier with a 2.0 °C (3.6 °F) warming to almost six weeks earlier with a 6.0 °C (10.8 °F) warming. Both of these changes are likely due to the relatively high elevation of the San Joaquin basin compared to the rest of the Sierra Nevada. The basin was not very sensitive to LFD, changing only slightly – about 1.5 weeks longer – with 6.0 °C (10.8 °F) warming.

Groundwater Dynamics

No comprehensive groundwater studies have been done in the area of the monument. Nonetheless, much can be gleaned from an examination of available information. The existence, extent, and movement of groundwater are largely a function of the rocks and/or unconsolidated sediments through which groundwater moves. Major factors are: (1) the ability of the rocks and/or sediments to store and transmit groundwater (rocks and/or sediments that store and transmit groundwater in appreciable quantities are called aquifers); and, (2) the 3-dimensional extent and continuity of the aquifers. Note that some of the information and most of the condition judgments reported in this section ("Groundwater Dynamics") are provided by the NPS Water Resources Division (L. Martin, pers. comm.; W. Van Liew, pers. comm.).

Hydrogeologic Setting

As stated in Section 4.3.2 "Geology" herein, "the rocks inside the monument are dominated by Cretaceous age granites and basalts, with minor portions of andesite, alluvium, and other surficial deposits. Outside of the monument there are substantial amounts of Reds Meadow tuff, dacite from Mammoth Pass, and basalt of Red Cones." The areal extent of these rocks is shown in Figure 4.4, and Table 4.6. The listed rocks are of three types: (1) alluvium, which is unconsolidated sediments transported by moving water; (2) granite, which is an intrusive igneous (i.e. crystalline) rock; and, (3) various volcanic rocks (basalt, andesite, dacite, and tuff), which are extrusive igneous rocks that were deposited by lava flows or air falls.

Alluvium exists within the monument in the floodplain of the MFSJ River, and likely in small amounts along Reds Creek. Much of the alluvium in the floodplain of the MFSJ River is known to be well sorted and very coarse-grained, and thus likely has a very high ability to transmit and store groundwater; however, it is limited in both lateral and vertical extent.

The Cretaceous-aged granite mapped in much of the monument and to the northeast (Figure 4.4) is present over much of this region of the Sierra Nevada Mountains, and is known to transmit and store little, if any, groundwater. It is generally massive and unfractured. The rock matrix does not transmit or store groundwater at all; and without fractures there is likely no groundwater transmitted or stored in this type of rock. Volcanic rocks comprise a substantial part of the monument and the adjacent volcanic Mammoth Mountain to the east. Although volcanic rocks typically don't comprise extensive aquifers, they exhibit high variability in their characteristics to transmit and store groundwater. Groundwater can be stored and transmitted through fractures, through openings formed by gas bubbles during volcanic deposition, in soil zones formed in the time between successive volcanic flows, and in brecchia deposits (i.e., rock rubble). However, due to the high degree of variability, the lateral and vertical extent of aquifers in volcanic deposits typically is not large. Much is still unknown about the extent and continuity of these features in the monument and the surrounding area, and their characteristics to store and transmit groundwater.

Hydrologic Setting

Groundwater recharge occurs from infiltration of precipitation and streamflow into rocks and unconsolidated sediments. In the area of the monument, most groundwater recharge is likely due to infiltration of snowmelt.

Groundwater movement occurs through rocks and sediments in response to changes in fluid elevation and pressure (i.e. hydraulic head). There are no existing maps of groundwater hydraulic head (known as potentiometric-surface maps) in the area of the monument. However, groundwater usually moves slowly in a generally downhill direction. It is reasonable to assume that groundwater in the area of the monument moves generally toward the MFSJ River and toward the downstream direction of the MFSJ River. If aquifers are continuous across surface-water divides, the ground-watershed can encompass an area larger than a surface-watershed. There is no evidence that this either does or does not occur in the area of the monument.

Groundwater discharge occurs as baseflow to streams, as discharge to springs and seeps, and as transpiration from vegetation. In the area of the monument, there might be subaqueous groundwater recharge to or groundwater discharge from the MFSJ River, or both along different reaches of the river, but this is unknown. The amount of such groundwater interaction with the MFSJ River is typically of a magnitude that is far less than the total flow of the MFSJ River in the monument, and thus is practicably impossible to measure directly. Some springs and seeps exist in and adjacent to the monument, which can be evaluated to glean some groundwater information.

Springs and Seeps

Springs represent the surface expression of groundwater. The largest known spring within the monument is Soda Springs, which is a cool-to-cold-water mineral spring located at river level in Soda Springs Meadow. This spring is submerged by the MFSJ River during high flow in spring, and usually becomes exposed by mid-summer. Rocks at the spring orifice are stained white and red, likely from precipitation of minerals (principally iron and carbonates) from the spring water and also possibly due to biochemical activity. Gas bubbles also emanate from the spring flow, in accordance with its name – Soda Springs. Furthermore, algal blooms occur periodically in the water in the vicinity of the spring outflow. Prior to 2001, a low-water level crossing for stock passed in close proximity to the spring. In 2001, the crossing was closed due to apparent trampling impacts to the spring and adjacent meadow. New alignment of the main trail approaching the spring, and better trail design may be needed to improve access and increase protection of the spring. Since there has been no long-term monitoring of the spring, it is unknown if there are any current stressors or threats to this spring. There are several spring orifices in the vicinity of the main Soda Springs. The USGS had recently sampled the spring water for minerals, though results were not available at the time of this writing. Hydrologic and hydrogeochemical monitoring of the spring and an investigation of the groundwater-surfacewater interactions are needed to help better understand the source of the gaseous, mineralized water to the spring, and to assess the possibility and likelihood of other, more regional threats, if any, to the springflow and water quality. A preliminary survey of other springs in the monument was conducted in 2009, though results were not available for this report.

Groundwater Wells

A shallow dug well was constructed in the coarse-grained stream alluvium approximately three meters (10 feet) east of the MFSJ River near the north end of the monument. The well was 1.5 meters (5 feet) in diameter, 6 meters (20 feet) deep, and reportedly produced up to 40 gallons per minute (gpm). It provided water to facilities at the visitor center, employee housing, and the campground for nearly 50 years. It also provided emergency water supply for fire fighting for the monument and the surrounding Inyo National Forest.

A new water-supply well was drilled in 2007 on the hill above and northwest of the campground. The new well is 67 meters (220 feet) deep and obtains water from fractured basalt. It was estimated by on-site personnel during the pumping test that the well could likely yield 100 gpm. This new well has replaced the older well for water supply at the monument. It currently is pumped intermittently at about 20 gallons per minute, and provides good quality water for use in nearby monument facilities. Well water temperature was found to be 6 to 8 °C (43 to 46 °F) and pH was 6.3 to 6.5. The well water meets all required drinking water standards. Mean annual withdrawals from this well currently total approximately 350,000 gallons (1.1 acre-feet per year). Since the manner of use of this groundwater is for the aforementioned domestic uses, most of the groundwater use is non-consumptive (i.e. showers, washing dishes, and toilet flushing) and likely returns to the aquifer through a septic leachfield. In summary, the total water use is very small, and the consumptive use is even smaller, typically about 10% of the total use for such domestic purposes. Therefore, impacts of pumping groundwater from both the old and new wells are miniscule, and essentially negligible.

Just northeast of the monument, the USGS drilled a bedrock groundwater monitoring well near the gravel pit. This well was installed as part of research regarding volcanic and seismic activity. It is reported that the well encountered basalt, which was water-bearing in places, underlain by impervious granite. The total depth of the monitoring well was about 100 meters (330 feet), and the well was screened across a water-bearing section immediately overlying the granite at a depth of about 43 meters (140 feet) (Roeloffs, 2006).

North of the monument, the U.S. Forest Service (USFS) drilled several test wells in the same general area as the USGS monitoring well in an attempt to provide drinking water for the five campgrounds that they operate along the MFSJ River (Larry Martin, NPS, written communication, 2006). They reportedly have a good-quality water-supply well located at the Pumice Flat campground north of the monument that is 26 meters (85 feet) deep, having penetrated 12 meters (40 feet) of alluvium underlain by 14 meters (45 feet) of basalt. The static water level in the well is reported to be six meters (20 feet) below ground surface. This well supplies drinking water to Pumice Flat, Upper Soda Springs, Minaret, and Reds Meadow Campgrounds. The USFS Agnew Meadows Campground, located about 5.6 kilometers (3.5 miles) north of the monument, has a water-supply well that is 21 meters (70 feet) deep and also reportedly produces good quality water. East of the monument, the USFS drilled two test wells at Reds Meadow Campground: one in the meadow and one in the pasture. Both wells produced hot, geothermal water and were abandoned. The USFS then drilled horizontal wells about nine meters (30 feet) into the hillside northeast of the Reds Meadow Campground in an area of diffuse seepage. These horizontal wells produced water but had high bacteriological counts and were thus abandoned. The Reds Meadow Resort located approximately 0.8 kilometers (0.5 miles) south of Reds Meadow Campground, however, is reported to have their own private water-supply well of acceptable water quality. No further information regarding this well is available at this time.

The USFS water-supply wells are not metered; however, water is pumped from these wells only during the short camping season. It is reasonable to assume that the total water usage in these public campgrounds is similar to or less than the total usage for domestic uses within the monument. Thus, it is likely that groundwater pumping at the USFS campgrounds also has negligible effect on the water resources in the area.

Within the monument, four monitoring wells, each less than three meters (10 feet) deep, were installed in Soda Springs Meadow in the summer of 2003 to monitor changes in the level of groundwater, and how this may be affected by soil compaction along the well-used trail that bisects the meadow. This monitoring has included periodic measurements of river stage height under nearby Soda Springs Bridge and water levels in the four wells in the meadow, two on the east side of the trail and two on the west. Data collection from the monitoring wells has occurred in the summer field season only and has not been consistent: 2003, 2004, part of 2005, 2006, 2009, and again in 2010. A protocol was established in 2006 to use standardized methods of data collection at a frequency of two to three times per week. Due to the shallow depth of the monitoring wells, the lack of annular sealants in the well construction, the short nature of this dataset, and the inconsistency of monitoring so far, no assessment can be made as yet. A shallow groundwater monitoring well with a datalogger was installed in Soda Springs Meadow in 2009 as part of the SIEN I&M wetlands monitoring project (Gage et al., 2009), but no long-term data are yet available.

From the information provided by the monument's water supply wells, the USFS campground water supply wells, the USGS monitoring well, the shallow wells in Soda Springs Meadow, and the existence of the Soda Springs and the Reds Meadow Hot Springs, the following conclusions can be reached:

(1) There is abundant groundwater in the shallow alluvium and wetlands adjacent to the MFSJ River, but the alluvial aquifer is of limited depth, likely on the order of 15 meters (50 feet) deep or so, and limited in areal extent;

(2) Groundwater does occur in volcanic rocks such as basalt in places in and adjacent to the monument, and there likely are water-bearing sections in volcanic rocks in fractures, at the interface

between volcanic flows, and possibly in voids left by gas bubbles during volcanic deposition and in breccia deposits, all of which are common in places in volcanic rocks;

(3) Granitic rocks are likely impervious and not water-bearing;

(4) At certain locations there is a hydrologic connection between surface water and groundwater, including groundwater that has surfaced from enough depth and/or with enough residence time underground to acquire substantial mineral content and/or heat; and,

(5) This information alone is insufficient to draw conclusions regarding the lateral extent or depth of any water-bearing zones in bedrock in the area or of any groundwater – surface water interactions in or adjacent to the monument.

Groundwater Dynamics – Current Condition Summary

Reference conditions would be a fully functioning groundwater system that is resilient and unimpaired by either human groundwater usage and/or by human driven climate change. While models anticipate a future reduction of snowfall and winter snowpack at higher elevations in the Sierra Nevada, no trend is yet evident. Snow is needed to recharge groundwater and to maintain groundwater levels and natural discharges. Current volumetric rates of groundwater pumping for domestic and campground uses within and near the monument in the MFSJ River valley are so small that they almost certainly have negligible effects on groundwater storage and capture. Thus, depletion of streamflow or springflow within the monument, or adverse effects to riparian and wetland water-dependent biological resources, is highly unlikely as a consequence of current pumping rates. Local groundwater pumping will continue to have negligible effects on resource conditions in the future as long as rates do not increase substantially.

It is theoretically possible that substantial and increasing volumetric rates of groundwater withdrawals for municipal and commercial uses by Mammoth Mountain Resort and the Town of Mammoth Lakes in a different surface-water drainage about 8 – 16 kilometers (5 - 10 miles) east of the monument may deplete groundwater storage and may capture and thus deplete surface-water resources within the monument in the future, but insufficient information currently exists to make a specific determination whether this is likely and/or if the depleted quantities, if any, would be substantial or negligible.

We conclude with moderate to high confidence that the groundwater system at DEPO is in good condition.

Groundwater Dynamics – Threats & Stressors

Human Impacts

It is theoretically possible that groundwater withdrawal by the Mammoth Mountain Resort and Town of Mammoth Lakes could impact groundwater and surfacewater resources at the monument. No quantitative hydrogeologic studies have been done to evaluate this possibility or to determine if the depleted quantities, if any, would be substantial. Mammoth Mountain property straddles the crest of the Sierra Nevada, with its eastern slope streams flowing into the Town of Mammoth Lakes and the western slope streams flowing into the Inyo National Forest and DEPO. Groundwater withdrawals on the northern slopes of Mammoth Mountain are unlikely to reduce groundwater storage on the western and southern slopes of the mountain, or to affect tributary stream flow into the monument and/or springs in and adjacent to the monument. The local groundwater withdrawals for operations and visitor use both inside and near the monument are mostly non-consumptive and are so small that they almost certainly will have negligible effects on groundwater resources anywhere.

There is some concern that groundwater withdrawals from volcanic rocks for water supply at nearby Mammoth Mountain Resort and the Town of Mammoth Lakes may impact groundwater resources and water-dependent processes in the monument. Although these areas are in a different watershed and on the eastern side of the Sierra Nevada crest, their close proximity may deserve some attention. Water usage for the Town of Mammoth Lakes from eight production wells in the Mammoth Basin watershed fluctuates in response to seasonal changes in visitor population and land-use activities. Demand is highest in the summer months when precipitation rates are low and water is needed for irrigation of residential and commercial landscapes (MCWD, 2005). Groundwater pumping is supplemental to surface water sources for the town. More groundwater is pumped during dry years when surface water is less abundant. Historically, groundwater pumping from the municipal wells has averaged around 2000-2500 acre-feet per year (afy) (MCWD, 2005), but is reported to be increasing in recent years. The municipal wells are completed in basalt on the north side of Mammoth Mountain. The degree of hydrologic connection, if any, of the water-bearing basalt on the north side of Mammoth Mountain with groundwater in water-bearing volcanic rocks or with springs within and adjacent to the monument on the west side of Mammoth Mountain, is unknown. It is theoretically possible that continuous permeable volcanic bedrock would allow groundwater flow east-west through the mountain, but no evidence of such continuity exists. Furthermore, groundwater pumping on the east side of Mammoth Mountain is more likely to capture and thus deplete nearby surface-water resources in amounts equal to its withdrawal rate than to propagate all the way to the other (west) side of the mountain and deplete surface waters there.

Water supply wells for Mammoth Mountain Resort are generally on the north side of Mammoth Mountain. No information is available to the NPS regarding the number or location of water-supply wells, their depth, the aquifer(s) that are the source of water, or the annual amount or seasonality of water being pumped for use at the resort. As a result, it is unknown whether groundwater pumping from the municipal wellfield on the north side of Mammoth Mountain would have any, a minimal, or a substantial impact on the water and water-dependent resources in the monument or on the west side of Mammoth Mountain adjacent to the monument. Also, it is unknown if such groundwater connection exists, and how long it would take for an effect to propagate to the monument. However, DEPO has submitted a Technical Assistance request to the NPS Water Resources Division to devise a scientifically sound approach to investigate this issue. NPS Water Resources Division is currently gathering information and working to develop a plan of investigation.

Sampling, testing, and analysis of spring and surface water in 2008 and 2009 to the north and east of DEPO has been completed, in order to characterize the quality of waters flowing from those springs and help determine the degree to which snowmelt was recharging aquifers (Burak, 2010). However, this study did not intend to and so did not explicitly address the question of groundwater-surface water interactions between the Mammoth Mountain area and the monument.

In conclusion, there is still much uncertainty regarding the groundwater dynamics of the monument. Soda Springs is a unique feature within the monument that may warrant further investigation. It is possible that increasing rates of groundwater pumping both within and outside the monument might adversely affect surface waters, wetland dynamics, and associated species in the monument in the future. In addition, changes in the regional climate regime and associated changes in precipitation patterns and amounts may influence groundwater dynamics. However, more information is needed before questions can be answered regarding how natural resources within the monument might be affected by groundwater pumping, and how Soda Springs and other springs might be affected.

Climate Change

As regional climate warms and continues to warm, snowpack will decline. However, recent evidence documents an increase in snowfall and snow water equivalent (SWE) at higher elevations of the central and southern Sierra Nevada over the past 50 - 60 years that is being driven by an increase in precipitation, and the opposite trend at low and mid elevations (Howat & Tulaczyk, 2005; Mote, 2006; Andrews, 2012). A reduction in snowpack and SWE has been recorded over most of the Western United States (Hamlet et al., 2005; Knowles et al., 2006; Mote, 2006). In addition, earlier snowmelt and spring runoff in the Sierra Nevada (Stewart et al., 2005; Peterson et al., 2008) will lead to a longer summer dry period. Winter snowpack is a very important mechanism for slowly recharging groundwater storage in the spring and for sustaining deeply-rooted vegetation, meadows, and surface streams through the dry summer months. Snowmelt is disproportionally important for groundwater recharge in the southwestern U.S. (Earman et al., 2006). If changes in climate cause a reduction of winter snowpack and a continuing trend of earlier spring snowmelt, one hydrologic consequence will be increased water shortages and decreased groundwater storage in summer and fall. Furthermore, as air temperatures increase, groundwater storage will be further depleted through elevated evapotranspiration rates.

<u>Snowpack</u>

Snowpack is discussed here rather than in the Weather and Climate section since snow is a form of water. Collection of manual snow course data in Soda Springs Meadow began in the winter of 2009/10. In the future, this data will provide valuable supporting data for the snow pillow. Sensors for snow depth and snow water equivalent (SWE) in Devils Postpile National Monument snow pillow site were installed in late 2006, though both sensors have many data gaps and data inconsistencies until late 2009. Data from the California Department of Water Resources snow pillow sensors are available online at the California Data Exchange Center (CDEC); the name of the snow pillow is DPO. This dataset is insufficient to determine conditions and trends of snowpack and snow water content within DEPO. However, near to the monument, a snow station and automated snow pillow at Mammoth Pass (MAM) run by the Los Angeles Department of Water and Power has been measuring daily snow depth and water content since 1970, and manual measurements have been taken monthly since 1928. The station is at 2,835 m (9,300 ft) elevation. Taking the manual snow course observations closest to April 1, a temporal analysis of April 1 SWE at the MAM station indicates high inter-annual variability but no trend up or down (least squares regression: $p = 0.84$) (Figure 4.7).

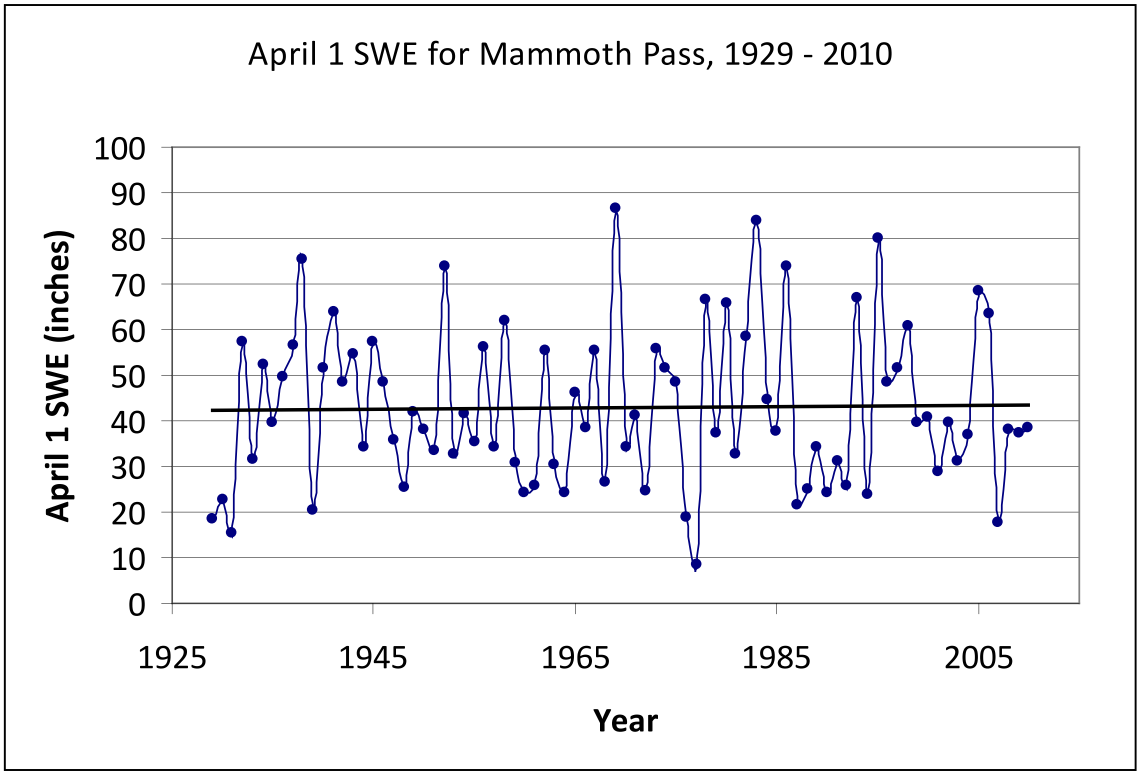

Figure 4.7. Mean annual snow water equivalent (in inches) at the Mammoth Pass snow course during the period 1929 to 2010. Linear regression line in black.

Several efforts to analyze SWE data in the Sierra Nevada to investigate trends in April 1 SWE have found decreases over time, with some exceptions. Most recently, Andrews (2012) focused on April 1 SWE for the area around the SIEN parks and drew similar conclusions to previous published studies. While Howat and Tulaczyk (2005) determined that the break point between increasing and decreasing April 1 SWE occurred at approximately 2,500 meters (~8,200 feet), Andrews (2012) determined that the transition occurred slightly higher at an elevation of approximately 2,600 meters (~8,500 feet). DEPO lies just below these elevation beak points. April 1 SWE decreased most at elevations near the lower limit of snowfall accumulation (< 2,135m (7,000 ft)) (Andrews, 2012). Only 2 of the 68 snow courses examined by Andrews demonstrated statistically significant trends, and only at $p < 0.1$. DEPO lies in the elevation range of ~2,200 m – 2,500 m (~7,200 ft - 8,200 ft) which is just below this transition zone and very close to the peak in SWE decline. If temperatures continue to rise, it is expected that snow levels will also rise and the rate of decreasing April 1 SWE at mid-elevations will increase.

Kapnick and Hall (2009) examined SWE and the center of mass for snow accumulation for 154 snow stations throughout the Sierra Nevada that have records of at least 30 years since 1930. The snow accumulation center of mass is the median day of the period during which snow is on the ground. Throughout the Sierra Nevada, this center of mass has been coming earlier in the year at a rate of 0.6

days/decade. The large majority of snow stations have also recorded decreasing trends in April 1 SWE, though most trends are not statistically significant (at $p < 0.05$). Trends in center of mass and April 1 SWE were strongly related to rising temperatures in the March-April time period.

In contrast to most locations in the western U.S., the Sierra Nevada has experienced an increase in snowfall and April 1 SWE at high elevations and a contemporaneous decrease at lower elevations over the past 53 years in response to trends of increasing precipitation and increasing temperatures (Howat & Tulaczyk, 2005; Andrews, 2012). Howat and Tulaczyk (2005) analyzed data from 177 snow courses and found no statistical temporal trends in April 1 SWE. Mote (2006) determined that the central and southern Sierra Nevada have experienced on average an increase in April 1 SWE over the period 1960 – 2002 that was driven by an increase in precipitation. The same is not true for the northern and the far southern part of the mountain range that both experienced similar reductions in snowfall and SWE as did the majority of locations in the western U.S. (Hamlet et al., 2005; Mote et al., 2005; Knowles et al., 2006). All this research concludes that high elevation areas such as the central and southern Sierra Nevada have received more snowfall in recent decades in response to an overall increase in precipitation, even as temperatures increased. Mid- to low-elevations experienced a drop in snowfall due to rising temperatures. As a result, spring snowmelt and runoff have begun 1-4 weeks earlier in the western U.S. compared to a half century ago, though trends in the southern half of the Sierra Nevada have been more muted (Stewart et al., 2005).

Snowpack – Current Condition Summary

Reference conditions would be a record of variable but long-term stable snowfall and winter snowpack, especially April 1 SWE, with no significant trends that are associated with greenhouse gas emissions and warming climate. No long-term data exists for the monument. From the snow station and snow course data from the Sierra Nevada and especially from the nearby Mammoth Pass snow course, DEPO has either experienced no trend in April 1 SWE or is experiencing a small but statistically insignificant decrease. Therefore, the current condition of snowpack in DEPO is good to excellent. In the future, the newly established snow pillow and snow sensor in DEPO will allow condition and trends analyses.

Snowpack – Threats & Stressors

Climate Change

Climate models for the Sierra Nevada region predict that accumulation and longevity of Sierra snowpack will decrease as a result of likely warming scenarios (Cayan et al., 2007) in which precipitation remains generally the same but more falls as rain instead of snow (Knowles et al., 2006). In support of this prediction, a decrease in April 1 snow water equivalent has been observed across most locations in the western United States (Mote et al., 2005), a trend that is attributed to a reduction of winter snow mass and earlier spring melt. This trend is expected to continue as regional and global temperatures increase (Knowles & Cayan, 2002). When a set of different climate model future projections, downscaled to a 12-kilomter grid, were used as inputs to the Variable Infiltration Capacity hydrologic model, results showed a range of impacts on snow accumulation in California mountains, though all of them substantial reductions. According to the modeled results, by 2100 total snow water storage volume declines 60-93% at 1,000 to 2,000 meters (3,280 – 6,562 ft) and 25-79% at 2,000 to 3,000 meters (6,562 – 9,843 ft) (Cayan et al., 2007).

A projected increase of ~2.5 °C (4.5 °F) by the end of the century would mean a lower snowpack volume at mid-elevations (Knowles & Cayan, 2002). Based on a range of climate change scenarios, Miller et al. (2003) projected a 50% reduction in snowpack in higher elevation basins of the Sierra Nevada by the end of the century. If projected trends of increasing temperatures and resultant decreasing snowfall and snow water equivalent in the western U.S. come to pass, then we may expect a significantly reduced snowpack in the DEPO area. Knowles and Cayan (2002) modeled a 46% reduction in April 1 SWE in the Sierra Nevada by the year 2060 and a 52% reduction by the year 2090. Knowles and Cayan (2004) then modeled future changes in Sierra Nevada snowpack based on the projected temperature increases from the Parallel Climate Model. Their hydrologic model predicts that peak decreases in SWE occur at approximately 2,500 meters (8,200 ft) for the period 2050-2069 compared to the historical period, with the most loss occurring at the lower and mid-elevations. Their modeling projected that a 1.6 °C (2.9 °F) increase in temperature by 2060 over the Sierra Nevada results in a reduction of April 1 SWE of about one-third. Maurer (2007) used a hydrologic model and different emissions scenarios to predict that by the end of this century, April 1 SWE will be reduced in all basins of the Sierra Nevada by 36% - 80%. Higher elevations are projected to experience the least changes, though they will still be significant.

Up until now, increasing trends in snowpack and SWE at higher elevations in the central and southern Sierra Nevada have been bucking the more general decreasing trend found across the western U.S. It is uncertain at this time if this contrarian trend will continue or if this part of the Sierra Nevada will begin to experience a decrease in snowfall and snow water content. However, we can expect snow levels to continue to rise if regional temperatures continue to rise. If snowpack does decrease in the future, ecosystems will be subjected to more severe and longer summer drought periods (Dettinger et al., 2005; Mote et al., 2005). It is likely that the increasing trend observed at high elevations in the central and southern Sierra Nevada have been driven by an increase in precipitation over the period.

The observed shift in the timing of spring snowmelt in the western U.S. has been statistically attributed to anthropogenic changes including greenhouse gas emissions (Hidalgo et al., 2009). Similarly, Pierce et al. (2008) concluded that the decline in the ratio of April 1 SWE to water year precipitation over the entire mountainous western U.S. was consistent with model results that included the effects of a buildup of atmospheric greenhouse gases. However, when the southern Sierra Nevada was examined separately, trends in April 1 SWE/water year precipitation before April 1 could not be distinguished from natural variability (Das et al., 2009). This may well be that this part of the Sierra Nevada is high enough to have been so far insulated from and insensitive to climate warming.

Water Quality

Common constituents that are used to assess water quality in the Sierra Nevada are temperature, pH, alkalinity, dissolved oxygen, dissolved carbon, turbidity, chlorophyll, chlorine, phosphates, nitrogen (nitrates and nitrites), suspended minerals, and living organisms like bacteria and macro-invertebrates. Concentrations or levels of these constituents beyond standards set by state or federal agencies and/or even abrupt changes (such as increasing or decreasing patterns) of any of these constituents would indicate a potential threat to water quality. Threats to water quality in the area of the monument are recreational use, atmospheric deposition, non-point source pollution from roads and parking lots (from road surfaces and fluids from autos), and former mining operations upstream of the monument.

The quality of surface and ground water in the monument is generally good, as seen in water quality data and reports from several sources. Primary sources of water quality data for the monument and upstream areas are: (1) The Baseline Water Quality Data Inventory and Analysis (NPS ,1998); (2) STORET Water Quality Database (U.S. EPA); (3) Fishery and Riparian Resources of Devils Postpile National Monument and Surrounding Waters report (Rowan et al., 1996); (4) Friends of the Inyo Water Quality Report on the Upper San Joaquin Watershed (Chamberlin, 2009); (5) recent water quality monitoring nearby DEPO by U.S. Forest Service staff; and, (6) 2009-2010 NPS water quality monitoring (Pettebone et al., 2010).

The Water Resources Division of the National Park Service compiled the results of surface water quality data for the Upper San Joaquin River Watershed and Devils Postpile National Monument from the EPA national databases (NPS, 1998). The report examined data taken from 18 monitoring stations in the area, five of which were in the monument, and all measured a total of 78 parameters (constituents), with 67 observations within the monument and an additional 358 observations outside and nearby between 1980 and 1997. The five stations within the monument as well as the closest four stations in nearby Reds Meadow Resort area are shown in Figure 4.8. Stations 1, 2, and 7-9 are in the MFSJ River main channel while stations 3-6 are springs in the Reds Meadow area.

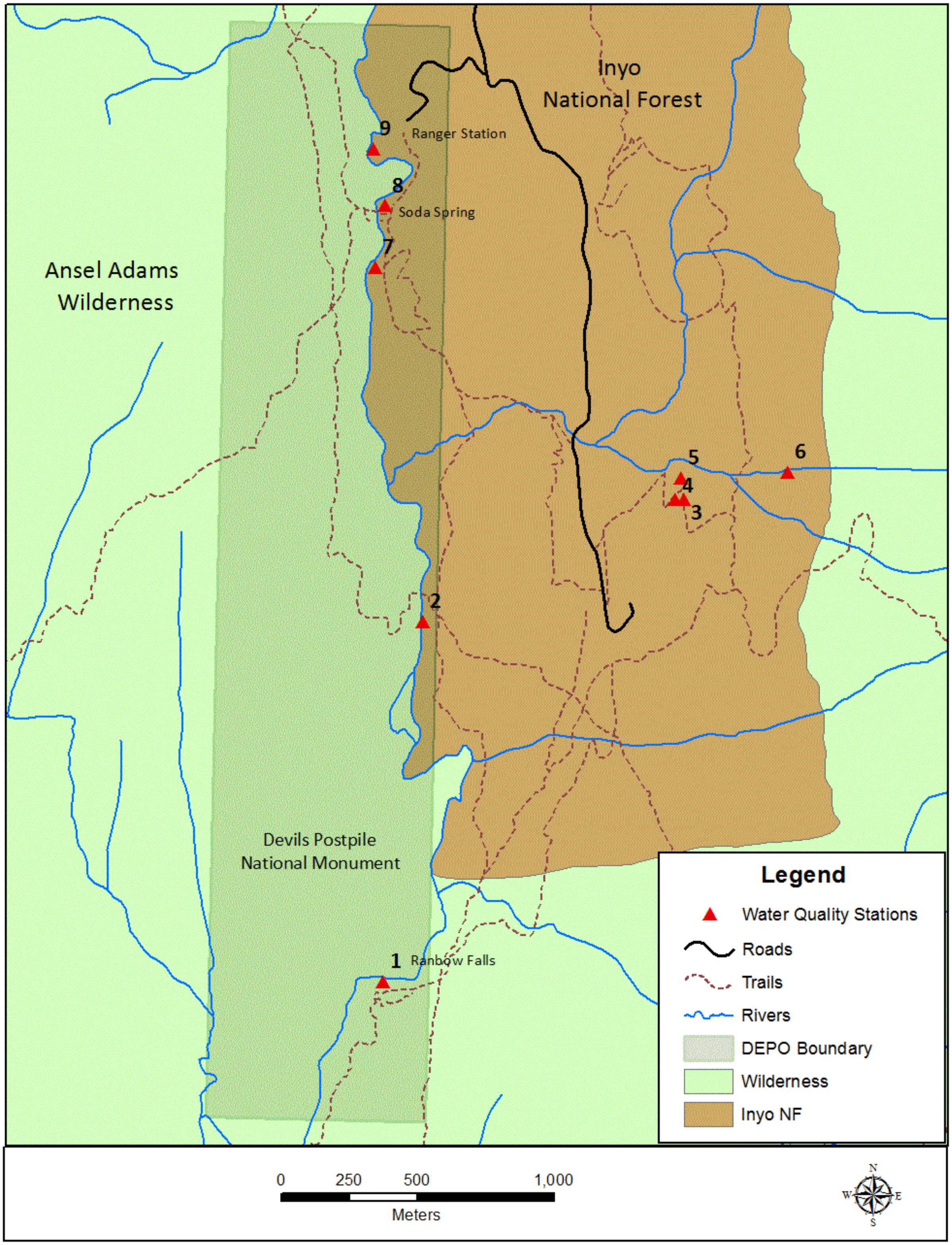

Figure 4.8. Water quality stations from the EPA STORET database within and nearby DEPO.

Most (13) of the 18 stations were one-time or single year sampling efforts, and so the data do not represent consistent long-term monitoring. The five sites that were monitored for more than one year include: MFSJ River just downstream of the Muir Trail crossing (Station 2), Reds Meadow Spring (Station 4 east of the monument), Devils Postpile picnic area (Station 7), a site just upstream from Soda Springs Bridge (Station 8), and a site 100 meters (328 ft) downstream from the DEPO Ranger Station (Station 9) (NPS, 1998). The data inventories compiled and reviewed by the NPS indicated a lack of long-term monitoring and the absence of some key water quality data, such as bacterial content, chlorophyll, and dissolved oxygen concentration.

Though generally good, water quality did vary by year and location (NPS, 1998). In some years at some locations within and nearby the monument (Stations 1-9, Figure 4.8), arsenic, chloride, fluoride, and pH exceeded standards or criteria. These included: 1) one exceedance of dissolved chloride at lower Soda Spring in 1984 (Station 8); 2) two exceedances of dissolved fluoride at nearby Reds Meadow Spring in 1984 and 1985 (Station 5); 3) two exceedances of arsenic in 1984, one at Reds Meadow Spring (Station 5) and the other at Lower Soda Spring (Station 8); and, 4) one exceedance of pH in 1984 and 1985 at Lower Soda Springs (Station 8). The report offers that potential anthropogenic sources of contaminants that led to exceedances include recreational use, atmospheric deposition, storm water runoff (likely from road surfaces), and mining operations (former).

Given the limitations of these data, conclusions about water quality conditions and trends in Devils Postpile National Monument are difficult to determine. However, the authors of the 1998 report conclude that the limited data do indicate that water quality in and around DEPO was generally good (through 1997). Since 1997, the STORET database (U.S. EPA) lists only one other one-time water testing of a well at Reds Meadow in September, 2006. This one-time testing specifically examined the concentration of nitrogen from nitrate and nitrite, and none was detected (Geotracker GAMA online database).

Longer-term water quality monitoring began in the summer 2009 when NPS staff tested water in the MFSJ River four times at each of three locations: just north of the campground, just south of the footbridge in Soda Springs Meadow, and below Rainbow Falls (Pettebone et al., 2010). Water was tested for fecal coliform bacteria, total dissolved nitrogen, nitrate and nitrite, total dissolved phosphorus, orthophosphate, total phosphate, and total petroleum hydrocarbons. Although there are no state or federal standards for total nitrogen, total dissolved phosphorus, and orthophosphate, results from the tests indicated levels well below standards for nitrate and nitrite and fecal coliform concentrations. All other constituents were also recorded at very low levels, and the authors conclude that the river water quality is very good. The authors do note that phosphorus concentrations showed an increase both over time during the 2009 season and with distance downstream. The contribution of natural and/or anthropogenic sources to this pattern is unknown. Data were collected again during the 2010 field season by DEPO staff but these data have yet to be analyzed.

Lutrick et al. (2010) tested surface water samples from the nearby Reds Meadow area in 2008. Fecal coliform concentrations were 50 MPN/ml (most probably number of colonies/milliliter) at two sites along Reds Creek upstream of the monument. Though apparently high, these levels are below water quality standards. All other constituents measured were well below standards and of no concern.

Rowan et al. (1996) collected water quality data in support of an assessment of fisheries of DEPO and surrounding waters. As part of the assessment, water temperature and pH were collected at several sites along the MFSJ River within the monument from June to October of 1994. Mean pH was 8.0, maximum temperature was 21.8 °C (71 °F) in August, and minimum temperature was -0.3 °C (31 °F) in early October. The data indicated nothing abnormal about temperature and pH.

The Friends of the Inyo in cooperation with the Inyo National Forest analyzed the quality of surface water in the San Joaquin River at multiple locations in the Inyo National Forest during July, August, and September of 2008 (Chamberlin, 2009). Three sites were sampled along Reds Creek and Sotcher Creek (tributaries of the MFSJ River) in a high-use area near Reds Campground to the east of DEPO. Results of these tests showed that water quality at the three sites met standards set by California's Lahontan Regional Water Quality Control Board and the San Joaquin Valley Basin. Parameters measured included: fecal coliform, total suspended solids, dissolved oxygen, pH, conductivity, turbidity, and nitrates/nitrites.

Atmospheric deposition of nutrients and other pollutants occurs as airborne particles slowly fall to the ground (referred to as "dry" deposition) but is accelerated during precipitation events (referred to as "wet" deposition). During cold months when precipitation falls as snow, nutrients will accumulate in the snowpack and flush into surface streams and lakes when the snow melts. Even minor changes in water chemistry and availability of nutrients like nitrogen, sulfur, and phosphorous can significantly alter the ecological balance of surface waters because they are dilute with low productivity (Nelson et al., 2008). Soils in the Sierra Nevada are generally thin and contain large areas of exposed or bedrock granite and metamorphic rock, providing weak buffering capacity with little or no biogeochemical retention or transformation of nutrients such as phosphorous or nitrogen (Horne & Goldman, 1994). No studies have been conducted on the chemical composition of winter snow or spring melt in the monument, but long-term monitoring of water quality at Emerald Lake in nearby SEQU suggests that seasonal eutrophication by phosphorous and nitrogen deposition observed at this site may be representative of a regional trend, such that large numbers of Sierra Nevada lakes may be experiencing at least mild eutrophication (Sickman et al., 2003). Fenn et al. (2003c) also found relatively high levels of nitrate in Sierra Nevada lakes, presumably from nitrogen deposition.

Clow et al. (2010) used data for nitrogen deposition rates to model deposition amounts throughout Yosemite. Using these estimates, they then modeled surface water nitrate concentrations throughout the park. The model predicted that high elevation sites with no or thin soils, and little to no vegetation were most susceptible to nutrient enrichment and acidification from nitrogen and sulfur deposition.

The USDA Forest Service Pacific Southwest Region's project LAKES has monitored lake water chemistry throughout the Sierra Nevada with the goal of detecting changes in water chemistry driven by atmospheric deposition. Twenty one lakes in Wilderness areas of the Sierra Nevada have been monitored for acid-base chemistry from 2002 to 2009. None has shown conditions or trends of acidification or nutrient buildup over that time period (Berg, 2010). Three lakes were monitored in the Ansel Adams Wilderness (beginning in 2004) and five lakes in the John Muir Wilderness (beginning in 2005). Only two lakes in the area, Walton Lake and Dana Lake in the Ansel Adams Wilderness had sufficient years of data for trend analysis – six years. Neither lake demonstrated any trends in any of the constituents measured over the period 2002 – 2009. Walton Lake is in an area of similar geology and lies approximately 24 kilometers (15 miles) directly west of DEPO at a higher elevation (3,560 meters (~11,700 ft)). It had low acid neutralizing capacity, and low concentrations of calcium, sodium, sulfate, and nitrate throughout the study period.

Although several recent monitoring projects have found levels of fecal coliform bacteria well below standards in waters within and nearby DEPO, there has been no collection and analysis of water specifically targeting other pathologic micro-organisms in natural waters in and near the monument. Several studies have looked at the presence of fecal bacteria in surface waters of the Sierra Nevada (Derlet & Carlson, 2006; Derlet et al., 2008; Ursem et al., 2009). These studies sampled water in the Yosemite and DEPO area and did find relatively high concentrations of chlorophyll-a (ostensibly due to exogenous nutrient enrichment), coliform bacteria (from animal feces), and *Escherichia coli* bacteria (from mammal and bird feces) at some sites. However the test methods utilized in these studies are non-standard and unpublished (and therefore not peer-reviewed). USGS scientists are currently investigating the spatial and temporal nature of water pathogens in SEKI.

The occurrence of pesticides has also not been specifically tested in water samples within or nearby DEPO. Several studies have documented the apparent transport and deposition of pesticides into lower elevations of SEQU (Aston & Sieber, 1997; McConnell et al., 1998; LeNoir et al., 1999), and higher elevations in the Tahoe Lake Basin (McConnell et al., 1998). LeNoir et al. (1999) found that transport of pesticides dropped off rapidly with elevation in SEQU. However, Landers et al. (2008) did find relatively high levels of pesticides in lake water samples, snow samples, sediments, and plant tissues at high elevations in SEKI and YOSE, with SEKI sites often recording the highest levels of all western U.S. parks studied. Therefore, transport of pesticides to DEPO is likely but may be limited, and any direct evidence is lacking.

In late 2005, Scripps installed a temperature sensor in the MFSJ River next to the new gaging station. Since then, it has recorded river temperatures continuously, though as of this writing, data were not yet available. In the future, these data will be useful for determining conditions and trends of river water temperature.

Water Quality – Current Condition Summary

Reference conditions for water quality would be water with concentrations of constituents below standards if they exist, or completely free of chemicals and pathogens of modern human origin (either directly or indirectly contributed) if no standard exists. Although data is very limited, these conditions appear to be mostly met, with minor exceptions including low pH, high Arsenic, and high chloride. All of these were found at a site near lower Soda Springs. This natural spring may be contributing to these local exceedances of water quality standards, though anthropogenically derived chemicals are also a possibility. Information within the monument on waterborne pathogens is sparse and their presence only speculation. Overall the condition of water quality in DEPO is good to excellent, but information on many constituents is not available, and data from the other SIEN parks suggest some pollutants may be present but not yet detected.

Water Quality – Threats & Stressors

Pollution

The biotic structure and metabolism of microbial communities in lakes and rivers of the Sierra Nevada have been impacted by nutrient loading due to atmospheric deposition and by stocking of introduced salmonids (Nelson et al., 2008). Research has shown that impacts are significant and lasting on a regional scale and include threatening the survival of endangered species, altering algal productivity, and changing the structure of zooplankton populations (Nelson et al., 2008). Local sources of pollution from soap, sunscreen, food particles, and human and animal waste are likely contributors to the growth of bacteria and algae (Derlet et al., 2008). Micro-organisms commonly found in water systems polluted by human and animal waste include coliforms, pathogenic bacteria, and protozoa such as *Giardia* or *Cryptosporidium* (Rockwell, 2000). Results of a study by Woodhams et al. (2007) suggest that the presence of certain naturally occurring aquatic micro-organisms promote defense of the yellow-legged frog against chytrid fungus and illustrate the importance of maintaining a natural balance of microbial communities.

Acid deposition in California and the Sierra Nevada is largely from wet deposition of nitrogen oxides (NO_x). Although acid precipitation has been documented in SEKI and other parts of the Sierra Nevada, deposition amounts were found to be relatively low compared to the eastern U.S. and urban areas of California (Stohlgren & Parsons, 1987). In addition, 14 years of data collection determined that the low recorded levels of acid precipitation had not led to any irreversible damage to surface water quality in the Sierra Nevada (Takemoto et al., 1995). Emissions from California sources of precursors to acid deposition have declined since the 1960s and so this is currently probably not a major threat to water quality in DEPO.

Recent data collection from the Western Airborne Contaminants Assessment Project (Landers et al., 2008) found that nutrients, pesticides, and other volatile organic compounds are being transported and deposited up into the Sierra Nevada (YOSE and SEKI). After deposition onto land and vegetation surfaces, these chemicals and nutrients are likely making their way into surface waters.

Climate Change

A warming climate is likely to exacerbate air pollution in the San Joaquin Valley (Luers et al., 2006), leading to more transport and deposition or nutrients, pesticides, and other chemicals within and around the monument. This is turn may contribute to eutrophication of lakes and streams and pollutant contamination, disturbing the natural ecological balances.

Nonnative species

Introduced salmonid density has shown a significant positive correlation with bacterial phylotype richness and diversity, suggesting that introduced trout have altered bacterioplankton community structure (Nelson et al., 2008) which may affect water quality. But whether that impact would be negative is unknown.

4.3.4 Condition Summary – Physical Indicators

Tables 4.7, 4.8, and 4.9 summarize the focal physical indicators. Table 4.7 is a summary assessment of the current conditions and trends of each indicator with some indicators expanded into indicator constituents. Table 4.8 is a summary of current conditions relative to reference conditions. Table 4.9 is a summary assessment of the stressors and threats for each indicator. When little or no data existed with which to assess the impacts of a particular threat and the current condition, expert opinion was utilized.

Table 4.7. Current condition and trend summary for physical indicators. Condition: Excellent, Good, Fair, Poor, Unknown, Variable. Trend: Improving, Deteriorating, Stable, Unknown, Variable. Strength of data/research to determine condition and trend: strong, moderate, weak, none.

INDICATOR	CONDITION	DATA STRENGTH	TREND	DATA STRENGTH
Air Quality	Fair to good	Moderate	Variable	Moderate
Ozone	Fair	Moderate	Stable or Improving	Moderate
Visibility	Fair to Good	Low	Unknown	Weak
Nitrogen & Sulfur	Fair to Good	Moderate	Stable or Deteriorating	Moderate
Pesticides	Fair to Good	Moderate	Stable or Deteriorating	Moderate
Mercury	Good	Moderate	Unknown	Weak
Weather & Climate	Fair to Good	Strong	Variable	Moderate
Temperature	Fair	Moderate	Deteriorating	Strong
Precipitation	Good to Excellent	Moderate	Stable	Strong
Geologic Features	Excellent	Weak	Unknown	None
Postpile columns	Good	Weak	Stable to Deteriorating	Weak
Rainbow Falls	Excellent	Weak	Unknown	None
Glacial features	Excellent	Weak	Unknown	None
The Buttresses	Excellent	Weak	Unknown	None
Water Dynamics	Good	Strong	Variable	Moderate
Surface Water	Fair to Good	Strong	Deteriorating	Moderate
Groundwater	Good	Weak	Unknown	None
Snowpack	Good to Excellent	Moderate	Stable	Moderate
Stream Channels	Good	Moderate	Unknown	Weak
Water Quality	Good to Excellent	Weak	Unknown	None
Temperature	Good to Excellent	Weak	Unknown	None
pH	Fair	Weak	Unknown	None
Alkalinity	Unknown	None	Unknown	None
Dissolved Oxygen	Unknown	None	Unknown	None
Dissolved Carbon	Unknown	None	Unknown	None
Chlorophyll	Unknown	None	Unknown	None
Nutrients (N, P)	Good to Excellent	Weak	Unknown	None
Turbidity	Unknown	None	Unknown	None
Chlorine	Fair	Weak	Unknown	None
Petroleum products	Good to Excellent	Weak	Unknown	None
Pesticides	Good to Excellent	Weak	Unknown	None
Arsenic	Fair	Weak	Unknown	None
Bacteria	Good to Excellent	Weak	Unknown	None

Table 4.8. Summary of current conditions relative to known or assumed reference conditions. Data sources: Empirical evidence from DEPO or very nearby (Local); relevant data or research from other parts of the Sierra Nevada, California, or North America (Inferred).

INDICATOR	Reference Condition	Reference Condition met?	Data Sources
Air Quality	No pollutants above standards or at levels impacting species	No	Local, Inferred
Weather & Climate	Variable but without trends linked to modern anthropogenic factors, and within historic variability	No	Local, Inferred
Geologic Features	No significant anthropogenic impacts	Yes	Local
Surface Water Dynamics	Amounts and timing within historic variability; no changes linked to anthropogenic factors	Uncertain	Local, Inferred
Groundwater Dynamics	Levels and flows within historic variability; no changes linked to anthropogenic factors	Uncertain	Inferred
Snowpack	Variable but stable trends in amounts and timing, within historic variability; no changes linked to anthropogenic factors	Uncertain	Local, Inferred
Stream Morphology	Stable geomorphology, without anthropogenic impacts	No	Local
Water Quality	No pollutants above standards or at levels impacting species; no anthropogenic effects	No	Local, Inferred

Table 4.9. Threat and stressor summary for physical indicators. For each threat or stressor, its level, spatial extent, and strength of data are indicated. Level: E = existing; P = potential; A = past; U = unlikely; UK = unknown. Extent (spatial): Global and Local. Data strength: Strong, Moderate (Mod), Poor, None. -- = Not Applicable.

		Stressor or Threat						
Indicator		**Climate Change**	**Pollution**	**Altered Fire Regime**	**Habitat Loss or Fragmentation**	**Nonnative Species**	**Visitor Use**	**Pests/ Pathogens**
Air Quality	Level	E	E	P	--	--	E	--
	Extent	Global	Global	Local	--	--	Local	--
	Data	Strong	Strong	Strong	--	--	Weak	--
Weather & Climate	Level	E	--	--	--	--	E	--
	Extent	Global	--	--	--	--	Local	--
	Data	Mod	--	--	--	--	Strong	--
Geologic Features	Level	E	P	--	--	--	E	--
	Extent	Global	Global	--	--	--	Local	--
	Data	Moderate	Weak	--	--	--	Weak	--
Surface Water Dynamics	Level	E	U	P	U	U	P	--
	Extent	Global	--	Local	Local	Local	Local	--
	Data	Strong	--	Mod	Mod	Weak	Weak	--
Groundwater Dynamics	Level	E	--	P	U	U	U	--
	Extent	Global	--	Local	Local	Local	Local	--
	Data	Mod	--	None	Weak	Weak	Weak	--
Snowpack	Level	E	P	--	--	--	--	--
	Extent	Global	Global	--	--	--	--	--
	Data	Strong	Mod	--	--	--	--	--
Stream Channel Morphology	Level	P	--	P	U	U	P	--
	Extent	Global	--	Local	Local	Local	Local	--
	Data	Mod	--	Mod	Mod	Weak	Mod	--
Water Quality	Level	E	E	P	U	E	E	E
	Extent	Global	Global	Local	Local	Local	Local	Local
	Data	Weak	Strong	Weak	Weak	Mod	Mod	Mod

4.3.5 Biological Integrity

Recent surveys of flora and fauna at Devils Postpile National Monument have generated a list of 556 species (excluding invertebrates) known to occur, even intermittently, within or nearby the monument. A list of species known or likely to occur in the monument was available through the NPS Integrated Resource Management Applications (IRMA) Portal (http://irma.nps.gov) (Accessed March, 2009), although there are some species on this list that have no record of observation in DEPO.

Numerous recent surveys and monitoring efforts have begun to assess the status and trends of important biological resources within DEPO. The following details the knowledge of selected biological resources and an assessment of their condition.

Flora

Due to its location near the Sierra Nevada crest, the monument contains species characteristic of both the wetter western slope and the drier eastern slope (Arnett & Haultain, 2005). The monument supports a mixture of meadows, conifer forests and woodlands, riparian forests, and chaparral that contain an abundance of plant species. See Appendix A for a complete listing of documented plant species within the monument.

Major Ecosystems

A vegetation mapping and classification project in the Yosemite area mapped vegetation to the association or alliance level based on 1997 imagery, and included the DEPO area (Aerial Information Systems, 2007). The results of this mapping and vegetation classification show that the monument is dominated by conifer forests, though much of this is relatively low in cover (ranging between 2% and 60% canopy cover). Dominant conifer species are red fir (*Abies magnifica*) and lodgepole pine (*Pinus contorta*), with small amounts of Jeffrey Pine (*Pinus jeffreyi*), white fir (*Abies concolor*), western white pine (*Pinus monticola*), western juniper (*Juniperus occidentalis*), and mountain hemlock (*Tsuga mertensiana*). Conifer-dominated vegetation covers 69.3% of the monument. Broadleaved trees including mountain alder (*Alnus incana*), black cottonwood (*Populus trichocarpa* ssp *balsamifera*), and quaking aspen (*Populus tremuloides*) cover only 2.9% of the monument. Shrub dominated ecosystems cover 17.5% of the monument with the dominant species including whitethorn ceanothus (*Ceanothus cordulatus*), huckleberry oak (*Quercus vaccinifoli*a), and manzanita (*Arctostaphylos* spp). According to the vegetation mapping, wetlands cover approximately 5% of the total monument land area, though a 2006 wetlands survey determined that wetlands covered 7.5% of the monument (Denn and Shorrock, 2009). Wetland species include, among others, willows (*Salix* spp), horsetail (*Equisetum* spp.), sedges (*Carex* spp.), and rushes (*Juncus* spp.). The extent and proportion of each major plant physiognomic type as well as rock dominated areas is presented in Table 4.10. The more detailed results of the 1997 mapping effort are presented in Figure 4.9 and Table 4.11 (Aerial Information Systems, 2007).

Table 4.10. Major vegetation and land cover types of DEPO. Data from Yosemite's 1997 vegetation map (Aerial Information Systems, 2007).

Type	**Acres**	**Percent of total**
Conifer forests & woodlands	554.4	69.3
Shrubs	140	17.5
Wetlands (including water bodies)	40	5.0
Broadleaf forests & woodlands	23.2	2.9
Grass/herbaceous	4.8	0.6
Rock outcrops/domes	37.6	4.7
Total	800	100

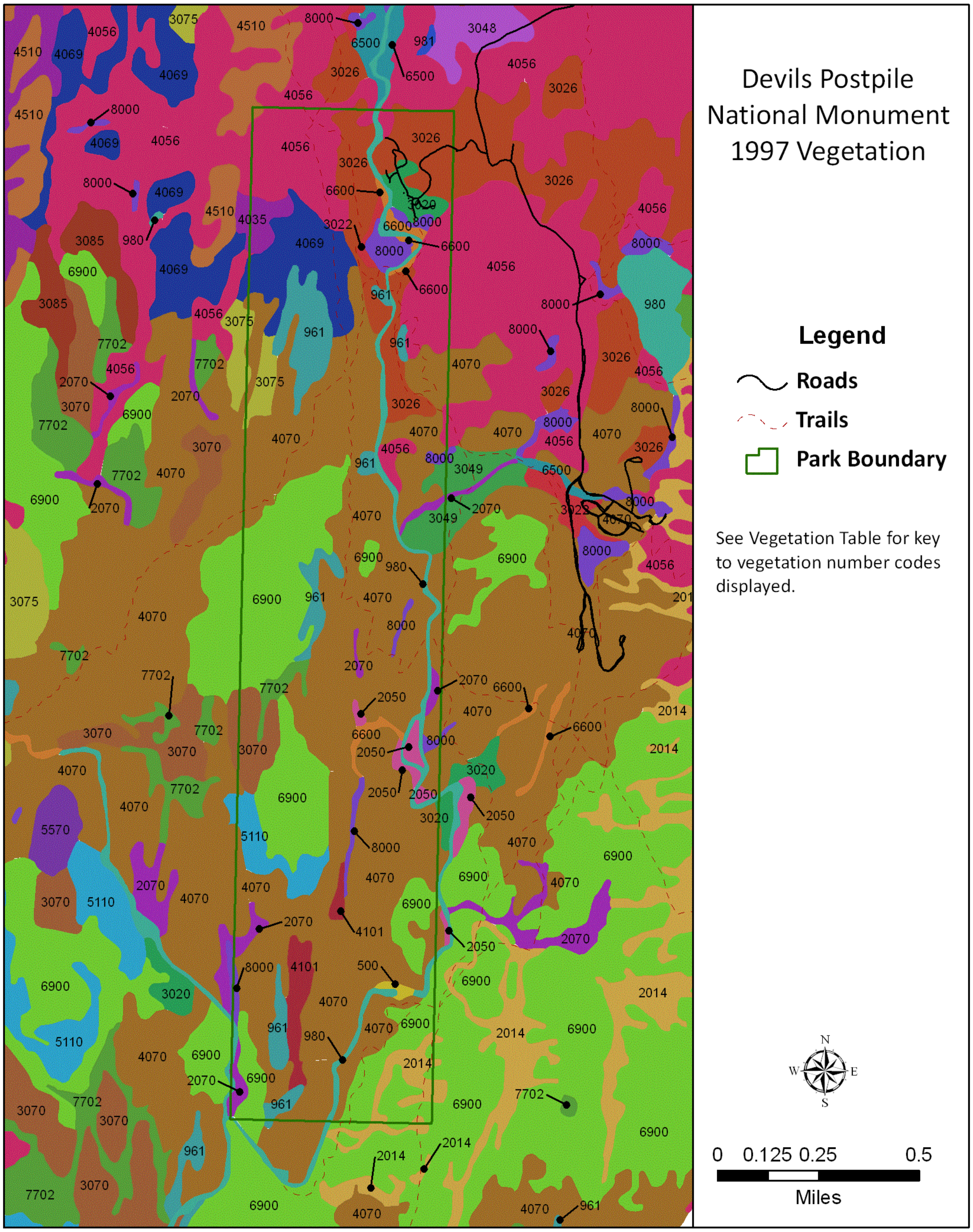

Figure 4.9. Vegetation of Devils Postpile National Monument (see Table 4.11 for explanation of Vegetation ID numbers shown). Data from the 1997 Vegetation mapping project for Yosemite National Park (Aerial Information Systems, 2007).

Table 4.11. Vegetation identification table (index for Figure 4.9). Parentheses around species indicate those species not required to be present (Keeler-Wolf et al., 2012).

Veg ID	Vegetation Community or Land Cover	Vegetation Alliance or Association
500	Barren	Mesic Rock Outcrop
961	Barren	Sparsely Vegetated to Non-Vegetated Exposed Rock
980	Water	Water
2014	Upper Montane Broadleaf	Quaking Aspen/Willow spp Talus mapping unit
2050	Lower Montane Broadleaf	Black Cottonwood Temporarily Flooded Forest Alliance
2070	Lower Montane Broadleaf	Mountain Alder mapping unit
3020	Subalpine Needleleaf	Sierra Lodgepole Pine Forest Alliance
3022	Subalpine Needleleaf	Sierra Lodgepole Pine/(Bog Blueberry) Forest mapping unit
3026	Subalpine Needleleaf	Sierra Lodgepole Pine Woodlands Superassociation
3048	Subalpine Needleleaf	Sierra Lodgepole Pine Mesic Forest Superassociation
3049	Subalpine Needleleaf	Sierra Lodgepole Pine Xeric Forest Alliance
3070	Lower Montane Needleleaf	Jeffrey Pine Woodland Alliance
3075	Lower Montane Needleleaf	Jeffrey Pine/Huckleberry Oak Woodland Association
3085	Lower Montane Needleleaf	Jeffrey Pine-California Red Fir Woodland Association
4035	Subalpine Needleleaf	Mountain Hemlock-(Western White Pine-Sierra Lodgepole Pine) Forest
4056	Upper Montane Needleleaf	California Red Fir-(Sierra Lodgepole Pine) Forest Superassociation
4069	Upper Montane Needleleaf	California Red Fir-(Western White Pine)/(Bush Chinquapin-Huckleberry Oak-Pinemat Manzanita) Forest Superassociation
4070	Upper Montane Needleleaf	California Red Fir-White Fir Forest Alliance
4101	Upper Montane Needleleaf	Sierra Juniper/(Oceanspray) Woodland Superassociation
4510	Upper Montane Needleleaf	Western White Pine-(California Red Fir-Sierra Lodgepole Pine) Forest Superalliance
5110	Chaparral	Whitethorn Ceanothus Shrubland Alliance
5570	Chaparral	Greenleaf Manzanita & Bush Chinquapin & Huckleberry Oak Shrubland Superalliance
6500	Meadow	Willow spp./Meadow Shrubland mapping unit
6600	Lower Montane Broadleaf	Willow spp. Riparian Shrubland mapping unit
6900	Chaparral	Mesic Montane Shrubland mapping unit
7702	Lower Montane Broadleaf	Mesic Post Fire Herbaceous mapping unit
8000	Meadow	Intermittently to Seasonally Flooded Meadow

Native Species

What we know about the native flora of the monument has come from one survey and one assessment of existing records in the past decade as well as casual observations prior to these. In association with the post-Rainbow fire forest and vegetation response, other vegetation status and trend data have also been collected. However, there has been no focused research on a particular native species or set of native species that would shed more light on status and trends. This may very well be the simple result of a lack of an indication that pointed to a need to check status and trends based on observations or a perceived threat, or lack of funding and staff to address these issues and needs.

Arnett and Haultain (2005) led a survey of the vascular plants of DEPO in 2001 with the dual goal of documenting at least 90 percent of the species with voucher specimens and describing the distribution and abundance of species of special concern (rare, endangered, threatened) and of nonnative invasive species. That survey covered the entire monument. An earlier assessment of existing plant records determined that the monument could have as many as 43 special status plant species that were either known to occur or expected to occur, although only two were confirmed present in the monument (Jones & Stokes, 2001).

The 2001 survey superseded the Jones & Stokes assessment and found a total of 371 native plant taxa (primarily species level) within the monument (Arnett & Haultain, 2005) (Appendix A). This more than doubled the number of native species documented in the monument since the last plant survey in 1980. However, 19 taxa that were previously documented with vouchers from DEPO were not found during the 2001 survey. The 371 native taxa within the 324 hectare (800 acre) monument translate into 1.15 taxa/ha (0.464 taxa per acre). Species diversity increases with area – a common relationship known as the species-area curve. However, the relationship is not linear, and it has been found that small areas have much higher diversity on a per-area basis than larger areas. For example, Yosemite, which has a total native diversity of approximately1400 native plant taxa distributed over 302,874 ha (748,419 acres), has 0.0046 taxa/ha (0.0019 taxa per acre). The difference in diversity per area is a result of the nature of species' distributions.

Native plant species richness varies throughout California and is highest in the Sierra Nevada, and especially the higher elevations (Thorne et al., 2009). While relatively high in total plant diversity, the high Sierra around DEPO is also relatively low in numbers of California endemic species. Thorne et al. (2009) did find that area had little effect on species richness in the Sierra Nevada. Rather it is believed that other factors such as topographic variability, climatic variability (Richerson & Lum, 1980), and isolation are more important in determining plant diversity. The Sierra Nevada as a whole has a higher number of endemic and native species than most other areas in the state due to the high variability in elevation, climate, soils, and geology (Thorne et al., 2009).

Three plant species documented within DEPO in 2001 were in the California Native Plant Society's (CNPS) Inventory of Rare and Endangered Plants of California (2001, 6th edition online): Bolander's woodreed (*Cinna bolanderi*), short-leaved hulsea (*Hulsea brevifolia*), and cut-leaved monkeyflower (*Mimulus laciniatus*). As of 2010, the 7th edition of the CNPS list had not yet been updated. No species that are found within the monument are currently listed at the state or federal level. At the time, *Cinna bolanderi* was considered rare and endangered in a portion of its range in California but potential for extinction was low. *Hulsea brevifolia* is also endangered over a portion of its range and is even more limited in its distribution. *Mimulus laciniatus* is rare but not endangered within California. Of the 86 sites surveyed for plants in 2001, one site contained *Cinna bolanderi*, and two sites each contained *Hulsea brevifolia* and *Mimulus laciniatus*. All occurrences of these three species were within the Wilderness portion of the monument, all to the west of the MFSJ River.

The general history of native plants within the monument is not well known. However, 19 previously-documented taxa (usually species) not found during the thorough 2001 survey (Arnett & Haultain, 2005) may represent real local extirpation or an example of how detection can vary even with conscientious survey work. There were several small plant collections/surveys conducted by ranger naturalists in the years 1972, 1977, 1978, and 1980, but the nature of these does not allow for assessment of conditions or trends. As of this writing, there are no known changes in the status (distribution and abundance) of the three special status species within DEPO.

Current Condition Summary

Reference conditions would be the presence of all species historically (recent past) present in the area with none locally threatened or endangered as a result of direct or indirect human activities, and local populations all healthy and all without significant impacts from direct or indirect human stressors. The three special status species in the monument that are on the CNPS list are threatened in other parts of their ranges and not within or around the monument. Potentially 19 species have been locally extirpated from the monument, though this is uncertain. The presence of nonnative and invasive plant species, direct human disturbances, and water and air pollution are all likely impacting species locally to some degree. Though there is limited information upon which to base the assessment, the current condition of the native flora community appears to be good. Following are the primary identified stressors and threats to native flora.

Threats & Stressors

Nonnative/Invasive Species

Nonnative and especially invasive species can be a significant threat to native species. The extent of the local threat of these species to DEPO native species and ecosystems is detailed in the following section. Impacts of nonnative species to ecosystems include changes to species composition and diversity and to community physiognomic structure, and disruptions to natural disturbance regimes and natural processes including hydrology, soil erosion, and decomposition (MacDonald et al., 1988; Mack & D'Antonio, 1998). A recent examination of the distribution and abundance of nonnative plants in nearby Yosemite determined that many nonnative species currently threaten native species by displacing them and outcompeting them for resources, and threaten to alter natural fire and hydrologic regimes (Gerlach et al., 2003).

Pollution

The transportation and deposition (both wet and dry) of air pollutants onto DEPO, including macronutrients, ozone, pesticides, and other volatile organic compounds from the Bay Area and agricultural lands of the San Joaquin Valley may pose a threat to native species. Bytnerowicz et al. (2010) collected air samples at DEPO throughout the summers of 2007 and 2008 and found that levels of 0_3 were higher than expected for the site. Late afternoon maxima in ozone concentrations are likely the result of upslope movement of polluted air from the San Joaquin Valley. However, other potential sources include local emissions of volatile organic compounds and NO_x from buses and other automobiles (Bytnerowicz et al., 2010) and regional emissions from upwind fires (Goldhammer et al., 2009). After the late afternoon maxima, atmospheric concentrations declined rapidly due to down slope movement of clean air from the eastern Sierra Nevada (Cisneros et al., 2010). The high afternoon levels of ozone that at times exceeded California and Federal standards may produce phytotoxic effects in at least some plant species within the monument, especially highly sensitive ones such as Jeffrey pine (Bytnerowicz & Grulke, 1992). The impacts of ozone on sensitive species are further discussed below in the section on Forests and Woodlands.

The transport of nitrogen oxides was found to drop off at a much steeper rate than ozone across an elevational gradient in the Sierra Nevada (Fenn et al., 2003c), though all pollutants were found to decline significantly with increasing elevation and distance from source (Bytnerowicz et al., 2002). Transport of particulates was as high as 1,800 meters (~6,000 ft) in SEKI, but transport was thought to drop off rapidly at higher elevations (Cahill, 1989). Based on these earlier studies it was expected that nitrogen was not transported much to higher elevations in the Sierra Nevada. However, Bytnerowicz et al. (2010) documented levels of atmospheric ammonia (NH_3) and nitric oxide (NO) that were higher than expected for a remote mountain location. The relatively high concentrations of these pollutants were likely the result of long-range transport from the San Joaquin Valley channeled by efficient upcanyon transport in the San Joaquin River canyon, regional forest fires (for NH_3), and local sources such as automobiles, buses, and campfires (for NO). The documented concentrations of nitrogenous gases were comparable to sites farther west and lower in elevation. Higher elevation systems with thin or no soils have a lower threshold for impacts due to their lower capacity to assimilate nitrogen (Fenn et al., 1998; Sickman et al., 2003) and so would be more sensitive to this pollution.

Fenn et al. (2010) estimated nitrogen deposition loads across California from various sources and compiled known critical loads of nitrogen from the literature. Lichen communities are particularly sensitive to nitrogen additions and critical loads for lichen species have been found to range between 3.1 and 5.2 kilograms of nitrogen per hectare per year (Fenn et al., 2008). A critical load is the level of exposure of nitrogen above which plants or communities begin to show signs of significant harmful effects. The estimates for lichen deposition loads in mixed conifer forests of the state includes an area in and around DEPO that is within the critical load range (3.1 – 5.2 kg/ha/yr) (Fenn et al., 2010).

Excess nitrogen directly affects individual vascular plant and lichen species and disrupts ecological systems and communities (Bytnerowicz & Fenn, 1996; Fenn et al., 2003a; Fenn et al., 2010). For example, nitrogen fertilization in N-limited systems such as the Sierra Nevada can impact some plants, and any added nitrogen from dry or wet atmospheric deposition to the ecosystems may alter species dominance relationships and may help to explain the distribution and abundance of alien species. Evidence from research strongly indicates that elevating soil nutrients in a grassland plant community beyond normal levels can elevate the degree to which it is subject to invasion by nonnative species (Huenneke et al., 1990; Maron & Jefferies, 1999). This may be true for meadows. At this time, it is believed that nitrogen deposition in the high elevation Sierra Nevada is likely low and no apparent negative terrestrial impacts have been documented so far at high elevations (Fenn et al., 2003c). However, in high elevation lakes of the eastern Sierra Nevada, the structure of algal (diatoms) communities was found to be very sensitive to even low levels of nitrogen deposition compared to terrestrial plants (Saros et al., 2010), though the degree of nitrogen enrichment is highly dependent on basin vegetation and geologic characteristics (Clow et al., 2010).

Acid rain (sulfur or nitrogen oxides in wet deposition) has been documented in SEKI (Stohlgren & Parsons, 1987) and other parts of the Sierra Nevada. However, deposition rates were relatively low compared to the eastern U.S. and urban areas of California (Stohlgren & Parsons, 1987), and 14 years of data collection determined that forests of the Sierra Nevada had not been irreversibly impacted by the levels of acid deposition. Although researchers found episodes of lake acidification resulting from acid deposition in a high altitude basin in SEKI, acid concentrations were low and no adverse effects to the lake system were observed (Melack et al., 1989). In the eastern U.S. where acid rain has been significant and chronic, it has caused serious disruptions to species and ecosystem processes. The decline of eastern red spruce in northeastern forests has been attributed to acid precipitation (NSTC, 1998).

Transport and deposition of pesticides that may negatively impact flora was once thought not to be a significant problem in the high Sierra Nevada because transport was thought to decline significantly with elevation. However, in the late 1990s pesticides were found at elevations above 3,000 meters (9,800 ft) in the southern Sierra Nevada (LeNoir et al., 1999). More recently, data collected from YOSE and SEKI during the years 2003 through 2007 confirmed that pesticides are found in relatively elevated concentrations in conifer needles and lichens at all elevations, and in many cases, concentrations in plant tissues actually increased with altitude (Landers et al., 2008). This increase with altitude was also true for pesticides in snow, water, and air and indicates a process of cold fractionation that increased the amount of pesticides available at higher elevations. Pesticides bioaccumulate in plant tissues and may disrupt plant physiology. Currently, the level of this specific threat to DEPO vegetation is unknown since specific targeted testing has not been done.

Climate Change

Research from around the globe has already documented the effects of a changing climate on plant distribution and abundance. In response to a warming climate, many plants have already shifted either up in elevation or poleward, though some have moved in the opposite direction (Parmesan & Yohe, 2003; Root et al., 2003). If plants in the southern Sierra Nevada are to move up in elevation according to some predictions and abundant evidence from around the globe, species may actually shift slightly to the south as more high elevation habitat is available there. However, species and groups of species may react differently. So far the results from the Sierra Nevada have been in line with predictions and results from around the world, with some lower elevation pines retracting their lower elevation limit upwards since the 1930s (Thorne et al., 2006). Still other research has found that within current ranges, small size classes of high elevation pines have increased in density since the 1930s while the largest size classes have decreased in density (Dolanc & Thorne, 2010). In the nearby White Mountains to the east, some evidence suggests that bristlecone pines (*Pinus longeava*) may be shifting their distribution both topographically (different aspects) and elevationally at the local or micro-scale, potentially in response to a warming climate (Weiss, 2010).

In the Sierra Nevada, research has documented recent mortality of trees that was probably linked to a changing (warming and drying) climate (Millar et al., 2007; van Mantgem & Stephenson, 2007), though no similar research has focused on shrubs, grasses, and other herbaceous species. We can expect those species with limited distributions, confined to high elevations, or with limited dispersal ability to be the most at risk within and around DEPO to a changing climate due to the monument's limited size and elevational distribution.

Using various combinations of emissions scenarios, General Circulation Models, and the alternatives of species dispersal and no dispersal, Loarie et al. (2008) projected that the southern Sierra Nevada will decline in species diversity under all combinations of a future changed climate regime. In the Sierra, high elevation species will tend to move southward to the generally higher elevation areas while lower elevation species will move up in elevation and northward. Allowing species to disperse under future climate changes, the models project that most species' ranges will expand under the best case scenario but contract in the worst case scenario of high emissions and high climate sensitivity to CO_2 emissions. In this case, the higher elevations of the far southern Sierra Nevada are projected to become refugia where many species with small range sizes will persist (Loarie et al., 2008). Based on their projections, we can conclude that the species that would be confined to small ranges within the high elevation southern Sierra Nevada would have an increased local extinction risk.

Humans/Visitors

Visitors cause direct and indirect impacts to native flora of the monument, including the obvious impact of direct trampling of plants (Holmquist & Schmidt-Gengenbach, 2008) and fragmentation of meadows and grasslands. High elevation meadow vegetation is particularly sensitive to trampling and recovers very slowly (Willard & Marr, 1971; Holmquist, 2004).

Visitors also inadvertently transport seeds of nonnative plants. Nonnative species are often found in areas that experience repeated disturbance such as roadsides and trails (Tyser & Worley, 1992; Forman et al., 2003; Frakes, 2005; Potito & Beatty, 2005), construction areas, and others. In general, there is an established link between the degree of disturbance an area receives and the frequency of nonnative species (Mooney & Drake, 1984; Alpert et al., 2000; Mack et al., 2000). In protected areas like national parks, nonnative species are most likely found in areas of repeated disturbance including campgrounds, residential areas, pack stations, trails, and picnic areas (MacDonald et al., 1988; Cowie and Werner, 1993). Exotic species are often early colonizers of these recently or repeatedly disturbed areas within protected areas because seeds or propagules of alien plants are transported to these locations via humans, pets, pack stock, vehicles, and construction equipment (Schmida & Ellner, 1983; Hodkinson & Thompson, 1997). Another location that experiences considerable repeated human and natural disturbance and thus is likely to have nonnative species present are river and stream banks and associated riparian corridors (DeFerrari & Naiman, 1994). Once introduced, nonnative species can outcompete and displace native species.

There is a substantial amount of evidence supporting the theory that disturbed plant communities are more invasible than those that are not disturbed (Elton, 1958; MacDonald et al., 1988; D'Antonio & Vitousek, 1992). We can conclude that those areas of the monument that receive more visitor use, either by hikers, pack stock, or fishermen, will receive a higher direct and indirect impact. These areas include the campground, visitor center, heavily used trails, and areas popular for fishermen (such as the Soda Springs Meadow complex).

Nonnative & Invasive Plants

Arnett and Haultain (2005) determined that the plant collections obtained between 1972 and 1980 documented only two nonnative species: common dandelion (*Taraxacum officinale*) and timothy (*Phleum pratense*). The 2001 plant survey of the monument found six new nonnative species, bringing the running total as of 2001 to eight species documented, or 2.5 species/square kilometer (6.4 species/mi^2) of park unit size. In comparison, Yosemite National Park had recorded 157 nonnative taxa as of January 2010, or 0.05 species/square kilometer (0.13 species/mi^2). Valentine Eastern Sierra Reserve is a small protected area closer in size (63 hectares (156 acres)) and elevation (~2,400 m – 2,600 m (~8,000 ft – 8,500 ft)) to DEPO and located nearby in Mammoth Lakes. This reserve had 14 nonnative species in 1998, though only two were considered invasive – common dandelion (*Taraxacum officinale*) and goat's beard (*Tragapogon dubius*) (Howald, 2000). These 14 nonnative species translates into 22.2 species/square kilometer (57.4/mi^2).

The documented history and diversity of nonnative plant species in the monument covers the period from approximately 1980 through 2010 (Table 4.12). Over this time period, 11 nonnative species have been documented in the monument. However, only three of these – Bull thistle (*Cirsium vulgare*), woolly mullein (*Verbascum thapsus*), and cheatgrass (*Bromus tectorum*) – are considered invasive by the California Invasive Plant Council (CalIPC) (Cal-IPC, 2006), though only at lower elevations and not within the Sierra Nevada. However, Gerlach et al. (2003) consider all three of these to be invasive species that are broadly distributed (mostly at lower elevations in the Sierra Nevada), are apparently increasing their distributions, and are known to have great impacts on native vegetation.

Of the six species documented in DEPO in 2001, only *Cirsium vulgare* demonstrated an invasive nature (Arnett & Haultain, 2005). Many of the populations of this species were found in The Buttresses area which is somewhat removed from areas that see substantial human impact. It has been speculated that this species has been introduced and continues to be spread by pack horses from Reds Meadow, though many of their populations were found far from trails. Off-trail pack stock use in this area is currently under investigation in DEPO. The abundance of populations in The Buttresses area would indicate that some vector is spreading them in the area, and the physical nature of the area or its disturbance history has made it more susceptible to invasion. At the time (2001) all populations of bull thistle were removed.

Table 4.12. The history of nonnative and invasive plant species in Devils Postpile National Monument. Species richness includes number of new species documented and running total (assuming no complete eradication) in parentheses. Abundance or area infested taken from published or unpublished estimates for populations only within the monument boundary. Surveyors: Arnett & Haultain (2005); CEPMT = California Exotic Plant Management Team.

Year	Exotic Species Richness	# new species added	Species present[a]	Abundance or Area (acres) Infested	Surveyors
1980	2		*Phleum pratense*	Unknown	DEPO Staff
			Taraxacum officinale	Unknown	
2001	8	6	***Cirsium vulgare***	Locally common	Arnett & Haultain
			Lactuca serriola	Locally common	
			Phleum pratense	Uncommon	
			Poa annua	Occasional	
			Poa pratensis	Uncommon	
			Spergularia rubra	Occasional	
			Taraxacum officinale	Locally common	
			Tragopogon dubius	Uncommon	
2002	5 (11)	3	***Bromus tectorum***	0.001	CEPMT
			Cirsium vulgare	16.98	
			Malva parviflora	Unknown	
			Tragopogon dubius	Unknown	
			Verbascum thapsus	1.43	
2003	4 (11)	0	***Bromus tectorum***	0.66	CEPMT
			Cirsium vulgare	1.61	
			Tragopogon dubius	1.13	
			Verbascum thapsus	0.19	
2004	4 (11)	0	***Cirsium vulgare***	1.98	CEPMT
			Lactuca serriola	1.58	
			Tragopogon dubius	1.87	
			Verbascum thapsus	0.29	
2005	4 (11)	0	***Bromus tectorum***	0.02	CEPMT
			Cirsium vulgare	0.32	
			Lactuca serriola	0.21	
			Tragopogon dubius	0.20	
2006	3 (11)	0	***Cirsium vulgare***	0.46	CEPMT
			Lactuca serriola[b]	0.02	
			Tragopogon dubius	0.38	
2009	4 (11)	0	***Bromus tectorum***	0.09	DEPO staff
			Cirsium vulgare	0.01	
			Lactuca serriola	0.01	
			Tragopogon dubius	0.001	
2010	1(11)	0	***Bromus tectorum***	0.02	DEPO staff

[a] Those in bold are considered invasive by the California Invasive Plant Council in other parts of the state (Cal-IPC, 2006) and in the Sierra Nevada by Gerlach et al., 2003.

[b] This species was not mentioned in the trip report for that year but was listed as present in the associated database for same year.

Of the other five nonnative species found in the monument in 2001, four (*Phleum pretense*, *Poa annua*, *Poa pratensis*, and *Spergularia rubra*) were found only within the Soda Springs Meadow complex immediately adjacent to the Ranger Station and visitor center and popular with anglers and other visitors. The current heavy visitor use of this area would make nonnative introductions a constant risk. In addition, sheep grazing occurred within the monument in the earlier years before 1933, and some nonnative introductions may have occurred then. Two of the six species (*Tragopogon dubius* and *Lactuca serriola*) were found only within The Buttresses area, while one of the species (*Taraxacum officinale*) found near popular fishing destinations was also found further south and not very close to the MFSJ River.

Following the 2001 vascular plant survey of DEPO, the California Exotic Plant Management Team (Cal EPMT) began a series of surveys and control efforts for nonnative plants that began in 2002 and continued every summer through 2006. In the summer of 2002 the Cal EPMT team extensively surveyed the monument and found three exotic species new to the monument: cheatgrass (*Bromus tectorum*), cheese weed (*Malva parviflora*), and wooly mullein (*Verbascum Thapsus*). These directed surveys did not find several species identified in the 2001 survey (Simpson, 2002). This may be due to the fact that the 2002 survey was less extensive and missed significant portions of the monument. Of all species encountered, *Cirsium vulgare* was by far the most abundant, with 3,319 plants removed from numerous locations covering a total of almost 7 hectares (17 acres).

In the summer of 2003, a Cal EPMT crew again surveyed targeted areas both within and outside the monument (Boughter & Ferrebee, 2003). Around the pack station and corrals at Reds Meadow (outside DEPO), populations of *Cirsium vulgare*, *Verbascum thapsus*, *Tragopogon dubius*, and *Bromus tectorum* were removed. Inside the monument around Rainbow Falls, populations of these same species were found and removed. Overall, the team found no "major infestations" of the exotic plants. A total of about 1.8 hectares (4.4 acres) (including inside and outside DEPO) contained some cover of these four species. No other species were encountered, although the focus of the surveys was only for the four species that were found and surveys were not spatially exhaustive.

Again in the summer of 2004, the Cal EPMT team conducted directed surveys in areas with previous nonnative presence or with the potential for nonnative presence (Jordan, 2004). As in the previous year, *Cirsium vulgare*, *Tragopogon dubius*, and *Verbascum thapsus* were found. However, *Bromus tectorum* was not found and *Lactuca serriola*, not seen since 2001 was encountered in a few areas. The team noted that all four species "…were found in small infestations in many locations throughout the park." As in previous years, other nonnative plants were not found, though many areas were not surveyed. The team also surveyed nearby areas around the monument and found several infestations of *Cirsium vulgare* and *Verbascum thapsus* to the west and south and *Lactuca serriola* to the east around the Reds Meadow Pack Station. Although DEPO staff had reported a large population of *Bromus tectorum* south of Reds Meadow, the Cal EMPT team did not find it. It was noted that most nonnative species have seeds that survive three years or less, with the exception of *Verbascum thapsus* which has seeds that may survive up to 100 years. This indicates that repeat visits to recorded infestation sites will be necessary for several years to several decades or more depending on the species.

In the summer of 2005, the Cal EPMT conducted another round of directed surveys (California EPMT 2005). The team estimated that the surveys covered 80 percent of the monument although spatial data files of survey areas that were provided indicate less than 50 percent. A survey of the Reds Meadow area outside the monument found a large infestation of a newly encountered species: *Chenopodium album* (lamb's quarters) around the corral and extending along the pack trail downhill (south). This population did not extend into the monument. In the lower Rainbow Falls area just south of the monument, only one *Cirsium vulgare* and four *Tragopogon dubius* plants were found in an area that had large populations of *C. vulgare* and *B. tectorum* in previous years. The Buttresses area (central west) of the monument had the greatest numbers of nonnative plants. One to many small populations of *B. tectorum*, *C. vulgare*, *L. serriola*, and *T. dubius* were found and removed there. A search of the large meadow between The Buttresses and the MFSJ River found only five *C. vulgare*. To the north of this meadow, a large population of *C. vulgare* was found in another meadow in the central part of the monument adjacent to a pond.

The last Cal EPMT survey and eradication outing took place in summer 2006 (Boughter & Simpson, 2006). At that time, only *C. vulgare* and *T. dubius* were found in surveyed areas. However, less than half of the monument was surveyed and areas targeted were those areas where nonnatives had been found in abundance in previous years. The California EPMT team felt that *V. thapsus* may have been eradicated, even though seeds may survive up to 100 years.

A 2006 wetland survey (Denn & Shorrock, 2009) noted that wetland habitats in the monument were degraded by invasions of Kentucky bluegrass (*Poa pratensis*) and possibly by nonnative *Bromus* species. *Poa pratensis* was not found in any of the CEPMT surveys from 2002 to 2006, though many wetland areas were not specifically surveyed during those outings, and *Poa pratensis* is a somewhat cryptic species.

After several years, a crew of interns and volunteers surveyed for and eradicated nonnatives in 2009 from a set of selected sites within and nearby the monument (NPS, unpublished data). Over a four day period in August, small crews surveyed along some trails and at specific locations and made estimates of numbers of individuals of each species found. A small population of *Cirsium vulgare* was found next to a small pond on the eastern monument boundary south of the Devils Postpile and approximately 75 meters (246 ft) from the main trail. More small populations of this species were also found in The Buttresses area in the central west part of the monument. Also within The Buttresses area, surveyors found one small population of *Tragopogon dubius* and one large infestation (500+ individuals) of *Lactuca serriola.* The other nexus of nonnative infestation, the area next to Rainbow falls, again had a sizeable population (500+) of *Bromus tectorum* on the slope to the south of the trail. A search of the riparian wetlands to the north and south of the John Muir Trail where it crosses the San Joaquin River in the central eastern part of the monument found no nonnatives. No species were also encountered along the trail from the ranger station to Rainbow falls.

In the summer of 2010, NPS monument staff again surveyed many of the locations in and outside the monument where nonnative species had been found during the 2002-2006 Cal EPMT surveys as well as the 2009 surveys. While the entire monument was not surveyed, and most but not all of the previous locations were re-visited, only one species – *Bromus tectorum* – was found within DEPO.

Two persistent populations at the horse corrals and along the stock trail near Rainbow Falls were eradicated. Nearby populations uphill and to the east and just outside the monument boundary were also eradicated. In addition, a new large population was found nearby and further to the east at Bear Crag (outside monument). Small populations were also found in the Reds Meadow Pack Station area and along the trail leading from this pack station southwest toward the monument. The surveys in 2010 were encouraging because three of the four persistent species were not found. However, the fact that many populations of cheatgrass were found inside and close to the monument (and some had already gone to seed) means this species will continue to persist unless a concerted eradication effort is applied.

It is difficult to address the condition of nonnative plant populations in DEPO because the condition would be a function of the current status and past trends in their abundance and distribution within the monument. Populations of these species were not systematically monitored; instead, surveys and eradication efforts were directed to known previously encountered populations. However, new populations continued to appear in new locations. Furthermore, survey effort, methods, and personnel varied over the years, making comparisons over time difficult.

Assuming effort and area surveyed were equivalent across all years (which is apparently not true) and then comparing the total acreage of nonnative cover throughout the years that data were collected and area estimated (2002 – 2006, 2009 – 2010), then the total cover of all species has declined significantly: from 7.4 hectares (18.4 acres) in 2002 to 0.36 hectares (0.9 acres) in 2006, to 0.008 hectares (0.02 acres) in 2010. However, the availability of data, their format, the extent of the annual surveys, the timing of those surveys, and the personnel involved introduce many potential errors in the estimated abundance or cover of any one species in DEPO. It appears that among the invasive species, *Verbascum thapsus* may have been eradicated within the monument and *Cirsium vulgare* appears to be declining in its extent and abundance and may also have been eradicated. Perhaps the only thing we can conclude with certainly is that cheatgrass (*Bromus tectorum*) is persisting in spots next to Rainbow Falls and outside the monument to the east. However, this species may be more widespread and other species may persist in locations not yet or inconsistently surveyed.

Unfortunately, known nonnative species and especially the invasive ones (*B. tectorum, C. vulgare, and V. thapsus*), and any new species that may arrive will continue to be a threat to native biodiversity, ecosystem function, fire ecology, and hydrology. The areas historically most impacted by nonnatives include the area of The Buttresses, around Rainbow Falls, and in and around the Soda Springs Meadow complex. Outside the monument, the area of most concern as a local source on nonnatives is the Reds Meadow Resort and associated corral, since it appears to be a nexus for nonnatives. The current policy of the Inyo and other California National Forests is to encourage the use of weed-free feed. This cannot be a requirement until the state of California establishes such a policy. The pack station at Reds Meadow appears to continue to be a nexus for new invasions.

Even though only one nonnative species was found in 2010, it may be too soon to conclude that all other species have been successfully eradicated. Some species may continue to persist at locations not surveyed and may spread further abroad. As the surveys in 2009 demonstrated, nonnative species can show up at locations not surveyed in any previous year. Some species may persist at some locations due to a persistent seed bank, new inadvertent reintroductions from visitors or pack stock, or failure to eradicate populations prior to seed dispersal. The current number of nonnative species in DEPO (in 2010) ranges from 1 to 11, though the number is probably one to a few. One to three species is equivalent to 0.3 – 0.9/km^2 (0.8 – 2.4/mi^2) of monument area. This is a much lower density than that found at Valentine Eastern Sierra Reserve (Valentine Camp portion) close to Mammoth Lakes which in 1998 had 14 nonnative species (Howald, 2000), equivalent to a density of 22.2 species/km^2 (57.4/mi^2) (the Camp is 63 hectares or 156 acres). The higher density at Valentine Camp may be explained by a number of reasons such as proximity to the Town of Mammoth Lakes and others.

Current Condition Summary

Reference conditions for the monument would have no nonnative and especially no invasive species within the monument or near the monument with a high potential to disperse into the monument. Currently there may only be one nonnative (and an invasive) species within the monument that is persisting in small populations, though populations of other species may still persist in locations not frequently or recently surveyed. The other two invasive species may have been reduced to small populations or even eradicated, but new invasions could be possible. Therefore, nonnative plants are currently a small but continuing threat to native species and natural processes, though the relatively small abundances make the threat low. For the purposes of identifying condition, the condition of nonnative plant species is good with an improving trend.

Threats & Stressors

Nonnative and invasive species are themselves a threat to many native species and natural processes. Therefore we do not discuss how other threats may negatively impact these species. Instead we only mention that other systemic stressors – climate change, pollution, fire regime, and direct human use – are likely to exacerbate the distribution and abundance of nonnative species in DEPO. The exact nature of these processes is discussed elsewhere in the report.

<u>Wetlands</u>

Although wetlands cover a small portion of DEPO, wetlands are recognized in relatively dry biomes and similar areas as extremely valuable components of the natural system that provide a disproportionate amount of ecosystem services – relative to their extent in a watershed – due to their high biodiversity and their role in carbon sequestration, water quality improvement, flood abatement, and other functions (Zedler & Kercher, 2005). Meadows are wetlands popular with visitors, but are fragile ecosystems that are subject to degradation from frequent human trampling (Holmquist & Schmidt-Gengenbach, 2008). Other wetland types within the monument include riparian systems and aquatic habitats.

The only systematic on the ground study of the wetlands of DEPO was conducted in 2006 when wetlands were mapped, classified, and their condition assessed (Denn & Shorrock, 2009). The earlier National Wetlands Inventory (NWI) effort was based on aerial photo interpretation with no known field work within the monument. The 2006 inventory mapped almost twice the area of wetlands: 24.3 hectares vs. 14.2 from NWI (60 acres vs. 35 from NWI). The 1997 vegetation map that covered Yosemite and Devils Postpile (Aerial Information Systems, 2007) and had a minimum mapping unit of 0.5 hectare (1.2 acre) mapped 16.2 hectares (40 acres) of wetlands, a third less than mapped in the 2006 field survey. Since the 2006 survey was entirely ground-based, it would be expected to be the most accurate of the three efforts to map wetland habitats. Field work in 2006 included assessing the current condition and ecological value of each wetland mapped. The survey and assessment identified fire, passive recreation, and active recreation as the three top threats (stressors) to wetland condition and integrity.

In 2006, wetlands were mapped using a combination of the US Army Corp of Engineers mapping protocol (Environmental Laboratory, 1987) and the US Fish and Wildlife Service wetland classification system (Cowardin et al., 1979). Wetlands were then classified according to the US Fish and Wildlife Service wetland classification system (Cowardin et al., 1979). Then, using the California Rapid Assessment Method for Wetlands (CRAM) (Collins et al., 2006), the 2006 survey team assigned qualitative metrics of wetland condition across four categories: 1) buffer and landscape context; 2) hydrology; 3) physical structure; and, 4) biotic structure. These metrics were used to classify each wetland (minimum mapping unit of 0.04 hectare (0.1 acre)) in terms of condition class: in desired condition, good condition, or poor condition.

While it can be a difficult task to determine desired conditions for any resource, the wetlands project staff created a definition of "desired conditions" that would be used as a gauge to determine condition in the field. Their standard for desired condition was whether they "overwhelmingly exhibit natural hydrology, unaltered physical structure, and a native vegetation community. They are surrounded on all sides by wetland or upland habitats with high ecological integrity. Few signs of intensive human activity are visible within or adjacent to these wetlands." This largely qualitative definition attempts to capture the critical aspects of wetland health.

All mapped wetlands were scored to determine condition. A wetland's condition was determined through a combination of overall CRAM score (derived from multiple grades), CRAM component attributes and scores, numbers of stressors observed within each wetland, and professional judgment. Scores were then ranked by converting each to a percentage of highest possible score. Finally, each wetland was designated as either: 1) in desired condition; 2) in good condition; or, 3) in poor condition. This determination was based largely on the condition score (highest scores placed in desired condition class, lowest scores in poor condition) and number of stressors observed, but some latitude and professional judgment was allowed to shift wetlands up or down.

Of the 324 hectare (800 acre) monument, 24.3 hectares (59.6 acres) were mapped as wetlands by Denn & Shorrock (2009) (approximately 7.5% of total). These ~24 hectares (60 acres) were spread across 23 distinct wetland polygons. All wetlands were classified as one of three types: depressional, riverine, and seep/slope. Riverine wetlands comprised the large majority of total wetland area (85%). Most wetland areas were in good condition (62.5%), some were in desired condition (37.1%), while very little was in poor condition (0.4%) (Table 4.13).

Table 4.13. Summary of derived wetland condition relative to desired condition.

			Desired Condition		Good Condition		Poor Condition	
Type	**N**	**Acres**	**N**	**Acres**	**N**	**Acres**	**N**	**Acres**
Depressional	8	3.19	4	1.85	2	1.11	2	0.23
Riverine	11	50.56	8	14.47	3	36.09	0	
Seep/Slope	4	5.81	3	5.77	1	0.04	0	
Total	23	59.56	15	22.09	6	37.24	2	0.23

Although most wetland acreage was classified as being in good condition, the authors concluded from their analysis of the results that as a whole the wetlands in DEPO were in excellent condition (and thus desired condition). They point to the fact that the CRAM assessment methods are geared toward more developed and impacted areas and certain condition criteria skewed DEPO wetlands away from the desired condition category even though no impacts were apparent. They determined that the small acreage of wetlands in poor condition was the result of forest loss from the 1992 Rainbow fire, rather from any direct anthropogenic disturbance. Although the authors concluded that almost all wetlands were in excellent condition, they still face ongoing stressors and threats that may impact their condition in the future. The authors of the 2006 survey and assessment identified passive and active recreation, and evidence of fire as the most commonly observed “anthropogenic” stressors visible within wetlands that may adversely affect wetland function and value. Most (19) of the 23 wetlands exhibited at least some evidence of passive recreation while 11 of 23 exhibited some evidence of active recreation and 9 of 23 exhibited evidence of fire.

Prior to the 2006 wetlands assessment, Soda Springs Meadow underwent restoration and rehabilitation in response to observations of severely degraded conditions in and around the meadow. The meadow is located in the northern part of the monument in close proximity to the developed area and receives a significant amount of human use (Figure 4.10). It was estimated that as much as 2.4 hectares (six acres) of the meadow were disturbed by social trailing and general visitor use. In 2002, restoration efforts began to restore the meadow, including the installation of a wooden fence that restricted and concentrated access to the meadow on the eastern side of the river. In 2004, restoration work continued with the rehabilitation of two head-cuts caused by erosion and a 20 foot section of heavily incised social trail within Soda Springs Meadow. A set of photo points was established in 2002/2003 and photographs have been repeated at these set locations each year through 2010. In the summer of 2009, a formal assessment of social trailing began in the meadow (Pettebone et al., 2010) with plans to continue the monitoring in the future. Although no quantitative or good qualitative data exist to assess the results of the restoration efforts, the fact that the 2006 comprehensive wetlands assessment (Denn & Shorrock, 2009) did find the meadow to be in good condition reflects the success of the restoration efforts.

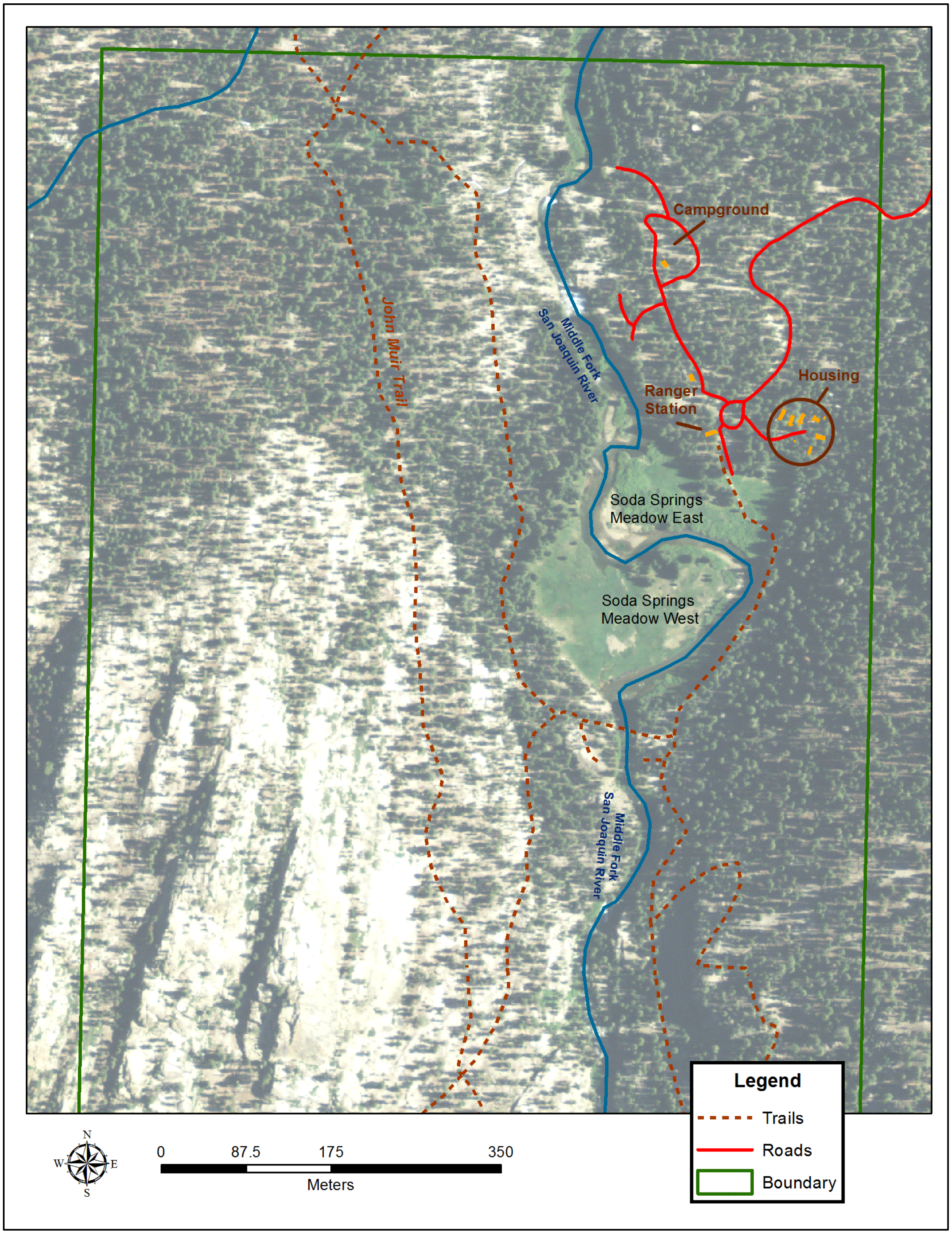

Figure 4.10. Location of Soda Springs Meadow in the northern part of the monument.

In 2005, DEPO staff began mapping and monitoring the recruitment patterns of lodgepole pine (*Pinus contorta* ssp *murrayana*) into Soda Springs Meadow. In that year all trees were mapped. With only one or two years of data, NPS cannot conclude whether recruitment of lodgepole pine into meadows of the monument is the result of natural successional processes, release from aboriginal fire management, or to direct or indirect consequences of human manipulation. Since many if not all meadows in the Sierra Nevada are experiencing the same recruitment phenomenon (e.g. Helms, 1987; Cunha, 1992; Millar et al., 2004), we can conclude that recruitment in Soda Springs Meadow and other meadows in DEPO is likely being driven by the same factors that appear to be acting region-wide. One potential explanation for patterns of recent recruitment into meadows is a changing or shifting climate regime. Millar et al. (2004) found that conifer recruitment into meadows in the Sierra Nevada was correlated with dry, cool periods with little variation in precipitation. Other explanations could include release from Native American burning practices.

Current Condition Summary

The comprehensive wetlands assessment concluded that the vast majority of wetlands in DEPO are in excellent condition, with minor disruptions related to the 1992 fire and apparently minor evidence of passive and active recreation throughout many of the wetlands (11-19 of the 23 wetlands). However, recent surveys in the last 10 years have found large numbers of a few nonnative plant species in many of the meadows in the monument. Although eradication of nonnative species appears to have been successful in many locations in DEPO, due to the nature of the nonnative plant surveys and eradication efforts (see Nonnative plant section above), we cannot be certain that nonnative plants have been reduced or eliminated in all meadows of the monument. Furthermore, conifer recruitment and extensive visitor trailing are occurring in a small portion in the largest meadow in the monument (Pettebone et al., 2010). Therefore, taking all evidence available at this time, we conclude that the conditions of the wetlands are good, rather than excellent. This conclusion differs slightly from that of Denn and Shorrock (2006) because it considers more information, more recent information, and is based on different criteria established earlier in this document. The condition is good rather than excellent because reference conditions would be all wetlands with no degradation from direct or indirect human influences. Although small, we consider all of the available evidence about the current visitor and nonnative plant impacts not to be insignificant.

Threats & Stressors

The most common threats to wetland condition in DEPO as identified by the authors of the 2006 wetland survey (Denn & Shorrock, 2009) are recreation and fire, or more specifically, the abnormally severe nature of the 1992 fire in some areas due to the long history of fire suppression that led to abnormally high fuel loads. In that report, the effects of the 1992 Rainbow fire were identified as an anthropogenic stressor commonly observed in the monument’s wetlands.

Fire

The two wetlands identified as being in poor condition by Denn & Shorrock (2009) were within an area that experienced high fire severity during the 1992 fire (Caprio et al., 2006) and were identified to be in poor condition because they appeared to be degraded from forest loss around them as a result of the high fire severity. These two depressional wetlands are in the southern part of the monument away from trails. These wetlands may return to healthy conditions if natural processes are allowed to proceed, but the nature of the fire, future fire events, and a changing climate may influence the successional process. If historic fire return intervals are not maintained either naturally or through management action, conditions may again be created that may result in high fire severity and impacted wetlands. However, a changing climate will likely alter the fire regime and fire frequency, so conditions will probably always be in flux on longer time scales.

Visitor Use

Recreational use of sensitive natural systems such as meadows is likely to have large and long-lasting impacts and can threaten those systems. Informal trail proliferation and recreational use in meadows, tundra, and riparian areas can lead to soil loss and erosion as well as soil compaction and stunting and loss of vegetation (Willard & Marr, 1970; Burden & Randerson, 1972; Liddle, 1975; Manning, 1979; Liddle, 1991; Fritzke, 1992; Hammitt & Cole, 1998; Monz et al., 2009). Furthermore, trails are known to be corridors for the spread of nonnative plants via human dispersal (Tyser & Worley, 1992; Frakes, 2005; Potito & Beatty, 2005). These exotic species may then threaten and degrade the native system.

At least some of the meadows in the monument have a history of being degraded by visitor use. In the 1982 Natural Resources Management Statement for DEPO (NPS, 1982), a primary management objective was to "Restore meadows damaged by past visitor use and protect them from future abuse." After some restoration of portions of Soda Springs Meadow in the early 2000s, a formal monitoring program began in 2009. In that year, the Soda Springs Meadow/wetland area was surveyed for informal trailing and associated habitat fragmentation in the summer (Pettebone et al., 2010). Some meadow restoration had occurred in the years preceding this monitoring effort. Only those portions of the meadows that were free of trees or shrubs were considered part of the meadow. Two portions were surveyed: the largest main meadow that is to the west and south of the river and the northern portion that is to the north and east of the river. In all, both of these meadow areas were lightly impacted by informal trailing, though effects to biota likely substantially increase the overall impacted area (e.g. Holmquist & Schmidt-Gengenbach, 2008). Most trailing occurred along the meadow edges next to the river and near formal trails. In almost all sections of informal trails, the condition was assigned as lightly used. In only one short trail section in the main meadow was there exposed ground along the trial, potentially resulting from heavier use.

In the main meadow portion, the trail density was 125 meters/hectare (165 ft/acre) while in the north portion the density was 206 meters/hectare (274 ft/acre). The spatial extent of the impact of informal trails in meadows can be measured as the total length and width of mapped trails or can include a zone of ecological influence outward from trails. Research in Yosemite found that invertebrate abundance and diversity was negatively impacted as far as 5 meters (16 ft) on either side of simulated trails in a meadow (Holmquist & Schmidt-Gengenbach, 2008). Without the zone of influence, the total area disturbed was 0.45% of the main meadow and 2% of the north meadow. Assuming Soda Springs Meadow would respond similarly to the meadow studied in YOSE, and we include the five meter buffer zone of influence, the area disturbed was 10.3% of the main meadow and 19.3% of the north meadow. It appears that management efforts including restoration and the restriction of access to the meadow have helped to keep informal trail impacts low. However, continued use of existing and new informal trails within this and other meadows or wetlands may pose a risk to native flora and fauna and the ecological integrity of these sensitive wetlands.

Climate Change

Although discussed, but not identified as a significant threat to wetlands in DEPO by Denn and Shorrock (2009), a changing climate can be expected to have negative impacts such as altered hydrology and fundamental changes to the ecosystem, including invasion by non-wetland species (conifers). Pulses in meadow encroachment by species of subalpine conifers were positively associated with increases in minimum monthly temperatures in the Sierra Nevada (Millar et al., 2004). This research found that average minimum temperatures increased 3.7 °C over the 20th century in the Sierra Nevada region. There was also an increasing trend in regional precipitation over the 20th century, with most of the increase occurring after 1975. Conifer invasion into meadows increased during periods of negative PDO (Pacific Decadal Oscillation) and when minimum temperatures were relatively high and precipitation was relatively low. There was a distinct pulse of conifer invasion into Sierra Nevada meadows during the period 1946 to 1976 while both minimum temperatures and precipitation were stable, though variable (Millar et al., 2004). Helms (1987) also documented a period of conifer encroachment in meadows of Yosemite during the same period 1948 to 1973. Franklin et al. (1971) also found that conifer encroachment into meadows in the Cascade Range of Oregon and Washington occurred during periods of low soil moisture. If DEPO wetlands are in fact drying out as regional climate becomes warmer, this could lead to loss or degradation of this ecosystem through changes in species composition.

Invasive Plants

Due to their nature and location in the landscape, wetlands are often invaded by nonnative plants that negatively impact community structure, biodiversity, productivity, and nutrient cycling (Zedler & Kercher, 2004). The 2001 plant survey of the monument identified at least five nonnative species that were occupying wetlands in DEPO (Arnett & Haultain, 2005). Wetlands in DEPO have not been systematically monitored for nonnative plants since then, though some surveys have visited some wetlands. An assessment of high elevation meadows in SEKI found nonnative plants to be relatively rare and never above five percent cover (D'Antonio et al., 2004). This suggests that meadows in DEPO are unlikely to be heavily invaded by *Poa pratensis*, *Bromus tectorum* and other invasive species. Furthermore, *Bromus tectorum* is not a wetland species and so would not be expected to be found in abundance within wetlands. However, a warming climate would be expected to increase the occurrence and abundance of these and other nonnative species at high elevations and potentially within wetlands if they begin to dry out. Currently, information is not available on how nonnative plants are affecting wetlands of the monument, though the impact is believed to be small, though not insignificant.

Forests & Woodlands

Little is known about the status and trends of tree dominated forest ecosystems in the monument, with the exception of some post-fire monitoring. All of the information at hand comes from this monitoring and from the 1997 vegetation mapping project that included Yosemite and Devils Postpile (see figure 4.9).

The dominant vegetation type in the monument by area is conifer forest and woodland, dominated by lodgepole pine (*Pinus contorta*) and red fir (*Abies magnifica*) at 69% of the monument area. Throughout much of the conifer dominated areas, the canopy closure is relatively low (less than 60%

and thus technically woodlands) and most of the forests and woodlands were impacted by the 1992 fire. In areas of high fire severity, the forests are still responding through natural succession. The rate and dynamics of that succession may be influenced by the severity of the fire as well as by a changing climate regime. The Rainbow fire occurred after a long period of fire absence, potentially as a result of active fire suppression in the area, but also potentially in response to a warming climate (e.g. Westerling et al., 2006).

The state of Sierra Nevada forests has changed dramatically over the past 150 years as natural fire regimes were halted or curtailed through a concerted effort of fire suppression (McKelvey et al., 1996). Even as late as 1982, NPS managers directed as a goal for DEPO to cooperate with National Forest and County officials "… in efforts to suppress fire …" (NPS, 1982). Following many decades of fire suppression, the NPS finally instituted a policy of attempting to return the landscape to as close to a natural fire regime as possible within all park units.

Much of the forest habitat of DEPO is in a state of transition following the 1992 Rainbow fire that burned approximately 84 percent of the monument. Fire severity varied; in the southern portion and in The Buttresses area severity was high and many trees were killed, while in other areas the fire was mostly a surface fire and fewer trees were killed. Tree mortality in these high severity areas in the southeast and western parts of the monument was nearly 100% (NPS, 2005).

Fire ecologists from SEKI have monitored post-fire forest succession on six 0.1 hectare plots, two each in low, moderate, and high fire severity areas. Five years after the fire, tree mortality was high in all burned plots (Cox & Keifer, 2002). Recruitment of new trees into all plots was relatively high after five years, though there was high variability by species. Fir species (either red fir, white fir, or both) had recruited in high densities in low fire intensity plots but in lower densities in moderate and high intensity fire plots. Jeffrey pine recruited in high densities in high intensity fire plots, but in low densities in the low and moderate intensity plots. Lodgepole pine had only very low levels of recruitment and only in the low and moderate intensity plots. Although no direct comparisons could be made due to small sample size, plant species diversity in the burned plots was much higher than in the unburned plots five years after the fire. This does not prove but suggests that the burn had at least temporarily increased plant species diversity at the local scale, five years post-fire.

After 10 years, DEPO post-fire plots were again surveyed in 2002 (Caprio & Webster, 2006a; Caprio & Webster, 2006b). The surveys found that recruitment of shrub, herbaceous, and tree species continued as was seen five years after the fire. In general, conifer seedling recruitment continued to be good in all fire severity classes. However, interior areas of high severity that lacked close surviving trees as seed sources continued to experience much lower conifer seedling recruitment. Recruitment of new individuals was occurring either through wind dispersed seeds from extant mature trees or from rodent and small mammal seed caches in the ground. Total cover of understory vegetation in the burned plots continued the increasing trend seen after five years, increasing to 28.3% cover after ten years. However, the composition of the understory vegetation did change with forbs decreasing and grasses and woody vegetation increasing in cover. Floristic diversity in the understory also continued to increase, reaching 36 species at 10 years in all plots combined (compared to only two species immediately post burn). Data collected in 2002 indicate that prior to the fire, most sites had little understory vegetation. The dramatic increase in understory cover and species richness through 10 years post-fire indicates that fire may be an important process for maintaining high plant species diversity through a patch dynamic where there are shifting patches of either burned or unburned or areas that experienced different fire history and severity.

In the 2005 fire management plan for the monument (NPS, 2005), it is stated that where severity was high in the 1992 fire, a shrub and herbaceous dominated habitat has replaced the conifer forests and this change in composition is believed to be outside the normal range of variability that would have occurred in the area prior to fire suppression. The fire effects plots will continue to be monitored with the next scheduled sampling to occur in 2012. In addition, a set of regeneration plots was established in 2004 to more fully quantify the recruitment of species into burned areas. Data from these plots will shed more light on how these forests are recovering.

Besides the six fire monitoring plots that are surveyed every five years, there has been no other research in DEPO that has assessed conditions or monitored aspects of forest or woodland plant communities. Research from Yosemite and other parts of the Sierra Nevada have found that after a long period of fire exclusion, forest species composition and density have been altered substantially (Lutz, 2008; Lutz et al., 2009a; Scholl & Taylor, 2010). This was also likely the case before the 1992 Rainbow fire and currently in the northern portion of the monument that did not burn in the 1992 fire.

An important broadleaf forest tree, quaking aspen (*Populus tremuloides*), only exists in small patches in the southeast corner of the monument. There has been no monitoring or research of this or other broadleaved species within or nearby the monument. In Colorado and across the Rocky Mountains, this species has experienced a recent dramatic dieback that has been associated with a continuing drought (Worrall et al., 2008). The local status of the species is not nearly as impacted as in the Rocky Mountains, though here they are believed to be in slow decline (Rogers et al., 2007; Morelli et al., 2009). In the western Lake Tahoe basin, an assessment of 542 aspen stands found 70% to be either at moderate or high risk of losing long-term viability from several threats, primarily a lack of recruitment and conifer succession into aspen stands (Shepperd et al., 2006). In the Sierra Nevada, declines of quaking aspen may be the result of fire exclusion, grazing, and/or an overabundance of deer (Rogers et al., 2007), the result of shifting climates, or a combination of any of these factors.

Current Condition Summary

Reference conditions would be a forest and woodland ecosystem that is experiencing a fire regime unaffected by modern human influences and that is a patchwork of different stand ages with varying tree densities and demographics. In the proportion of the monument affected by the 1992 fire (~84%), this is largely the case. However, there are some early indications that areas that burned with unusually high fire severity and experienced high or complete tree mortality may be converting to shrubland. The remaining 16% unburned area that has not experienced fire for at least 124 years is likely out of natural balance based on the knowledge of pre-fire suppression fire regimes (see Fire Regime section below). Therefore the condition of conifer and broadleaf forests in the monument is good, but they suffer from several threats and stressors that either are or may be degrading the health and integrity of forests and woodlands.

Threats & Stressors

Climate Change

A changing climate will continue to affect the montane and subalpine ecosystems of the monument, possibly in different and complex ways. If recent trends of increasing temperatures continue, then decreases in snowpack, earlier snowmelt, longer and drier summers, and increased lightning strikes would lead to conditions more favorable to wildland fires in the area. See Threats and Stressors discussion in Section 4.2 above for more on climate change.

Some research in the Sierra Nevada has linked tree mortality to changing climate. van Mantgem and Stephenson (2007) documented a doubling in young conifer mortality rate over a recent 22-year period in the Sierra Nevada. Mortality was best predicted by soil water deficits, indicating that as climate warms regionally, available moisture is decreasing even though precipitation remained unchanged – a trend that is likely to continue. Other research in Yosemite documented a relationship between increased conifer death rates and lower April 1 snowpack and thus longer Spring/Summer drought periods (Guarin & Taylor, 2005), drawing a link between conifer forest health and a warming and drying climate. Using downscaled data for future climate scenarios, Battles et al. (2008) modeled a decrease in conifer growth rates and rise in death rates as future climate warms for the northern Sierra Nevada over the next century. Over the future modeled period, temperatures increase while precipitation remained unchanged, though variable, indicating that drought stress will be a likely driver in forest change.

Altered Fire Regime

The National Park Service has and still maintains a policy of suppressing unplanned fires within the monument. In order to return the forests in DEPO and the surrounding forest lands to a "natural" fire regime, a program of prescribed fires would need to be implemented. If prescribed fires are deemed too risky, mechanical thinning of forests can reduce fuel loads. However, mechanical thinning does not produce the same ecological results and benefits as does fire. Monitoring the effects of prescribed fires, if used, would be an essential part of adaptive forest conservation. Some coordinated stand thinning has taken place in and around DEPO in recent years in an effort to reduce high fuel loads.

Although there is no evidence directly from the monument, research from nearby Yosemite National Park indicates that decades of fire suppression may have resulted in higher tree mortality and thus may result in higher fire severity when fires do occur. Guarin & Taylor (2005) found that conifer mortality in Yosemite increased during years when the Palmer Drought Severity Index (PDSI) was high and April 1 snowpack was relatively low. Where conifer density was higher on north facing slopes, the density of dead trees was also higher, suggesting that dense tree stands that resulted from fire suppression were not buffered by their relatively cooler and wetter microclimate. This same phenomenon may have resulted in high or relatively high tree mortality rates and thus fire severity during the 1992 fire in at least some portions of the monument. If fire suppression continues within the monument and silvicultural methods are not used to remove excess fuels if and where they exist, the same situation may set up in the future. As Bulaon and MacKenzie (2008) conclude, high densities of lodgepole pine (probably as a result of a long history of fire exclusion) in the northeast part of the monument likely contributed to elevating their susceptibility to insect attack, resulting in some mortality.

Air Pollution

Takemoto et al. (2001) concluded that the greatest air pollution threats to forests of California are nitrogen infusion through deposition and injury from ozone. The monument is within the San Joaquin Valley Unified Air Pollution Control District which is usually in serious non-attainment status for ozone (8 hr), and in extreme non-attainment status for ozone (1 hr). This nonattainment is due to the preponderance of sources within the California Central Valley and San Francisco Bay Area that are transported east and up slope.

Ozone is known to damage pine needles, and ponderosa and Jeffrey pine are especially susceptible to damage (Bytnerowicz et al., 1989; Miller et al., 1991). Although pollutants are in much higher abundance within the San Joaquin Valley and nearby foothills closer to the source, the higher elevation forests and woodlands of DEPO will continue to be threatened at least somewhat by ozone and other pollutants. Fenn et al. (2003c) concluded that nitrogen deposition and ozone are not a serious threat to forest tree species and ecosystems in the upper elevation Sierra Nevada. However, recent research has revealed that ozone and nitrogenous pollutants are present in higher abundance within DEPO than previously thought. After monitoring air quality at a site in DEPO during the summers of 2007 and 2008, Bytnerowicz et al. (2010) found that ozone, nitric oxide, and ammonia were in higher concentrations than expected for such a remote site with ostensibly clean mountain air (see Air Quality section). With wide diurnal fluctuations, ozone peaked every day in late afternoon, sometimes exceeding state and federal standards. Ozone increased to levels that may be phytotoxic to species such as Jeffrey pine. Therefore, there is an existing threat of phytotoxic damage to Jeffrey pine and other forest species within the monument. A risk assessment by the NPS Air Resources Division determined that Jeffrey pines in the monument are at high risk of foliar injury by ozone (Kohut, 2007).

If current ozone concentrations in the Sierra Nevada remain relatively constant or increase, long-term damage could cause shifts in forest structure and composition (Miller, 1973; Miller, 1996), and contribute to increased susceptibility to fatal insect attacks, death rates, and decreased recruitment (Ferrell, 1996). Peterson et al. (1989) found that reductions in ponderosa pine (closely related to Jeffrey pine) growth rates were correlated with ozone exposure and ozone injury. Somers et al. (1998) discovered that yellow poplar trees with evidence of foliar ozone injury had a significantly reduced radical growth rate compared to trees that did not exhibit any ozone damage. Although this species does not occur in the monument or the Sierra Nevada, a related species – black cottonwood – does, and may be experiencing similar impacts. However, substantial evidence exists that at least some species can adapt to the stress of air pollutants through selection for resistance (e.g. Roose, 1991; Tonsor & Kalisz, 1991). It is possible that this could occur in pine populations.

Recent data collected from YOSE and SEKI found that concentrations of some pesticides were relatively high in the tissues of conifer needles even at elevations above DEPO (Landers et al., 2008). The effect that pesticides are having on forest trees in DEPO is unknown at this time.

Insects and Fungi (Pests & Pathogens)

As a whole, native insect and fungi species are present and abundant throughout all Sierra Nevada forest types, though they are often referred pejoratively as "pests" or "pathogens" (Furniss & Carolin, 1977; Sharpf, 1993). While insects, fungi, and other damage-causing species are capable of seriously injuring and killing trees, it is believed that they attack individuals and populations under stress from other systemic factors and so outbreaks of these pests are considered symptoms of poor forest health (Wickman, 1992). In North America, insect outbreaks and their effects on trees is the most important agent of natural disturbance in forest systems. Although fire is also a major natural disturbance, the total forest area impacted by insects and pathogens in the U.S. is almost 45 times the area affected by fire (Dale et al., 2001).

For decades, research has investigated the role of fire suppression and the resulting increase in stand densities on the incidence of insect and pathogen outbreaks and much of the work has found a link (e.g. Stevens et al., 1980; Sherman & Warren, 1988; Savage, 1994; Hagle et al., 1995). However, others have found no relationship between fire exclusion and insect or pathogen incidence. For example, van Mantgem et al. (2004) found no association between past fire exclusion and tree mortality from insects.

There is also the possibility that regional warming may increase the occurrence and severity of insect and pathogen outbreaks. That is the conclusion of Logan et al. (2003) whose review of the literature found that research has documented that drier weather patterns have already increased insect outbreaks in forests of the southwestern U.S. Conifer mortality in the Sierra Nevada through bark beetle activity were correlated with warm and dry periods (Millar et al., 2007). In addition, van Mantgem and Stephenson (2007) determined that an increase in the mortality rates of pines and firs in SEKI and YOSE was best explained by water deficits – a warming climate was reducing the available water and increasing water stress. Weakened trees were eventually killed by bark beetle damage but the ultimate cause was thought to be a warming climate.

In DEPO, there were small infestations of mountain pine beetle in lodgepole pines around the campground and administrative areas in the northeast corner of the monument in May of 2008 (Bulaon & MacKenzie, 2008). There was some mortality in older trees but the overall problem was deemed minor by the Forest Service entomologist and pathologist who visited the site. They speculated that a combination of dense stands that likely resulted from an absence of fire along with recent trends in decreased precipitation at lower to mid-elevations and increases in minimum temperatures likely contributed to the beetle attacks. Lodgepole needle miner moths have been a persistent agent of large-scale tree mortality in nearby Yosemite National Park. However, damage from this species has not been documented in and around DEPO in the last ~20 years. An abnormally high tree density in conifer stands has been shown to be associated with higher rates of insect and pathogen damage and mortality (Slaughter & Parmeter, 1989; Ferrell et al., 1994; Oliver, 1995; Ferrell, 1996). The pine beetle attacks of 2008 occurred within the area that did not burn in the 1992 fire. Recommendations included mechanical thinning (in absence of prescribed fire) to reduce risk, removal of the small number of dead or dying trees, or direct beetle control with pesticides (Bulaon

& MacKenzie, 2008). Another localized infestation of mountain pine beetle in 2010 was reported in the housing area of the monument but was determined to be minor and not requiring treatment.

Fauna

According to all sources, there are 163 - 179 vertebrate species known or suspected of occurring in DEPO (as of 2010). Counts vary by source, with those in the NPSpecies (NPS IRMA) database different from the sum of independent research. While little information is known about some animal families such as amphibians and reptiles, much more is known about others, including birds and macro-invertebrates. All animal species known or suspected of using habitat in the monument, either seasonally, permanently, or intermittently are listed in Appendix B.

Birds

According to all recent surveys in DEPO (since 2002), there have been 96 species of birds detected, with 80 of those considered a regular breeder (Steel et al., 2012). Including surveys that go back to the mid-1990s, the total number of species detected within DEPO is at least 109 and as many as 128. Some of the earlier records for bird species presence were not confirmed, and so probably should not be included in any assessments.

Bird populations have been monitored within the monument since 2002 using two parallel methods. From 2002 to 2006 PRBO Conservation Science (PRBO) operated a Monitoring Avian Productivity and Survivorship (MAPS) station at Soda Springs Meadow and surveyed 15 point count stations along the San Joaquin River within monument boundaries. In addition, a one-time point count survey was conducted in 2003 by The Institute for Bird Populations (IBP) (Siegel et al., 2004). In 2009 and 2010, PRBO re-sampled the San Joaquin River point counts and all of the point count surveys established by IBP in 2003 that were subsequently adopted for use in the bird monitoring protocol for the Sierra Nevada Network (Siegel et al., 2010). In addition, in 2009 PRBO converted the MAPS station to a post-breeding constant effort mist-netting station following the recommendations made after five years of operating the site as a MAPS station. Through a cooperative agreement with the Park Service, IBP is scheduled to continue the point counts in future years.

MAPS – Constant Effort Mist-netting

Over the initial five year MAPS monitoring period (2002-2006), the number of species captured in mist nets varied, but the total number of captures per 100 net hours increased each year. Total individuals captured/100 net hours increased from 44.97 in 2002 up to 67.14 in 2006. Ratios of hatching year birds (young) to after hatching year (adult) birds captured for the five most captured species (as an index of productivity) showed no consistent trends for all species pooled (Heath, 2007). The total number of species captured in the mist nets was variable over the years, with 30 in 2002, 23 in 2003, 37 in 2004, 29 in 2005, and 24 in 2006. There is no upward or downward trend in species richness over the period (Heath, 2007).

In a summary of MAPS data from 2002-2004 for monitoring stations in Sierra Nevada Network parks, DeSante et al. (2005) found that bird capture rates from the one MAPS station in DEPO were intermediate compared to those in YOSE and Kings Canyon National Park (KICA). Calculated productivity rates from the DEPO station were comparable to those found in KICA. An examination of all SIEN stations found that the relationship between bird species richness and elevation is linear and negative. In contrast, the relationships between bird capture rates and productivity rates and elevation are curvilinear, with maximum adult population densities occurring at approximately 1,800 m (5,900 ft), and maximum juvenile population densities and productivity rates occurring slightly higher at approximately 2,200 m (7,200 ft). The MAPS stations in the SIEN parks were located at various elevations: the five in YOSE ranged in elevation from 1,311 meters (4,300 ft) to 2,402 meters (7,880 ft); the two in KICA ranged from 1,280 meters (4,200 ft) to 1,853 meters (6,080 ft); the one station in DEPO is at 2,350 meters (7,710 ft).

Averaged over the three or four years of data collection (2001-2004), adult capture rates for all species pooled at DEPO were less than those at YOSE, but greater than for KICA (DeSante et al., 2005). Comparing the DEPO station to White Wolf in YOSE as both are at similar elevations (though differ greatly in topographic location), adult capture rates were much lower in White Wolf (108 captures/600 net hrs) versus DEPO (173 captures/600 net hrs). Adult species diversity was similar for both of these stations: 27 at White Wolf and 31 at DEPO. In contrast, capture rate of young birds was much lower at DEPO (74 captures/600 net hrs) compared to the average of all five stations in YOSE (251 captures/600 net hrs). Again comparing only White Wolf to DEPO, the young capture rates were similar: both were approximately 74 individuals/600 net hrs. Juvenile species diversity was also the same at 22 species for each site. Juvenile survival rates at DEPO are the same as those at YOSE when elevation is taken into account. The proportion of young captured (an index of population productivity) paralleled the other findings, with DEPO (0.298) much lower than YOSE (0.540) but similar to KICA (0.288) (DeSante et al., 2005). This reflects not a low juvenile abundance, but a relatively high adult abundance in DEPO compared to similar elevations in YOSE. Overall, sites that have relatively higher numbers of adult captures versus juvenile captures are more important to the species since juveniles often occupy secondary habitat. One cautionary note regarding these findings is that since field captures occurred from mid- or late-May to early August each year, the bird capture data may include both resident and non-resident species. If needed, closer inspection of the data could provide resident and non-residents indices separately.

Based on relationships between elevation and population and demographic indices for all the SIEN MAPS stations, population productivity rates during the period 2002-2004 at DEPO were below those expected (modeled) and the authors argue that a likely explanation is either sub-regional (park or watershed level) or local (station specific) effects (DeSante et al., 2005). In nearby Yosemite, a time series comparison of YOSE MAPS data (1993-2003) resulted in a statistically significant -2.7% relative population decline for all species (DeSante, 2005; DeSante et al, 2005). Due to lack of data and small sample size, a similar analysis is not possible for the DEPO station.

After several years, mist netting occurred again in 2009, with similar results compared to the 2002 – 2006 period (Richardson & Moss, 2010). However, the 2009 methods were altered to target post-breeding banding and so are not directly comparable to numbers from the 2002 – 2006 period. Capture rates for all species over the six years trended upward from a low in 2002 of 57 captures/100 net hours to a high in 2006 of 76 captures/200 net hours. In 2009 this rate was 72 captures/100 net hours. In 2009, total species diversity of 35 was within the range previously recorded during the 2002

– 2006 period (24-37 species). Some quantitative assessments can be drawn from the MAPS mist netting data for the six years. Capture rate does indicate an increase in total bird abundances from 2002 through 2009. However, analysis of variance (ANOVA) finds that the trend is weakly significant ($F_{1,4} = 6.163$; $p < 0.068$). A relatively small sample size may contribute to a lack of statistical significance at the standard 5% level. ANOVA for species diversity over the years from the mist netting also shows no upward or downward trend ($F_{1,4} = 0.38$; $p < 0.57$).

Looking across the region, in a Sierra Nevada-wide monitoring effort of landbird species, Siegel and Kaschube (2007) analyzed data on productivity and survivorship (MAPS program) from 29 stations. Some stations began operating as early as 1990, while others began in later years. The MAPS station in DEPO began operation in 2002. Pooling all Sierra Nevada stations, data through 2005 were analyzed for trends in population sizes, productivity, and survivorship. Examining 39 species that were captured in sufficient frequency, 11 (28%) showed statistically significant downward population trends. Those with the steepest declines over the monitoring period were: 1) downy woodpecker; 2) chipping sparrow; 3) Lazuli bunting; 4) purple finch; 5) Cassin's finch; and, 6) lesser goldfinch. In contrast, 10 (26%) species demonstrated statistically significant upward trends in population sizes over the same period. Those with the steepest increases were: 1) hairy woodpecker; 2) northern flicker; 3) brown creeper; and, 4) western tanager. However, capture and recapture rates for hairy woodpecker and northern flicker were very small, making them susceptible to apparent large or small increases due to normal inter-annual variation. When all species are pooled, there is no statistically significant population trend, up or down over the time period of analysis (Siegel & Kaschube, 2007).

In the same analysis, adult survivorship rates were calculated for 42 species and ranged from a low of 0.142 for golden-crowned kinglet to a high of 0.739 for Pacific-slope flycatcher (Siegel & Kaschube, 2007). The mean value for all species was 0.472. About equal numbers of species had a significantly decreasing trend (4) in productivity as had a significantly increasing trend (6); most (32) had no significant trend up or down. However, species of greatest concern that already have low population levels (such as willow flycatcher) were not captured in adequate numbers at MAPS stations to allow for statistical trend assessment.

Point Count Surveys

Using very limited resources, the point count surveys are designed to detect changes in species richness and estimated abundances over time of all species detected. Abundances are estimated with the inclusion of detection probabilities. Since this monitoring has only occurred since 2002, no statistical analysis of trends in total abundances (population sizes) of individual species, nor in total combined abundances, nor in overall species diversity can be made with statistical confidence. The data collected so far can confirm presence (but not necessarily absence) and estimate abundance across all species detected, with explicit assumptions on detection probabilities for each species.

Avian point count surveys in the monument were established in 2002 by PRBO along the Middle Fork San Joaquin River and by IBP in 2003 in a systematic spatially comprehensive grid across all habitats in the park. Five of the stations from the river transect were incorporated into the systematic grid. All point count stations were surveyed using standardized five-minute point counts with distance sampling (Buckland et al., 2001; Rosenstock et al., 2002). In summary, all birds detected during the five minute period were recorded along with their distance from observer and detection cue (e.g. song, visual, or call). Fifteen point count stations spaced 250 meters (820 ft) apart were established along the San Joaquin River from the northern monument boundary to the southern boundary and were operated from 2002 through 2005 (Heath, 2007) and again in 2009. The systematic grid first established in 2003 contained 42 points evenly distributed across the monument (Siegel et al. 2004). After a three-year break in bird monitoring (due to a lack of funding), PRBO again conducted point count surveys in the monument in 2009 (Richardson & Moss, 2010) and 2010. In 2009 the original 15 point count locations along the San Joaquin River were re-surveyed as well as all but two (inaccessible sites) in the systematic grid established by IBP in 2003.

Over the initial four year period surveying the 15 point count stations along the San Joaquin River, the frequency of occurrence for some species increased while others decreased (Heath, 2005a; Heath, 2005b). Total bird abundances followed the same pattern. Species richness was variable, though 2005 had the lowest richness at 19 species. Species richness and bird abundance was over twice as high at the Reds Meadow creek location (11 spp) than at any other location. The author attributes this to the diversity of breeding habitats around this point count location: white alder, burned lodgepole pine forest, unburned lodgepole pine forest, and wet meadow (Heath, 2005a). All other point count locations had species richness values from two to five.

A total of 59 species was documented during the June 2003 survey effort of the systematic grid (Siegel et al, 2004). Forty seven species were documented during the point counts while the remaining 12 were observed outside of the official five-minute survey periods. Seven of the species – Virginia rail, Vaux's swift, white-throated swift, Anna's hummingbird, rock wren, common yellowthroat, and red-winged blackbird – had not been detected previously. The most abundant species (based on detectability and adjusted densities) was brown creeper followed by dark-eyed junco, and mountain chickadee (Table 4.14). The 11th most abundant species – olive-sided flycatcher – is a species of increasing conservation concern throughout the mountain Western U.S. (Altman & Sallabanks, 2000; Meehan & George, 2003).

Table 4.14. The twelve most abundant landbird species documented in 2003 by Siegel et al. (2004) in DEPO.

Species	**Density (birds/ha)[a]**
Brown creeper	0.63
Dark-eyed junco	0.59
Mountain chickadee	0.58
Yellow-rumped warbler	0.52
Fox sparrow	0.37
Golden-crowned kinglet	0.34
Western wood-pewee	0.33
MacGillivray's warbler	0.31
Warbling vireo	0.29
American robin	0.18
Olive-sided flycatcher	0.18
Hairy woodpecker	0.10

[a] Density adjusted after accounting for variable detectability by species.

The 50 point count stations were surveyed again in 2009 and thirteen new species were detected within the monument (Richardson & Moss, 2010). The following species were first detected in 2009: Gadwall, Ruddy Duck, Eared Grebe, Great Blue Heron, Sharp-shinned Hawk, Red-shouldered Hawk, Osprey, Northern Pygmy-Owl, Black Phoebe, Pygmy Nuthatch, Cedar Waxwing, Vesper Sparrow, and Indigo Bunting. Many of the new species detected can be attributed to having biologists in the monument in the fall which was never the case in previous years. This is a considerable increase and shows that different species utilize the monument during fall migration. Since all previous PRBO reports have included species detected by other surveyors such as the monument-wide survey by the Institute of Bird Populations (Siegel et al, 2004) and by Parker and Parker (2001) this represents a real increase in species richness over the period of record. However, it is likely that the 13 new species were not new to the monument in 2009, but were first detected in that year due to the expanded surveys.

During the point count surveys from 2002 to 2005 and 2009, 21 listed species were detected (Table 4.15).

Table 4.15. Listed species detected at DEPO during PRBO surveys 2002-2005 and 2009 or by other surveys, or thought to occupy the monument, even occasionally. CBSSC = California bird species of special concern (Shuford & Gardali, 2008); USFWS = US Fish and Wildlife Service birds of special concern, region 9 and 15 (USFWS, 2008); Audubon = Audubon WatchList (Audubon, 2007). California status from California Department of Fish and Game and Shuford & Gardali (2008).

Common Name	**Listing**	**California Status**
Bald Eagle	USFWS	State endangered
Northern Goshawk	CBSSC, USFWS	Species of Special Concern
Golden Eagle	USFWS	None
Northern Harrier	USFWS	Species of Special Concern
Great Gray Owl	USFWS	State endangered
Spotted Owl	USFWS	Species of Special Concern
Long-eared Owl	USFWS	Species of Special Concern
Black Swift	CBSSC, USFWS, Audubon	None
Calliope Hummingbird	USFWS, Audubon	None
Williamson’s Sapsucker	USFWS, Audubon	None
Cassin’s Finch	USFWS	None
Lewis’ Woodpecker	USFWS, Audubon	None
White-headed Woodpecker	USFWS	None
Willow Flycatcher	USFWS, Audubon	State Endangered
Olive-sided Flycatcher	CBSSC, Audubon	Species of Special Concern
Yellow Warbler	CBSSC	Species of Special Concern
Hermit Warbler	Audubon	None
Green-tailed Towhee	USFWS	None
Brewer’s Sparrow	USFWS	None
Mountain Quail	Audubon	None
Eared Grebe	USFWS	None

With limited funding for monitoring and limited data collected to date, we cannot conclude with high confidence the condition of bird species and populations in DEPO. From the data we know that most species appear in the monument year after year while rare species are only seen in one or a few years at low rates. Capture numbers from five years of MAPS station data were insufficient to estimate adult survival rates. In order to estimate adult survival rates in the future, more mist net locations would need to be added or more years of data collected. Due to the short season that DEPO is open, variation in snowpack, runoff, and flooding of meadows, in many years it is not feasible to survey for birds early enough in the season to determine arrival dates for breeders and spring migrants. More frequent banding should improve the ability to document arrival dates of summer and fall migrants. The inclusion of more net capture days into the monitoring protocol in 2009 will improve the understanding of variability in fall migration, dispersal, and breeding phenology. In time, continued monitoring will shed more light on the population trends of the most common species, their relative abundances, and habitat associations.

In the summer of 2011, the SIEN bird monitoring protocol was implemented at DEPO where the intention is to monitor the 42 point count stations on an annual basis (Siegel et al., 2010). This monitoring will provide information about changes in bird abundances and distribution across the monument over time. The MAPS stations will continue to be operated and provide complementary information about bird productivity and survivorship.

Taking advantage of a longer dataset, we can take a broader look regionally. Several long-term monitoring programs in the United States, particularly the Breeding Bird Survey (BBS), have collected enough data to strongly suggest that many land bird populations appear to be in serious and steady decline in the Sierra Nevada and North America (Peterjohn et al.,1995; Siegel & DeSante, 1999; Sauer et al., 2003).

Breeding Bird Survey

The Breeding Bird Survey (BBS) is the most spatially comprehensive survey across the United States. The BBS has established 36 transects in the Sierra Nevada since 1968. Although no transects occur within or close to DEPO, the data from the other transects would be indicative of conditions within the Sierra Nevada as a whole. An early assessment of the Sierra Nevada BBS data (through 1991) concluded that those species that appeared to be declining the most were resident birds (e.g. red-breasted sapsucker, white-crowned sparrow, American robin, chipping sparrow) that move between the San Joaquin Valley and foothills and higher elevations (Sierra Nevada Ecosystem Project, 1996b). [The SNEP report refers to the species named in the preceding sentence as short distance migrants. However, IBP considers these species to be residents.] A much later assessment found that while these species continued to decline until about 1997, populations increased or stabilized through 2003 (Institute for Bird Populations: http://www.birdpop.org/). A decline in the population sizes of these local migrants would not be unexpected since their wintering habitats in the foothills and San Joaquin Valley have been heavily impacted by development, land use conversion, and cattle ranching/grazing.

An analysis of data from the 36 BBS transects within the Sierra Nevada (data from Sauer et al., 2008) for data from 1968 through 2007 shows that of the 80 species detected in the surveys, three that do occur in DEPO have shown a significant positive trend over the period (Table 4.16). Positive and negative trends are included only for trends where there is less than a 5% chance of accepting the null hypothesis that there is no trend when it should be rejected (when $p < 0.05$).

Table 4.16. Breeding Bird Survey results 1968 – 2007 for 36 transects in the Sierra Nevada. Trend analysis results for species with significantly increasing trends only ($p < 0.05$). Listed in order of increase from most to least. The estimated trend is the mean change in population size per year over the time period and accounts for the relative precision of the estimation. Data from Sauer et al., 2008. Species Type: R = resident; NM = neotropical migrant; SDM = short distance migrant

Species	P value	Est % Change/yr	Species Type
Anna's Hummingbird	0.004	11.2	R
Common Raven	0.027	6.2	R
White-headed Woodpecker	0.01	2.5	R

In contrast, 17 species that occur in DEPO show a significant negative trend (at $p < 0.05$) in the Sierra Nevada over the same period (Table 4.17). The remaining species that occur in DEPO either had no statistical trends or were not detected in sufficient numbers at the 36 transects.

Table 4.17. Breeding Bird Survey results 1968 – 2007 for 36 transects in the Sierra Nevada. Trend analysis results for species with significantly decreasing trends only ($p < 0.05$). Listed in order of decline from most to least. The estimated trend is the mean change in population size per year over the time period and accounts for the relative precision of the estimation. Data from Sauer et al., 2008. Species Type: R = resident; NM = neotropical migrant; SDM = short distance migrant

Species	P value	Est % Change/yr	Species Type
California Gull	0.02	-15.4	SDM
Vaux's Swift	0.04	-11.5	NM
Wilson's Warbler	0.022	-5.8	NM
Brown-headed cowbird	0.0001	-3.9	SDM
Olive-sided Flycatcher	0.0001	-3.5	NM
Golden-crowned Kinglet	0.026	-3.5	SDM
Chipping Sparrow	0.002	-3.4	R
Nashville Warbler	0.002	-3.0	NM
Cassin's Finch	0.005	-2.8	SDM
Orange-crowned Warbler	0.2	-2.5	NM
Brewer's Blackbird	0.0497	-2.3	SDM
Purple Finch	0.01	-2.2	SDM
Dark-eyed Junco	0.031	-2.2	SDM
Western Wood-Pewee	0.021	-1.9	NM
American Robin	0.001	-1.9	R
Mountain Chickadee	0.016	-1.5	R
Steller's Jay	0.004	-1.2	R

Sixty six of the 80 BBS bird species of the Sierra Nevada have been detected at DEPO. Seven of the 30 (23%) short distance migrants detected in at least 15 of the 36 Sierra Nevada transects that also occur in DEPO are in decline while none has increased since 1968. Four of 12 (25%) resident bird species in the Sierra Nevada that also occur in DEPO are in decline, while three of 12 (25%) are on the increase since 1968. For neotropical migrants, six of 24 (25%) in the Sierra Nevada that occur in DEPO are in decline while none have been increasing since 1968. It appears that throughout the Sierra Nevada, there is a decline of about one-quarter of the species, and include residents, short distance migrants and neotropical migrants. These decreasing trends are at least partially attributable to the loss of habitat within their winter or non-breeding habitat. Resident species are somewhat stable with small and equal numbers increasing and decreasing, while most show stable populations over time.

A look at all species detected along at least 15 of the 36 Sierra Nevada transects (not just those occurring in DEPO) finds a total of 80 species that had large enough abundances to estimate trends. Of these, 17 percent show a significant decline in relative abundance from 1968 through 2007 while 15 percent showed a significant increase over the same period (at $p < 0.05$) (Sauer et al., 2008). About half of the species detected were only detected on fewer than 15 of the 36 transects and so are considered to have a sample size too small to estimate changes in relative abundance. In total, 151 species were detected at least once across all survey transects.

The BBS data has several limitations that may cause species to appear in decline or on the increase when in fact they may not be. Because most of the species in the Sierra Nevada that were detected in the surveys are relatively rare, becausesampling methods have small sample sizes, and because some species may have short detection intervals for the analysis, spurious or inconsistent results from the analysis may occur (Sauer et al., 2008). The trends analysis uses bootstrapping methods to estimate population trends and so trend estimates will vary from run to run and may sometimes be very different if the species has a small sample size. Steel et al. (2012) used the same data set and came up with different results because of these facts. Therefore, the trend analysis results of BBS data should be interpreted with extreme caution.

At least some of the declines in species (if real) could be associated with regionally warming climate. Comparing the observations of birds from the 1911 – 1928 period with a resurvey in the 2003 – 2008 period, Tingley et al. (2009) found that 91% of species had adjusted their range by tracking their ecological climate niche (based largely on temperature and precipitation). This may have resulted in moving up in elevation or northward, but not necessarily.

Current Condition Summary

It is difficult to draw general conclusions on the current condition and trends of bird species that occur in DEPO. Although substantial amounts of data have been collected in DEPO and the Sierra Nevada, the nature of these species and the difficulty in monitoring them prevents drawing conclusions with better than low confidence at this time. More monitoring and collection of additional data would be needed to better assess conditions and trends. However, we do realize that accomplishing this may be difficult given the nature of the logistics at DEPO. Although we may not conclude with much confidence given the limitations of the data collected, we do believe that the short term studies discussed above give some indication of potential trends in species richness, relative population sizes, and productivity. The MAPS and point count programs in DEPO indicate that at least some of the bird species that use DEPO could be in decline, while some are increasing over the short period of study. Over this time period, overall bird abundance appeared to be rising. However, data from the MAPS program indicate that population productivity rates during the period 2002-2004 at DEPO were below those expected. The Sierra Nevada BBS data indicate many more species are in decline than are increasing in relative abundance, though trends may not be real. About one-quarter of all species is in decline, independent of bird life history.

Reference conditions of the bird community in DEPO would be presence of all species known to historically use the monument and all with healthy reproductive, stable populations, and population sizes within historic variability. Although some critical information is missing, the research available helps us to conclude that the condition of the bird community in DEPO is fair to good. The current condition of the bird community has likely been negatively impacted by a number of threats that could have already caused declines and/or likely will lead to population declines in the future.

Threats & Stressors

Research has documented some general declines in many species of birds in North America in the last several decades (Robbins et al., 1989; Askins et al., 1990; Sauer & Droege, 1992; Rappole & McDonald, 1994). The declines have been linked to a variety of causes including loss or degradation of breeding, wintering, and migration route habitats, suppression of natural disturbance (e.g. fire), climate change, cowbird parasitism, and food availability. Bird species will be affected by a different subset of environmental or anthropogenic factors depending on their life history. Neotropical migrants that winter in the neotropics may be influenced by loss or degradation of habitat both here and in the wintering grounds. The same is true for short distance migrants that migrate down to southern California and northern Mexico. These species will be affected by changes throughout their migratory range. Resident birds migrate between the DEPO area and lower elevations in the Sierra Nevada foothills or San Joaquin Valley and would be affected by factors that influence locations utilized throughout the year. Some of the most widely discussed threats to bird species in North America and the Sierra Nevada are discussed below.

Nonnative Species

An existing threat to birds in the region is brown-headed cowbird (*Molothrus ater*) nest parasitism. Although this bird is a native to North America, it is expanding its range through successful parasitism of nests, and due to its association with human development is considered an invasive species. This species was first noted around Mono Lake in 1916 and has been directly linked to or implicated in the decline of several song bird species in California, especially the yellow warbler, willow flycatcher, least Bell's vireo, song sparrow, and chipping sparrow (Gaines, 1974; Laymon, 1987; Sierra Nevada Ecosystem Project, 1996b). In Michigan, the near extinction of Kirtland's warbler in the 1960s was directly linked at least partially to nest parasitism by brown-headed cowbirds (Probst, 1986).

Brown-headed cowbird nest parasitism is extremely high in some species, including warbling vireo (Ward & Smith, 2000). This and most other species at two eastern Sierra Nevada sites experienced lower nest success and fewer young in cowbird parasitized nests versus nonparasitized nests (Heath et al., 2010). Warbling vireo does occur within the monument and shows no statistical decline since 1968 from the BBS data for the 36 transects within the Sierra Nevada (Sauer et al., 2008). However, four species that have been detected recently in DEPO and are known to be targeted by cowbirds include: the willow flycatcher which has undergone a dramatic decline in the region; yellow warbler (a California species of concern); chipping sparrow which is significantly declining across the Sierra

Nevada; and, song sparrow. However, willow flycatchers are not known breeders in DEPO, and so may not be affected by brown-headed cowbirds locally. Brown-headed cowbirds are also one of the short distance migrants that show a significant decline in the Sierra Nevada since 1968 according to the BBS trend analysis (Table 4.16). It is uncertain what may be driving this decline, but declines in their host species is one likely explanation.

In nearby Yosemite, Halterman and Laymon (1999) monitored neotropical migrant birds and cowbirds with point counts as well as surveys of cowbird nest parasitism at several locations in 1995 and 1996. In 1995, just 2 of 61 (3.2%) visited nests of potential cowbird hosts had been parasitized – one nest each of dusky flycatcher and song sparrow. In 1996, only one nest of 100 (1%) potential host nests was parasitized. The authors concluded that cowbirds were not having an effect on nesting success of the birds monitored. The research found that cowbirds were most frequent around stables. A similar study was conducted within Sequoia and Kings Canyon National Parks with essentially the same results (Halterman & Laymon, 2000). Since both studies were of short duration, small spatial extent, and now somewhat dated, the impacts of cowbirds may now be different in DEPO and the Sierra Nevada, but empirical information is lacking. Verner and Ritter (1983) concluded that the impact of brown-headed cowbirds to host species in the Sierra National Forest was small at that time.

Altered Fire Regime

Fire suppression or exclusion has been found to result in shifts in habitat composition and structure (Hejl, 1994; Chang, 1996; Gruell, 2001) and is generally thought to be detrimental to bird species (Sierra Nevada Ecosystem Project, 1996b). Some research has investigated the response of bird species following fires of varying intensity and size, and the results have been variable. In the northern Sierra Nevada, a pair of plots – one recently burned and the other unburned – was monitored for vegetation changes and bird usage over a 20-year period. Total bird abundance varied year to year but was essentially the same on the two plots. Bird species diversity however, was slightly greater on the burned plot and was attributed to an increase in habitat diversity during the post-fire forest successional period (Raphael et al., 1987). Across conifer dominated forests of the Western U.S., many species were found to be more abundant in areas that recently burned, though salvage logging and burn intensity were confounding factors (Kotliar et al., 2002). Both timber harvest and fire suppression have been implicated in the decline of birds in North America (Hejl, 1994).

The response of bird species to fire suppression and the resulting forest structure change is likely to be species specific as some prefer burned habitats while others do not. Some species have been positively associated with recently burned forest, such as black-backed woodpeckers (Hanson & North, 2008), while others like the golden-crowed kinglet are not associated with recently burned forests (Gaines, 1992). However, olive-sided flycatchers, a species known to be associated with burned forest, were found to be less abundant in recently burned areas of northern California (Meehan & George, 2003). This was attributed to decreased food availability. In ponderosa pine forests of the Rocky Mountains, nest success of some species was improved in recently high severity burned areas, though unburned areas remained important for other species (Saab et al., 2005). In Yosemite, research found no differences in total bird abundance and bird diversity one year after a fire in areas that experienced a low intensity wildfire compared to unburned sites (Abraham, 1983). Four years post-fire, California spotted owls showed a clear preference for foraging in burned areas of all severity classes (Bond et al., 2009). It can be expected that overall bird diversity would increase within a heterogeneous landscape that contains a patchwork of fire history and severity.

Since bird monitoring in DEPO did not begin until 10 years after the 1992 Rainbow fire, we do not know how the bird community or individual species responded in the few years post fire. No research has specifically examined bird communities and the relationship to fire and fire severity in DEPO.

Climate Change

A recent review of the status of North American bird species and climate change found that species occupying forests have fared and will likely fare better than species occupying other habitat types (NABCI, 2010). Of the 312 forest species in the U.S., only 2% are considered to have high vulnerability, and 30% medium vulnerability to climate change. Those most at risk are expected to be high elevation breeders and insectivores as insects respond independently to climate.

Tingley et al. (2009) found that the large majority of bird species in the Sierra Nevada have already responded to climate change over the past ~90 years by shifting their distributions to track their ecological niche. Steel et al. (2012) used the available limited data to predict the potential consequences of future climate change for all 145 bird species known to occur within any of the four Sierra Nevada Network parks. While these are only educated guesses, they predict that 77 species will be negatively affected while 18 will see a positive effect on distribution and abundance. However, most of those are expected to be minor impacts: 67/77 for negative and 17/18 for positive impacts.

Bird species have already shifted and will likely continue to shift their ranges either up in elevation or poleward and shift life cycles if climate continues to warm regionally and continentally. In the southern Sierra Nevada, this may mean that species actually move slightly southward to the higher elevations of the SEKI area. Globally, Parmesan & Yohe (2003) examined data for 309 species of birds for distribution shifts over a period of 20 to 50 years, and 168 bird species for phenological shifts over a period of 21 to 132 years. For phenological shifts, 46% of bird species shifted their lifecycles significantly earlier in the spring or later in the fall. For distribution and abundance changes, 52% of bird species have responded in ways predicted by climate change (such as range boundaries shifting poleward or up in elevation). Their analysis of 99 species of birds, butterflies and alpine herbaceous plants for shifts in range boundaries documented a mean advancement of 6.1 kilometers (3.8 miles) per decade poleward and 6.1 meters (20 ft) per decade up in elevation, consistent with predictions of changing climate.

An evaluation of forest breeding birds in the United States from 1966 through 2006 found a mean northward shift in species range of approximately 140 km (87 miles) or 35 km per decade (22 miles/decade) (NABCI, 2010). LaSorte & Thompson (2007) examined distribution changes for 254 bird species using the Christmas Bird Count data from 1975 through 2004 for Canada, the United States, and northern Mexico. While some species saw a southward movement in their northern range boundary, center of occurrence, and center of abundance, most saw a northward movement of these parameters. On average, species moved north: 1.48 km/yr (0.92 miles/yr) for the northern distribution boundary; 0.45 km/yr (0.28 miles/yr) for the center of occurrence of the species; and, 1.03 km/yr (0.64 miles/yr) for the center of abundance for the species. In eastern North America, Hitch and Leberg (2007) used BBS data to document the statistically significant northward movement of the distributions of 13 bird species since 1967 that were linked to climate change. However, six species also saw a significant southward extension of their ranges.

Climate change can lead to shifts in distribution or shifts up in elevation or a decline in population sizes as a result of variable phenological shifts in predator and prey species. Declines in species abundances due to a disruption or dislocation of phenological events is less well known but perhaps more important than range shifts (Crick, 2004). One example is provided by a study of the migratory pied flycatcher in the Netherlands (Both et al., 2006). Over a two decade period, populations of the species declined on average 90% in locations where food availability for nestlings (caterpillars) had shifted sooner in the spring than did the bird's breeding, resulting in a mistiming of phenological events important to the survival of a species.

Habitat Fragmentation & Loss

The effects of habitat fragmentation on birds are mixed, and some have found that fragmentation does not affect bird abundances and distribution, with abundances of species generally greater in more heterogeneous landscapes (McGarigal & McComb, 1995). Since the monument is surrounded by the Inyo National Forest and Wilderness where currently no timber harvest occurs, there is no local threat of habitat loss and fragmentation from logging for birds utilizing the area for all or part of their life history. For resident birds that migrate to lower elevations on the western slope of the Sierra Nevada, logging and development leading to habitat fragmentation in these lower elevation areas, especially in the rapidly developing foothills to the west would be of concern to birds that use the monument for a number of reasons (Hansen et al., 2005; Schlesinger et al., 2008). Even many years after stand harvest, the even aged stands that follow do not provide the structural diversity needed for healthy bird habitat (Graber, 1996). The foothills have undergone rapid land use conversion and will continue to be impacted by suburban development. The fact that a significant portion of the species showing declines in the Sierra Nevada that occur in DEPO are short distance migrants or residents that utilize habitat in the lower elevations suggests that lower elevation habitat loss and fragmentation is an issue, though no empirical evidence exists for the DEPO area to link cause and effect.

Human Impacts

A number of direct and indirect human impacts are known to affect avian species. Direct disturbance of nesting sites by hikers and campers can negatively impact nesting success in some bird species (Squires & Reynolds, 1997; Kelly et al., 2009).

Pollution

We can expect that pollution negatively impacts birds as it does humans and other mammals. Since the 1960s, much research has documented major impacts of pollutants to many bird species, such as the impacts of DDT on songbirds of eastern U.S. (Carson, 1962) and on Peregrine falcons (Cade et al., 1971), and DDD on birds in northern California (Rudd, 1964). Other persistent pollutants have also impacted bird species, such as organochlorine pesticides and petroleum hydrocarbons (Fry, 1995) and heavy metals such as mercury (Scheuhammer, 1987). Birds may be affected by direct exposure or through ingestion of pollutants in their prey. Since the presence of mercury (Hg), other heavy metals, pesticides, and other pollutants are known to biomagnify up the food chain and bioaccumulate in fish, piscivorous birds may be at risk in the DEPO area. High concentrations of many pollutants were found in fish from two lakes within Sequoia National Park, not far from DEPO and at elevations above DEPO (Landers et al., 2008). In the WACAP study, fish collected at two lakes in SEKI did not have any indications of physical or physiological abnormalities, suggesting that concentrations of pollutants in their flesh are not high enough to cause problems to the fish themselves. However, mean levels of mercury in the brook trout at SEKI lakes (~100 ng/g) were well above the contaminant health thresholds for the piscivorous species belted kingfisher (~30 ng/g) (Lazorchak et al., 2003).

Pathogens

The West Nile Virus arrived in California in 2003 and is known to infect a number of species in the state, leading to mortality in many cases (Wheeler et al., 2009). Mortality of birds has been reported in cities of the San Joaquin Valley in Madera County and in Mono County (California Department of Public Health website). In 2010, there were 13 reported bird deaths in Madera County and one in Mono County from the virus (California west Nile virus website: westnile.ca.gov).

Grazing

Grazing of cattle or other stock in Forest Service lands is potentially the biggest negative factor facing landbirds as important meadow and riparian habitats are degraded (Graber, 1996; Sierra Nevada Ecosystem Project, 1996b). Although grazing of cattle or sheep does not occur on public lands close to DEPO, stock grazing does occur at nearby meadows including Reds Meadow and Agnew Meadow as well as at lower elevations on the western slope and can therefore affect those species with ranges that include any grazed areas. Indirectly, brown-headed cowbirds associated with stock, corrals, and pack stations pose a serious threat to nest success for many bird species (Heath et al., 2010). Those species most dependent on intact and undisturbed meadows and riparian zone vegetation, such as willow flycatcher, yellow warbler, and great gray owl, would be particularly affected by grazing in these areas.

Mammals (non-volant)

With the exception of bats, there is no population size, status, or trend data for any species of mammal in the monument. Here we summarize the sparse knowledge of mammals in the monument. Knowledge on mammals largely comes from one time surveys and anecdotal observations. Bats receive more discussion due to the data and literature available.

The 1982 Natural Resources Management Statement for Devils Postpile National Monument notes that golden-mantled ground squirrels, lodgepole chipmunks, chickarees, Belding ground squirrels, porcupines, coyotes, long-tailed weasels, martens, marmots, mule deer, and black bears were known to occur in the monument (NPS, 1982). An inventory of species confirmed or suspected of being present in the monument is maintained through the NPSpecies program (now incorporated into

IRMA). See Appendix B for a complete list of mammal species known or believed to occur in the monument.

A comprehensive survey of vertebrates occurred in 2003 and focused on small mammals, and excluded fish, bats, and birds (Werner, 2004). The survey began with a developed list of species thought to occur in the monument (including those not yet found, or taxa from current species lists that were questionable). Crews set Sherman live traps for rodents, Tomahawk live traps for small carnivores, and pit-traps for shrews and salamanders. The traps were set along seven trap lines in each of seven different habitat types:

1) low-gradient montane meadow;

2) mixed-conifer forests on moderately steep slopes;

3) open mixed-conifer forest on moderate to slightly steep slopes;

4) low-gradient montane meadow along the river;

5) low-gradient montane meadow with willows within a conifer forests;

6) low to moderate-gradient stand of willows and montane grasses surrounded by steep rocky terrain and mixed-conifer forest; and,

7) low-gradient burned mixed-conifer forest.

Other vertebrates were also captured opportunistically during the field visits. In the live traps, a total of 62 individuals, representing nine vertebrate species, were captured in DEPO. From all survey methods (including opportunistic observations), the survey recorded 10 mammal species (excluding humans) (Appendix B). Two new mammal species were added to the list of known species within the monument: montane shrew (*Sorex monticolus*), and brush mouse (*Peromyscus boylii*). With the additions from this survey, there are 135 vertebrate species known to occur in DEPO within the recent past (http://www.nps.gov/depo/naturescience/animals.htm), though this number does not agree with that found on the NPSpecies web site. Examining DEPO rodents only, a calculated diversity index (Shannon) of 1.5 and a calculated evenness index (Pielou) of 0.84 were the highest recorded compared to nine sites in SEKI (Werner, 2004).

The grizzly bear (*Ursus arctos horribilis*) is currently the only known native carnivore that has been extirpated from the Sierra Nevada (Graber, 1996; Zielinski, 2004). Two of the other 20 Sierra Nevada native carnivores were thought to have been extirpated but recent sightings place this in doubt. The wolverine (*Gulo gulo*) historically occupied the Sierra Nevada and has been absent for many decades (Aubry et al., 2007). An individual recently sighted in the Tahoe area was determined to be a long-distance migrant from the Rocky Mountains, but another sighting at nearby Red Cones area may mean a small local population may exist. In addition, the Sierra Nevada red fox (*Vulpes vulpes necator*) was thought to be locally extinct, but recent confirmed sightings near Sonora pass means they now are locally rare. This species is thought to occur in DEPO, though this has not been confirmed.

Mesocarnivores (intermediate-sized mammals) such as the fisher (*Martes pennanti pacifica*) and American marten (*Martes americana*) are a particularly important component of the ecosystems of the Sierra Nevada because they function in a diversity of ecological roles (Buskirk & Zielinkski, 2003). Fisher have never been recorded within DEPO and American marten was recorded in the 2003 survey. The fisher distribution within the Sierra Nevada has declined significantly and is now thought only be to present from the southern part of Yosemite southward (Mazzoni, 2002; Zielinski et al., 2004; S. Stock, pers. comm.), though in that range it is believed to be abundant in appropriate habitat. Historically it was believed to occupy habitat across the entire Sierra Nevada, then became somewhat rare in the northern Sierra Nevada in the mid-20th century, and then went locally extinct in this area by the 1990s (Zielinski et al., 1995). In 2009 and 2010, multiple photo-documentation of both fisher and marten in the subalpine to montane zones in YOSE suggests there are healthy populations of both species where there is suitable habitat in the area (S. Stock, pers. comm.). High densities of generalist mammals such as gray fox (*Urocyon cinereoargenteus*), and striped skunk (*Mephitis mephitis*) (neither of which has been documented in DEPO) may be partly responsible for the loss of fishers in the northern Sierra Nevada since these species are thought to be antagonistic to fishers (Campbell, 2004). The distribution and abundance of American marten has also contracted somewhat since the 1930s (Zielinski, 2004), but in the early 1990s they were found to be well distributed across the Sierra Nevada (Zielinski et al., 1997) and today they are present but uncommon within suitable habitat.

The high elevation southern Sierra Nevada is the far southern limit of the range of the fisher in North America and thus it would probably be sensitive to a warming climate. This species is currently a candidate for protection under the California Endangered Species Act and is awaiting ruling for endangered listing at the federal level. Much more research on mesocarnivore mammal species in the Sierra Nevada is needed to determine population conditions and trends. For those species with no trend or population data such as the American marten and fisher, expert opinion from NPS wildlife biologists is that they are stable throughout the Sierra Nevada in appropriate habitat (H. Werner, pers. comm.), though many are less abundant than they were historically due to several threats discussed below.

The only ungulate present within and around the monument is mule deer (*Odocoileus hemionus californicus*). Inyo National Forest Service biologists provided spatial data that indicated that mule deer only occupied the DEPO area during summer (California Dept of Fish and Game, unpub data), and the eastern Sierra Nevada deer herd that migrates into the DEPO area during summer is estimated to be approximately 3,000 animals (R. Perloff, pers. comm.). It is uncertain how many animals may be migrating into the DEPO area from the western Sierra Nevada. Mule deer are known to be frequent visitors to the meadows of the monument and are often seen browsing the native shrubs and trees (such as willows and manzanita). Beyond these casual observations, there is no direct evidence to suggest that mule deer are overbrowsing any species within DEPO and the professional opinion of an Inyo wildlife biologist is that overbrowsing is not an issue (R. Perloff, pers. comm.). Then again, no research or monitoring has specifically looked at the potential issue of deer overbrowsing in DEPO. However, it has long been recognized within the National Park Service that many park units have an unnaturally high density of ungulates (Leopold et al., 1963), but management solutions have proven elusive (Porter & Underwood, 1999). The overabundance results from either the extirpation of predators or through an alteration of predator behavior in relation to humans and their activities. Overabundance and overbrowsing have often been difficult to perceive or understand until close investigation exposed the problem. Unusually high densities of ungulates can have wide ranging and usually negative impacts on native flora and ecosystems (e.g. Healy, 1997; Alverson & Waller, 1997; Beschta, 2005; Ripple & Beschta, 2006). Recent research has linked or hypothesized declines of California black oak in Yosemite Valley to an overabundant deer herd (Ripple & Beschta, 2008; Kuhn & Johnson, 2008), and anecdotal evidence in other parts of Yosemite suggests deer may be overbrowsing and negatively impacting other species. Local declines of quaking aspen in the Sierra Nevada may be partially caused by an overabundance of mule deer (Rogers et al., 2007).

An occasionally seen generalist mammal in DEPO – the black bear (*Ursus americanus*) – is believed to be doing well throughout the Sierra Nevada. However, human-bear interactions in urban and suburban areas can often lead to population sinks (Beckmann & Lackey, 2008) reducing abundances. It is uncertain if elevated mortalities from human interactions is leading to a long-term decline in this species, but populations appear to be healthy. Since actions were taken to reduce bear access to human food and garbage in 1980, their activity within DEPO declined (NPS, 1982). It is not known whether they reside or den in the monument.

We can make inferences of the status and trends of mammals as a whole in DEPO from research in other parts of the Sierra Nevada. We know from recent research that many small mammals have altered their distributions in the Sierra Nevada, probably in response to a regionally warming climate (Moritz et al., 2008; Moritz et al., 2011). Following the previous work of Grinnell and Storer (1924), Moritz et al. (2008; 2011) surveyed for 28 small mammal species along a wide transect from the Central Valley to the Eastern Sierra Nevada that passed through Yosemite. Compared to the Grinnell survey of 1914-1920, most species' elevation limits shifted upward, and more frequently for their lower elevation limits than for upper limits. Lower elevation limits increased for 10 species, while upper elevation limits increased for 4 species. Five species experienced an opposite lowering of their limits. High-elevation species typically found in DEPO usually saw range contractions as would be expected as temperatures warm. These contractions were all from increases in the lower elevation limit while none expanded their upper limit. High and mid-elevation species that contracted their elevational ranges included the pika (*Ochotona princeps*), Belding's ground squirrel (*Spermophilus beldingi*), water shrew (*Sorex palustris*), alpine chipmunk (*Tamais alpinus*), golden-mantled ground squirrel (*Spermophilus lateralis*) and long-tailed vole (*Microtus longicaudus*). Range "collapse" (rise in lower limit and fall in upper limit) occurred in two species: shadow chipmunk (*Tamais senex*) and bushy-tailed woodrat (*Neotoma cinerea*). The species that shifted up in elevation did so 500 meters (1,640 ft) on average. Most of the species that shifted upward are confirmed present or former inhabitants of DEPO while the others may also occupy habitats in and around DEPO.

Moritz et al. (2008; 2011) modeled the likely historic range as well as the current elevation range of each species based on survey results. From their analysis they concluded that three species should now have ranges that used to include DEPO but that now have shifted above it: Belding's ground squirrel, alpine chipmunk, and pika. However, while both alpine chipmunk and pika have never been officially recorded in DEPO in recent history, pika is still active at lower elevations at similar latitudes (Millar & Westfall, 2010). In addition, Belding's ground squirrel is still frequently seen in the monument though was last officially documented in 2003 (Werner, 2004). As a result, according to available empirical evidence, species richness in the high elevation zone that includes DEPO may have declined slightly since 1920, though it is highly possible that no species have been lost. However, since limited vertebrate surveys have been conducted at DEPO, additional work is needed to fully document the status of mammals and other species in and near the monument.

Current Condition Summary

Although a list of mammal species detected in or believed to occur in the monument is a good start to establishing species richness of mammals, nothing else is known about the status and trends of mammal species' populations within the monument. Reference conditions of mammal species in the monument would be the presence of all species that historically used upper elevations of the Central and southern Sierra Nevada west slope and none that are locally or regionally endangered, threatened, or rare as a result of one or more stressors. We know that three species that likely used the monument or areas around it in the past have been either extirpated from the Sierra Nevada or are currently very rare. While empirical evidence and modeling from the Yosemite area concluded that two or three species may have shifted their ranges above DEPO, local evidence contradicts this for at least two of the three species. These shifts are likely related to various environmental changes including climate change and perhaps altered fire regimes. Local-scale climate regimes around DEPO may be responsible for the differences in reality versus modeled distributions. The fisher may also be absent or rare within or near the monument. With the exception of bats which are discussed separately below, the current condition of mammals within the monument is good considering extinctions, potential losses, and declining trends of some species Sierra Nevada-wide. Survey data from 2003 give a baseline of species likely still present. There are local, regional, or global stressors and threats that are or likely are impacting species that use the monument as habitat.

Threats & Stressors

Climate Change

Here in the Sierra Nevada, Moritz et al., (2008; 2011) documented that half of 28 small mammals surveyed had shifted their elevation ranges upward approximately 500 meters (1,640 ft) since 1920. These shifts were consistent with recorded increases in regional temperatures. Throughout the Great Basin of the Western U.S., American pika has been locally extirpated from lower elevation sites that have experienced higher temperatures and a high frequency of warmer days during recent years (Wilkening et al., 2011). Around the globe, Parmesan and Yohe (2003) and Root et al. (2003) found numerous examples of the effects of a warming climate on mammal species. Many species had moved their distribution up in elevation or poleward and/or had adjusted their seasonal life cycles. While most species moved in directions predicted by climate shifts, some did the opposite. Some species will likely be lost from the monument if regional temperatures continue to rise. High elevation species with a relatively high lower elevation limit and species at their southern geographic limit would be most sensitive to a warming climate and mostly likely to be lost from the monument.

Habitat loss & fragmentation

As with birds, habitat loss and fragmentation in non-wilderness National Forest lands around the monument is a minor threat. For non-volant mammals, the size of an individual's range varies greatly, from tens of square meters to tens of square kilometers. As such, fragmentation through logging and development in the wider Sierra Nevada will negatively affect those wide ranging species such as the mountain lion and wolverine, of which only the mountain lion is known to have used the monument in last 10-20 years.

Altered fire regimes

Altered fire regimes in the Sierra Nevada can be expected to impact mammal species. Although there is no regional research that has specifically examined the effects of fire suppression on mammals in the Sierra Nevada or other western U.S. forests, some research has documented the effects of fire on mammals. For example, recent research has documented the effects of fire severity and spatial complexity on small mammals in Yosemite. Roberts et al. (2008) found that the abundance of species of rodents varied with fire severity and habitat complexity formed by the fire history of the area. While deer mouse (*Peromyscus maniculatus*) abundance declined with fire severity, the abundance of ground squirrels (*Spermophilus beecheyi*) and chipmunks (*Neotamias* spp) increased with an increase in spatial habitat complexity (as a result of local fire history and severity patterns). Research has also found that fishers depend on large diameter trees (and especially hardwoods) and dense forests with canopy closure (Truex & Zielinski, 2005). However, it is unclear how the natural fire regime or fire suppression can affect this species.

Human Impacts

Due to the proximity of the Town of Mammoth Lakes and the Mammoth Mountain Ski Area, direct human interactions and interference of mammal habitat and behavior are likely to increase over time. If the number of visitors to the monument and the surrounding National Forest lands increases, we would also expect negative impacts to mammal species as a result of both inadvertent and intentional interference. Within the monument and close by, humans have altered wildlife habitat and created new ones (such as campgrounds) that may discriminate for or against native species, and have created new conflicts between humans and wildlife.

Empirical information on the interaction of black bears and humans in the monument and the effect of this interaction on bear behavior and ecology does not exist. However, we can infer from Yosemite and other locations that human-bear interactions are almost always negative through habituation of the animals to human food, alteration of their natural behavior, and premature mortality (Hastings et al., 1981; National Park Service, 2002; Beckmann & Berger, 2004; Matthews et al., 2006).

The degradation of natural soundscapes by automobiles and air traffic from overflights servicing the Mammoth Lakes area is also likely to have negative impacts on mammals. Noise can negatively impact animals by alteration of physiology, diversions in time and energy, failure to detect important cues, impairment of acoustical communication, and a reduction in the utilization of habitats or resources (Hatch & Fristrup, 2009). Four threats are associated with unnatural noise: 1) diversion of attention and disruption of behavior; 2) habituation to noise; 3) masking of important signals; and, 4) spurious physiological stimulation. A variety of research has documented the impacts of low level, chronic noise sources to marine mammals (Payne & Webb, 1971; Southall, 2005; Hatch et al., 2008; Southall & Scholik-Schlomer, 2009), ground squirrels (Rabin et al., 2006), and terrestrial birds (Habib et al., 2007).

The existence of roads both within and nearby DEPO is also a concern for mammals, though the length and density of roads in the area are relatively small. Roads are known to alter animal behavior, increase mortality (from roadkill), reduce gene flow, and negatively impact populations (Trombulak & Frissell, 2000; Forman et al., 2003).

Pollution

The ecological consequences of contaminants such as pesticides and other hydrocarbons are complex. Bioaccumulation and biomagnification of pollutants and metals in animals can cause a wide range of problems (van der Oost et al., 2003). These contaminants are deposited on the land through dry and wet deposition and eventually make their way into surface waters where they will have the most effects. Once in these waters, they biomagnify up the food chain and become bioaccumulated within high tropic level fish and the mammals and birds that eat them (Mackay & Fraser, 2000). Therefore, species most at risk are piscivorous birds and mammals. Thresholds for some mammal and birds species have been determined (Lazorchak et al., 2003) (Table 4.18). Mercury is toxic to fish at 1-5 ug/g and lethal to rainbow trout at 10-20 ug/g (Niimi & Kissoon, 1994).

Table 4.18. Thresholds for biota, in ng/g wet weight. From Lazorchak et al. (2003). PCBs = polychlorinated biphenyls; DDTs = DDT and its metabolites (DDD, DDE).

Contaminant	Birds	Mammals
Mercury	30	70-100
PCBs	440	130-180
DDTs	20	360-490
Chlordanes	4.5	830-1140
Dieldrin	360	20-30

<u>Bats</u>

Bats are treated separately here from all other mammals as there is much more information available for them than any of the non-volant mammals. The first documented occurrences of bat species in the monument were made at four mist netting sites and with 5-10 acoustic monitors during a short two-night survey in August of 2001. At that time 10 species were identified (Pierson & Rainey, 2002) – eight in mist nets and two acoustically. The authors of that report expect that up to 13 bat species should use all or part of the monument. Seventeen species are known or believed to occur in the Sierra Nevada. Using both nets and acoustic sampling, Pierson and Rainey (2009) surveyed bats again at six mist net sites and 5-10 acoustic monitoring sites for three nights in July of 2004. From these surveys, the same 10 species were recorded along with potentially three new species (see Table 4.20 below). These three new species had not been previously documented and acoustic records of them were not definitive even though they were unlikely to be anything else.

For both sampling years, a total of eight species and 111 individuals were captured in mist nets. One species – the big brown bat (*Eptesicus fuscus*) – accounted for 51.4% of the captures. Another two species – silver-haired bat (*Lasionycteris noctivagans*) and little brown bat (*Myotis lucifugus*) – accounted for another 26.1% of captures. The remaining five species accounted for the remaining 22.5% of captures. Two species were only detected acoustically – western mastiff bat (*Eumops perotis*) and spotted bat (*Euderma maculatum*), while two other acoustic records were attributed to pallid bat (*Antrozous pallidus*) and fringed myotis (*Myotis thysanodes*), though the recordings were equivocal and therefore the species are considered absent; if present they are likely rare. Another species, western red bat (*Lasiurus blossevillii*), was also only detected acoustically once, and that record was also equivocal, leading to the conclusion that if the species is present, it occurs only seasonally during spring and fall migrations.

One site in particular appeared to be important to bats in the monument – a small bog in the central part of the monument. This pond yielded more bat captures per unit effort that any other site and represented 59% of all captures during both sampling years. Evidence from other bat surveys suggests that similar mountain tarns (small lakes or bogs) are very important to bats (Pierson & Rainey, 2009). There are one or two other small ponds in the monument that may also be important habitat for bats.

There are six bat species that occur in DEPO that have been have been recognized as having special status by several groups (Table 4.19). Designations were based on issues facing bat species outside of park service units; however, they still highlight regional concerns and underscore the importance of park units as refugia and the importance of activities or management actions that may affect bats within NPS units.

Table 4.19. Bat species of special concern in Devils Postpile National Monument. USDA = U.S. forest Service; CDFG = California Dept of Fish and Game; WBWG = Western Bat Working Group. * = unconfirmed acoustic record but species are likely to occur in monument.

Species	Designation	Designating Group
Euderma maculatum	Species of Special Concern High Priority	CDFG WBWG
Myotis volans	High Priority	WBWG
Antrozous pallidus *	Sensitive Species of Special Concern High Priority	USDA CDFG WBWG
Eumops perotis	Species of Special Concern High Priority	CDFG WBWG
Lasiurus blossevillii *	Sensitive Species of Special Concern High Priority	USDA CDFG WBWG
Myotis thysanodes *	High Priority	WBWG

Bats are known to travel large distances between roosting habitat and foraging habitat, between 25 and 40 kilometers (15 – 25 miles) (Rabe et al., 1998; Chambers et al., 2006; Brown & Berry, 2007). Due to the small size of the monument and limited habitat variability, it is highly likely that at least some species occurring in DEPO either only roost or only forage within the monument (Pierson &

Rainey, 2009). Different land uses outside of DEPO on Forest Service or private land may be affecting bat species that use the monument for foraging or roosting. It has been found that reproductive females tend to use the warmest and thus lowest habitats available, and thus would be outside DEPO (i.e. downstream in the Upper San Joaquin River watershed).

Pierson & Rainey (2009) ranked all species documented in the monument as to the extent that they rely on habitat types (Table 4.20). Most if not all roosting sites in the monument would be in trees and in small caves or overhangs in rock outcrops and small cliff areas. Several habitats within DEPO are important foraging areas for bats: 1) water, either river pools or ponds; 2) meadows (wet and dry); 3) rocks (outcrops and exposed river banks); and, 4) forests and forest edges. It would be critical to recognize the importance of these habitats for bats. Fire, or lack of fire, climate change, and visitor use would present potential disturbances to bat roosting and foraging habitats. The Sierra Nevada Ecosystem Project concluded that bat population numbers seemed to have been declining (as of mid-1990s) and suggested that pesticide use, loss of large old trees and snags, and loss of riparian habitats were to blame (Sierra Nevada Ecosystem Project, 1996b), though at the time, no evidence supported these conclusions. Few data are available on the longer-term population status and trends of bat species in the Sierra Nevada. Several threats of concern identified by Pierson & Rainey (2009) and are discussed below.

Table 4.20. Rankings of the importance of different habitat elements for each bat species (Roosting and Foraging columns) and the degree to which threats are a concern (Life History columns). 0 = none; U = unknown; 1 = minimally; 2 = moderately; 3 = heavily. Life History columns show level of threat of three identified stressors. WNS = white nose syndrome. From Pierson & Rainey (2009).

	Roosting				**Foraging**				**Life History**		
Species	**Caves/ Mines**	**Cliffs/ Rock**	**Trees**	**Human Structures**	**Water Sites**	**Meadows**	**Rock**	**Forest/ Forest Edge**	**Climate Change**	**Fire**	**WNS**
Antorozous pallidus	2	2	3	3	1	3	2	3	2	2	2
Eptesicus fuscus	1	2	2	2	2	2	1	2	2	2	2
Euderma maculatum	U	3	0	0	1	3	2	3	2	1	1
Eumops perotis	0	3	0	0	1	3	3	2	2	1	1
Lasionycteris noctivagans	0	0	3	0	2	1	1	2	2	3	1
Lasiurus blossevillii	0	0	3	0	1	3	1	1	2	3	1
Lasiurus cinereus	0	0	3	0	1	3	2	1	2	3	1
Myotis evotis	2	2	2	2	2	1	1	3	3	2	2
Myotis lucifugus	U	3	U	U	3	1	1	1	3	1	3
Myotis thysanodes	3	2	3	1	2	2	1	3	2	2	2
Myotis volans	2	U	3	U	2	1	1	3	2	2	2
Myotis yumanensis	2	U	2	3	3	1	1	1	2	1	2
Tadarida brasiliensis	1	3	0	3	1	3	2	1	2	1	1

Current Condition Summary

The reference conditions for bat species within the monument would be the presence of all species that have historically occupied or used the monument as all or part of their habitat, healthy stable populations of each species, and none that are locally threatened or endangered as a result of one or more stressors. Of the 10 species known to occupy the monument, six have been identified as having special status due to low population levels or high degree of threat from stressors. Based on the limited data available, we believe the current conditions of bat species within the monument are fair to good. Regional declines do suggest a potential problem to the health of at least some species. Following is a short discussion of stressors and threats to bat species in and around the monument.

Threats & Stressors

As part of the latest inventory and assessment of bat species in DEPO, Pierson and Rainey (2009) identified three primary threats to these species: fire, climate change, and white nose syndrome (see Table 4.20 above).

Fire

The lack of fire (with the exception of the portion of the monument that burned in the 1992 fire) or the lack of a natural fire regime may pose a threat to the health and persistence of bats. Recent research suggests that while fire likely reduces bat roosting and foraging habitat in the short term, it enhances it for many species in the long term, and is especially true of species that roost in snags, under flaking bark, or in fire scar hollows (Pierson & Rainey, 2009). Lacki et al. (2009) studied *Myotis septentrionalis*, an eastern long-eared species ecologically analogous to *Myotis evotis* and *M. thysanodes* (which are present in the monument), and found them tolerant of prescribed fire, adjusting both roosting and foraging sites in response to fire. Another study on a tree-roosting species in the eastern U.S. (*Nycticeius humeralis*) found that prescribed fire created habitat (Boyles & Aubrey, 2006).

Climate Change

As with birds and other mammals, a changing (and usually warming) climate can be expected to have impacts on bat species in and around the monument. If regional climate continues to warm, we can expect bat species to alter their elevational and latitudinal distributions (Humphries et al., 2004). While some species may be able to move up in elevation, those currently using higher elevations may be forced northward and become locally extinct, or even slightly southward to higher elevations in the SEKI area (e.g. Loarie et al., 2008). Those species with distributions already confined to higher elevations or within narrow elevational limits would be the most affected by regional warming. In particular, the subspecies of *Myotis lucifugus* in the Sierra Nevada is likely currently found only above 1,525 m (5,000 ft) and raises their young exclusively at higher elevations. *Myotis evotis* also tends to be a high elevation species and could become locally extinct if temperatures warm dramatically. If bats respond as small mammals and birds did (Moritz et al., 2008; Tingley et al., 2009), we may expect that higher elevation species and those with restricted elevation ranges may be lost from DEPO in the future if climate continues to warm. Warmer average temperatures and lower precipitation or changes in precipitation patterns may also negatively affect bat health and reproductive success. Adams (2009) found that in Colorado, female bat reproductive success declined significantly as mean monthly temperatures rose and precipitation and stream flows decreased over a 12-year period. This may be at least partially due to a phenological dislocation between bats and their food sources.

White Nose Syndrome

White nose syndrome is caused by a cold-loving fungus and has devastated populations of hibernating bats in caves of the eastern U.S. It has been rapidly expanding its range westward and is expected to eventually reach the western U.S. (Gargas et al., 2009). Whether or not the fungus will reach the Sierra Nevada and become a serious problem is unknown at this point (Pierson & Rainey, 2009). Furthermore, although most species found in DEPO could be expected to hibernate (and thus be susceptible to white nose syndrome), very little is known about bat hibernation behavior in California. There is some documented hibernation in caves and mines for *A. pallidus*, *E. fuscus*, *L. noctivagans*, *M. ciliolabrum*, *M. evotis*, *M. volans*, and *P. Hesperus* (Pearson et al., 1952; Barbour & Davis, 1969; Marcot, 1984; Szewczak et al., 1998).

Amphibians and Reptiles

Although no surveys specifically targeting amphibians or reptiles have taken place in DEPO, several efforts have documented their presence. Most recently, Werner (2004) captured and observed amphibian and reptile species during 2003 field visits even though they were not specifically targeted in that survey. From all survey methods (including opportunistic observations), the survey recorded one amphibian, Pacific tree frog (*Hyla regilla*), and three reptile species (Appendix B): sagebrush lizard (*Sceloporus graciosus*), western fence lizard (*Sceloporus occidentalis*), and northern alligator lizard (*Elgaria coerulea*). The sagebrush lizard had not previously been recorded in the monument. The Pacific tree frog, the lone amphibian known to occur within the monument, is a common widespread species found throughout diverse habitats in western North America. Earlier, Rowan et al., (1996) surveyed potential amphibian habitats (small lakes and ponds) as part of a larger riparian and fisheries survey in the mid-1990s. They found only the Pacific tree frog and note that the apparent absence of Yosemite toad (*Bufo canorus*) at the time was unexplained. In recent years, NPS staff has noted the presence of five other reptiles, including three snakes, one racer, and one skink. In total, eight reptiles and one amphibian have been recently documented to occur in the monument (see species list in Appendix B).

Species endemic to the Sierra Nevada, such as the Yosemite toad and the Sierra Nevada yellow-legged frog (*Rana sierrae*), may have historically occupied habitats within or nearby the monument. It is likely that *Rana sierrae* occupied habitat within or adjacent to the San Joaquin River in the monument prior to the introduction of fish but no records exist to confirm this (R. Knapp, pers. comm.). Stebbins (2003) describes the species as previously inhabiting ponds, lakes, and streams within the Sierra Nevada and Peninsular and Transverse Ranges of southern California. The monument is well within the present and historic elevation range of the species. Surveys in the adjacent U.S. Forests Service lands in 2001 and 2005 found populations of *Rana sierrae* in many lakes higher in elevation approximately 5-15 kilometers (3 – 9 miles) away to the west and north of the monument (California Dept of Fish and Game, unpublished data). Yosemite toad was also found upstream in the Thousand Lakes basin in 2001 (California Dept of Fish and Game, unpublished data).

Current Condition Summary

No information is available about the conditions and trends of amphibian and reptile species within DEPO. We can conclude that the Pacific tree frog may be threatened by introduced fish (see Threats & Stressors section below). The absence of Yosemite toad and the Sierra yellow-legged frog are cause for concern as they may have historically occupied habitats within the monument. Reference conditions would be healthy populations of species that historically occupied the monument. Since some species have probably been lost, nonnative trout threaten amphibian species, and significant declines of these native amphibians in the Sierra Nevada are currently underway, we conclude that current conditions of amphibians are poor to fair while those specifically for reptiles are unknown.

Threats & Stressors

Nonnative Species

Introduced fish that are known to exist in the monument pose a potential and significant threat to native amphibian species. The only amphibian species present – the Pacific tree frog – does use riparian and riverine habitats where the fish are present. Matthews et al. (2001) found a significant negative relationship between introduced fish presence and Pacific tree frog distribution and abundance, suggesting that this species has declined in the Sierra Nevada in areas that have high occupancy of introduced fish. If the Sierra Nevada yellow-legged frog does occur or did occur in the monument, the presence of nonnative trout would be a significant threat to their existence or reintroduction if already locally extinct. Considerable research has linked the decline of several native amphibian species to nonnative fish (Knapp & Matthews, 2000; Knapp, 2005). Over the past century, the extirpation of Sierra Nevada yellow-legged frog from at least 90% of its historic range has been linked to several factors including introduced fish (Knapp & Matthews, 2000; Vredenburg, 2001; Knapp et al., 2007).

Climate Change

If climate continues to warm and precipitation patterns follow current trends, this may pose a threat to the eight reptile and one anphibian species that occupy the monument as well as two other high elevation amphibians if they are present. Particularly sensitive will be high elevation species that have limited available habitat and will be forced to shift northward or up in elevation and go locally extinct. Since the Pacific tree frog is widespread across a wide elevation range, they are likely to endure a warming climate. Other species that may have been present in the monument and that still occur in the central Sierra Nevada are likely more vulnerable to a changing climate.

The decline of a wide variety of amphibian and reptile species has been linked to a number of factors including changing climate (Wake, 2007; Wake & Vredenburg, 2008). In the Central and South American tropics, a strong relationship between the timing of local extinctions of *Atelopus* toads (inferred to be the result of fungal infections) and temperature extremes implicated climate change (Pounds et al., 2006), though this does not prove cause and effect. Results from tropical locations may not be representative of Sierra Nevada temperate systems. In the Sierra Nevada, an analysis of observed amphibian species declines with changes in climate that followed hypothesized climate warming found no linkage (Davidson et al., 2001). Yet, in other parts of the United States, a warming and drying climate has been implicated in amphibian declines. For example, in Yellowstone, the decline of four native amphibian species over a 16-year period was linked to warming temperatures and decreased precipitation that dried out habitat for the species (McMenamin et al., 2008). In the western U.S., there was a connection between increased amphibian embryo mortality and warming or drying conditions (Kiesecker et al., 2001). Dropping water levels in ponds and lakes resulted in increased UV-B exposure, making the embryos more vulnerable to infection by water mold, causing death. Evidence of the impacts of climate change on reptiles is limited. One study has linked the disappearance of two neotropical species to a drying climate thought to be a response to globally changing climate (Pounds et al., 1999).

Pathogens

Although no affected species are known to occur in DEPO at this time, chytrid fungus (*Batrachochytrium dendrobatidis*) is an important stressor to the native Sierra Nevada yellow-legged frog and others. The chytrid fungus is cited as a significant factor in the decline of some species of amphibians in the Sierra Nevada and globally, and has been implicated in the precipitous decline of many species (Berger et al., 1998; Daszak et al., 1999; Rachowicz et al., 2006; Fellers et al., 2007). However, Sierra Nevada yellow-legged frog and the chytrid fungus have not been detected nor surveyed for within the monument.

Salmonid density has demonstrated a significant positive correlation with bacterial phylotype richness and diversity, suggesting that introduced trout have altered bacterioplankton community structure (Nelson et al., 2008). Results of a study by Woodhams et al. (2007) suggest that presence of certain native micro-organisms promote defense of the Sierra Nevada yellow-legged frog against chytrid fungus, illustrating the potential importance of maintaining a natural balance of microbial communities.

Pollution

Although the amounts of wet and dry deposition of locally produced and transported pollutants is unknown, and limited water quality monitoring in and near the monument indicates very low levels of measured pollutants (when targeted), the transport and introduction of many pollutants from local and distant sources may be expected to occur within the monument. Based on estimated nitrogen deposition, Clow et al. (2010) modeled surface water nitrate concentrations throughout Yosemite. The model predicted that high elevation sites with no or thin soils, and little to no vegetation were most susceptible to nutrient enrichment and acidification from nitrogen and sulfur deposition. Bytnerowicz et al. (2010) recently documented relatively high levels of certain nitrogen compounds in air sampled in the monument, indicating a potential for nitrogen deposition in the area.

In other parts of the Sierra Nevada, research has documented the presence of pesticides and their byproducts in the tissues of amphibians (Datta et al., 1998) and in the lakes where they are found (LeNoir et al., 1999). Much research has also documented the deleterious effects of pesticides to amphibian reproduction, development, and survival (Sparling et al., 2001a; Sparling et al., 2001b). LeNoir et al. (1999) found that transport of pesticides from the Central Valley into the southern Sierra Nevada declined rapidly with elevation, and especially above approximately 2,000 meters (6,300 ft). However, in contrast, a recent thorough testing of pesticides in air, snow, and plant tissues found that levels of many pesticides actually increased in elevation in YOSE and SEKI up to very high elevations (Landers et al., 2008).

Although Pettebone et al. (2010) conducted limited water testing for the presence of hydrocarbons in the Middle Fork of the San Joaquin River in DEPO in 2009 and found none, pesticides have not been specifically targeted in surface waters of DEPO. The recent evidence from YOSE and SEKI (Landers et al., 2008) suggests pesticides may be present within DEPO's waters and monitoring for these pollutants would shed more light on this matter.

Direct Human Effects

Humans may inadvertently disrupt or kill amphibians through normal activities within DEPO. In addition, roads have many negative impacts on amphibians and reptiles including roadkill, fragmentation of habitat, disruption of movement and flow of genes, and changes in behavior (Fahrig et al., 1995; Lehtinen et al., 1999; Andrews et al., 2008; Eigenbrod et al., 2008). Trails may have similar, though weaker effects.

Macro-invertebrates

The knowledge of macro-invertebrates within DEPO comes from two surveys. The first focused on aquatic invertebrates in the Middle Fork of the San Joaquin River within and upstream of the monument. The second was more comprehensive and included both freshwater and terrestrial invertebrates.

In 1994, Schroeter and Harrington (1995) sampled for freshwater invertebrates in six riffle habitats, four within the monument and two outside and upstream of the monument. At each site, three collections were made along three cross-river transects. At each collection site, an area of 0.19 m^2 (2 $ft^{2)}$ was disturbed and scraped to remove and collect the invertebrates; total area sampled per transect was 0.56 m^2 (6 ft^2). A total of 94 taxa (usually genus level) were collected from the 6 riffle sites. Taxa diversity across the four sites within the monument ranged 30 to 46 taxa per transect (53.6/m^2 – 82.1/m^2 (4.9 – 7.7/ft^2)) with an average across sites of 72.8/m^2 (6.7/ft^2). Taxonomic diversity would be higher if specimens were identified to species level. A diversity index that takes into account taxa richness and evenness (based on the Shannon-Weaver index) was moderate to high in all four sites, ranging 3.59 to 4.5 (0-5 scale). Estimates of total number of invertebrates collected during sampling from the four sites within the monument ranged 580 to 1510 per transect (1036/m^2 – 2696/m^2 (96 – 250/ft^2)). A biotic index that summarizes family level tolerance to disturbed conditions (primarily organic pollution) was relatively low (3.34 – 3.71) indicating excellent water quality at the sample sites. The biotic index was based on Hilsenhoff (1987) and has a range of 0 to 10 with higher values representing poorer water quality. The authors of the study conclude that the aquatic macroinvertebrate community within the monument was good and was a reflection of the good water quality.

A later and more spatially comprehensive invertebrate survey took place at DEPO in the summers of 2003 and 2004 from snowmelt until snow fall, with some preliminary data collected in the summer of 2002. These surveys focused on the riparian corridor of the Middle Fork of the San Joaquin River and adjacent meadows. Using various sampling methods, invertebrates were collected in both wet meadows during flooded and dry states and in river/stream habitats. River aquatic invertebrates were sampled at 14 randomly placed sites in both pools and riffles. Pool sampling covered a surface area of 0.02 m^2 (0.22 ft^2) and a volume of 0.0072 m^3 (0.25 ft^3) while each riffle sample enclosed a surface area of 0.1 m^2 (1.1 ft^2). Surveys documented 77 invertebrate taxa within meadows during the dry phase, 29 taxa within meadows in flood phase, and 51 taxa within riverine habitat of the MFSJ River (Holmquist & Schmidt-Gengenbach, 2005a). Compared to the earlier 1994 aquatic survey (Schroeter & Harrington, 1995), this study found 46% less aquatic taxa (usually at genus level). This may be due to the different sampling techniques used and the patchiness of the animal populations. The samples were divided into early (June) and late (August) season. Early season samples from riverine riffles usually contained less than half the number of individuals than late season samples.

The later survey (Holmquist & Schmidt-Gengenbach, 2005a) found that flooded wet meadow (temporarily flooded meadows) and riverine habitats had much higher animal abundance than the wet meadow during the dry phase. While the unflooded meadows contained approximately 200 animals per square meter (19/ft^2), flooded meadows and riffles contained about 800 animals per square meter (74/ft^2). The riverine pool habitat had an enormous abundance – 87,000 specimens per cubic meter (2,462/ft^3). Even accounting for depth, these samples had much higher abundances than riffles and wet meadows, though these high numbers may still be due to sampling techniques rather than a real difference. There were no inter-annual trends in total animal abundances in meadows (between 2003 and 2004). There was however, significant inter-annual variation in riffle habitat where animal abundances declined dramatically from 1172/m^2 (109/ft^2) in 2003 to 443/m^2 (41/ft^2) in 2004. There was also significant intra-annual variation in production (abundances) in both wet meadow and riverine riffle habitats. Animal abundance declined significantly in the wet meadows from a peak during the wet phase early season during spring runoff to a low at the end of the summer season when meadows had dried out. In contrast, abundance in riverine riffles increased throughout the spring-summer season. This is consistent with other western US aquatic systems (Minshall, 1981; Leland et al., 1986). Overall invertebrate diversity in the DEPO meadows was similar to that of Tuolumne Meadows in Yosemite (Holmquist & Schmidt-Gengenbach, 2005b).

Current Condition Summary

Based on the two surveys in DEPO, we conclude that the conditions of freshwater invertebrates are good to excellent and are a reflection of the good water quality. Terrestrial meadow invertebrates are also in good condition in a reflection of the generally good meadow quality. However, the presence of introduced fish may be impacting the freshwater invertebrate community in ways that have not been adequately examined. The social-trailing within parts of Soda Springs Meadow is also likely having negative impacts on terrestrial invertebrates, though the overall impact is probably small. In terms of a qualitative assessment of macro-invertebrate biodiversity in DEPO, data are insufficient to determine this, but recent research in YOSE and SEKI found relatively high invertebrate diversity (Kimsey & Cranston, 2002; Holmquist & Schmidt-Gengenbach, 2005b). Reference conditions for both freshwater and terrestrial invertebrates would be the presence of all species historically known to occupy all habitat types in DEPO and none that demonstrate significant declines. With no historic data and no data from upland sites, we do not have a complete understanding of reference and current conditions and cannot say at this time if reference conditions are met. Suspected or known threats and stressors to macro-invertebrate health are discussed below.

Threats & Stressors

Visitor Impacts

Visitor use of meadows and aquatic habitats is possibly the greatest threat to the condition of invertebrates within them. Although the authors of the later invertebrate study did not quantitatively measure visitor use or degree of trailing or disturbance, they did observe that the temporarily flooded meadows of Soda Springs Meadow on the east side of the river were more heavily used than those on the west side (Holmquist & Schmidt-Gengenbach, 2005a), though this may have changed since the restoration and addition of fences. They also documented significantly fewer invertebrate taxa in the eastern meadow compared to the western meadow. In both 2002 and 2004, there were orders of magnitude more animals in the west flooded meadows than in the eastern flooded meadows. In 2003, while there were more animals again in the western meadows, the difference was not as great. The relationship was different for the meadows during the dry phase where the more heavily used east side meadows had greater invertebrate abundance in 2002 but less abundance in 2004 compared to west side meadows; there was no difference in abundance in 2003. No quantitative data on visitor use or degree of trailing are available for the years 2002 – 2004, so no quantitative relationship can be developed. However, the data do suggest that invertebrates in wet meadows may be responding negatively to visitor use of those habitats based on a qualitative assessment of visitor use in the meadows.

There is substantial evidence for the effects of human trailing and trampling in meadows on vegetation and associated invertebrates. In Yosemite, one study documented a dramatic reduction of invertebrate abundances in meadows in response to simulated trailing (Holmquist & Schmidt-Gengenbach, 2008). Ant abundances were 1.6/m^2 (0.15/ft2) along trails, and 5.0/m^2 (0.47/ft^2), 9.0/m^2 (0.84/ft^2), and 63.6/m^2 (5.9/ft^2) in vegetation next to trails, two meters (6.6 ft) from trails, and 5-10 meters (16 – 49 ft) from trails, respectively. Including all invertebrate taxa, they found a mean of 10.2 animals/m^2 (0.95/ft^2) along trails versus 157.5/m^2 (14.6/ft^2) in core meadow habitat (undisturbed areas). These findings echoed earlier results on the negative effects of human trampling on vegetation (Bayfield, 1979; Cole, 1995; Cole & Monz, 2002), soil fauna (Chappell et al., 1971; Dozsa-Farkas, 1987), and meadow invertebrates (Holmquist & Gengenbach, 2004). Holmquist and Schmidt-Gengenbach (2008) conclude that invertebrates appear to be much more sensitive to disturbance than the plants on which they depend for habitat. Ernhardt and Thomas (1991) also found insects to be much more sensitive to environmental change than their host plants. In aquatic systems, similar results were also found (Eckrich & Holmquist, 2000; Uhrin & Holmquist, 2003). Holmquist and Schmidt-Gengenbach (2005b) argue that due to their sensitivity to disturbance, importance to ecosystems, and ubiquitous presence, invertebrates are a better indicator (or ecosystem vital sign) than vertebrates or plants.

It is likely that most visitor impacts to meadows and aquatic habitats where invertebrates are in abundance are within the northeastern non-wilderness portion of the monument. Visitor services, campgrounds, and fishing access are all concentrated here, though visitors do get to other parts of the monument. To best document the relationship between visitor use of habitat and the organisms that occupy those habitats, quantitative data on visitor use should be collected. Without that linkage, we can only postulate that visitor use of wetlands may be negatively affecting invertebrate diversity and abundance. Applying the findings of Holmquist and Gengenbach (2004) and Holmquist and Schmidt-Gengenbach (2008), a visitor use study in the summer of 2009 mapped informal trailing within Soda Springs Meadow and riverbank conditions nearby (Pettebone et al, 2010). This is a good start to linking visitor use to ecological impacts.

Pollution

The biotic structure and metabolism of microbial communities in lakes and rivers of the Sierra Nevada have been impacted by nutrient loading due to atmospheric deposition and by stocking of introduced salmonids (Nelson et al., 2008). Aquatic invertebrates may be particularly sensitive to the addition of nutrients and organochlorines that make their way into aquatic habitats via wet and dry deposition. Studies have shown that impacts are significant and lasting on a regional scale and include threatening the survival of endangered species, altering algal productivity, and changing the structure of zooplankton populations (Nelson et al., 2008). Local sources of pollution from soap, sunscreen, food particles, and human and animal waste promote survival and growth of bacteria and algae (Derlet et al., 2008). Micro-organisms commonly found in water systems polluted by human and animal waste include coliforms, other pathogenic bacteria, and protozoa such as *Giardia* or *Cryptosporidium* (Rockwell, 2000).

The relative proximity of the monument to the polluted air of the southern San Joaquin Valley would warrant further monitoring of invertebrates. Unfortunately, collection of surface water quality data within the monument has been limited and inconsistent. A surface water quality monitoring program was begun and 2009 and in time will benefit ecological management. In 2009, surface water at one location in the river was found to have low levels of nitrogen (Pettebone et al., 2010). There has been no targeted monitoring of many pollutants in surface waters of DEPO (such as pesticides).

The high abundance and diversity of invertebrates within the riverine habitats of DEPO supports the conclusion that water quality is high and pollution is likely not a great issue. While some modeling research has concluded that transport of nutrients such as nitrogen oxides to high elevation systems of the Sierra Nevada is not a great concern (Bytnerowicz et al., 2002; Fenn et al., 2003c), a recent air quality study within the monument did discover higher concentrations of ammonia and nitric oxide than expected for the location (Bytnerowicz et al., 2010). Landers et al. (2008) also found relatively high concentrations of many pollutants in air, snow, and plant tissues in high elevation sites of both YOSE and SEKI. This indicates that wet and dry deposition of many pollutants may be impacting local water quality and aquatic invertebrates, but recent water quality data have not confirmed this.

Nonnative Species

Nonnative or introduced fish are known to significantly alter aquatic invertebrate and invertebrate communities (Knapp et al., 2001). Much research has documented the negative impacts of introduced fish on invertebrates in mountain lakes, including greatly reduced numbers and even some extirpations of invertebrate species compared to naturally fishless lakes (Stoddard, 1987; Bradford et al., 1998; Carlisle & Hawkins, 1998).

Overall Biodiversity

The biodiversity of the monument is the sum of the species from all taxa that are known or suspected of currently using or occurring within the monument for all or part of their lives. There are several taxa for which we have no or insufficient data including upland terrestrial invertebrates (insects and related taxa) and nonvascular plants such as lichens and mosses. A tally of the most well surveyed taxa for the monument and the Sierra Nevada is presented in Table 4.21. Values are presented for both independent surveys and observations as well as the tally from the NPSpecies site (now incorporated into IRMA) (NPS, 2010b). Values from NPSpecies differ from those tallied from independent sources because the NPSpecies list contains a small number of species that have not been documented in the monument, but are only suspected of occurring in the monument.

Table 4.21. Numbers of species identified in the NPSpecies (IRMA) database for Devils Postpile as well as through source data from independent surveys and observations. Not all species in NPSpecies have been confirmed present within the monument. For comparative purposes, the total numbers of species believed or documented to exist within the Sierra Nevada bioregion are included (from the Sierra Nevada Ecosystem Project, 1996).

	# Species in DEPO				**# Speciesin Sierra Nevada**
Taxa	**NPSpecies**	**Independent surveys**	**Known or Likely to occur**	**Unconfirmed Spp**	
Mammals	35	37	33	Pallid bat water shrew	110
Birds	118	112	128	American pipit Canyon wren Pacific slope flycatcher Hutton's vireo Acorn woodpecker Long-eared owl Great grey owl Spotted owl	189[b]
Reptiles	8	8	7	Striped racer	32
Amphibians	1	1	1		30
Fish	5	4	4		40
Invertebrates	-	149	hundreds		thousands
Vascular plants	378 [a]	384[a]	384		~3500
Totals	545	689[c]	556		3901

[a] Includes 11 nonnative species

[b] The Sierra Nevada Ecosystem Project identified 401 vertebrate species that occupy the Sierra Nevada. The number of birds was determined using this number. Number of species in the Sierra Nevada are based on the extensive review of the Sierra Nevada Ecosystem Project and particular chapters: Chapter 5, Plants and Terrestrial Wildlife; Chapter 25, Status of Terrestrial Vertebrates; Chapter 31, Status of Amphibians; and, Chapter 33, Status of Fishes and Fisheries.

[c] This total includes invertebrates while the other estimates do not.

Table 4.21 indicates that there are discrepancies in the numbers of mammals, birds, fish, and vascular plants that occupy the monument. Although there have been surveys of invertebrates within the monument, the spatial scope of those surveys were limited to riverine and meadow habitats and so missed a large proportion of the monument. We do know that of the 540 to 557 species known or thought to use the monument (except invertebrates), that at least 16 are not native to the monument (one bird, all four fishes, and 11 vascular plants). Nonnative species then constitute only about 3 percent of all species. This percentage is low and is likely the result of the location of the monument at high elevation and its relatively low visitation rate relative to most other western park units.

As a percentage of the number of species thought to occur in the Sierra Nevada, mammal species in DEPO comprise ~32% of the total diversity, birds species are ~59% of the Sierra total, reptiles are 25% of the total, and native vascular plants are ~11% of the total in the Sierra Nevada. Percentages vary depending on life history traits (size, dispersal, migrations, etc.).

Without comprehensive surveys of the monument for all taxa, it is not possible to quantitatively assess the total biodiversity. It has been assumed that the overall biodiversity of the monument is high, although this is a relative assessment as overall biodiversity varies dramatically within California, the United States, and the globe. In addition, there are different spatial scales at which diversity can be quantified, including alpha and beta diversity. Biodiversity can also be expressed in several ways, including diversity of native species, diversity of endemic native species, and diversity of restricted (narrow ranged) native and endemic species. Each of these measurements has potentially different implications for conservation.

Taxonomic diversity does vary spatially throughout the monument. Although we do not have spatially explicit data in many cases, most surveys have either targeted riverine, riparian, or wetland habitats, while upland habitats have much less information. Based on these limited data and patterns from other parts of the Sierra Nevada and California, we suspect that overall biodiversity is highest in wetlands (including meadows) and riparian areas. This of course includes the Middle Fork of the San Joaquin River and its associated wetlands. However, other small meadows and other wetlands exist throughout other portions of the monument. The upland areas that have little to no soils support fewer species in general.

Current Condition Summary

We have not compared the overall species or taxonomic diversity of DEPO to areas of similar sizes in California, the United States, and elsewhere in the world. The taxonomic diversity in DEPO is thought to be high, but this is relative. Other parts of the state, the country, and the world have higher diversity and lower diversity. We have not found sufficient data with which to analyze temporal changes in the overall species diversity in the monument, so we cannot conclude if there have been any trends over time. We can only guess that the taxonomic diversity has been relatively stable over the recent past, although with some likely extinctions that have been discussed in previous sections. Therefore the overall taxonomic diversity is good, though this has low confidence.

<u>Summary of Biological Indicators</u>

Tables 4.22, 4.23, and 4.24 summarize the focal biological indicators. Table 4.22 is a summary assessment of the current conditions and trends of each indicator. Table 4.23 is a summary of current conditions relative to reference conditions. Table 4.24 is a summary assessment of the threats for

each indicator. When few or no data existed with which to assess current condition or the impacts of a particular threat, expert opinion was utilized.

Table 4.22. Current condition and trend summary for biological indicators. Condition: Excellent, Good, Fair, Poor, Unknown, Variable. Trend: Improving, Deteriorating, Stable, Unknown, Variable. Strength of data/research to determine condition and trend: strong, moderate, weak, none. For nonnative plants, good condition would be a complete absence of these species and an improving trend would be a decline in distribution and abundance.

INDICATOR	CONDITION	DATA STRENGTH	TREND	DATA STRENGTH
Native Plants	Good	Moderate	Unknown	None
Nonnative plants	Good	Moderate	Improving	Moderate
Forests & Woodlands	Fair to Good	Weak	Variable	Weak
Wetlands	Good	Strong	Unknown	None
Birds	Fair to Good	Strong	Variable	Moderate
Mammals	Good	Weak	Stable to Deteriorating	Weak
Bats	Fair to Good	Moderate	Stable to Deteriorating	Moderate
Amphibians & Reptiles	Poor to Fair	Moderate	Deteriorating	Moderate
Macro-invertebrates	Good to Excellent	Moderate	Unknown	Weak
Biodiversity	Good	Moderate	Stable to Deteriorating	Moderate

Table 4.23. Summary of current conditions relative to known or assumed reference conditions. Data sources: Empirical evidence or research from DEPO or very nearby (Local); relevant data or research from other parts of the Sierra Nevada, California, or North America (Inferred).

INDICATOR	Reference Condition	Reference Condition met?	Data Sources
Native Plants	All species historically present, healthy stable populations	Yes	Local, Inferred
Nonnative plants	No significant persistent populations of invasive species	No	Local
Forests & Woodlands	Experiencing fire regime uninfluenced by modern anthropogenic stressors, varied stand ages, stable composition, all within historic variability	No	Local, inferred
Wetlands	All with healthy plant and animal communities, functioning hydrology, no invasive species	No	Local
Birds	All species historically present, healthy stable populations	No	Local, Inferred
Mammals	All species historically present, healthy stable populations	Uncertain	Local, Inferred
Bats	All species historically present, healthy stable populations	Uncertain	Local
Amphibians & Reptiles	All species historically present, healthy stable populations	No	Local, Inferred
Macro-invertebrates	All species historically present, healthy stable populations	Uncertain	Local
Biodiversity	Total number of taxa not declining from historic levels	No	Local, inferred

Table 4.24. Threat and stressor summary for biological indicators. For each threat or stressor, its level, spatial extent, and strength of data are indicated. Level: E = existing; P = potential; A = past; U = unlikely; UK = unknown. Extent (spatial): Global or Local. Data strength: Strong, Moderate (Mod), Weak, None. -- = Not Applicable. *For nonnative plants, threats are considered factors that may contribute to their success.

		Stressor or Threat						
Indicator		**Climate Change**	**Pollution**	**Altered Fire Regime**	**Habitat Loss or Fragmentation**	**Nonnative Species**	**Visitor Use/ Human Effects**	**Pests/ Pathogens**
Native Plants	Level	E	P	E	P	E	E	E
	Extent	Global	Global	Local	Local	Local	Local	Local
	Data	Strong	Strong	Mod	Strong	Strong	Mod	Mod
Nonnative Plants*	Level	E	E	E	P	--	E	--
	Extent	Global	Global	Local	Local	--	Local	--
	Data	Mod	Strong	Mod	Mod	--	Strong	--
Forests & Woodlands	Level	E	P	E	P	E	P	E
	Extent	Global	Global	Local	Local	Local	Local	Local
	Data	Mod	Mod	Strong	Strong	Mod	Mod	Strong
Wetlands	Level	E	P	E	U	E	E	U
	Extent	Global	G/L	Local	Local	Local	Local	Local
	Data	Mod	Weak	Weak	Mod	Mod	Mod	None
Birds	Level	E	P	E	E	E	E	P
	Extent	Global	Global	Local	Local	Local	Local	Global
	Data	Strong	None	Mod	Strong	Strong	Strong	Mod
Mammals	Level	E	U	P	P	U	P	U
	Extent	Global	Global	Local	Local	Local	Local	Local
	Data	Mod	None	Weak	Mod	Weak	Mod	None
Bats	Level	E	P	P	P	U	P	P
	Extent	Global	Global	Local	Local	Local	Local	Local
	Data	Weak	None	Weak	Mod	None	None	Mod
Amphibians & Reptiles	Level	E	E	P	U	E	P	P
	Extent	Global	Global	Global	Local	Local	Local	Global
	Data	Mod	Mod	Weak	Strong	Strong	Weak	Strong
Macro-invertebrates	Level	P	P	P	P	E	P	U
	Extent	Global	G/L	Local	Local	Local	Local	Local
	Data	Weak	Mod	None	Weak	Weak	Mod	None
Biodiversity	Level	E	P	E	P	E	E	E
	Extent	Global	Global	Local	Local	Local	Local	Local
	Data	Mod	Mod	Mod	Strong	Strong	Mod	Strong

4.3.6 Landscapes – Ecosystem Environment, Patterns, and Processes

Natural Soundscapes

Natural sounds are an important component of the broader landscape environment as well as air resources in national parks. The National Park Service has committed to preserve, to the greatest extent possible, the natural sounds of the parks (NPS, 2006). The Natural Sounds Program was established in 2000 to help parks manage sounds by offering guidance and a consistent approach to regulating and monitoring ambient (natural) sounds in the nation's parks. Natural or ambient sounds are those that exist in the absence of human activity and are used to define the baseline condition in the parks.

An acoustic monitoring project was undertaken by the National Park Service Natural Sounds Program for the Sierra Nevada Network parks, and included four acoustic data collection campaigns at Devils Postpile National Monument. Three sites were monitored in DEPO from summer to early autumn of 2005, and one was re-sampled in winter to early spring of 2006 (Formichella et al., 2007). Methods of on-site listening (staff recorded and analyzed audible sounds while at the monitoring site) were combined with off-site listening (staff analyzed audible recordings that were taken automatically) to define parameters such as sound source, period of time between noise events, percent of time each sound source was audible, and length of sound occurrence. In addition, sampling stations collected sound intensity (wave amplitude measured in decibels) and pitch (wave frequency measured in hertz). Estimates of natural ambient (intrinsic) sound levels at each site were made by subtracting sounds from human-caused (extrinsic) sources. Overall condition was evaluated by comparing total ambient sound levels with estimated natural ambient sound levels.

The sites chosen for monitoring supplied a representative sample of the monument. Factors such as vegetation, elevation, exposure, proximity to high-traffic areas and visitor use were considered. The first site chosen was within the non-wilderness portion in a small meadow near the Visitor Center and employee housing at an elevation of 2,304 meters (7,560 ft), and near a parking lot, a bus stop, the ranger station, a picnic area, and a campground. The second site was called one-10^{th} Dome and was located in montane forest within Wilderness 800 meters (0.5 miles) to the west of the visitor center at an elevation of 2,487 meters (8,160 ft). The third site called the Buttresses was next to the King Creek trail near the western monument boundary, located at an elevation of 2,400 meters (7,874 ft) in an area of chaparral/open shrubland with standing dead snags that had burned in the Rainbow fire of 1992. This site was monitored once in summer and once in winter. It was located far from the most frequently used areas within DEPO. The two Wilderness sites were monitored for 30 days while the non-Wilderness site was monitored for eight days.

Results of this study show that the site near the visitor center is the loudest of the three sites (Table 4.25). It had the highest mean percent time of audible extrinsic (non-natural) sound at 46%, the highest percent audible extrinsic sound estimated for a single hour at 82%, and the highest peak sound intensity at 48 dBA. [dBA are decibels using the A filter that accounts for differences in human hearing across the sound frequency spectrum]. Noise levels at the 10^{th} Dome site showed a similar pattern of source, intensity, and diurnal fluctuation except that all values are lower and the prominent source of extrinsic noise came from vehicles rather than from people. At the Buttresses site, all extrinsic noise levels were less than those observed at the other two sites. Aircraft accounted for nearly all of the extrinsic sound, with other sources being domestic animals (in summer) and snowmobiles (in winter). At the Buttresses, the percent of time that aircraft was audible was greater than at the other two sites. The reason for this was not that more aircraft were flying over the Buttresses, but rather that they were more audible due to lower overall ambient sound intensity. This highlights an issue of complexity in that sounds overlap one another, causing the softest sounds to be lost completely. It also highlights the importance of maintaining natural ambient sound levels in order to allow ecological systems to function well and naturally.

It should be noted that decibels are not a linear scale, but rather are measured on a logarithmic scale. Therefore, an increase of 10 dBA represents a perceived doubling of the sound pressure level. So, the peak noise level at the visitor center station was twice the level as the peak of the Buttresses station in summer.

Table 4.25. Results from Devils Postpile study of natural sounds, 2005-2006. Audibility of extrinsic sounds are presented including the total percent of time that extrinsic noises were heard, total percent of time aircraft noise was heard, the most frequent sources of extrinsic noises, and the proportion of time extrinsic noises were heard during a one hour period at peak noise activity. Peak ambient intensity of noise is in decibels (dB) using an A weighted filter that accounts for differences human hearing across the sound frequency spectrum.

	Audibility of Extrinsic Sounds (% of time)						
Site	**Total**	**Aircraft**	**Most Frequent Sources**		**Peak Hour**	**Peak Ambient Intensity(dBA)**	**Monitoring duration**
One-10th Dome	30.1%	8.7%	Vehicles	15%	64%	42	30 days
Visitor Center	45.6%	5.3%	People Vehicles	20% 18%	82%	48	8 days
Buttresses (summer)	16.9%	15.9%	Aircraft	15.9%	38%	38	30 days
Buttresses (winter)	19.1%	18.3%	Aircraft	15.9%	40%	34	30 days

Conclusions drawn from this research are that the noise of visitors (voices, vehicle traffic, and domestic animals) threatens natural sounds in the high-use areas like the visitor center and nearby campground. Noise of aircraft is audible and of concern in all areas of the monument, although it is less audible in high-use areas because the nearby noises of visitors are more intense and mask out the aircraft noise.

Disturbance of the natural quiet by aircraft overflights became a widely recognized problem in national parks and monuments beginning in the 1940s when floatplanes threatened the solitude of the Boundary Waters Canoe Area Wilderness. Since then land managers have been struggling to balance the needs of public lands with commercial, private, and military rights to airspace (NPS, 1994). A survey of National Park Service superintendents in 1992 collected information about the numbers of park units experiencing aircraft overflight problems, the types of aircraft operations affecting each park, the types of impacts produced by the noise of overflights, and additional details about the park managers' perception of aircraft overflights and associated problems. The individuals surveyed most often identified the sound of aircraft overflights as having a negative impact on visitors. Parks with perceived overflight problems rated aircraft as their most important sound problem, followed by vehicular traffic, power generators, and audio devices (NPS, 1994).

Current Condition Summary

Reference conditions would be levels of extrinsic sounds that are below levels to negatively impact wildlife and affect the visitor experience. Local data confirm a moderately to severely degraded natural soundscape that is probably impacting the visitor experience, while research has linked sounds to wildlife impacts elsewhere. Therefore, we conclude that the current condition of natural soundscapes in the monument is poor to fair.

Threats & Stressors

Visitor Use and Human Effects

As the population of the state of California and the Town of Mammoth Lakes increases, the natural quiet and solitude of Devils Postpile National Monument will continue to be threatened. Air traffic into and out of the Mammoth Lakes airport has been increasing and is expected to increase further in the future, making overflights a significant concern for natural soundscapes in DEPO.

Aircraft and vehicles were the most frequent sources of extrinsic sounds in all areas of the monument that were monitored. Since the early 1990s, there have been a number of acoustic monitoring studies conducted within national parks, with many focused on noise from airplane and helicopter traffic. Miller (1999) summarized the effects of overflights on visitor experience at three national parks: Grand Canyon, Haleakala, and Hawaii Volcanoes. Using sound monitoring and visitor interviews, the author found that the percentage of visitors who were annoyed or who believed the aircraft noise interfered with the natural quiet steadily increased as the aircraft noise level increased. This was also true for the percentage of time that aircraft could be heard. Two of the four sampling locations were next to parking lots while the other three were a short hike from parking lots. The results of the study found that people who had walked a short distance away from the parking area were much more annoyed and experienced interference with natural quiet than those people interviewed next to the parking areas.

A summary of acoustic data collected from eight national park units (several Hawaiian units, Yosemite, Grand Canyon, Mount Rushmore, and Cumberland Island) from 1989 to 1995 found that aircraft noise was always audible at all sites, however remote. The percentage time aircraft noise was audible varied from about 10% up to over 90% (NPS, 1994).

In Yosemite, visitor surveys in a number of places found that 51% of visitors rated aircraft noise as annoying and unacceptable (Newman et al., 2006). From those who heard vehicle noises, they were rated as slightly annoying and slightly unacceptable. The sound of voices received an average rating of neutral (neither annoying nor pleasing). In contrast, all natural sounds (e.g. wind, birds) were rated as pleasing and acceptable to visitors.

Landscape Dynamics

Much of the information in this section was extracted from the NPScape program data for Devils Postpile National Monument (NPS, 2010c-h).

Conservation Status

DEPO is surrounded by federal lands administered by the U.S. Forest Service (Figure 4.11). To the west, south, and southeast, the monument is bordered by the Ansel Adams Wilderness, a designated roadless area that is not subject to extractive uses found on non-Wilderness Forest Service land. This Wilderness border represents 69% of the monument's boundary. On the northeast side and most of the eastern side, the monument is bordered by the non-Wilderness portion of the Inyo National Forest, representing the remaining 31% of the monument's boundary. The Ansel Adams Wilderness is designated as GAP (Gap Analysis Program) status 1, while the non-wilderness Inyo NF is designated as GAP status 3 (after Scott et al., 1993; Edwards et al., 1994; Crist et al., 1996). GAP 1 and 2 status lands include lands with permanent protection from land conversion and prohibition of extractive uses (such as logging), while GAP 3 status lands permit extractive uses.

In a 30-kilometer (~19 mile) circular buffer zone around the monument that includes the local landscape context, federal lands comprise 95.5% of the total land area, municipal water districts own 2.5%, and privately held lands comprise only approximately 2% of this area (NPS, 2010c). The private lands include the towns of Mammoth Lakes and June Lake, areas near Silver Lake and Grant Lake (both in the June Lake area), areas near the Highway 395 and 203 intersection, and areas upstream of Crowley Lake in Long Valley. Although the federal lands are not likely to decrease in their extent, the town of Mammoth Lakes will likely continue to grow in density within its development footprint.

Within the same 30-km landscape zone around the monument, lands that are categorized as GAP status 1 or 2 comprise approximately 60% of the area. GAP status 1 and 2 lands include the Ansel Adams Wilderness, the John Muir Wilderness, the designated wilderness within Yosemite, the Mono Basin National Forest Scenic Area, the Indiana Summit Research Natural Area, and the Sentinel Meadow Research Natural Area (NPS, 2010c). All other federal lands within the landscape area (40% of total) are primarily to the northeast of the monument and are subject to extractive uses and not under permanent projection.

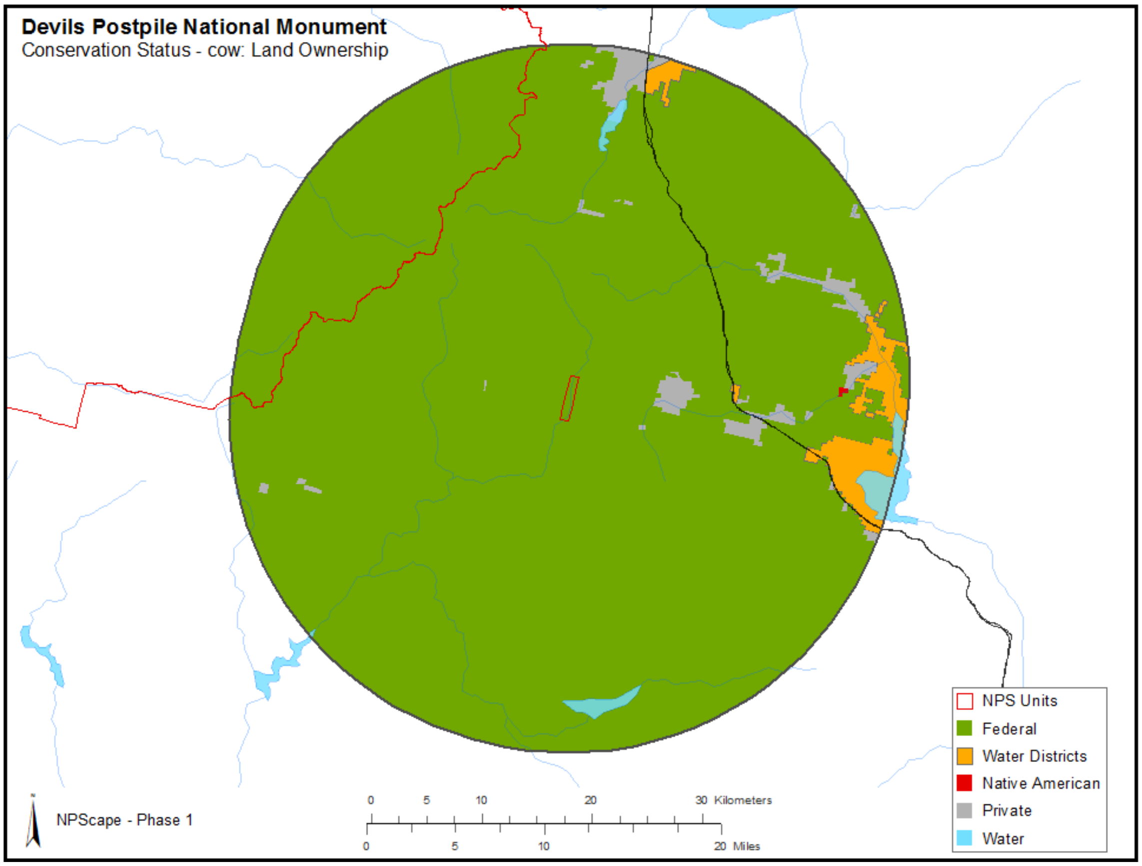

Figure 4.11. Land conservation status in 30-km area around DEPO.

Land Cover

Using the 2001 National Land Cover Dataset (NLCD), the NPScape analysis calculated that within the 30 km circular buffer zone around the monument, only 0.6% had been converted from natural to built-up land (Figure 4.12) (NPS, 2010e). This converted land includes roadways, buildings, parking lots, golf courses, and other developed land. Comparing the land cover data from 1992 with that from 2001, most of the conversion during that time period was within the Town of Mammoth Lakes and was almost entirely a conversion of natural land cover (forests and shrublands) to urban. This conversion represents a tiny fraction (0.0008%) of the landscape area around the monument in the 30-km buffer zone. However, due to the proximity of Mammoth Lakes to the monument, the gradual and continued urbanization of the city will create potential hazards to the monument in the form of increased light pollution, sound pollution, air pollution, and associated water pollution. However, due to the insular nature of DEPO and its location over the Sierra Nevada crest from Mammoth Lakes, land cover changes and associated impacts are anticipated to be low.

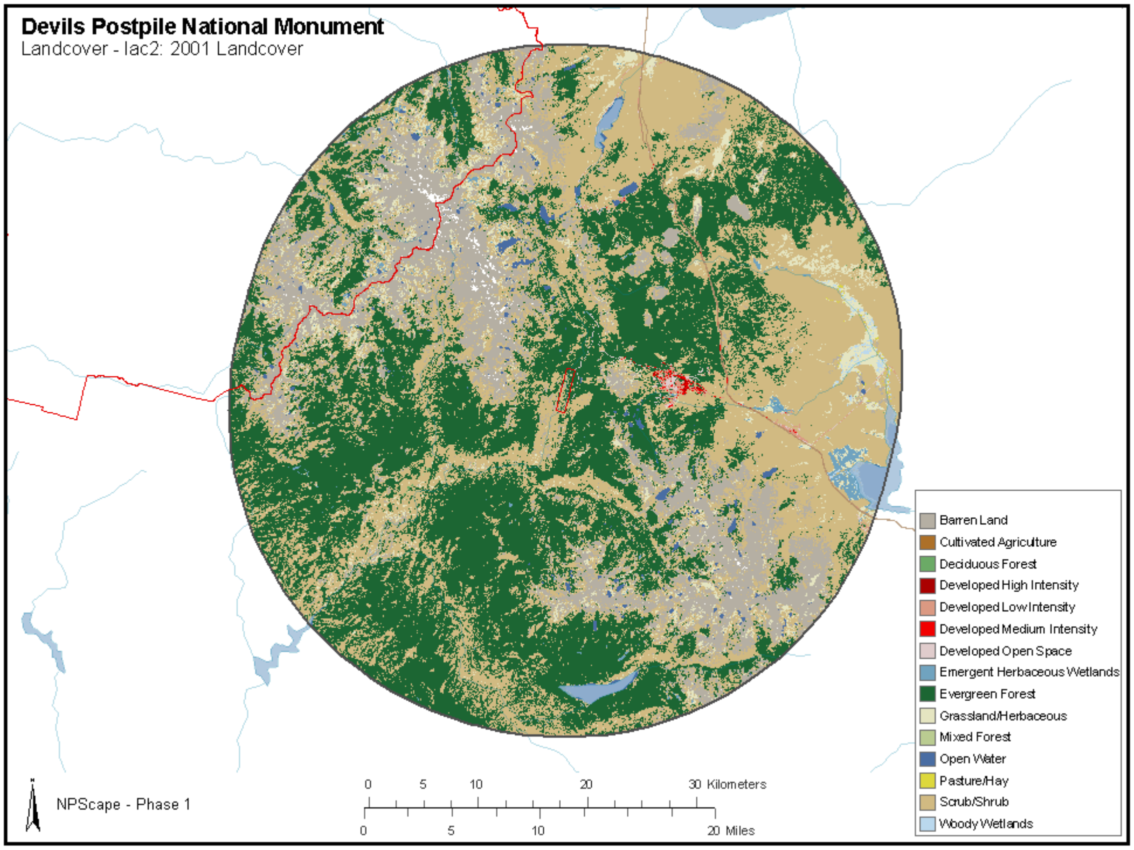

Figure 4.12. Land cover in 30-km area around DEPO. Data from the National Land Cover Dataset. Analysis provided by the NPScape project.

Landscape Pattern

Within the same 30-km buffer area around DEPO, the NPScape analysis again used the 2001 NLCD to assign each 30m pixel to one of several land type classes to map the spatial mosaic of forest and grass dominated habitats. The 30-km buffer zone was dominated (60%) by nonforest habitats such as unvegetated rock outcrops, shrublands, and grasslands. However, core patches of forested habitat did comprise most (27%) of the remainder of the total area (NPS, 2010f). Pixels classified as forest edge comprised 6% of the total area. This mosaic dominated by nonforest is likely typical of the high elevation Sierra Nevada, the east slope, and the high desert. The 27% cover of core forest patches represents the extent and arrangement of habitat for those wildlife species associated with forest dominated ecosystems.

Examining grass dominated areas within the same 30-km landscape zone around the monument, it isn't surprising that less than 1% of the area is considered core grassland habitat while almost 95% is considered all other land cover types. This is also likely typical of the high elevation western Sierra Nevada and eastern Sierra Nevada that are dominated by conifer forests and woodlands on the slopes and pinion pine and western juniper woodlands as well as sparse shrublands on the adjacent high elevation deserts to the east. In the Sierra Nevada, these grasslands surely represent the numerous meadows that dot the landscape but cover a very small fraction. These grassland or meadow habitats however, are an extremely important and diverse habitat type within the region.

Population

Devils Postpile is located in the far eastern corner of Madera County, but is only accessible through the eastern Sierra Nevada via Mono County. Madera County had about 125,000 residents in 2000 and its population is projected to rise 118% to about 273,000 by the year 2030, a dramatic rise (California Dept of Finance website, 2010). Using population projections, the population of Mono County is expected to rise to approximately 23,000 (~77% increase) between 2000 and 2030 (California Dept of Finance website, 2010). Mammoth Lakes, the largest and closest city to DEPO, had a population of approximately 7,100 in the 2000 census, more than half the total of 12,853 for Mono County. In the decade following the 1990 census, the population size of Mammoth Lakes increased by 48% while population density roughly doubled (Town of Mammoth Lakes, 2007a; 2007b). The Town of Mammoth Lakes estimated that the city population in 2004 had increased to 7,569 permanent residents, 2,264 seasonal residents, and an average peak seasonal population of 34,265 (Town of Mammoth Lakes, 2007b).

In its 2007 General Plan, the Town of Mammoth Lakes maintains a policy of limiting the peak combined total population, including permanent residents and seasonal visitors, to 52,000 people (Town of Mammoth Lakes, 2007b). However, there is flexibility in the plan to actually increase this limit to 60,700 by the year 2024. This general plan, which stays in effect until 2027, predicts that the city population of permanent residents will grow at a rate of between 1.4% and 2.4% per year.

Even though the Town of Mammoth Lakes grew rapidly in the last 10-20 years and will continue to grow, and the seasonal influx of visitors can be large, the California Air Resource Board believes that local sources of pollution are not considered to have a considerable impact on ambient levels of ozone due to climate patterns in the region (Garcia et al., 2001). The largest threat to general air quality is still the influx of ozone and other pollutants from California's Central Valley. Projections of population growth in Madera and neighboring counties in the next 20-40 years are enormous (California Dept of Finance website, 2010). A future increase in human populations in the counties around DEPO will definitely result in a higher level of some stressors and threats to its natural resources.

Housing

Echoing the trends in population size and density, there have been steady and large increases in housing density in the small municipal and private lands in the 30-km around DEPO from 1950 through 2000 (NPS, 2010d). Housing density is perhaps a better indicator for environmental or land use change than is population size or density because it accounts for second or third homes as well as vacation rental properties that all do not have permanent residents. Current housing units are concentrated in Mammoth Lakes and other small unincorporated areas to the west, east, and north of DEPO (Figure 4.13). Housing densities are projected to rise as population rises over the next 20-40 years. However, that ever growing population will still be confined to the limits of the small city footprints of Mammoth Lakes and June Lake, and the Hwy 395 corridor.

In the monument, all housing and associated infrastructure are concentrated in the northeast corner of the monument. As a result, resources are most heavily impacted in this area.

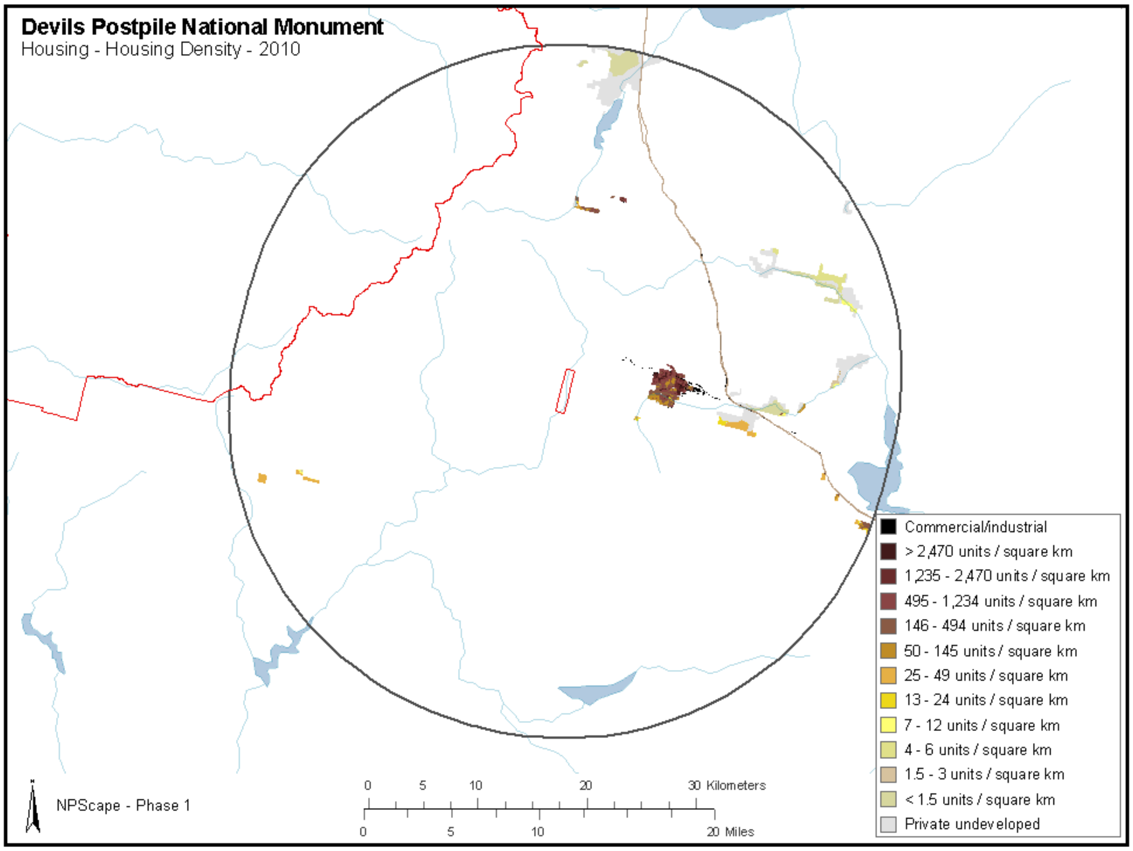

Figure 4.13. Current housing density as of 2010 in the 30-km area around DEPO. Housing density in number of housing units/square kilometer.

Roads

Locally within the monument, roads are few but concentrated in the far northeast corner. The host of documented negative impacts of roads on ecosystems, species, hydrology, and geomorphology (Furniss et al., 2000; Lugo & Gucinski, 2000; Trombulak & Frissell, 2000; Gucinski et al., 2001; Wemple et al., 2001) means that the resources in this area of the monument are likely to be impacted by roads in numerous and complicated ways. In addition, hydrological effects will be felt in the water and river channels downstream of roaded areas. Local and downstream impacts include the introduction of pollution from the road itself and from automobile fluids (Trombulak & Frissell, 2000), and the altered hydrology and geomorphology that is associated with road building and maintenance (Gucinski et al., 2001). There are few roads in and near the monument, but there is extensive roading in habitats further to the northeast (Figure 4.14) (NPS, 2010g). Most of these roads are dirt roads within Inyo National Forest.

Both paved and unpaved roads outside the monument to the east in the Reds Meadow Area and to the north are also likely negatively impacting the hydrology and water quality of the Middle Fork of the San Joaquin River and its local tributaries, though the impacts may be small. Unpaved roads are a major contributor of sediment to streams (Gucinski et al., 2001; Wemple et al., 2001), and also contribute pollutants to rivers.

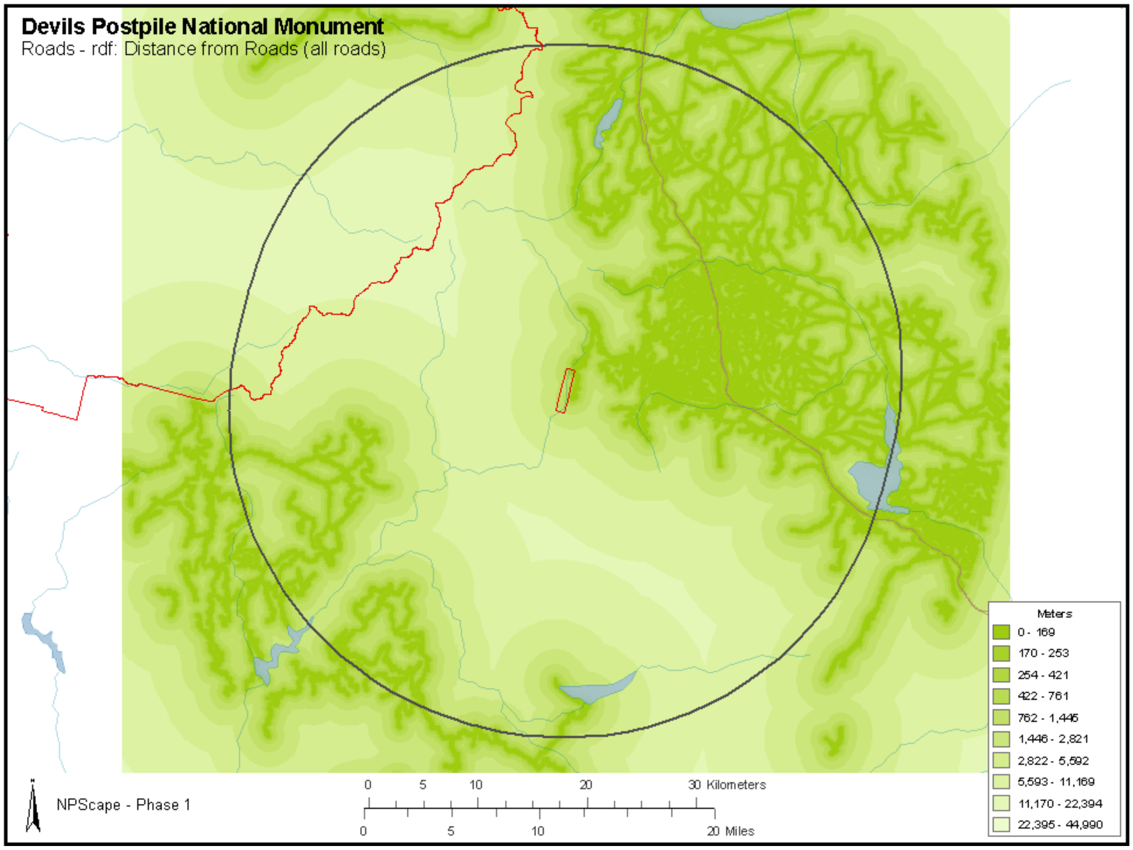

Figure 4.14. A metric of the distance from roads (in meters) as an assessment of the degree to which DEPO and the areas around it are being affected by roads.

Current Condition Summary

Evaluating the metrics of landscape dynamics together, we conclude that the status and arrangement of land use and land cover around the monument have not undergone significant changes in the recent past and so are in good condition. However, the presence of roads is probably the largest negative quality of the landscapes around the monument, though few roads exist in and nearby the monument. Therefore the landscape dynamics currently do not meet reference conditions of a stable complex of natural and protected lands around the monument not significantly altered by human impacts, though much of the area shows little if any impacts. The current condition of the landscape context around DEPO is good.

Threats & Stressors

Land Use Conversion (Habitat loss & fragmentation)

Since there are no extractive uses in the Wilderness areas around DEPO and the Inyo National Forest is currently not a logged forest (though some small-scale thinning does occur, related to commercial firewood operations), and the fact that the matrix of federal lands around DEPO are unlikely to change in the foreseeable future, the threat of habitat loss in the local landscape context is low. However, some impacts from road building, increased population and housing densities in small towns will pose a small threat to the overall natural dynamic.

Fire Regimes

Fire is known to be an important natural process within the Sierra Nevada. Prior to Eurasian settlement, fires in the Sierra Nevada were relatively common, some even burning for months and covering large areas. Extensive research in mixed-conifer forests of the Sierra Nevada has found that low intensity surface fires tended to maintain a patchwork with more open canopies and variable stand densities (Biswell, 1961; Kilgore, 1971; Kilgore, 1973; Harvey et al., 1980).

Historically, fire played a significant role in shaping the ecosystems of the Sierra Nevada (Davis & Moratto, 1988; Smith & Anderson, 1992; Skinner & Chang, 1996; Anderson & Smith, 1997). Fire was part of the system and was a significant factor in soil and nutrient cycling, decomposition, hydrology, vegetation structure and species composition, and the dynamics of forest pests and pathogens (Kilgore, 1973; Chang, 1996; McKelvey et al., 1996; Sierra Nevada Ecosystem Project, 1996a). Relatively frequent ground surface fires kept down fuel accumulations, and their variable nature created a patchwork of stands with different recent fire histories and ages, and thus variable forest/woodland structures. Historically, the frequency, size, intensity, and severity of fires varied widely in their spatial and temporal extent. This variation was controlled by timing and spatial configuration of ignitions, climate, weather, elevation, topography, vegetation, fuels, and edaphic conditions (Skinner & Chang, 1996; van Wagtendonk, 2004).

Until the late 1960s, federal resource agency policy was to suppress all fires. The success of this policy led to a dramatic change in the structure and composition of forests, woodlands, shrublands, and grasslands within the Sierra Nevada. These ecosystems that evolved with fire experienced a long relatively fire-free period although the climate would have supported frequent and sometimes large fires.

Since the creation of Devils Postpile in 1911, only one fire is known to have occurred within the monument – the 1992 Rainbow fire. Ignitions certainly occurred in the area, but fires were actively suppressed (according to Inyo NF fire history GIS data). The relatively high intensity of the 1992 lightning ignited fire was the result of a six-year drought while very hot conditions and high winds aided the spread and intensity of the fire that started in August of that year. Fires in the area of the monument were originally thought to be rare (National Park Service, 1982), but a fire history study in 2004 and 2005 attempted to reconstruct pre-Euro-American fire history within the monument. This research determined that fire return intervals ranged from 8 to 33 years, with a mean of 14 to18 years, and with the last fires occurring in approximately the 1873 to 1886 time period (Caprio et al., 2006). Furthermore, Stephens (2001) found that fire return intervals near the Town of Mammoth Lakes on the eastern Sierra Nevada slope near Devils Postpile were 24.7 years for montane conifer forest (red fir, lodgepole pine) and nine years for Jeffrey pine woodlands.

Based on the results of the two fire history studies in the area, lodgepole pine forests historically burned every 14 to 33 years in and around DEPO and most of them last burned in 1992. Prior to that burn, these forests had last burned at least once in approximately 1876 (Caprio et al., 2006). Over the past 135 years, fires have only occurred once in lodgepole pine in the area, well above the historical fire frequency. In Jeffrey pine the historical fire return interval was likely lower than that for lodgepole pine (~ 8 to 18 years) and so its fire return interval is even further away from its historic interval. Therefore, fire as a process is currently not within historic conditions assuming fire return intervals will not return to historic intervals in the near future. However, it is customary among fire ecologists to reset the departure from natural fire return intervals once a fire occurs. In that case, the 86% of the monument that burned in 1992 is just now surpassing the mean historic return interval of 18 years while the 14% of the monument that did not burn is still well beyond the historic fire return interval. Prescription burning, wildfire fire use, and mechanical thinning would be several management actions available to maintain or return the forests of the monument to within historic parameters.

Although only one fire has burned within DEPO since approximately 1876, there have been many ignitions and small fires in the greater watersheds (both west and east of the Sierra Nevada crest) around the monument since that time. The fire history data for California's National Forests (USDA Forest Service, 2010) includes 17 recorded fires within the three level 6 watersheds in and around DEPO between approximately 1878 and 2010 (Figure 4.15). Many small fires also occurred in the Mammoth Lakes area on the east side of the Sierra crest (many not shown in Figure 4.15). The 17 fires on the western side of the crest were started either by lightning (9 of 16) or were of unknown origin. All but one were eventually suppressed and therefore relatively small. The fires on the west side of the range crest ranged in size between 4.2 ha and 3,383 ha (10.4 – 8,359 acres). The spatial data do not capture all fires within the time frame as reporting in earlier years was not consistent, and often, small fires (less than 4 hectares (10 acres)) were not recorded. Therefore, there may have actually been more fire starts than are represented in the data.

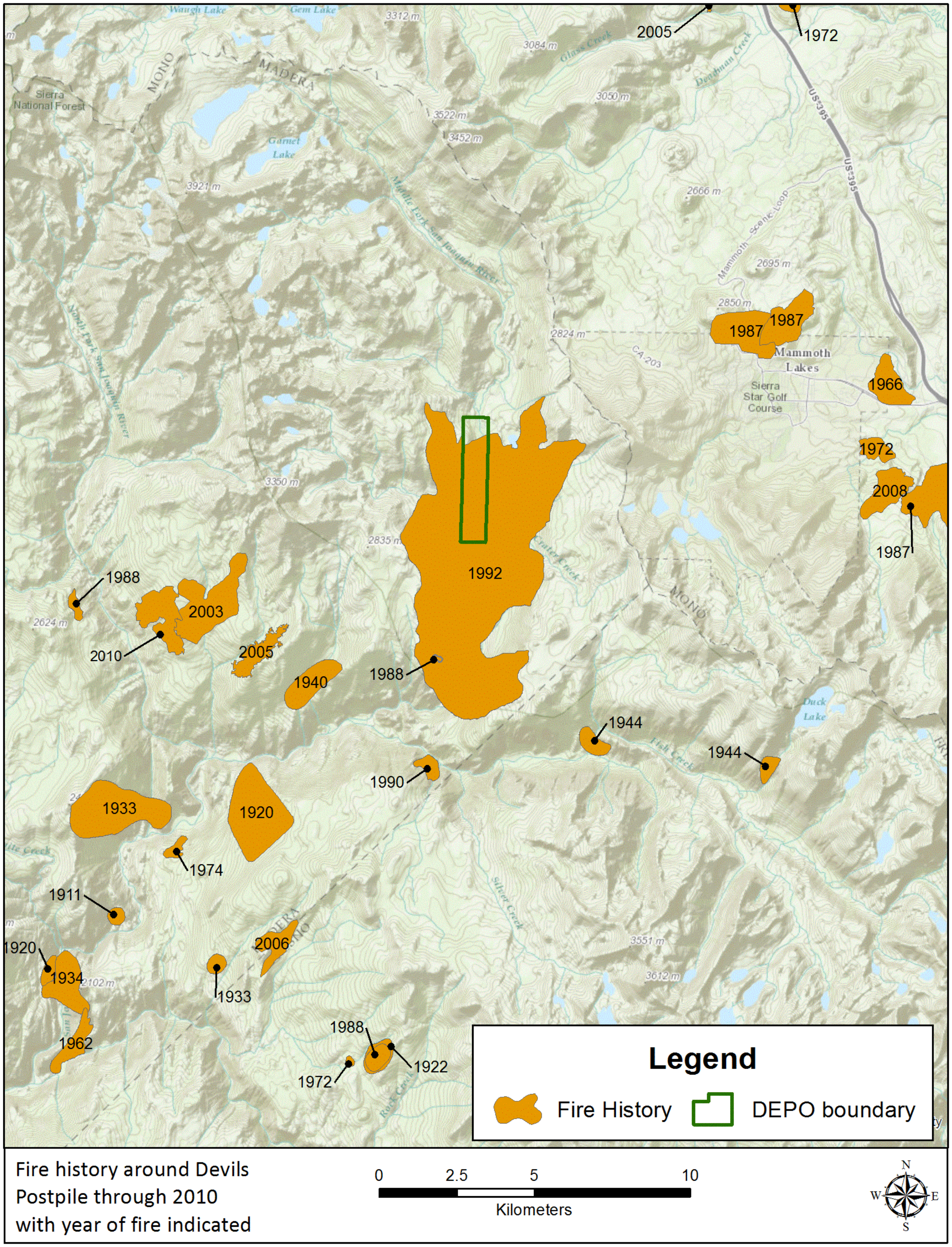

Figure 4.15. Fire history around Devils Postpile through 2010. Polygons represent fire footprints. Year of fire indicated. Data from USDA Forest Service (2010).

The fire return interval departure (FRID) spatial data for the Inyo National Forest (USDA Forest Service, 2010) indicates that most of the monument has been classified as having a presettlement fire regime of moist mixed conifer with a mean reference fire return interval (FRI) of 15 years. This includes areas dominated in the canopy by Jeffrey pine and lodgepole pine. The other presettlement fire regimes included red fir with a mean FRI of 40 years and montane chaparral with a mean FRI of 35 years. Areas dominated either by moist environment plant associations such as riparian forests and wetlands or areas devoid of vegetation do not have an assigned fire regime. FRIDs are calculated as:

(Mean Reference FRI – Years since last fire)/Mean Reference FRI

FRID values less than one indicate that it is outside of the natural fire return interval while positive values indicate it is still within the historic FRI. Figure 4.16 presents the reference FRIs as derived from point data, calculated FRIs through 2008, and the resulting FRID values for all fire regime polygons within DEPO.

We can see from the data and calculated FRID values that most of the monument that burned in 1992 is now marginally outside of the normal FRI, with the exception of some small areas dominated red fir and chaparral that are still within the normal FRI. The portion of the monument that did not burn in 1992 still remains far outside the normal FRI.

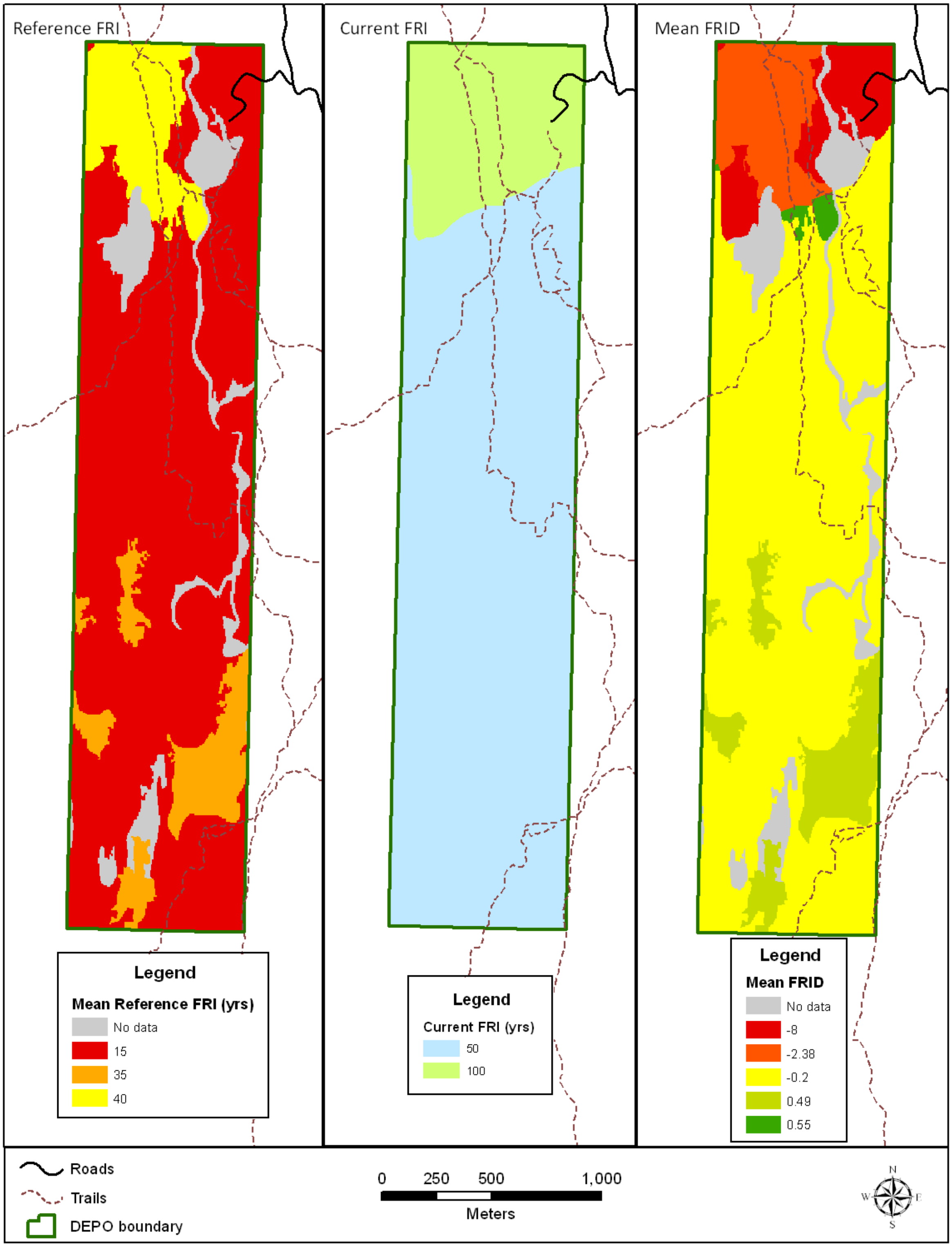

Figure 4.16. Historic reference fire return interval (FRI) (in years), current FRI, and calculated fire return interval departure (FRID). Data from USDA Forest Service Region 5 Fire Return Interval spatial FRID geodatabase for Inyo County (USDA Forest Service, 2010). Current FRI uses data through 2008.

Current Condition Summary
Reference conditions for fire regime would be a natural regime that is uninfluenced by direct and indirect human causes such as greenhouse gas driven climate changes. This would include a return interval similar to historic intervals (8 - 33 years), all areas with variable FRID values that are not too far from zero, and a regime that has sufficient spatial variation to produce a patchwork of forest and woodland stands of varying age and density. Due to the small size of DEPO, fires are likely to burn most or all of the area when they occur, though fuel limitations may protect some areas or at least alter fire severity. Since 14% of the monument is still well beyond historical conditions and the 1992 fire burned only after a very long period of fire exclusion, we conclude that the current fire regime is in poor to fair condition.

Threats & Stressors

Climate Change
Considerable research has found a link between past climates and fire regimes. During warmer, drier times, fire frequency, severity, and extent were greater than in cooler, wetter periods (Swetnam, 1993; Brunelle & Anderson, 2003). Swetnam (1993) used fire scar analysis of Giant Sequoias to reconstruct climate over the previous 2,000 years and determined a strong link between past climates and fire frequency. In the northern Sierra Nevada, research has determined that in the recent past, fire frequency increased during dry years and drier periods (Taylor & Beaty, 2005; Moody et al., 2006). Under a future climate that is expected to be warmer, even if precipitation remains unchanged, conditions will become drier. A warming climate is likely to increase lightning ignitions and thus the frequency and severity of fires in the Sierra Nevada (Miller & Urban, 1999; Lutz et al., 2009b; Westerling et al., 2009). Analysis of data from the Sierra Nevada over the previous 21 years found a positive association between drought severity in spring and area burned the following summer (Westerling et al., 2003). In addition, Westerling et al. (2006) examined large wildland fire history for the western U.S. since 1970 and found a strong positive association between fire activity and both high spring and summer temperatures and earlier spring snowmelt. Climate projections for California include both higher temperatures and an earlier spring snowmelt.

Nonnative species
The existence and persistence of cheatgrass within the monument, though very limited in distribution and density at this time, will continue to pose a small threat to the natural fire regime. Cheatgrass and other nonnative species are known to disrupt and usually increase the frequency of fire in the woodlands and forests that they have invaded (Keeley et al., 2003; Brooks et al., 2004). In ponderosa pine forests in Arizona, cheatgrass and other exotic annuals were much more abundant post-fire in areas that burned at high or moderate severity (Crawford et al., 2001). In Yosemite, Kaczynski (2007) found that exotic species cover increased with burn severity post-fire. While cheatgrass is known to occur within and around the monument, the spatial distribution and cover of this and other species are unknown since exotic plant surveys have not been consistent temporally or spatially. The presence and abundance of cheatgrass and certain other exotic species will continue to pose a threat to natural fire regimes in and around the monument.

Summary of Landscape Indicators

Tables 4.26, 4.27, and 4.28 summarize the landscape indicators. Table 4.26 is a summary assessment of the current conditions and trends of each indicator. Table 4.27 is a summary of current conditions relative to reference conditions. Table 4.28 is a summary assessment of the stressors and threats for each indicator. When little or no data existed with which to assess the impacts of a particular threat and the current condition, expert opinion was utilized.

Table 4.26. Current condition and trend summary for landscape indicators. Condition: Excellent, Good, Fair, Poor, Unknown, Variable. Trend: Improving, Deteriorating, Stable, Unknown, Variable. Strength of data/research to determine condition and trend: strong, moderate, weak, none.

INDICATOR	CONDITION	DATA STRENGTH	TREND	DATA STRENGTH
Soundscapes	Poor to Fair	Strong	Deteriorating	Weak
Landscape Dynamics	Good	Strong	Stable to Deteriorating	Strong
Fire regime	Poor to Fair	Moderate	Variable	Moderate

Table 4.27. Summary of current conditions relative to known or assumed reference conditions. Data sources: Empirical evidence or research from DEPO or very nearby (Local); relevant data or research from other parts of the Sierra Nevada, California, or North America (Inferred).

INDICATOR	Reference Condition	Reference Condition met?	Data Sources
Soundscapes	No extrinsic sounds that impact species or visitor experience	No	Local, Inferred
Landscape Dynamics	No significant change in land use and land cover in local area; landscape dominated by expected potential vegetation	No	Local, Inferred
Fire Regime	Experiencing natural fire regime, within historic variation, and no changes linked to anthropogenic factors	No	Local, Inferred

Table 4.28. Threat and stressor summary for landscapes by indicator. For each threat or stressor, its level, spatial extent, and strength of data are indicated. Level: E = existing; P = potential; A = past; U = unlikely; UK = unknown. Extent (spatial): Global and Local. Data strength: Strong, Mod (moderate), Weak, None. -- = Not Applicable.

		Stressor or Threat						
Indicator		**Climate Change**	**Pollution**	**Altered Fire Regime**	**Habitat Loss or Fragmentation**	**Nonnative Species**	**Visitor Use & Human Effects**	**Pests & Pathogens**
Soundscapes	Level	U	U	U	U	U	E	U
	Extent	--	--	--	--	--	Global & Local	--
	Data	--	--	--	--	--	Mod	--
Landscape Dynamics	Level	P	--	P	P	--	E	--
	Extent	Global	--	Global	Local	--	Local	--
	Data	Mod	--	Strong	Strong	--	Strong	--
Fire Regime	Level	E	U	E	P	P	P	U
	Extent	Global	--	Global	Local	Local	Local	--
	Data	Strong	--	Strong	Mod	Mod	Mod	--

4.4 Condition Summary

In our assessment of all physical, biological, and landscape indicators we have included the "excellent" class as an option for current condition though we have applied this condition class to only a small proportion of the indicators. To meet the excellent condition class, an indicator would have to clearly demonstrate no impacts and conditions consistent with those that probably existed prior to Eurasian settlement. Therefore, while a resource may ostensibly look to be in excellent condition, the empirical or inferred information that is available suggests that conditions are in fact not as good as they may appear, though may still be very good relative to other more impacted locations. This sums up the assessment of the natural resources of Devils Postpile National Monument. While at first look, most or all of the resources appear to be in excellent condition, a thorough review of the available literature and data revealed that conditions were not as good as appeared. Compared to other locations and national parks in the U.S., however, the conditions of natural resources are still relatively good. Below are brief condition summaries of the three indicator categories.

4.4.1 Physical Resources

The physical resources of the monument vary in their current condition from poor to excellent. The assessment of physical resources heavily relied on data and research from outside of DEPO for most cases as information from the monument is very limited at this time. Data collection for a variety of indicators has recently begun within the monument, but we had to look elsewhere for longer-term data to be able to infer conditions on site. When data were limited or absent, the opinions of monument managers and staff familiar with resources as well as NPS or other researchers familiar with a particular resource were used. Due to its relative isolation and its position within a largely intact landscape dominated by Wilderness, resources within the monument enjoy a relatively unimpacted environment. However, there still are significant stressors and threats for which we have local or regional empirical evidence or local anecdotal evidence.

Although limited data collection from the monument indicates that both air and water quality are fair to excellent, the spatial and temporal extent of the data collection and the pollutants targeted are limited. More thorough testing of air, water, and snow from other locations in the central and southern Sierra Nevada have found some pollutants in air, water, and snow at levels to be of concern. Therefore, we conclude that both air and water quality may be worse than what the limited local data would lead us to believe. This is in large part due to the proximity of the polluted air from the California Bay Area and Central Valley. The San Joaquin Valley is consistently found to be one of the most polluted air masses in the U.S. for some constituents, and research has shown that at least some of those pollutants are making their way up into the high Sierra Nevada.

While at first look the surface and groundwater dynamics of the monument may appear to be functioning normally, data and research from within the Sierra Nevada have found some apparent alterations of temporal surface flow patterns, if not total annual flows. This change is likely in response to regionally rising temperatures that have resulted in an earlier spring snowmelt, earlier peak surface flows, and longer periods of summer and fall low flows. Information on groundwater dynamics is currently so limited that we cannot conclude if they are impacted at this time, though small changes in surface water dynamics suggests they could be. The snowpack at lower elevations in the Sierra Nevada has decreased while at higher elevations it has increased in the recent past. Snow water content and April 1 snowpack have remained unchanged in the elevations between these, which is right where DEPO sits. If regional climate continues to warm, we can expect DEPO will start to experience decreased snowpack and snow water content.

The geologic resources of the monument are in good to excellent condition, but this is entirely based on anecdotal evidence. While we would not expect that the geologic resources (e.g. the Postpile, Rainbow Falls, granitic domes) to have been degraded by one or more stressors, no empirical monitoring has occurred to support this assumption.

4.4.2 Biological Resources

The native flora of the monument appear to be faring better than other areas of the Sierra Nevada bioregion, particularly the lower elevation western foothills that are heavily impacted by development, grazing, and nonnative invasive plants. Only three of the documented 371 native plant species are listed as species of concern by the California Native Plant Society while no species are listed at the state or federal level. The presence of nonnative and invasive plants in DEPO is a persistent though relatively minor stressor for native flora and natural processes at this time. However, reintroductions or persistence of some alien species seems to be occurring and therefore some species may continue to be a low level threat. This threat may grow if regional climate trends continue.

The state of forests and woodlands within the monument has largely been determined by the 1992 Rainbow fire that burned much of the monument. Although the fire varied in severity and some pockets were spared, much of the monument is still in post-fire succession today. While some post-fire monitoring of forest tree species and vegetation communities has been encouraging, it is too early to determine if the fire will have long-term impacts on forest composition or structure, and if a shifting climate is having an impact. In addition, a small proportion of the forests and woodlands in DEPO have not burned in over 135 years, leaving them far out of their natural fire return interval. Therefore, the current state of the forests is fair to good, but may improve in the future.

A spatially comprehensive though one-time snapshot of all wetlands within DEPO in 2006 found most wetlands to be in excellent condition using standard assessment protocols. Fire was the only identified factor that degraded two small wetlands, though these two may fully recover. The presence of some persistent, though small populations of nonnative invasive species in at least some of the wetlands combined with documented, though small, impacts of direct human use in many of the wetlands force us to reduce the overall condition of wetlands to good.

While there have been many years of avian monitoring within the monument, the authors of that monitoring readily admit that due to constraints in budget and time, the available data do not permit a quantitative assessment of the conditions of individual species using the monument. Lack of long-term data does not permit us to make assessments of trends in overall species diversity or in abundances of any species within the monument. Regional long-term data (Breeding Bird Survey) are mixed, but do indicate that some species have been in decline and many more appear to be in decline as appear to be increasing in abundance. Birds from all life histories have apparently been equally impacted, with about one-quarter experiencing a recent decline. This may very well be explained by loss or degradation of wintering habitat at lower elevations in the foothills and in the neotropics, and by a rapidly changing climate. With the information available, we conclude that condition of the bird species and the entire bird community is fair to good.

Empirical information on mammals, with the exception of bats, is limited for the monument. While several surveys have documented the presence of bats, rodents, carnivores, and others, there is no local research on any one species or groups of species. This lack of evidence is not endemic to the monument, but is true of the entire Sierra Nevada where lack of data and information on mammals is a general rule. Exceptions to this do occur – such as for the California black bear. Several species have been regionally extirpated and these species likely inhabited the monument, at least part of the time. Recent evidence from the Yosemite area has confirmed that many small mammals have shifted up in elevation potentially in response to climate change, though other factors such as altered fire regimes may also play a role. Though not confirmed, DEPO may have lost some species based on the shifts documented in Yosemite. With these limited data, we conclude that the condition of mammal species and the entire mammal community are fair to good, though any one species may be better or worse.

We can only speculate that sensitive amphibian species such as the Yosemite toad and Sierra Nevada yellow-legged frog may have or likely did use habitat within the monument in the past. The presence of introduced and nonnative fish may be preventing the re-establishment of populations of these species, and are also likely impacting species known to be present. Overall condition of amphibians and reptiles is poor to fair considering the documented global and regional declines of many species in response to pathogens and climate change.

Macro-invertebrates were studied on two separate occasions in the recent past. Both found apparently healthy populations and a diversity of taxa. Although no long-term monitoring has documented any changes in these invertebrates as a result of fish introductions or altered water quality, it appears that today the conditions for these animals are good to excellent.

Taking the entire set of species together, the overall condition of the biodiversity of the monument is also good. Several species have likely been locally or regionally extirpated from the monument in the last 100 years. In addition, warming climate may have driven a small number species to elevations above DEPO. A complete inventory of all species would need to be made to make a fully quantitative assessment of the monument's biodiversity. Some species groups have not been studied or studied well, including terrestrial invertebrates, amphibians, some mammals, fungi, and lichens.

4.4.3 Landscapes

Due to its relative isolation, and location within a matrix dominated by federal lands and designated Wilderness areas, the landscape context of the monument is good. Though tourism to the monument and especially to nearby Mammoth Lakes and ski resort will continue to increase, the patterns of landscape ownership and use will remain static for the foreseeable future. DEPO benefits from its location embedded within other protected lands. Though surrounded by protected lands, roads and their effects are probably contributing to at least some degradation of natural resources in the monument.

Fire regimes are in poor to fair condition, but may be able to return to good condition if sensibly and proactively managed. With only one known fire in the last approximately 135 years (that occurred in 1992 and burned 86% of the monument), the monument is far from a normal fire regime with a historic fire return interval of 8-33 years. However, using the conventional FRID metric, most of the monument is very close to normal, with the exception of the 14% of the monument that did not burn in 1992.

Natural soundscapes are currently threatened by a number of unnatural or human noises, most significantly from airplane overflights to and from the Mammoth Lakes airport and from buses and cars. Unfortunately, overflights will probably continue and could increase in number in the future. Therefore, the natural soundscape of the monument may continue to deteriorate over time. Recent data collection would indicate that the natural soundscape condition is poor to fair, and may not improve.

4.4.4 Threats and Stressors to Natural Resources

We have identified several threats and stressors that are known or suspected to impact species, process, and ecosystems. The effects of these threats and stressors have been documented elsewhere in the Sierra Nevada or other parts of the globe. With this information, we can conclude that some of the systemic threats and stressors identified at the beginning will continue to impact all aspects of the natural resources of DEPO. Most threatening to the resources of the monument are climate change and pollution. These will surely continue to threaten and impact a wide variety of natural resources in and around the monument. Other threats or stressors such as pathogens and nonnative species also threaten particular species or processes, though to a smaller extent. Monitoring of the resources will in time reveal how they are being affected by all threats and stressors.

4.4.5 Spatial Variation in Condition

The northeast corner of the monument (that portion in non-Wilderness) appears to be the most negatively impacted. This is where the housing, camping, and associated infrastructure are located, where the roads are located, and also where much of the day use (especially fishing) is concentrated. This is also the location of one of the most sensitive environments – Soda Springs Meadow – which has experienced a history of adverse impacts from social trailing to stream bank erosion to invasion by nonnative plants. All of these impacts are the result of direct or indirect human causes. Use also spills over into the western side of Soda Springs Meadow and this area also sees some impacts. A large proportion of visitors also frequent the Postpile and Rainbow Falls, areas that have experienced invasions of nonnative plant species on a consistent basis, at least since 2002.

The remainder of the monument, the area to the west of the river and in the Ansel Adams Wilderness experiences much less direct human impacts and so the resources here are generally in much better condition. An exception is the persistence of many populations of nonnative species in The

Buttresses area. The reasons for the reoccurrence of invasive species in this area are unknown but may be a result of human foot and pack stock travel to the area.

The important global stressors – climate change and pollution – affect all parts of the monument, though the impact varies with the resource of concern. The Middle Fork of the San Joaquin River and its associated wetlands are where impacts appear to be concentrated.

CHAPTER 5. Discussion

5.1 Data Gaps & Recommendations

Overall

In our review of the data and research available for DEPO, we found that more often than not, data have been collected for relatively short time periods (usually one year or less), inconsistently, and often without standardized methods. There are of course many exceptions to this – some very good research and some monitoring has been conducted on resources in the monument. Many of the shortcomings can be directly tied to a lack of funding to plan and pay for high quality data collection. In those cases where data have been collected by DEPO staff over a period of two years or longer, sometimes we found that methods and timing of data collection were not consistent. Again, this is likely the result of staffing and budgeting insufficiencies. We recommend in the future, that when starting a data collection/monitoring effort, DEPO management should consider whether or not the data collected will be worth the effort and if they are, produce a formal plan to consistently collect that data and schedule the work into staff work plans each year so that it will be accomplished. In recent years, much standardized and automated data collection has begun, and over time this monitoring will provide valuable information to document potential changes and impacts.

There still are some data and information gaps, though recently, monitoring and research has been implemented to fill many of those gaps. Here we offer some apparent remaining data gaps and recommendations to fill them. These are only recommendations and they should be reviewed with the assistance of scientific advisors and subject matter experts to prioritize and determine both what is necessary and what is feasible with limited budgets. Recommended actions could be achieved through NPS staff time, through independent researchers, or through cooperation with other agencies

5.1.1 Physical Resources

<u>Air quality</u>

Very few air quality data have been collected within the monument. The recent short term data collection from the summers of 2007 and 2008 represents the only air quality data collected on site. The data found surprisingly high concentrations of certain air pollutants but the source of those pollutants is a question needing further research. Prior to the 2007-2008 research, it was assumed that air quality in and near DEPO was excellent due to its remote and high altitude location. The results of the study challenge that assumption.

In addition, data collected from YOSE and SEKI indicate very high concentrations of some pesticides and other pollutants in air samples, fish, conifer needles, and lichens, even at high elevations. No monitoring of pesticides in air or water has occurred within DEPO although they could be a significant concern and threat.

Recommendations:

1. Develop methods and strategies to further inventory air pollutants and implement long-term monitoring of air quality status and trends.

2. Include research and monitoring of other potential pollutants not yet targeted in the monument, including pesticides and organic nitrogenous pollutants.

3. Evaluate the contribution of local air pollution from combustion engine vehicles (especially diesel engine buses) on the monument's air quality.

4. Use monitoring and research to identify sources of pollutants detected.

Weather & Climate

The onsite climate station and array of sensors is currently monitoring weather and climate of the monument. If this station and all sensors continue to operate into the future, they will provide a significant dataset with which to assess conditions and trends of precipitation, climate, humidity, and other parameters.

Recommendations:

1. The data collected from each sensor should be regularly checked to determine consistency and reliability of collection. Coordinate with USGS and Scripps Institute of Oceanography if data collection fails.

2. Ensure that data are archived and are accessible in a central repository for climate data, such as the Western Regional Climate Center.

3. If microclimate investigations identify the Middle Fork of the San Joaquin River, including DEPO, as having a unique temperature regime relative to surrounding areas, then research should further explore the consequences of this small-scale variability to hydrology as well as species and communities.

Water quality

Up until very recently, much water quality monitoring in and around the monument has been haphazard, with monitoring occurring for different reasons. Although some data on well water do exist for the monument, they are not currently in a form to be useful. Some of these data may prove to be useful, but as of yet have not been checked, compiled, or analyzed. Surface water quality with respect to pollutants was not consistently monitored in the streams and ponds within DEPO. In the summer of 2009, a monitoring protocol was implemented and continued in 2010. The SIEN I&M program is developing a rivers and streams surface water monitoring protocol that will include the MFSJ River (Skancke et al., in prep.) and a wetlands protocol that will provide some groundwater monitoring at Soda Springs Meadow (Gage et al., 2009).

Recommendations:

1. In order to determine the potential effects of pollutants to aquatic wildlife and aquatic and riparian vegetation, the current water quality monitoring program should be regularly assessed to see if it is fulfilling its goals and modified if necessary.

2. Water quality monitoring should target some pollutants that may be significant, such as pesticides.

3. If possible, water quality monitoring should span the entire field season to capture and assess the variability in various pollutants through the seasons and associated changes in river flows.

Surface Water Dynamics

Up until recently, there were limited data on surface water flows. It is important to continue to monitor surface water dynamics in DEPO. With the recent establishment of a permanent gaging station and a temperature sensor in the monument, changes in surface flows and water temperatures can now be monitored well into the future. We suggest a regular examination of these data to check for consistency. Gages from outside the local watershed and/or far downstream are currently used to assess the status and dynamics of surface water flow on a longer time scale.

Recommendations:

1. Coordinate with USGS operators of the gaging station and temperature sensor to periodically check automated data collection for consistency and reliability.

2. The few ponds within the monument are important for birds and bats and may be potential habitat for amphibians. Monitor status of these water bodies. This could include water levels, water quality and water temperature.

Groundwater Dynamics

No investigations have sought to determine if there is any connection between the watershed of the MFSJ River and the watershed draining the north and east slopes of Mammoth Mountain. As the potential impacts of any future groundwater extractions in the Mammoth Mountain area remain a concern to DEPO management, cost effective methods to determine any watershed connections and potential or real impacts could be explored. The NPS Water Resources Division is currently investigating the feasibility and necessity of a comprehensive groundwater resources study.

Recommendations:

1. Develop a plan and explore further research to establish if groundwater resources in the monument are being impacted by a changing climate and by water extractions from the Town of Mammoth Lakes and Mammoth Mountain Ski Area and resort.

Snowpack

The recently installed snow pillow and snow sensors next to the weather station in the monument are important for monitoring snow depth and snow water equivalent. The addition of manual snow course data collection in the past few years will add valuable supporting data. Recent research has determined that snowfall and snow accumulations below approximately 2,590 m (~8,500 ft) have been declining, and so it would be important to establish if this continues to occur within DEPO.

Although the snow sensors were installed in 2006, data collection was inconsistent and unreliable until late 2009.

Recommendations:

1. Coordinate with the Scripps Institute of Oceanography, USGS, and California Department of Water Resources operators of the snow sensors to ensure consistent and reliable data collection.

2. Compare snow pillow data with manual snow course measurements made in DEPO.

Geologic Resources

While little is known about the conditions of geologic resources, we would not expect them to be changing over human time scales. However, those geologic attractions popular with visitors (Devils Postpile & Rainbow Falls) may be experiencing some forms of direct human impact.

Recommendations:

1. Impacts to important geologic resources should be monitored more closely using a standardized protocol so that potential disturbances can be quantified or at least qualified. Data can then be used to make management decisions to protect resources. If a full monitoring protocol is not possible, identify resources of concern that are currently experiencing impacts and manage them to minimize those impacts.

5.1.2 Biological Resources

Native Plants

Although a thorough survey of native plants occurred in 2001, no information exists on the status and trends of any species, especially species of local or region concern or significance. It is unknown at this time if any species present in the monument would be a candidate for local extinction as a result of systemic stressors such as climate change. Several species may be impacted by insects, pathogens, or pollutants

Recommendations:

1. Monitor impacts to Jeffrey pines and other sensitive species from ozone damage.

2. Monitor extent and severity of insect and pathogen damage to lodgepole pines and other affected species.

3. Since quaking aspen is undergoing severe declines in other western states, monitor the status and trends of their population dynamics in the monument.

4. Identify species that would be most at risk to local extinctions due to a warming climate and monitor their distribution and abundance in the monument.

Nonnative plants

Nonnative plants will probably continue to be a perennial though small threat to DEPO's resources, though they could become more of a problem if climate continues to warm. The distribution and abundance of invasive species should be monitored closely and populations eradicated.

Recommendations:

1. Although both the California Exotic Plant Management Team and DEPO staff have been surveying for and eradicating nonnative species since 2002, and the monument has a weed management plan, currently there is not a comprehensive view of what species are present and in what abundance. If there is a goal of eradicating nonnative plants from the monument or at least to control their spread, then we would suggest constructing a spatial geodatabase of the history of known locations and abundances of each species found. In addition, a standardized protocol of survey methods would help to determine the persistence and spread of all species. Protocols should include surveying in areas of previously eradicated populations as well as potential or likely new areas of invasions. Implementation of the recently completed invasive management plan for the monument will help meet these recommendations.

2. A close cooperation with the Forest Service and the Red's Meadow Resort is critical to eliminate or minimize the spread of nonnative species from the resort and other hot spots (such as corrals) into the monument.

Wetlands

Wetlands are an important resource within the monument. The current important local stressors of nonnative species, especially invasive species (such as cheatgrass), and direct human impacts through trailing, and the systemic regional threat of warming climate are perhaps the greatest threats to this valuable resource.

Recommendations:

1. Continue to support the monitoring of social trailing and riverbank conditions in Soda Springs Meadow.

2. Monitor presence and distribution of any nonnative plant species within Soda Springs Meadow and other meadows or wetlands as these areas are susceptible to invasions and associated impacts.

3. Continue monitoring ground water dynamics in Soda Springs Meadow. Consider expanding this monitoring to include more temporal variation.

4. Continue to monitor the "invasion" or recruitment of conifers into Soda Springs Meadow and other meadows/wetlands. Use standardized methods to determine rates of recruitment and areas affected.

Forests & Woodlands

The limited monitoring of forest change over time and especially since the 1992 Rainbow fire is extremely valuable. It is important to understand the impacts of altered fire regimes to these systems and the influence of changing climates. Pesticides may be accumulating in plant tissues, and may have negative impacts.

Recommendations:

1. Continue to support the post-fire monitoring. Consult with fire ecologist leading this project to see if it could and should be expanded to yield more beneficial information.

2. Monitor conifer forests and woodlands for signs of insect or pathogen disturbance. While these agents are natural to the system, lack of fire and/or warming climates may exacerbate their impact on native trees. Coordinate with USDA Forest Service specialists.

3. Monitor whitebark and western white pines for signs of white pine blister rust.

4. Consider sampling plant tissues (conifer needles, lichens) to determine if there are accumulations of pesticides as was discovered in Yosemite and Sequoia and Kings Canyon.

Birds

Birds have been monitored within the monument since 2002. Using limited resources, this monitoring has begun to determine the status and relative abundances of bird species that use the area as habitat. At this time, the authors of the PRBO reports are candid when they state that the data they are collecting are not sufficient to draw conclusions about status and trends. Currently PRBO is working to update study designs for the MAPS monitoring in Soda Springs Meadow in coordination with the implementation of the I&M bird monitoring protocol. Implementation of this protocol is the best way to monitor birds in the future.

In addition, the degree of nest parasitism by brown-headed cowbirds within DEPO is unknown. Dated research from YOSE and SEKI indicated they were not a problem to neotropical migrants. However, we suggest a more thorough look at this species and its effects on DEPO birds is warranted.

Recommendations:

1. Continue to support the I&M funded bird monitoring.

2. Continue the MAPS program if funds are available.

3. Consult with bird specialists to determine if monitoring the impact of brown-headed cowbirds is warranted.

Mammals

There is no direct available information on the health of populations of any species of large or small mammal that utilizes the monument. However, since mammals tend to be widespread throughout the Sierra Nevada, their conditions throughout this region can be used as a proxy for local conditions. Recently, wildlife biologists at Yosemite began to monitor American martens and fishers. A closer look at certain species that are somewhat rare in the region and that may be in decline, such as the Pacific fisher, American marten, and red fox would be recommended. This would require coordination with Inyo National Forest wildlife biologists. Initial surveys of bats identified many species of special concern and potential threats to their populations.

Recommendations:

1. Consider monitoring species sensitive to systemic stressors in order to determine if they are declining in abundance in and around the monument.

2. Monitor bat species to determine any trends in species diversity and population abundances as well as important habitats within the monument.

3. Evaluate habitat availability and monitor detections and abundances of species that are predicted to be most affected by a regionally shifting climate (e.g. alpine chipmunk, American pika, and Belding's ground squirrel).

4. Consider repeating the 2003 comprehensive non-volant mammal survey in the monument in the future to document any changes.

5. Cooperate with the California Department of Fish and Game to monitor mule deer population trends in the area and to determine if any research related to this species is warranted.

Amphibians

There have been no surveys in the monument that have specifically targeted amphibians. In addition, the presence of introduced trout may have locally extirpated one or more species and their continued presence could also prevent the reintroduction of these species back into the monument if it is determined that habitat is available.

Recommendations:

1. Survey for amphibians and potential habitat within and around the monument. In particular, Yosemite toad and Sierra Nevada yellow-legged frogs should be targeted.

2. Determine if levels of pollutants in surface waters are high enough to negatively impact amphibians.

3. Consider investigations to determine if introduced trout are impacting the Pacific tree frog.

Reptiles

Other than knowing there are species of reptiles present, nothing is known of their status and distribution in the monument or how they are being affected by local, regional, or global stressors. Research from outside the region suggests reptiles could be responding negatively to a warming climate.

Recommendations:

1. Determine status and distribution of reptilian species in the monument.

Macro-invertebrates

These animals have only been surveyed in two meadows and within benthic riverine habitats. The status and trends of these species in all other parts of the monument is unknown. Currently there is no reason to believe this community is threatened.

Recommendations:

1. Expand surveys to other wetland and upland sites to better understand taxonomic diversity throughout the monument.
2. Expand meadow monitoring to include the impacts of social trailing on the abundance and diversity of macro-invertebrates.

5.1.3 Landscapes

Soundscapes

Additional monitoring to develop current sound baselines for the monument is needed. The recent data collection was a great start to establishing current noise levels. An expansion of commercial flights servicing the Mammoth-Yosemite airport in Mammoth Lakes is cause for concern. Future monitoring of the potential impacts of this source of noise would be important to begin to establish links to resource degradation.

Data recently collected identified some major degradations of the natural soundscape. More data collection would be wise to more fully understand the spatial and temporal nature of natural and unnatural sounds heard in the monument and to monitor the potential increase in overflight noises if expanded air service to Mammoth-Yosemite airport continues.

Recommendations:

1. Consider establishing a protocol to efficiently monitor natural and human generated sounds in the monument to build on baseline data collected in 2005 and 2006. This would be important to establish if air overflights or other noises are trending up or down.

Nightsky

There has been no formal monitoring to develop baseline nightsky indicators in the monument and to assess the potential impact of development in nearby Mammoth Lakes and resort area. Due to the isolation of DEPO, no significant degradation of nightsky from local sources is expected. However, if this resource is an important component of the physical resources of the monument, then some monitoring should occur to develop a current profile.

Recommendations:

1. If nightskies are an important resource to the monument, then consult with nightsky specialists on how to establish nighttime light regimes at various places throughout the monument.

Fire Regime

The impacts of the 1992 Rainbow fire are still evident. Continuing to monitor tree recruitment and mortality, species composition, and vegetation cover is important to understanding the effects of the fire and an exacerbating warming climate. Since wildland fire management is currently not a management option with the boundaries of the monument, the use of prescribed fire or silvicultural techniques would be needed to restore the forests to a more natural state.

Recommendations:

1. Continue to support and consider expanding post-fire forest monitoring to cover more habitats and spatial variability.
2. Using the existing Fire and Fuels Management Plan as a guide, consult with NPS and USDA Forest Service fire ecologists to determine if prescribed fire and/or mechanical thinning would be useful tools to use in parts of the monument.

Landscape Dynamics

The SIEN Inventory and Monitoring Program had explored implementing a landscape dynamics protocol that would monitor the dynamics of vegetation cover throughout DEPO into the foreseeable future. However, at this time, there is no plan to implement the protocol. The national I&M Program may also initiate landscape monitoring standards. Using remote sensing to monitor the landscape context and longer-term changes would be an efficient way to capture large-scale changes in vegetation and land cover and monitor post-disturbance recovery throughout the monument and around it.

Recommendations:

1. Support research that uses remote sensing data to monitor landscape changes and evaluate the degree of spatial and temporal changes in the region around the monument.

Literature Cited

Aber, J. D. 1992. Nitrogen cycling and nitrogen saturation in temperate forest ecosystems. *Tree* 7**:** 220–224.

Abraham, S. A. 1983. The effects of a Sierran forest fire on bird habitat usage. California State University, Hayward, CA

Adams, R. A. 2009. The dark side of climate change: warmer and drier weather patterns significantly curtail reproductive efforts for western bats. *Integrative and Comparative Biology* 49 (Suppl 1).

Aerial Information Systems. 2007. Vegetation spatial database coverage for the Yosemite National Park Vegetation Mapping Project: Yose_1997veg_final_poly [vector digital data]. National Park Service.

Agee, J. K., R. H. Wakimoto & H. H. Biswell. 1978. Fire and fuel dynamics of Sierra Nevada conifers. *Forest Ecology and Management* 1**:** 255-265.

Allen, E. B., P. E. Padgett, A. Bytnerowicz & R. Minnich. 1998. Nitrogen deposition effects on coastal sage vegetation of southern California. In *International Symposium on Air Pollution and Climate Change Effects on Forest Ecosystems,* A. Bytnerowicz, M. J. Arbaugh & S. L. Schilling, (eds.). pp. 131-139. Pacific Southwest Research Station, USDA Forest Service, Riverside, California. General Technical Report PSW-GTR-166.

Allen-Diaz, B., R. Barrett, W. Frost, L. Huntsinger & K. Tate. 1999. Sierra Nevada Ecosystems in the Presence of Livestock. University of California, Berkeley.

Alpert, P., E. Bone & C. Holzapfel. 2000. Invasiveness, invasibility and the role of environmental stress of the spread of non-native plants. *Perspectives in Plant Ecology, Evolution and Systematics* 3/1**:** 52-66.

Altman, B. & R. Sallabanks. 2000. Olive-sided Flycatcher (*Contopus cooperi*). In *The Birds of North America,* A. Poole, and F. Gill (eds), (ed.) pp. The Birds of North America, Inc., Philadelphia, PA.

Alverson, W. S. & D. M. Waller. 1997. Deer populations and the widespread failure of hemlock regeneration in northern forests. In *The Science of Overabundance: deer ecology and population management,* W. J. McShea, and H.B. Underwood (eds.), pp. 280-297. Smithsonian Institution Press, Washington, DC.

Anderson, M. K. 2005. *Tending the Wild: Native American knowledge and the management of California's natural resources,* University of California Press, Berkeley.

Anderson, M. K. & M. J. Moratto. 1996. Native American land-use practices and ecological impacts. University of California, Centers for Water and Wildland Resources, Davis.

Anderson, R. S. 1990. Holocene forest development and paleoclimates within the central Sierra Nevada, California. *Journal of Ecology* 78(2)**:** 470-489.

Anderson, R. S. 1994. Paleohistory of a giant sequoia grove: The record from Log Meadow, Sequoia National Park. In *Proceedings of the Symposium on Giant Sequoias: Their place in the ecosystem and society*, P. S. Aune, (ed.). pp. 49-55. USDA Forest Service Gen. Tech. Rep. PSW-151.

Anderson, R. S. & S. J. Smith. 1997. The sedimentary record of fire in montane meadows, Sierra Nevada, California, USA: A preliminary assessment. In *Sediment Records of Biomass Burning and Global Change,* J. S. Clark, H. Cachier, J. G. Goldammer & B. Stocks, (eds.). pp. 313-328. Springer Verlag, Berlin, Heidelberg, Germany.

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* 71(3)**:** 355-366.

Andrews, E. D. 2012. Hydrology of the Sierra Nevada Network national parks: Status and trends. Natural Resource Report NPS/SIEN/NRR—2012/500. National Park Service, Fort Collins, Colorado.

Andrews, K. M., J. W. Gibbons & D. M. Jochimsen. 2008. Ecological effects of roads on amphibians and reptiles: a literature review. *Herpetological Conservation* 3**:** 121-143.

Arnett, M. & S. Haultain. 2005. Vascular plants of Devils Postpile National Monument, Madera County, California. National Park Service, Three Rivers, CA.

Askins, R. A., J. F. Lynch & R. S. Greenberg. 1990. Population declines in migratory birds in eastern North America. *Current Ornithology* 7(1)**:** 57.

Aston, L. S. & J. Seiber. 1997. Fate of summertime airborne organophosphate pesticide residues in the Sierra Nevada mountains. *Journal of Environmental Quality* 26**:** 1483-1492.

Aubry, K., K. McKelvey & J. Copeland. 2007. Distribution and broadscale habitat relations of the wolverine in the contiguous United States. *Journal of Wildlife Management* 71(7)**:** 2147-2158.

Audubon. 2007. Audubon's WatchList 2007 in taxonomic order by geographic region: Red species list continental U.S. and Alaska. http://web1.audubon.org/science/species/watchlist/broswewatchlist.php (last accessed September 29, 2009).

Bailey, R. A. 1989. Geologic map of Long Valley caldera, Mono-Inyo Craters volcanic chain, and vicinity, eastern California. Miscellaneous Investigations Series Map I-1933, Scale 1:62,500, 11 pp. and 2 oversize sheets. U.S. Geological Survey.

Balmat, J. & D. K. Scott. 2010. Weather Data Inventory Devils Postpile National Monument. National Park Service, Fort Collins, CO. Natural Resources Report NPS/SIEN/NRDS--2010/113.

Barbour, R. W. & W. H. Davis. 1969. *Bats of America*, University of Kentucky Press, Lexington, KY.

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa & A. A. Mirin. 2008. Human-induced changes in the hydrology of the western United States. *Science* 319(5866)**:** 1080.

Baron, J. S., H. M. Rueth, A. M. Wolfe, K. R. Nydick, E. J. Allstott, J. T. Minear & B. Moraska. 2000. Ecosystem responses to nitrogen deposition in the Colorado Front Range. *Ecosystems* 3(4)**:** 352-368.

Barrett, G. W., G. M. Van Dyne & E. P. Odum. 1976. Stress Ecology. *Bio Science* 26**:** 192-194.

Barrett, S. W., T. W. Swetnam & W. L. Baker. 2005. Indian Fire Use: Deflating the Legend. *Fire Management Today* 65(3)**:** 31-33.

Basagic, H. J., IV. 2008. Quantifying twentieth century glacier change in the Sierra Nevada, California. MS Thesis. Portland State University, Portland, OR.

Bateman, P. C. 1992. Plutonism in the central part of the Sierra Nevada batholith, California. U.S. Geological Survey Paper 1483.

Bateman, P. C., L. D. Clark, N. K. Huber, J. G. Moore & C. D. Rinehart. 1963. The Sierra Nevada batholith: A synthesis of recent work across the central part.

Battles, J. J., T. Robards, A. Das, K. Waring, J. K. Gilless, G. Biging & F. Schurr. 2008. Climate change impacts on forest growth and tree mortality: a data-driven modeling study in the mixed-conifer forest of the Sierra Nevada, California. *Climatic Change* 87(Supplement 1)**:** 193-213.

Bayfield, N. G. 1979. Recovery of four montane heath communities on Cairngorm, Scotland, from disturbance by trampling. *Biological Conservation* 15(165-179).

Beckmann, J. P. & J. Berger. 2004. Rapid ecological and behavioural changes in carnivores: the responses of black bears (*Ursus americanus*) to altered food. *Journal of Zoology (London)* 261(02)**:** 207-212.

Beckmann, J. P. & C. W. Lackey. 2008. Carnivores, urban landscapes, and longitudinal studies: a case history of black bears. *Human-Wildlife Conflicts* 2(2)**:** 168-174.

Belisle, M., A. Desrochers & M.-J. Fortin. 2001. Influence of forest cover on the movements of forest birds: a homing experiment. *Ecology* 82(7)**:** 1893-1904.

Berg, N. 2010. Water Quality Review: Sierra Nevada 2009 Lake Monitoring.

Berger, L., R. Speare, P. Daszak, D. E. Green, A. A. Cunningham, C. L. Goggin, R. Slocombe, M. A. Ragan, A. D. Hyatt, K. R. McDonald, H. B. Hines, K. R. Lips, G. Marantelli & H. Parkes. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. *Proceedings of the National Academy of Sciences of the United States of America* 95(15)**:** 9031-9036.

Beschta, R. L. 2005. Reduced Cottonwood Recruitment Following Extirpation of Wolves in Yellowstone's Northern Range. *Ecology* 86(2)**:** 391-403.

Best, L. B., T. M. Bergin & K. E. Freemark. 2001. Influence of landscape composition on bird use of rowcrop fields. *The Journal of Wildlife Management* 65(3)**:** 442-449.

Biswell, H. H. 1961. The big trees and fire. *National Parks Magazine* 35**:** 11-14.

Bond, M. L., D. Lee, E., R. B. Siegel & J. P. Ward, Jr. 2009. Habitat use and selection by California Spotted Owls in a postfire landscape. *Journal of Wildlife Management* 73(7)**:** 1116-1124.

Bonfils, C., B. D. Santer, D. W. Pierce, H. G. Hidalgo, G. Bala, T. Das, T. P. Barnett, D. R. Cayan, C. Doutriaux & A. W. Wood. 2008. Detection and attribution of temperature changes in the mountainous western United States. *Journal of Climate* 21**:** 6404-6424.

Bonnicksen, T. M. & E. C. Stone. 1978. An analysis of vegetation management to restore the structure and function of pre-settlement giant sequoia-mixed conifer forest mosaics. Sequoia and Kings Canyon National Parks, CA.

Bonnicksen, T. M. & E. C. Stone. 1982. Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach. *Ecology* 63(4)**:** 1134-1148.

Both, C., S. Bouwhuis, C. M. Lessells & M. E. Visser. 2006. Climate change and population declines in a long-distance migratory bird. *Nature* 441(7089)**:** 81-83.

Boughter, D. & T. Ferrebee. 2003. California Exotic Plant Management Team report of work completed at Devils Postpile National Monument: July 16-23, 2003. California Exotic Plant Management Team.

Boughter, D. & B. Simpson. 2006. Report of work completed at Devils Postpile National Monument, July 26 - August 1, 2006. California Exotic Plant Management Team.

Boyles, J. G. & D. P. Aubrey. 2006. Managing forests with prescribed fire: implications for a cavity-dwelling bat species. *Forest Ecology and Management* 222(1-3)**:** 108-115.

Bradford, D. F. 1989. Allotropic distribution of native frogs and introduced fishes in high Sierra Nevada lakes of California: Implication of the negative effect of fish introductions. *Copeia* 3**:** 775-778.

Bradford, D. F., S. D. Cooper, T. M. Jenkins, Jr., K. Kratz, O. Sarnelle & A. D. Brown. 1998. Influences of natural acidity and introduced fish on faunal assemblages in California alpine lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 55(11)**:** 2478-2491.

Bradford, D. F., M. S. Gordon, D. F. Johnson, R. D. Andrews & W. B. Jennings. 1994. Acidic deposition as an unlikely cause for amphibian population declines in the Sierra Nevada, California. *Biological Conservation* 69(2)**:** 155-161.

Bradford, D. F., F. Tabatabai & D. M. Graber. 1993. Isolation of remaining populations of the native frog, *Rana muscosa*, by introduced fishes in Sequoia and Kings Canyon National Parks, California. *Conservation Biology* 7(4)**:** 882-888.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant & D. Pyke. 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54(7)**:** 677-688.

Brown, P. E. & R. D. Berry. 2007. Foraging habitat and the large home range of Allen's big-eared bat (*Idionycteris phyllotis*) in the Arizona desert by radiotelemetry. *Bat Research News* 48(4)**:** 187-188.

Bruna, E. M., I. J. Fiske & M. D. Trager. 2009. Habitat fragmentation and plant populations: is what we know demographically irrelevant? *Journal of Vegetation Science* 20(3)**:** 569-576.

Brunelle, A. R. & R. S. Anderson. 2003. Sedimentary charcoal as an indicator of late-Holocene drought in the Sierra Nevada, California, and its relevance to the future. *The Holocene* 13(1)**:** 21-28.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers & L. Thomas. 2001. *Introduction to distance sampling estimating abundance of biological populations*. Oxford University Press, Oxord, UK.

Bulaon, B. M. & M. MacKenzie. 2008. Trip Report. An evaluation of recent tree mortality and current stand conditions at Devils Postpile National Monument. US Forest Service.

Burak, S. 2010. Geochemical Composition of Springs and Surface Water - Devils Postpile National Monument.

Burden, R. & P. Randerson. 1972. Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. *Journal of Applied Ecology* 9(2)**:** 439-457.

Buskirk, S. W. & W. J. Zielinski. 2003. Small and mid-sized carnivores. In *Mammalian community dynamics: Management and conservation in the coniferous forests of western North America.* C. J. Zabel & R. G. Anthony (eds.). pp. 207-249. Cambridge University Press, Cambridge, UK.

Bytnerowicz, A., M. Arbaugh & P. Padgett. 2004. Evaluation of ozone and HNO_3 vapor distribution and ozone effects on conifer forests in the Lake Tahoe Basin and eastern Sierra Nevada. USDA Forest Service, Pacific Southwest Research Station, Riverside, CA. Contract No. 01-334 Final Report April 2004.

Bytnerowicz, A., J. D. Burley & J. D. Ray. 2010. Air quality at Devils Postpile National Monument during the 2007 and 2008 summer seasons. Report to Devils Postpile National Monument. USDA Forest Service, Pacific Southwest Research Station, Riverside, CA

Bytnerowicz, A., J. J. Carroll, B. K. Takemoto, P. R. Miller, M. E. Fenn & R. C. Musselman. 2000. Distribution and transport of air pollutants to vulnerable California ecosystems. In *Integrated Assessment of Ecosystem Health*, K. Scow, G. E. Fogg, D. E. Hinton & M. L. Johnson, (eds.). pp. 93-118. Ann Arbor Press, Chelsea MI.

Bytnerowicz, A. & M. E. Fenn. 1996. Nitrogen deposition in California forests: a review. *Environmental Pollution* 92(2)**:** 127-146.

Bytnerowicz, A. & N. E. Grulke. 1992. Physiological effects of air pollutants on western trees. In *The Response of Western Forests to Air Pollution*. D. Binkley, R. Olson & M. Bohm (eds.). pp. 183-233. Springer-Verlag.

Bytnerowicz, A., P. R. Miller, D. M. Olszyk, P. J. Dawson & C. A. Fox. 1987. Gaseous and particulate air pollution in the San Gabriel Mountains of southern California. *Atmospheric Environment* 21(8)**:** 1805-1814.

Bytnerowicz, A., D. M. Olszyk, S. Huttunen & B. Takemoto. 1989. Effects of photochemical smog on growth, injury, and gas exchange of pine seedlings. *Canadian Journal of Botany* 67**:** 2175-2181.

Bytnerowicz, A., M. Tausz, R. Alonso, D. Jones, R. Johnson & N. Grulke. 2002. Summer-time distribution of air pollutants in Sequoia National Park, California. *Environmental Pollution* 118**:** 187-203.

Cahill, T. A. 1989. Monitoring of atmospheric particles and ozone in Sequoia National Park: 1985–1987. Air Quality Group, Crocker Nuclear Laboratory, Davis, CA.

Cahill, T. A., J. J. Carroll, D. H. Campbell & T. E. Gill. 1996. Chapter 48: Air Quality. In *Sierra Nevada Ecosystem Project: Final report to Congress, Vol. II, Assessments and Scientific Basis for Management Options.* pp. 1227-1260. University of California, Centers for Water and Wildland Resources, Davis, CA. 2.

California Department of Finance. 2010. Population projections. http://www.dof.ca.gov/research/demographic/reports/view.php#objCollapsiblePanelProjectionsAnchor (last accessed January, 2010).

California Department of Water Resources. 2009. California Water Plan Update 2009, San Joaquin River Hydrologic Region.

California Exotic Plant Management Team. 2005. Work summary and overall recommendations for Devils Postpile National Park, July 13 - 20, 2005. California Exotic Plant Management Team.

California Invasive Plant Council (Cal-IPC). 2006. Inventory List of Invasive Non-native Plants that threaten Wildlands in California. California Invasive Plant Council online database.

Campbell, L. A. 2004. Distribution and habitat associations of mammalian carnivores in the central and southern Sierra Nevada. PhD Dissertation. University of California, Davis, CA.

Caprio, A. C., C. Conover, M. Keifer & P. Lineback. 2002. Fire management and GIS: A framework for identifying and prioritizing fire planning needs. In: *Proceedings of the symposium: Fire in California ecosystems: Integrating ecology, prevention and management*. N. G. Sugihara & M. E. Morales (eds.). pp. 102-113. Assoc. for Fire Ecology Misc. Pub., San Diego, CA. San Diego, CA, Nov.17-20, 1997.

Caprio, A. C. & D. M. Graber. 2000. Returning fire to the mountains: Can we successfully restore the ecological role of pre-Euroamerican fire regimes to the Sierra Nevada? In: *Proceedings: Wilderness Science in a Time of Change. Wilderness Ecosystems, Threats, and Management*. D. N. Cole, S. F. McCool, W. T. Borrie & J. O'Loughlin (eds.). pp. 233-241. Missoula, MT and Ogden, UT, May 23-27, 1999.

Caprio, A. C., M. Keifer & K. Webster. 2006. Long-term effects of the 1992 Rainbow Fire, Devils Postpile National Monument, California. In *AFE 3rd International Fire Ecology Congress*, pp. 6 pp. AFE, San Diego, CA.

Caprio, A. C. & P. Lineback. 2002. Pre-twentieth century fire history of Sequoia and Kings Canyon National Parks: A review and evaluation of our knowledge. In *Proceedings of the Symposium: Fire in California Ecosystems: Integrating Ecology, Prevention and Management.* N. G. Sugihara, M. E. Morales & T. J. Morales (eds.). pp. 180-199. Assoc. for Fire Ecology Misc. Pub., San Diego, CA.

Caprio, A. C. & K. Webster. 2006a. Fire effects monitoring on the 1992 Rainbow Fire, Devils Postpile National Monument: Vegetation response ten years postfire. Division of Natural Resources, Sequoia and Kings National Parks, Three Rivers, CA.

Caprio, A. C. & K. Webster. 2006b. National Park Service fire ecology annual report Sequoia and Kings Canyon National Parks and Devils Postpile National Monument, calendar year 2005. Sequoia and Kings Canyon National Park.

Carlisle, D. & C. Hawkins. 1998. Relationships between invertebrate assemblage structure, 2 trout species, and habitat structure in Utah mountain lakes. *Journal of the North American Benthological Society* 17(3)**:** 286-300.

Cassel, E. J., S. A. Graham & C. P. Chamberlain. 2009. Cenozoic tectonic and topographic evolution of the northern Sierra Nevada, California, through stable isotope paleoaltimetry in volcanic glass. *Geology* 37(6)**:** 547-550.

Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree & A. Gershunov. 2010. Future dryness in the southwest US and the hydrology of the early 21st century drought. *Proceedings of the National Academy of Sciences* 107(50)**:** 21271.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio & D. H. Peterson. 2001. Changes in the onset of spring in the western United States. *Bulletin of the American Meteorological Society* 82**:** 399-415.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree & K. Hayhoe. 2007. Climate change scenarios for the California region. *Climatic Change* 87(Supplement 1)**:** 21-42.

Chamberlin, L. 2009. Friends of the Inyo water quality report Upper San Joaquin watershed assessment. Friends of the Inyo, Bishop, CA.

Chambers, C. L., M. J. Herder, W. M. Masters & D. Vleck. 2006. Movement areas for spotted bats (*Euderma maculatum*), northern Arizona. *Bat Research News* 47**:** 94.

Chang, C.-R. 1996. Chapter 39 Ecosystem responses to fire and variations in fire regimes. In *Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options*, Centers for Water and Wildlands Resources, (ed.) pp. 1071-1099. University of California, Centers for Water and Wildlands Resources, Davis, CA.

Chappell, H. G., J. F. Ainsworth, R. A. D. Cameron & M. Redfern. 1971. The Effect of Trampling on a Chalk Grassland Ecosystem. *Journal of Applied Ecology* 8(3)**:** 869-882.

Cisneros, R., A. Byternowicz, D. Schweizer, S. Zhong, S. Traina, T. Procter & D. Bennett. 2010. Ozone, nitric oxide and ammonia air pollution unhealthy for people and ecosystems in the southern Sierra Nevada, California. *Environmental Pollution* 158: 3261-3271.

Clark, J. S. 1990. Fire and Climate Change During the Last 750 Yr in Northwestern Minnesota. *Ecological Monographs* 60(2)**:** 135-159.

Clow, D. W. & K. R. Collum. 1986. Geology of the volcanic rocks at Devils Postpile, California. *Journal of Natural Sciences* 1**:** 18-21.

Clow, D. W., L. Nanus & B. Hugget. 2010. Use of regression-based models to estimate sensitivity of aquatic resources to atmospheric deposition in Yosemite National Park, USA. *Water Resources Research* 46(W09529).

Cole, D. N. 1995. Experimental Trampling of Vegetation. I. Relationship Between Trampling Intensity and Vegetation Response. *The Journal of Applied Ecology* 32(1)**:** 203-214.

Cole, D. N. & C. A. Monz. 2002. Trampling Disturbance of High-Elevation Vegetation, Wind River Mountains, Wyoming, U.S.A. *Arctic, Antarctic, and Alpine Research* 34(4)**:** 365-376.

Collins, J. N., E. D. Stein, M. Sutula, R. Clark, A. E. Fetscher, L. Grenier, C. Grosso & A. Wiskind. 2006. California rapid assessment method (CRAM) for wetlands and riparian areas. Version 4. 136.

Conservation International. 2010. Biodiversity -- California Floristic Province. http://www.conservation.org/where/priority_areas/hotspots/north_central_america/California-Floristic-Province/Pages/default.aspx (last accessed 7/23/2010).

Cowardin, L. M., V. Carter, F. C. Golet & E. T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Cowie, I. D. & P. A. Werner. 1993. Alien plant species invasive in Kakadu National Park, tropical northern Australia. *Biological Conservation* 63**:** 127-135.

Cox, M. & M. Keifer. 2002. Fire effects monitoring at Devils Postpile National Monument: Post-fire response five years following the Rainbow Fire.

Cox, P., A. Delao, A. Komorniczak & R. Weller. 2009. The California almanac of emissions and air quality - 2009 Edition. California Air Resources Board, Planning and Technical Support Division, Sacramento, CA.

Crawford, J. A., C. H. A. Wahren, S. Kyle & W. H. Moir. 2001. Response of exotic plant species to fires in *Pinus ponderosa* forests in northern Arizona. *Journal of Vegetation Science* 12**:** 261-268.

Crick, H. Q. P. 2004. The impact of climate change on birds. *Ibis* 146(s 1)**:** 48-56.

Crist, P. J., B. H. Thompson & J. Prior-Magee. 1996. Land management status categorization for Gap Analysis: A potential enhancement. *Gap analysis bulletin* 5**:** 20-22.

Crozier, L. 2003. Winter Warming Facilitates Range Expansion: Cold Tolerance of the Butterfly *Atalopedes campestris*. *Oecologia* 135(4)**:** 8pp.

Cunha, S. 1992. Invasion of Tuolumne Meadows by *Pinus murrayana*, Yosemite National Park, California. University of California, Davis. 45.

Dale, V., L. Joyce, S. McNulty, R. Neilson, M. Ayres, M. Flannigan, P. Hanson, L. Irland, A. Lugo & C. Peterson. 2001. Climate change and forest disturbances. *Bioscience* 51(9)**:** 723-734.

D'Antonio, C. M., E. L. Berlow & K. L. Haubensak. 2004. Invasive Exotic Plant Species in Sierra Nevada Ecosystems. USDA Forest Service. Gen. Tech. Rep. PSW-GTR-193.

D'Antonio, C. M. & P. M. Vitousek. 1992. Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Change. *Annual Review of Ecology and Systematics* 23(1)**:** 63-87.

Das, T., H. G. Hidalgo, D. W. Pierce, T. P. Barnett, M. D. Dettinger, D. R. Cayan, C. Bonfils, G. Bala & A. Mirin. 2009. Structure and Detectability of Trends in Hydrological Measures over the Western United States. *Journal of Hydrometeorology* 10(4)**:** 871-892.

Daszak, P., L. Berger, A. A. Cunningham, A. D. Hyatt, D. E. Green & R. Speare. 1999. Emerging infectious diseases and amphibian population declines. *Emerging Infectious Diseases* 5(6)**:** 735-748.

Datta, S., L. Hansen, L. McConnell, J. Baker, J. LeNoir & J. N. Seiber. 1998. Pesticides and PCB contaminants in fish and tadpoles from the Kaweah River basin, California. *Bulletin of Environmental Contamination and Toxicology* 60(6)**:** 829-836.

Davey, C. A., K. T. Redmond & D. B. Simeral. 2007. Weather and climate inventory National Park Service Sierra Nevada network. Western Regional Climate Center, Desert Research Institute, Reno, NV. Natural Resources Technical Report NPS/SIEN/NRTR--2007/042.

Davidson, C., H. B. Shaffer & M. R. Jennings. 2001. Declines of the California red-legged frog: climate, UV-B, habitat, and pesticides hypothesis. *Ecological Applications* 11(2)**:** 464-479.

Davis, F. W. & D. M. Stoms. 1996. Chapter 23 Sierran Vegetation: a gap analysis. In *Sierra Nevada Ecosystem Project: Final report to Congress, Vol. II, Assessments and Scientific Basis for Management Options*. University California, Centers for Water and Wildlands Resources, Davis, CA.

Davis, O. K. & M. J. Moratto. 1988. Evidence for a warm dry early Holocene in the western Sierra Nevada of California: Pollen and plant macrofossil analysis of Dinkey and Exchequer Meadows. *Madroño* 35**:** 132-149.

DeFerrari, C. M. & R. J. Naiman. 1994. A multi-scale assessment of the occurrence of exotic plants on the Olympic Peninsula, Washington. *Journal of Vegetation Science* 5**:** 247-258.

Denn, M. & D. Shorrock. 2009. Devils Postpile National Monument Wetland Inventory and Conditions Assessment. U.S. National Park Service, Water Resources Division, Washington, DC.

Derlet, R. W. & J. R. Carlson. 2006. Coliform bacteria in Sierra Nevada wilderness lakes and streams: What is the impact of backpackers, pack animals, and cattle? *Wilderness & Environmental Medicine* 17(1)**:** 15-20.

Derlet, R. W., K. A. Ger, J. R. Richards & J. R. Carlson. 2008. Risk factors for coliform bacteria in backcountry lakes and streams in the Sierra Nevada mountains: A 5-year study. *Wilderness & Environmental Medicine* 19(2)**:** 82-90.

DeSante, D. F. 2005. The status, distribution, abundance, population trends, demographics, and risks of the landbird avifauna of the Sierra Nevada mountains. The Institute for Bird Populations, Pt. Reyes Station, CA.

DeSante, D. F., P. Pyle & D. R. Kaschube. 2005. The Monitoring Avian Productivity and Survivorship (MAPS) program in Sequoia and Kings Canyon and Yosemite National Parks and Devils Postpile National Monument: A comparison between time periods and locations. The Institute for Bird Populations, Point Reyes Station, CA.

Dettinger, M. 2005a. Changes in Streamflow Timing in the Western United States in Recent Decades. National Streamflow Information Program, U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, California.

Dettinger, M. D. 2005b. From climate-change spaghetti to climate-change distributions for 21st century California. *San Francisco Estuary and Watershed Science* 3(1)**:** 14.

Dettinger, M. D. & D. R. Cayan. 1995. Large-scale atmospheric forcing of recent trends toward early snowmelt in California. *Journal of Climate* 8**:** 606-623.

Dettinger, M. D., D. R. Cayan, N. Knowles, A. Westerling & M. K. Tyree. 2004a. Recent Projections of 21st-Century Climate Change and Watershed Responses in the Sierra Nevada. In *Sierra Nevada Science Symposium*, pp. 43-46. U.S. Forest Service, Kings Beach, California. PSW-GTR-193.2004.

Dettinger, M. D., D. R. Cayan, M. Meyer & A. E. Jeton. 2004b. Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099. *Climatic Change* 62(1-3)**:** 283-317.

Dettinger, M., K. Redmond & D. Cayan. 2005. Winter Orographic-Precipitation Ratios in the Sierra Nevada - Large-Scale Atmospheric Circulations and Hydrologic Consequences. *Journal of Hydrometeorology* 5**:** 1102-1116.

Didham, R. K., J. Ghazoul, N. E. Stork & A. J. Davis. 1996. Insects in fragmented forests: a functional approach. *Trends in Ecology and Evolution* 11(6)**:** 255-260.

DiTomaso, J. M., M. L. Brooks, E. B. Allen, R. Miniich, P. M. Rice & G. B. Kyser. 2006. Control of invasive weeds with prescribed burning. *Weed Technology* 20(2)**:** 535-548.

DiTomaso, J. M., K. L. Heise, G. B. Kyser, A. M. Merenlender & R. J. Keiffer. 2001. Carefully timed burning can control barb goatgrass. *California Agriculture* 55(6)**:** 47-53.

DiTomaso, J. M., G. B. Kyser & M. S. Hastings. 1999. Prescribed burning for control of yellow starthistle (*Centaurea solstitialis*) and enhanced native plant diversity. *Weed Science* 47(2)**:** 233-242.

Dolanc, C. R. & J. H. Thorne. 2010. Widespread shifts in stand structure of subalpine conifers of the central Sierra Nevada over the last 75 years. In *Mountain Climate Research Conference*, pp. USDA Forest Service, Blue River, OR.

Donovan, T. M. & C. H. Flather. 2002. Relationships among North American songbird trends, habitat fragmentation, and landscape occupancy. *Ecological Applications* 12(2)**:** 364-374.

Dozsa-Farkas, K. 1987. Effect of human treading on enchytraeid fauna of hornbeam-oak forests in Hungary. *Biology and Fertility of Soils* 3**:** 91-93.

Drake, J. A., H. A. Mooney, F. d. Castri, R. H. Groves, F. J. Kruger, M. Rejmanek & M. Williamson. 1989. *Biological Invasions: a global perspective*. Wiley & Sons, Chichester, UK.

Earman, S., A. R. Campbell, F. M. Phillips & B. D. Newman. 2006. Isotopic exchange between snow and atmospheric water vapor: Estimation of the snowmelt component of groundwater recharge in the southwestern United States. *Journal of Geophysical Research* 111(D9)**:** D09302.

Eckrich, C. E. & J. G. Holmquist. 2000. Trampling in a Seagrass Assemblage: Direct Effects, Response of Associated Fauna, and the Role of Substrate Characteristics. *Marine Ecology Progress Series* 201**:** 199-209.

Edwards, L. M. & K. T. Redmond. 2011. –Climate assessment for the Sierra Nevada Network Parks. Natural Resource Report NPS/2011/NRR—2011/482. National Park Service, Fort Collins, CO.

Edwards, T., C. Homer & S. Bassett. 1994. Land management categorization: A users' guide. *A handbook for gap analysis, version* 1.

Eigenbrod, F., S. J. Hecnar & L. Fahrig. 2008. Accessible habitat: an improved measure of the effects of habitat loss and roads on wildlife populations. *Landscape Ecology* 23(2)**:** 159-168.

Elton, C. S. 1958. *The Ecology of Invasions by Animals and Plants*, Methuen & Co. Ltd., London.

Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. US Army Corps of Engineers, Vicksburg, MS. Y-87-1.

Ernhardt, A. & J. A. Thomas. 1991. Lepidoptera as indictors of change in the semi-natural grasslands of lowland and upland Europe. In *The conservation of insects and their habitats. 15th symposium of the Royal Entomological Society of London*, N. M. Collins, and J.A. Thomas, (ed.) pp. 213-236. Academic Press, London, UK.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics* 34**:** 487-515.

Fahrig, L., J. Pedlar, S. Pope, P. Taylor & J. Wegner. 1995. Effect of road traffic on amphibian density. *Biological Conservation* 73(3)**:** 177-182.

Fancy, S., J. Gross & S. Carter. 2009. Monitoring the condition of natural resources in US national parks. *Environmental Monitoring and Assessment* 151(1)**:** 161-174.

Fellers, G. M., D. F. Bradford, D. Pratt & L. L. Wood. 2007. Demise of repatriated populations of mountain yellow-legged frogs (*Rana muscosa*) in the Sierra Nevada of California. *Herpetological Conservation and Biology* 2(1)**:** 5-21.

Fenn, M. E., E. B. Allen, S. B. Weiss, S. Jovan, L. H. Geiser, G. S. Tonnesen, R. F. Johnson, L. E. Rao, B. S. Gimeno, F. Yuan, T. Meixner & A. Bytnerowicz. 2010. Nitrogen critical loads and management alternatives for N-impacted ecosystems in California. *Journal of Environmental Management* 91(12)**:** 2404-2423.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson & P. Neitlich. 2003a. Ecological effects of nitrogen deposition in the western United States. *Bioscience* 53(4)**:** 404-420.

Fenn, M. E., R. Haeuber, G. S. Tonnesen, J. S. Baron, S. Grossman-Clarke, D. Hope, D. A. Jaffe, S. Copeland, L. Geiser, H. M. Rueth & J. O. Sickman. 2003b. Nitrogen emissions, deposition, and monitoring in the western United States. *Bioscience* 53(4)**:** 391-403.

Fenn, M. E., S. Jovan, F. Yuan, L. Geiser, T. Meixner & B. S. Gimeno. 2008. Empirical and simulated critical loads for nitrogen deposition in California mixed conifer forests. *Environmental Pollution* 155(3)**:** 492-511.

Fenn, M. E., M. A. Poth, J. D. Aber, J. S. Baron, B. T. Bormann, D. W. Johnson, A. D. Lemly, S. G. McNulty, D. F. Ryan & R. Stottlemyer. 1998. Nitrogen excess in North American ecosystems: Predisposing factors, ecosystem responses, and management strategies. *Ecological Applications* 8(3)**:** 706-733.

Fenn, M. E., M. A. Poth, A. Bytnerowicz, J. O. Sickman & B. Takemoto. 2003c. Effects of ozone, nitrogen deposition, and other stressors on montane ecosystems in the Sierra Nevada. In *Ozone Air Pollution in the Sierra Nevada: Distribution and Effects on Forests,* A. e. Bytnerowicz, (ed.) pp. pp. 11-156. Elsevier.

Ferrell, G. T. 1996. Chapter 45, The influence of insect pests and pathogens on Sierra forests. In *Sierra Nevada Ecosystem Project: Final report to Congress, Vol. II, Assessments and Scientific Basis for Management Options.* Pp. 1177-1192. University California, Centers for Water and Wildlands Resources, Davis, CA.

Ferrell, G. T., W. J. Otrosina & C. J. Demars. 1994. Predicting susceptibility of white fir during a drought-associated outbreak of the fir engraver, *Scolytus ventralis*, in California. *Canadian Journal of Forest Research* 24(2)**:** 302-305.

Findlay, C. S. & J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. *Conservation Biology* 11(4)**:** 1000-1009.

Forister, M. L., A. C. McCall, N. J. Sanders, J. A. Fordyce, J. H. Thorne, J. O'Brien, D. P. Waetjen & A. M. Shapiro. 2010. Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity. *Proceedings of the National Academy of Sciences* 107(5)**:** 2088-2092.

Forman, R. T., D. Sperling, J. S. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine & T. C. Winter. 2003. *Road Ecology: Science and Solutions*, Island Press, Washington.

Formichella, C., K. Fristrup, D. Joyce, E. Lynch & E. Pilcher. 2007. Devils Postpile National Monument acoustic monitoring report 2005 & 2006. National Park Service, Natural Sounds Program, Fort Collins, CO.

Fraczek, W., A. Bytnerowicz & M. Arbaugh. 2003. Use of geostatistics to estimate surface ozone patterns. In *Ozone Air Pollution in the Sierra Nevada: Distribution and Effects on Forests.* A. Bytnerowicz, M. Arbaugh & R. Alonso (eds.). pp. 215-247. Elsevier, Oxford, UK. 2.

Frakes, N. O. 2005. A case study of exotic plant invasion into the Rawah Wilderness, Colorado: the role of propagule introduction and survivorship. M.S. Thesis. University of Colorado at Boulder, Boulder, CO.

Franklin, J., W. Moir, G. Douglas & C. Wiberg. 1971. Invasion of subalpine meadows by trees in the Cascade Range, Washington and Oregon. *Arctic and Alpine Research* 3(3)**:** 215-224.

Fritzke, S. L. 1992. Soil Erosion and Vegetation Loss Accelerated by Visitor Use of Paradise Meadows, Mount Rainier National Park. M.S. Thesis. Oregon State University, Corvallis, OR.

Fry, D. M. 1995. Reproductive effects in birds exposed to pesticides and industrial chemicals. *Environmental Health Perspectives* 103(Suppl 7): 165-171.

Furniss, M., S. Flanagan & B. McFadin. 2000. Hydrologically-connected roads: an indicator of the influence of roads on chronic sedimentation, surface water hydrology, and exposure to toxic chemicals. *Stream Notes* July 2000.

Furniss, R. L. & V. M. Carolin. 1977. Western forest insects. USDA Forest Service, Washington, DC. Miscellaneous publications 1339.

Gage, E. A., L. Chow, D. J. Cooper, S. A. Haultain, J. G. Holmquist, J. R. Jones, S. T. McKinney, P. E. Moore, L. S. Mutch, L. A. H. Starcevich & H. Werner. 2009. Wetlands ecological integrity monitoring protocol for Sierra Nevada Network national parks: version 1.4 Draft. National Park Service, Fort Collins, CO. Natural Resource Report NPS/SIEN/NRR--2009/DRAFT.

Gaines, D. 1974. A new look at the nesting riparian avifauna of the Sacramento Valley, California. *Western Birds* 5(3)**:** 61-79.

Gaines, D. 1992. *Birds of Yosemite and the East Slope*. Artemesia Press Books, Lee Vining, CA.

Gallopín, G. C. 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change* 16(3)**:** 293-303.

Garcia, C., S. Gouze & J. Wright. 2001. Assessment of the impacts of transported pollutants on ozone concentrations in California. California Environmental Protection Agency, Air Resources Board, Sacramento, CA.

Gargas, A., M. T. Trest, M. Christensen, T. J. Volk & D. S. Blehert. 2009. *Geomyces destructans* sp. Nov. associated with bat white-nose syndrome. *Mycotaxon* 108**:** 147-154.

Gerlach, J. D., Jr., P. E. Moore, B. Johnson, D. G. Roy, D. M. Whitmarsh, D. M. Lubin, D. M. Graber, S. Haultain, A. Pfaff & J. Keeley. 2003. Alien Plant Species Threat Assessment and Management Prioritization for Sequoia-Kings Canyon and Yosemite National Parks. U.S. Geological Survey, Carson City, Nevada. 02-170.

Gershunov, A., T. P. Barnett & D. R. Cayan. 1999. North Pacific interdecadal oscillation seen as factor in ENSO-related North American climate anomalies. *EOS* 80(3)**:** 25-30.

Gershunov, A., T. P. Barnett, D. R. Cayan, A. Tubbs & L. Goddard. 2000. Predicting ENSO impacts on intraseasonal precipitation statistics in California: the 1997-1998 event. *Journal of Hydrometeorology* 1(6)**:** 201-210.

Gibbons, J. W., D. E. Scott, T. J. Ryan, K. A. Buhlmann, T. D. Tuberville, B. S. Metts, J. L. Greene, T. Mills, Y. Leiden, S. Poppy & C. T. Winne. 2000. The global decline of reptiles, deja vu amphibians. *Bioscience* 50(8)**:** 653-666.

Gibbs, J. P. 2001. Demography versus habitat fragmentation as determinants of genetic variation in wild populations. *Biological Conservation* 100(1)**:** 15-20.

Goldhammer, J. G., M. Statheropoulos & M. Andreae. 2009. Impacts of vegetation fire emissions on the environment, human health, and security: a global perspective. In *Wildland Fires and Air Pollution, Development in Environmental Science 8*, A. Byternowicz, M. Arbaugh, A. Riebau & C. Andersen (eds.). pp. pp. 3-36. Elsevier, Amsterdam.

Graber, D. M. 1996. Chapter 25 Status of terrestrial vertebrates. In *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options*. pp. 709-734. University of California, Centers for Water and Wildland Resources, Davis, CA.

Graham, J. 2009. Devils Postpile National Monument Geologic Resources Inventory Report. National Park Service, Denver, CO. Natural Resources Report NPS/NRPC/GRD/NRR -- 2009/160.

Grinnell, J. & T. I. Storer. 1924. *Animal Life in the Yosemite: An account of the mammals, birds, reptiles, and amphibians in a cross-section of the Sierra Nevada*, University of California Press, Berkeley.

Gruell, G. E. 2001. Fire in Sierra Nevada forests: a photographic interpretation of ecological change since 1849. Mountain Press, Missoula.

Guarin, A. & A. H. Taylor. 2005. Drought triggered tree mortality in mixed conifer forests in Yosemite National Park, California, USA. *Forest Ecology and Management* 218(1-3)**:** 229-244.

Gucinski, H., M. J. Furniss, R. R. Ziemer & M. H. Brookes. 2001. Forest roads: a synthesis of scientific information. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW-GTR-509.

Gurd, D. B., T. D. Nudds & D. H. Rivard. 2001. Conservation of mammals in eastern North American wildlife reserves: how small is too small? *Conservation Biology* 15(5)**:** 1355-1363.

Guthery, F. S., M. C. Green, R. E. Masters, S. J. DeMasso, H. M. Wilson & F. B. Steubing. 2001. Land cover and bobwhite abundance on Oklahoma farms and ranches. *The Journal of Wildlife Management* 65(4)**:** 838-849.

Habib, L., E. M. Bayne & S. Boutin. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. *Journal of Applied Ecology* 44(1)**:** 176-184.

Hageman, K. J., S. L. Simonich, D. H. Campbell, G. R. Wilson & D. H. Landers. 2006. Atmospheric deposition of current-use and historic-use pesticides in snow at national parks in the western United States. *Environmental Science and Technology* 40(10)**:** 3174-3180.

Hagle, S., S. Kegley & S. Williams. 1995. Assessing pathogen and insect succession functions in forest ecosystems. Forest Health Through Silviculture: proceedings of the 1995 National Silviculture Workshop. Mescalero, New Mexico: 117-127.

Halterman, M. D. & S. A. Laymon. 1999. The effects of brown-headed cowbird parasitism on neotropical migrants in Yosemite National Park. Kern River Research Center, Weldon, CA.

Halterman, M. D. & S. A. Laymon. 2000. The effects of brown-headed cowbird parasitism on neotropical migrants in Sequoia and Kings Canyon National Parks. Kern River Research Center, Weldon, CA.

Hamlet, A. F., P. W. Mote, M. P. Clark & D. P. Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the western United States. *Journal of Climate* 18(21)**:** 4545-4561.

Hammitt, W. & D. Cole. 1998. *Wildland recreation: ecology and management*, Wiley,

Hansen, A., R. Knight, J. Marzluff, S. Powell, K. Brown, P. Gude & K. Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. *Ecological Applications* 15(6)**:** 1893-1905.

Hanson, C. T. & M. P. North. 2008. Postfire woodpecker foraging in salvage-logged and unlogged forests of the Sierra Nevada. *The Condor* 110(4)**:** 777-782.

Hargis, C. D., J. A. Bissonette & D. L. Turner. 1999. The influence of forest fragmentation and landscape pattern on American martens. *Journal of Applied Ecology* 36(1)**:** 157-172.

Harvey, H. T., H. S. Shellhammer & R. E. Stecker. 1980. Giant Sequoia Ecology: Fire and Reproduction. USDI NPS, Washington, D.C.

Hastings, B. C., B. K. Gilbert & D. L. Turner. 1981. Black bear behavior and human-relationships in Yosemite National Park. University of California, Davis, CA. CPSU Technical Report Number 2.

Hatch, L., C. Clark, R. Merrick, S. Van Parijs, D. Ponirakis, K. Schwehr, M. Thompson & D. Wiley. 2008. Characterizing the relative contributions of large vessels to total ocean noise fields: a case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. *Environmental Management* 42(5)**:** 735-752.

Hatch, L. T. & K. M. Fristrup. 2009. No barrier at the boundaries: implementing regional frameworks for noise management in protected natural areas. *Marine Ecology Progress Series* 395**:** 223-244.

Hauer, F. R. & C. N. Spencer. 1998. Phosphorus and nitrogen dynamics in streams associated with wildfire: A study of immediate and long-term effects. *International Journal of Wildland Fire* 8**:** 183-198.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan & J. H. Verville. 2004. Emissions pathways, climate change, and impacts on California. *National Academy of Sciences (PNAS)* 101(34)**:** 12422-12427.

Healy, W. M. 1997. Influence of deer on the structure and composition of oak forests in central Massachusetts. In *The Science of Overabundance: deer ecology and population management*. W. J. McShea, and H.B. Underwood (eds.). pp. 249-266. Smithsonian Institution Press, Washington DC.

Heath, S. K. 2005a. Bird Monitoring and Visitor Education at Devils Postpile National Monument: 2005 Progress Report. Point Reyes Bird Observatory, Point Reyes.

Heath, S. K. 2005b. Bird monitoring in montane meadow and riparian habitats of Devils Postpile National Monument: Final report 2002-2004. Point Reyes Bird Observatory, Stinson Beach, CA.

Heath, S. K. 2007. Avian Demography Monitoring and Visitor Education at Devils Postpile National Monument, 2002 - 2006. PRBO Conservation Science, Petaluma, CA. 1552.

Heath, S. K., L. A. Culp & C.A. Howell. 2010. Brood parasitism and nest survival of brown-headed cowbird hosts at high-elevation riparian sites in the eastern Sierra Nevada, California. *Western North American Naturalist* 70(3): 364-376.

Hejl, S. J. 1994. Human induced changes in bird populations in coniferous forests in western North America during the past 100 years. *Studies in Avian Biology* 15**:** 232-246.

Helms, J. A. 1987. Invasion of *Pinus contorta* Var. *murrayana* (Pinaceae) into mountain meadows at Yosemite National Park, California. *Madroño* 34(2)**:** 91-97.

Hickey, E., J. Clayburgh & S. Raborn. 2005. Planning for the Future: a Sierra Nevada land use index. Sierra Nevada Alliance.

Hickman, J. C. 1993. *The Jepson Manual: Higher Plants of California*, University of California Press, Berkeley, CA. 1400 pp.

Hidalgo, H. G., T. Das, M. D. Dettinger, D. R. Cayan, D. W. Pierce, T. P. Barnett, G. Bala, A. Mirin, A. W. Wood, C. Bonfils, B. D. Santer & T. Nozawa. 2009. Detection and attribution of streamflow timing changes to climate change in the western United States. *Journal of Climate* 22**:** 3838-3855.

Hildreth, W. 2011. Senior Scientist, USGS. Menlo Park, CA.

Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. *Great Lakes Entomology* 20(31-39).

Hitch, A. T. & P. L. Leberg. 2007. Breeding distributions of North American bird species moving north as a result of climate change. *Conservation Biology* 21(2)**:** 534-539.

Hobbs, R. J. & L. F. Huenneke. 1992. Disturbance, diversity and invasion: Implications for conservation. *Conservation Biology* 6**:** 324-337.

Hobbs, R. J. & C. J. Yates. 2003. Impacts of ecosystem fragmentation on plant populations: generalizing the idiosyncratic. *Australian Journal of Botany* 51(5)**:** 471-488.

Hodkinson, D. J. & K. Thompson. 1997. Plant dispersal: the role of man. *Journal of Applied Ecology* 34**:** 1484-1496.

Holmquist, J. G. 2004. Trails and meadow fragmentation in Yosemite National Park: effects on invertebrate fauna and patterns of abundance and biodiversity. White Mountain Research Station, Bishop, CA.

Holmquist, J. G. & J. M. Gengenbach. 2004. User-mediated meadow fragmentation in Yosemite National Park: effects on invertebrate fauna.

Holmquist, J. G. & J. M. Schmidt-Gengenbach. 2005a. Inventory of Invertebrate Fauna in Devils Postpile National Monument: final report. White Mountain Research Station, Bishop, CA.

Holmquist, J. G. & J. M. Schmidt-Gengenbach. 2005b. Interim Report: A pilot study and assessment of the efficacy of invertebrates as indicators of meadow change in Sierra Nevada Network Parks. White Mountain Research Institute, University of California.

Holmquist, J. G. & J. M. Schmidt-Gengenbach. 2008. Effects of experimental trampling addition and reduction on vegetation, soils, and invertebrates and assessment of current conditions in Tuolumne Meadows. University of California White Mountain Research Station, Bishop, CA.

Horne, A. & C. Goldman. 1994. Streams and rivers. In *Limnology*, pp. 356-383. McGraw-Hill, New York, NY.

Howat, I. M. & S. Tulaczyk. 2005. Climate sensitivity of spring snowpack in the Sierra Nevada. *Journal of Geophysical Research* 110: Article F04021.

Huber, N. K. 1987. The Geologic Story of Yosemite National Park. U.S. Geological Survey. 1595.

Huber, N. K. & W. W. Eckhardt. 2001. The Story of Devils Postpile: A land of volcanic fire, glacial ice, and an ancient river. The Sequoia Natural History Association, Three Rivers, CA.

Huber, N. K. & C. D. Rinehart. 1965. Geologic map of Devils Postpile Quadrangle, Sierra Nevada, California.

Huenneke, L. F., S. P. Hamburg, R. Koide, H. A. Mooney & P. M. Vitousek. 1990. Effects of soil resources on plant invasion and community structure in Californian [USA] serpentine grassland. *Ecology* 71(2)**:** 478-491.

Humphries, M. M., J. Umbanhowar & K. S. McCann. 2004. Bioenergetic prediction of climate change impacts on northern mammals. *Integrative and Comparative Biology* 44**:** 152-162.

Hunsaker, C., A. Bytnerowicz, J. Auman & R. Cisneros. 2007. Air pollution and watershed research in the central Sierra Nevada of California: Nitrogen and ozone. *The Scientific World Journal* 7(S1)**:** 206-221.

IPCC. 2001a. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Portchester, New York.

IPCC. 2001b. Climate change 2001: The scientific basis. Intergovernmental Panel on Climate Change.

IPCC. 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Intergovernmental Panel on Climate Change, Brussles.

IPCC. 2007b. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, Bangkok, Thailand.

Jennings, M. R. 1996. Chapter 31 Status of Amphibians. In *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options* pp. 921-944. University of California, Davis, Centers for Water and Wildland Resources., Davis, CA.

Johnson, C. 2010. National Park Service, Pacific West Regional office. Seattle, WA.

Johnson, C. E. & C. Palmer. 2010. At the Headwaters of History: Devils Postpile and the Shaping of a Region DRAFT. National Park Service, Pacific West Regional Office, Seattle, WA.

Johnson, D. W., R. B. Susfalk & R. A. Dahlgren. 1997. Nutrient Fluxes in Forests of the Eastern Sierra Nevada Mountains, United States of America. *Global Biogeochemical Cycles* 11(4)**:** 673-681.

Jones and Stokes. 2001. Draft list of the special status vascular plants of Devils Postpile National Monument. Sequoia and Kings Canyon National Parks, National Park Service.

Jordan, J. 2004. Summary of work performed at Devils Postpile National Monument, August 11-15, 2004. California Exotic Plant Management Team.

Kaczynski, K. 2007. Invasive species in Wilderness as a function of burn severity: A case study in Yosemite National Park, California. M.A. Thesis. University of Colorado, Boulder, Boulder, CO.

Kapnick, S. & A. Hall. 2009. Observed Changes in the Sierra Nevada Snowpack: Potential Causes and Concerns. California Climate Change Center.

Kattelmann, R. 1996. Chapter 30, Hydrology and Water Resources. In *Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options*. University of California, Centers for Water and Wildland Resources, Davis, CA.

Keeler-Wolf, T., P. E. Moore, E. T. Reyes, J. M. Menke, D. N. Johnson, and D. L. Karavidas. 2012. Yosemite National Park vegetation classification and mapping project report. Natural Resources Report NPS/YOSE/NRTR--2012/598. National Park Service, Fort Collins, CO.

Keeley, J. E. 2001. Fire and invasive species in Mediterranean-climate ecosystems of California. In *Fire Conference 2000: The First National Congress on Fire Ecology, Prevention and Management. Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species.* K. E. M. Galley & T. P. Wilson (eds.). pp. 81-94. Tall Timbers Research Station. Vol. 11.

Keeley, J. E., D. Lubin & C. J. Fotheringham. 2003. Fire and grazing impacts on plant diversity and alien plant invasions in the Southern Sierra Nevada. *Ecological Applications* 13(5)**:** 1355-1374.

Kelly, J. F., E. S. Bridge & M. J. Hamas. 2009. Belted Kingfisher (*Megaceryle alcyon*), The Birds of North America Online. http://bna.birds.cornell.edu/bna/species/084

Kenk, G. & H. Fischer. 1988. Evidence from nitrogen fertilization in the forests of Germany. *Environmental Pollution* 54(3-4)**:** 199-218.

Kiesecker, J. M., A. R. Blaustein & L. K. Belden. 2001. Complex causes of amphibian population declines. *Nature (London)* 410(6829)**:** 681-684.

Kilgore, B. M. 1971. The role of fire in managing red fir forests. *Transcript North America Wildlife Natural Research Conference* 35**:** 405-416.

Kilgore, B. M. 1973. The ecological role of fire in Sierran conifer forests: Its application to national park management. *Quaternary Research* 3**:** 496-513.

Kilgore, B. M. & H. H. Biswell. 1971. Seedling germination following fire in a giant sequoia forest. *California Agriculture* 25**:** 8-10.

Kilgore, B. M. & R. W. Sando. 1975. Crown-fire potential in a Sequoia Forest after prescribed burning. *Forest Science* 21**:** 83-87.

Kim, J., T. K. Kim, R. W. Arritt & N. L. Miller. 2002. Impacts of Increased Atmospheric CO_2 on the Hydroclimate of the Western United States. *Journal of Climate* 15**:** 1926-1942.

Kimsey, L. S. & P. Cranston. 2002. Final report for the inventory of the insect fauna of Sequoia/Kings Canyon National Parks. University of California, Davis, Davis, CA.

Knapp, R. 2010. Amphibian biologist. Lee Vining, CA: University of California, Santa Barbara.

Knapp, R. A. 2005. Effects of nonnative fish and habitat characteristics on lentic herpetofauna in Yosemite National Park, USA. *Biological Conservation* 121(2)**:** 265-279.

Knapp, R. A., D. M. Boiano & V. T. Vredenburg. 2007. Removal of nonnative fish results in population expansion of a declining amphibian (mountain yellow-legged frog, *Rana muscosa*). *Biological Conservation* 135(1)**:** 11-20.

Knapp, R. A., P. S. Corn & D. E. Schindler. 2001. The introduction of nonnative fish into wilderness lakes: Good intentions, conflicting mandates, and unintended consequences. *Ecosystems* 4(4)**:** 275-278.

Knapp, R. A. & K. R. Matthews. 2000. Non-native fish introductions and the decline of the mountain yellow-legged frog from within protected areas. *Conservation Biology* 14**:** 428-438.

Knapp, R. A., K. R. Matthews & O. Sarnelle. 2001. Resistance and resilience of alpine lake fauna to fish introductions. *Ecological Monographs* 71(3)**:** 401-421.

Knowles, N. & D. R. Cayan. 2001. Global climate change: Potential effects on the Sacramento/San Joaquin watershed and the San Francisco estuary. *IEP Newsletter* 14(3)**:** 23-29.

Knowles, N. & D. R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. *Geophysical Research Letters* 29(18)**:** 1891.

Knowles, N. & D. R. Cayan. 2004. Elevational dependence of projected hydrologic changes in the San Francisco Estuary and watershed. *Climatic Change* 62(1-3)**:** 319-336.

Knowles, N., M. D. Dettinger & D. Cayan. 2007. Trends in snowfall versus rainfall for the western United States, 1949-2001. California Energy Commission, PIER Energy-Related Environmental Research Program, Sacramento, CA. CEC-500-2007-032.

Knowles, N., M. D. Dettinger & D. R. Cayan. 2006. Trends in Snowfall versus Rainfall in the Western United States. *Journal of Climate* 19(18)**:** 4545-4559.

Kohut, R. 2007. Assessing the risk of foliar injury from ozone on vegetation in parks in the US National Park Service's Vital Signs Network. *Environmental Pollution* 149**:** 348-357.

Kondolf, G. M., R. Kattelmann, M. Embury & D. C. Erman. 1996. Status of Riparian Habitat. In *Sierra Nevada Ecosystem Project: Final report to Congress. Volume II, Assessments and Scientific Basis for Management Options.* pp. 1009-1030. University of California, Centers for Water and Wildland Resources, Davis, CA.

Kotliar, N. B., S. J. Hejl, R. L. Hutto, V. A. Saab, C. P. Melcher & M. E. McFadzen. 2002. Effects of fire and post-fire salvage logging on avian communities in conifer-dominated forests of the western United States. *Studies in Avian Biology* 25**:** 49-64.

Kuhn, B. & B. Johnson. 2008. Status and trends of Black Oak (*Quercus kelloggii*) populations and recruitment in Yosemite Valley. Yosemite National Park, Yosemite, CA.

Kurki, S., A. Nikula, P. Helle & H. Linden. 2000. Landscape fragmentation and forest composition effects on grouse breeding success in boreal forests. *Ecology* 81(7)**:** 1985-1997.

Lacki, M. J., D.R. Cox, L. E. Dodd & M. B. Dickinson. 2009. Response of northern bats, *Myotis septentrionalis*, to prescribed fires in Eastern Kentucky forests. *Journal of Mammalogy* 90(5)**:** 1165-1175.

Landers, D. H., S. Simonich, D. Jaffe, L. Geiser, D. H. Campbell, A. Schwindt, C. Schreck, M. Kent, W. Hafner, H. E. Taylor, K. Hageman, S. Usenko, L. Ackerman, J. Schrlau, N. Rose, T. Blett & M. M. Erway. 2008. The fate, transport, and ecological impacts of airborne contaminants in western National Parks (USA). U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, OR. EPA/600/R-07/138.

Landers, D. H., S. M. Simonich, D. Jaffe, L. Geiser, D. H. Campbell, A. Schwindt, C. Schwindt, C. Schreck, M. Kent, W. Hafner, H. E. Taylor, K. Hageman, S. Usenko, L. Ackerman, J. Schrlau, N. Rose, T. Blett & M. M. Erway. 2010. The Western Airborne Contaminant Assessment Project (WACAP): An Interdisciplinary Evaluation of the Impacts of Airborne Contaminants in Western U.S. National Parks. *Environmental Science & Technology* 44(3): 855-859.

LaSorte, F. A. & F. R. Thompson III. 2007. Poleward Shifts in Winter Ranges of North American Birds. *Ecology* 88(7)**:** 1803-1812.

Laymon, S. A. 1987. Brown-headed cowbirds in California: historical perspectives and management opportunities in riparian habitats. *Western Birds* 18**:** 63-70.

Lazorchak, J. M., F. H. McCormick, T. R. Henry & A. T. Herlihy. 2003. Contamination of fish in streams of the Mid-Atlantic Region: An approach to regional indicator selection and wildlife assessment. *Environmental Toxicology and Chemistry* 22(3)**:** 545-553.

Lehtinen, R., S. Galatowitsch & J. Tester. 1999. Consequences of habitat loss and fragmentation for wetland amphibian assemblages. *Wetlands* 19(1)**:** 1-12.

Leland, H. V., S. V. Fend, J. L. Carter & A. D. Mahood. 1986. Composition and abundance of periphyton and aquatic insects in a Sierra Nevada, California, stream. *Great Basin Naturalist* 46**:** 595-611.

LeNoir, J. S., L. L. McConnell, G. M. Fellers, T. M. Cahill & J. N. Seiber. 1999. Summertime transport of current-use pesticides from California's Central Valley to the Sierra Nevada Mountain Range, USA. *Environmental Toxicology and Chemistry* 18(12)**:** 2715-2722.

Leopold, A. S., S. A. King, C. M. Cottam, I. N. Gabrielson & T. L. Kimball. 1963. Wildlife Management in the National Parks. *Transactions of the North American Wildlife and Natural Resources Conference* 28**:** 29-42.

Liddle, M. J. 1975. A Selective Review of the Ecological Effects of Human Trampling on Natural Ecosystems. *Biological Conservation* 7**:** 17-34.

Liddle, M. J. 1991. Recreation Ecology: Effects of Trampling on Plants and Corals. *TREE* 6(1)**:** 13-17.

Lin, Y. & I. C. Jao. 1995. A Numerical Study of Flow Circulations in the Central Valley of California and Formation Mechanisms of the Fresno Eddy. *Monthly Weather Review* 123(11)**:** 3227-3239.

Lioy, P., R. Taylor & G. Wolff. 1987. The diurnal variations of ozone at different altitudes on a rural mountain in the eastern United States. *JAPCA* 37**:** 45-48.

Liu, Y., J. Stanturf & S. Goodrick. 2010. Trends in global wildfire potential in a changing climate. *Forest Ecology and Management* 259(4)**:** 685-697.

Loarie, S., B. Carter, K. Hayhoe, S. McMahon, R. Moe, C. Knight & D. Ackerly. 2008. Climate change and the future of California's endemic flora. *PLoS ONE* 3(6).

Logan, J., J. Régnière & J. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment* 1(3)**:** 130-137.

Luers, A. L., D. R. Cayan, G. Franco, M. Hanemann & B. Croes. 2006. Our Changing Climate: Assessing the Risks to California. California Climate Change Center.

Lugo, A. E. & H. Gucinski. 2000. Function, effects, and management of forest roads. *Forest Ecology and Management* 133(3)**:** 249-262.

Lundquist, J. D. & D. R. Cayan. 2007. Surface temperature patterns in complex terrain: Daily variations and long-term change in the central Sierra Nevada, California. *Journal of Geophysical Research-Atmospheres* 112(D11)**:** 15.

Lutrick, E., S. Weis, L. Sims, L. Murphy, S. Burak, L. Chamberlain, M. Slaton, T. Ellsworth & K. A. Stone. 2010. Upper San Joaquin Watershed Assessment. USDA Forest Service, Inyo National Forest.

Lutz, J. A. 2008. Climate, fire, and vegetation change in Yosemite National Park. PhD Dissertation. University of Washington, Seattle, WA.

Lutz, J. A., J. W. van Wagtendonk & J. F. Franklin. 2009a. Twentieth-century decline of large-diameter trees in Yosemite National Park, California, USA. *Forest Ecology and Management* 257**:** 2296-2307.

Lutz, J. A., J. W. van Wagtendonk, A. E. Thode, J. D. Miller & J. F. Franklin. 2009b. Climate, lightning ignitions, and fire severity in Yosemite National Park, California, USA. *International Journal of Wildland Fire* 18**:** 765-774.

MacDonald, I. A. W., D. M. Graber, S. DeBenedetti, R. H. Groves & E. R. Fuentes. 1988. Introduced species in nature reserves in Mediterranean-type climatic regions of the world. *Biological Conservation* 44(1-2)**:** 37-66.

Mack, M. C. & C. M. D'Antonio. 1998. Impacts of biological invasions on disturbance regimes. *Tree* 13(5)**:** 195-198.

Mack, R. N., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout & F. A. Bazzaz. 2000. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications* 10(3)**:** 689-708.

Mackay, D. & A. Fraser. 2000. Bioaccumulation of persistent organic chemicals: mechanisms and models. *Environmental Pollution* 110(3)**:** 375-391.

Mahood, G., J. Ring, S. Manganelli & M. McWilliams. 2010. New 40Ar/39Ar ages reveal contemporaneous mafic and silicic eruptions during the past 160,000 years at Mammoth Mountain and Long Valley caldera, California. *Geological Society of America Bulletin* 122(3-4)**:** 396.

Mammoth Community Water District (MCWD). 2005. Groundwater Management Plan for the Mammoth Basin Watershed.

Mammoth Lakes, Town of. 2007a. Town of Mammoth Lakes General Plan 2007. Mammoth Lakes, CA.

Mammoth Lakes, Town of. 2007b. Town of Mammoth Lakes General Plan, Update 2007, Chapter 4: Population, Housing, and Employment. Mammoth Lakes, CA.

Manning, R. E. 1979. Impacts of recreation on riparian soils and vegetation. *JAWRA Journal of the American Water Resources Association* 15(1)**:** 30-43.

Marcot, B. G. 1984. Winter use of some northwestern California caves by western big-eared bats and long-eared *Myotis*. *Murrelet* 65(2)**:** 46.

Maret, M. P. & M. V. Wilson. 2000. Fire and Seedling Population Dynamics in Western Oregon Prairies. *Journal of Vegetation Science* 11(2)**:** 307-314.

Maron, J. L. & R. L. Jefferies. 1999. Bush lupine mortality, altered resource availability, and alternative vegetation states. *Ecology* 80(2)**:** 443-454.

Martin, L. 2012. Hydrogeologist, NPS Water Resources Division.

Matthews, K. R., K. L. Pope, H. K. Preisler & R. A. Knapp. 2001. Effects of nonnative trout on Pacific Treefrogs (*Hyla regilla*) in the Sierra Nevada. *Copeia* 2001(4)**:** 1130-1137.

Matthews, S. M., J. J. Beecham, H. Quigley, S. S. Greenleaf & H. M. Leithead. 2006. Activity patterns of American black bears in Yosemite National Park. *Ursus* 17(1)**:** 30-40.

Maurer, E. P. 2007. Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios. *Climatic Change* 82(3)**:** 309-325.

Maurer, E. P., I. T. Stewart, C. Bonfils, P. B. Duffy & D. Cayan. 2007. Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada. *Journal of Geophysical Research-Atmospheres* 112(D11)**:** D11118.

Mazzoni, A. K. 2002. Habitat use by fishers (*Martes pennanti*) in the southern Sierra Nevada, California. MS Thesis. California State University, Fresno, CA.

McConnell, L. L., J. S. LeNoir, S. Datta & J. N. Seiber. 1998. Wet deposition of current-use pesticides in the Sierra Nevada mountain range, California, USA. *Environmental Toxicology and Chemistry* 17(10)**:** 1908-1916.

McGarigal, K. & W. C. McComb. 1995. Relationships between landscape structure and breeding birds in the Oregon Coast Range. *Ecological Monographs* 65(3)**:** 235-260.

McKelvey, K., S., C. N. Skinner, C.-R. Chang, D. C. Erman, S. J. Husari, D. J. Parson, J. W. van Wagtendonk & C. P. Weatherspoon. 1996. Chapter 37, An overview of fire in the Sierra Nevada. In *Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options*. University of California, Centers for Water and Wildlands Resources, Davis, CA.

McMenamin, S. K., E. A. Hadly & C. K. Wright. 2008. Climatic change and wetland desiccation cause amphibian decline in Yellowstone National Park. *Proceedings of the National Academy of Sciences of the United States of America* 105(44)**:** 16988-16993.

Meehan, T. D. & T. L. George. 2003. Short-term effects of moderate- to high-severity wildfire on a disturbance-dependent flycatcher in northwest California. *Auk* 120(4)**:** 1102-1113.

Melack, J. M., S. Hamilton, J. Sickman & S. D. Cooper. 1989. Effects of atmospheric deposition on ecosystems in Sequoia National Park: ecological impacts on aquatic habitats. National Park Service.

Millar, C. I., R. P. Neilson, D. Bachelet, R. Drapek & J. Lenihan. 2006. Climate change at multiple scales. In *Forests, Carbon, and Climate Change.* H. Salwasser & M. Cloughesy (eds.). pp 30-60. Oregon Forest Resources Institute.

Millar, C.I. & R.D. Westfall. 2010. Distribution and Climatic Relationships of the American Pika (*Ochotona princeps*) in the Sierra Nevada and Western Great Basin, U.S.A.; Periglacial Landforms as Refugia in Warming Climates. *Arctic, Antarctic, and Alpine Research* 42(1)**:** 76-88.

Millar, C. I., R. D. Westfall & D. L. Delaney. 2007. Response of high-elevation limber pine (*Pinus flexilis*) to multiyear droughts and 20th-century warming, Sierra Nevada, California, USA. *Canadian Journal of Forest Research* 37**:** 2508-2520.

Millar, C. I., R. D. Westfall, D. L. Delany, J. C. King & L. J. Graumlich. 2004. Response of subalpine conifers in the Sierra Nevada, California, U.S.A., to 20th-century warming and decadal climate variability. *Arctic, Antarctic, and Alpine Research* 36(2)**:** 181-200.

Miller, C. & D. L. Urban. 1999. Forest pattern, fire, and climatic change in the Sierra Nevada. *Ecosystems* 2**:** 76-87.

Miller, D. F. & P. A. Walsh. 1991. Air quality and acidic deposition in the southeastern Sierra Nevada. In *84th Air & Waste Management Association annual meeting,* pp. 22 pp., Vancouver, BC, Canada.

Miller, J. D., H. D. Safford, M. Crimmins & A. E. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. *Ecosystems* 12(1)**:** 16-32.

Miller, N. L. 2003. California Climate Change, Hydrologic Response, and Flood Forecasting. pp. 1-11. International Expert Meeting on Urban Flood Management, World Trade Center Rotterdam, the Netherlands.

Miller, N. L., K. E. Bashford & E. Strem. 2003. Potential impacts of climate change on California hydrology. *Journal of the American Water Resources Association* 39(4)**:** 771-784.

Miller, N. P. 1999. The effects of aircraft overflights on visitors to US National Parks. Harris Miller Miller & Hanson, Inc. Burlington, MA.

Miller, P. R. 1973. Oxidant-induced community change in a mixed-conifer forest. In *Air pollution damage to vegetation.* J. A. Naegele (ed.). pp. 101-117. Washington, D.C.

Miller, P. R. 1996. Biological effects of air pollution in the Sierra Nevada. In *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol III Assessments, Commissioned Reports, and Background Information.* pp. 1227-1261. University of California, Davis, Centers for Water and Wildland Resources, Davis, CA.

Miller, P. R., S. L. Schilling, R. D. Wilborn, A.P. Gomez, J. Wilborn & N. E. Grulke. 1991. Ozone injury to important tree species of Sequoia and Kings Canyon National Parks. Denver, CO.

Minshall, G. W. 1981. Structure and temporal variations of the benthic macroinvertebrate community inhabiting Mink Creek, Idaho, a third order Rocky Mountain stream. *Journal of Freshwater Ecology* 1**:** 13-26.

Monz, C., A. D'Antonio, S. Lawson, P. Newman, D. Pettebone & L. Gamble. 2009. Quantifying the natural resource consequences of day use in Rocky Mountain National Park. In *George Wright Society biennial conference on parks, protected areas, and cultural sites*.

Moody, T. J., J. Fites-Kaufman & S. L. Stephens. 2006. Fire History and Climate Influences from Forests in the Northern Sierra Nevada, USA. *Fire Ecology* 2(1)**:** 115-141.

Mooney, H. A. & J. A. Drake. 1984. *Ecology of Biological Invasions in North America and Hawaii*, Springer-Verlag, New York. 321 pp.

Moore, C. 2000. 1999 Annual Sequoia Watershed Report. In *1999 Annual Fire Report on Research, Monitoring and Inventory*. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Morelli, T., C. Millar, D. Delany & R. Westfall. 2009. Status of quaking aspen (*Populus tremuloides*) in the Sierra Nevada.

Moritz, C., J. L. Patton, C. J. Conroy, A. Leache, A. Rush & S. R. Beissinger. 2011. A resurvey of the Grinnell-Storer vertebrate transect through Yosemite National Park, California. National Park Service, Fort Collins, CO. Natural Resource Technical Report NPS/SIEN/NRTR--2011/439.

Moritz, C., J. L. Patton, C. J. Conroy, J. L. Parra, G. C. White & S. R. Beissinger. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. *Science* 322(5899)**:** 261-264.

Mote, P. W. 2006. Climate-driven variability and trends in mountain snowpack in western North America. *Journal of Climate* 19(23)**:** 6209-6220.

Mote, P. W., A. F. Hamlet, M. P. Clark & D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. *Bulletin of the American Meteorological Society* 86**:** 39-49.

Mutch, L. S., M. G. Rose, A. M. Heard, R. R. Cook & G. L. Entsminger. 2008a. Sierra Nevada Network Vital Signs Monitoring Plan. DOI National Park Service, Fort Collins, CO. Natural Resources Report NPS/SIEN/NRR-2008/072.

Mutch, L. S., M. G. Rose, A. M. Heard, R. R. Cook & G. L. Entsminger. 2008b. Sierra Nevada Network Vital Signs Monitoring Plan: Appendices A-H. DOI National Park Service, Fort Collins, CO. Natural Resources Report NPS/SIEN/NRR--2008/072.

Nash, T. H. & L. L. Sigal. 1999. Epiphytic lichens in the San Bernardino Mountains in relation to oxidant gradients. In *Oxidant Air Pollution Impacts on the Montane forests of Southern California: A Case Study of the San Bernardino Mountains.* P. R. Miller & J. R. McBride (eds.). pp. 223-234. Springer-Verlag, New York. 134.

National Assessment Synthesis Team (NAST). 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. US Global Change Research Program, Washington, DC.

National Park Service. 1974. Natural Resources Management Plan, Sequoia and Kings National Parks and Devils Postpile National Monument. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 1982. Natural Resources Management Statement for Devils Postpile National Monument. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 1991. Natural Resources Management Guideline. National Park Service, Washington D.C. NPS-77.

National Park Service. 1994. Report on Effects of Aircraft Overflights on the National Park System. Department of the Interior.

National Park Service. 2002. Yosemite National Park human-bear management plan. Yosemite National Park.

National Park Service. 2005. Fire and fuels management plan. National Park Service.

National Park Service. 2006. Management Policies 2006. U. S. Department of the Interior, Fort Collins, CO: National Park Service. 180 pp.

National Park Service. 2009. DRAFT Foundation Plan. National Park Service.

National Park Service. 2010a. Climate Change Response Program. Fort Collins, Colorado. http://www.nature.nps.gov/orgs/ccrp (last accessed 9/14/2010).

National Park Service. 2010b. Integrated Resource Management Applications. https://irma.nps.gov/App/Portal/Home (last accessed January 16, 2010).

National Park Service. 2010c. NPScape conservation status measure - Phase 1 metrics processing SOP: Ownership, ownership by category, and percent protected metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.

National Park Service. 2010d. NPScape housing measure - Phase 1 metrics processing SOP: Current housing density, historic housing density, and projected housing density metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.

National Park Service. 2010e. NPScape landcover measure - Phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.

National Park Service. 2010f. NPScape pattern measure - Phase 1 metrics processing SOP: Landscape morphology metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.

National Park Service. 2010g. NPScape road measure - Phase 1 metrics processing SOP: Road density, distance from roads, and area without roads metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.

National Park Service. 2010h. NPScape: monitoring landscape dynamics of US National Parks. GIS data and products. (last accessed 7/23/2010).

National Park Service, Air Resources Division. 2009. Air Quality in National Parks: 2008 Annual Performance & Progress Report. National Park Service, Denver, CO. NPS/NRPC/ARD/NRR-2009/151.

National Park Service, Water Resources Division. 1998. Baseline water quality data inventory and analysis, Devils Postpile National Monument. National Park Service, Water Resources Division, Fort Collins, CO. NPS/NRWRD/NRTR-98/189.

National Science and Technology Council (NSTC). 1998. National acid precipitation assessment program biennial report to Congress. NSTC, Committee on Environment and Natural Resources.

Neiman, P. J., F. M. Ralph, G. A. Wick, J. D. Lundquist & M. D. Dettinger. 2008. Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West Coast of North America based on eight years of SSM/I satellite observations. *Journal of Hydrometeorology* 9**:** 22-47.

Nelson, C. E., C. A. Carlson & J. M. Melack. 2008. Nutrient deposition and alteration of food web structure in high-elevation lakes of the Sierra Nevada: response by microbial communities. University of California Water Resources Center, UC Berkeley, Berkeley, CA.

Newman, P., E. Pilcher & D. Stack. 2006. Yosemite National Park Phase I Soundscape Report. Yosemite National Park and Colorado State University, Department of Natural Resource Recreation and Tourism.

Niimi, A. J. & G. P. Kissoon. 1994. Evaluation of the critical body burden concept based on inorganic and organic mercury toxicity to rainbow trout (*Oncorhynchus mykiss*). *Archives of Environmental Contamination and Toxicology* 26(2)**:** 169-178.

North American Bird Conservation Initiative (NABCI). 2010. The State of the Birds 2010 Report on Climate Change, United States of America. Washington, D.C.

Null, S. E., J. H. Viers & J. F. Mount. 2010. Hydrologic Response and Watershed Sensitivity to Climate Warming in California's Sierra Nevada. *PLoS ONE* 5(4)**:** e9932.

Parker, J. & D. Parker. 2001. Devil's Postpile National Monument and Vicinity Bird Observations: May 26 - September 9, 2001. A report to Devils Postpile National Monument.

Parmesan, C. & G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421**:** 37-42.

Parsons, D. J. & S. H. DeBenedetti. 1979. Impact of fire suppression on a mixed-conifer forest. *Forest Ecology and Management* 2**:** 21-31.

Parsons, D. J. & T. J. Stohlgren. 1989. Effects of varying fire regimes on annual grasslands in the southern Sierra Nevada of California. *Madroño* 36**:** 154-168.

Payne, R. & D. Webb. 1971. Orientation by means of long range acoustic signaling in baleen whales. *Annual NY Academy of Science* 188**:** 110-141.

Pearson, O. P., M. R. Koford & A. K. Pearson. 1952. Reproduction of the lump-nosed bat (*Corynorhinus rafinesquesi*) in California. *Journal of Mammalogy* 33(3)**:** 273-320.

Pechony, O. & D. T. Shindell. 2010. Driving forces of global wildfires over the past millennium and the forthcoming century. *Proceedings of the National Academy of Sciences, USA* 107(45)**:** 19167.

Perloff, R. 2011. Wildlife biologist. Bishop, CA: Inyo National Forest.

Peterjohn, B. G., J. R. Sauer & C. S. Robbins. 1995. Population trends from the North American Breeding Bird Survey. In *Ecology and Management of Neotropical Migratory Birds.* T. E. Martin, and D.M. Finch (eds.). pp. 3-39. Oxford University Press, New York, NT.

Peterson, D. H., I. Stewart & F. Murphy. 2008. Principal hydrologic responses to climatic and geologic variability in the Sierra Nevada, California. *San Francisco Estuary and Watershed Science* February 2008**:** 1-21.

Peterson, D. L. & M. J. Arbaugh. 1992. Mixed conifer forests of the Sierra Nevada. In *The Response of Western Forests to Air Pollution,* R. K. Olson, D. Binkley & M. Bohn, (eds.). pp. 433-459. Springer-Verlag, New York. Ecological Studies Vol. 97.

Peterson, D. L., M. J. Arbaugh & L. J. Robinson. 1989. Ozone injury and growth trends of ponderosa pine in the Sierra Nevada. In *Transactions: Effects of Air Pollution on Western Forests*.

Anaheim, CA. R. K. Olson & A. S. Lefohn (eds.). Air & Waste Management Association, Pittsburgh, PA.

Peterson, D. L., D. L. Schmoldt, J. M. Eilers, R. W. Fisher & R. D. Doty. 1992. Guidelines for evaluating air pollution impacts on Class I wilderness areas in California. U. S. Forest Service.

Pettebone, D., B. Meldrum, T. Newburger, J. Roche & B. Woiderski. 2010. Devils Postpile National Monument Visitor Use Assessment DRAFT. Yosemite National Park, National Park Service, El Portal, CA.

Pierce, D. W., T. P. Barnett, H. G. Hidalgo, T. Das, C. Bonfils, B. D. Santer, G. Bala, M. D. Dettinger, D. R. Cayan & A. Mirin. 2008. Attribution of declining western US snowpack to human effects. *Journal of Climate* 21(23)**:** 6425-6444.

Pierson, E. D. & W. E. Rainey. 2002. Preliminary surveys for bat species at Devils Postpile National Monument. National Park Service.

Pierson, E. D. & W. E. Rainey. 2009. Bat inventory for Sequoia-Kings Canyon National Parks and Devils Postpile National Monument.

Pither, J. & P. D. Taylor. 1998. An experimental assessment of landscape connectivity. *Oikos* 83(1)**:** 166-174.

Porter, W. F. & H. B. Underwood. 1999. Of elephants and blind men: deer management in the U.S. national parks. *Ecological Applications* 9(1)**:** 3-9.

Potito, A. P. & S. W. Beatty. 2005. Impacts of recreation trails on exotic and ruderal species distribution in grassland areas along the Colorado Front Range. *Environmental Management* 36(2)**:** 230-236.

Pounds, J. A., M. R. Bustamante, L. A. Coloma, J. A. Consuegra, M. P. L. Fogden, P. N. Foster, E. La Marca, K. L. Masters, A. Merino-Viteri, R. Puschendorf, S. R. Ron, G. A. Sanchez-Azofeifa, C. J. Still & B. E. Young. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature* 439(7073)**:** 161-167.

Pounds, J. A., M. P. L. Fogden & J. H. Campbell. 1999. Biological response to climate change on a tropical mountain. *Nature* 389**:** 611-615.

Price, C. & D. Rind. 1991. Lightning activity in a greenhouse world. In: *Proceedings of the 11th Conference of Fire and Forest Meteorology*. Pp. 598-604. Society of American Foresters, Bethesda, Maryland.

Probst, J. R. 1986. A review of factors limiting the Kirtland's Warbler on its breeding grounds. *American Midland Naturalist* 116(1)**:** 87-100.

Rabe, M., M. Siders, C. Miller & T. Snow. 1998. Long foraging distance for a spotted bat (*Euderma maculatum*) in northern Arizona. *The Southwestern Naturalist* 43(2)**:** 266-269.

Rabin, L. A., R. G. Coss & D. H. Owings. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). *Biological Conservation* 131(3)**:** 410-420.

Rachowicz, L. J., R. A. Knapp, J. A. T. Morgan, M. J. Stice, V. T. Vredenburg, J. M. Parker & C. J. Briggs. 2006. Emerging infectious disease as a proximate cause of amphibian mass mortality. *Ecology* 87(7)**:** 1671-1683.

Rachowicz, L. J. & V. T. Vredenburg. 2004. Transmission of *Batrachochytrium dendrobatidis* within and between amphibian life stages. *Diseases of Aquatic Organisms* 61**:** 75-83.

Ralph, F. M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan & A. B. White. 2006. Flooding on California's Russian River: Role of atmospheric rivers. *Geophysical Research Letters* 33**:** 1-5.

Raphael, M. G., M. L. Morrison & M. P. Yoder-Williams. 1987. Breeding bird populations during twenty-five years of postfire succession in the Sierra Nevada. *The Condor* 89(3)**:** 614-626.

Rappole, J. H. & M. V. McDonald. 1994. Cause and Effect in Population Declines of Migratory Birds. *The Auk* 111(3)**:** 652-660.

Regonda, S. K., B. Rajagopalan, M. Clark & J. Pitlick. 2005. Seasonal cycle shifts in hydroclimatology over the western United States. *Journal of Climate* 18**:** 372-384.

Reynolds, R. D. 1959. Effect of natural fires and aboriginal burning upon the forests of the Central Sierra Nevada. PhD Dissertation. University of California, Berkeley.

Richardson, D. M., P. Pysek, M. Rejmanek, M. G. Barbour, F. D. Panetta & C. J. West. 2000. Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distributions* 6**:** 93-107.

Richardson, T. W. & S. S. Moss. 2010. Bird Monitoring at Devils Postpile National Monument - Results from the 2009 Field Season. PRBO Conservation Science, Petaluma, CA. PRBO Contribution #1729.

Richerson, P. J. & K. Lum. 1980. Patterns of plant species diversity in California: relation to weather and topography. *American Naturalist* 116(4)**:** 504-536.

Ripple, W. J. & R. L. Beschta. 2006. Linking a cougar decline, trophic cascades, and a catastrophic regime shift in Zion National Park. *Biological Conservation* 133**:** 397-408.

Ripple, W. J. & R. L. Beschta. 2008. Trophic cascades involving cougar, mule deer, and black oaks in Yosemite National Park. *Biological Conservation* 141(5)**:** 1249-1256.

Rizzo, D. M. & G. W. Slaughter. 2001. Root disease and canopy gaps in developed areas of Yosemite Valley, California. *Forest Ecology and Management* 146(1-3)**:** 159-167.

Robbins, C. S., J. R. Sauer, R. S. Greenberg & S. Droege. 1989. Population declines in North American birds that migrate to the neotropics. *Population Biology* 86**:** 7658-7662.

Roberts, S. L., J. W. van Wagtendonk, A. K. Miles, D. A. Kelt & J. A. Lutz. 2008. Modeling the effects of fire severity and spatial complexity on small mammals in Yosemite National Park, California. *Fire Ecology* 4(2)**:** 83-104.

Rockwell, R. 2000. Wilderness water purity, especially in the High Sierra. *The American Alpine News* 11**:** 238-240.

Roeloffs, E. 2006. Coupling of hydrologic effects to borehole strain data. U.S. Geological Survey. 28 pp. Available at: http://cws.unavco.org:8080/cws/straindata/Notesfrom2005class/hydro_coupling.pdf

Rogers, P. C., W. D. Shepperd & D. L. Bartos. 2007. Aspen in the Sierra Nevada: regional conservation of a continental species. *Natural Areas Journal* 27(2)**:** 183-193.

Roose, M. L. 1991. Genetics of Response to Atmospheric Pollutants. In *Ecological Genetics and Air Pollution.* G. E. Taylor, Jr., L. F. Pitelka & M. T. Clegg (eds.). pp. 111-126. Springer-Verlag, New York, NY.

Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig & J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. *Nature* 421**:** 57-60.

Rosenberg, K. V., J. D. Lowe & A. A. Dhondt. 1999. Effects of forest fragmentation on breeding tanagers: a continental perspective. *Conservation Biology* 13(3)**:** 568-583.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering & M. F. Carter. 2002. Landbird counting techniques: Current practices and an alternative. *The Auk* 119(1)**:** 46-53.

Rowan, D. E., S. C. Parmenter & W. W. Eckhardt. 1996. *Fishery and riparian resources of Devils Postpile National Monument and surrounding waters*. U. S. Dept. of the Interior, National Park Service, Devils Postpile National Monument.

Saab, V. A., H. D. W. Powell, N. B. Kotliar & K. R. Newlon. 2005. Variation in fire regimes of the Rocky Mountains: implications for avian communities and fire management. *Studies in Avian Biology* 30**:** 76-96.

Saros, J. E., D. W. Clow, T. Blett & A. P. Wolfe. 2010. Critical Nitrogen Deposition Loads in High-elevation Lakes of the Western US Inferred from Paleolimnological Records. *Water, Air, & Soil Pollution***:** 1-10.

Sauer, J. R. & S. Droege. 1992. Geographic patterns in population trends of Neotropical migrants in North America. In *Ecology and conservation of Neotropical migrant landbirds.* J. M. I. Hagan & D. W. Johnson (eds.). Smithsonian Institution Press, Washington, D.C.

Sauer, J. R., J. E. Fallon & R. Johnson. 2003. Use of North American Breeding Bird Survey data to estimate population change for bird conservation regions. *Journal of Wildlife Management* 67(2)**:** 372-389.

Sauer, J. R., J. E. Hines & J. Fallon. 2008. The North American Breeding Bird Survey, results and analysis 1966-2007. (last accessed 9/26/2010).

Savage, M. 1994. Anthropogenic and natural disturbance and patterns of mortality in a mixed conifer forest in California. *Canadian Journal of Forest Research* 24(1149-1159).

Schlesinger, M. D., P. N. Manley & M. Holyoak. 2008. Distinguishing stressors acting on land bird communities in an urbanizing environment. *Ecology* 89(8)**:** 2302-2314.

Schmida, A. & S. Ellner. 1983. Seed dispersal on pastoral grazers in open Mediterranean chaparral, Israel. *Israel Journal of Botany* 32**:** 147-159.

Scholl, A. E. & A. H. Taylor. 2010. Fire regimes, forest change, and self-organization in an old-growth mixed-conifer forest, Yosemite National Park, USA. *Ecological Applications* 20(2)**:** 362-380.

Schroeter, R. E. & J. M. Harrington. 1995. Benthic macroinvertebrate community assessment of the Middle Fork San Joaquin River, Madera County, California. California Department of Fish and Game, Water Pollution Control Laboratory, Rancho Cordova, CA.

Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards, Jr., J. Ulliman & R. G. Wright. 1993. Gap Analysis: A Geographic Approach to Protection of Biological Diversity. *Wildlife Monographs* (123)**:** 3-41.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. P. Huang, N. Harnik, A. Leetmaa & N. C. Lau. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science* 316(5828)**:** 1181.

Sharpf, R. F. 1993. *Diseases of Pacific Coast conifers*, USDA Forest Service, Albany, CA. Agriculture Handbook 521.

Shepperd, W. D., P. C. Rogers, D. Burton & D. L. Bartos. 2006. Ecology, biodiversity, management, and restoration of aspen in the Sierra Nevada. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. RMRS-GTR-178.

Sherman, R. J. & R. K. Warren. 1988. Factors in *Pinus ponderosa* and *Calocedrus decurrens* mortality in Yosemite Valley, USA. *Vegetatio* 77(1/3)**:** 79-85.

Shuford, W. D. & T. Gardali. 2008. *California bird species of special concern: a ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California*. Western Field Ornithologists and California Department of Fish and Game, Camarillo, CA. pp.

Sickman, J. O., J. M. Melack & D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. *Limnology and Oceanography* 48(5)**:** 9.

Siegel, R. B. & D. F. DeSante. 1999. The draft avian conservation plan for the Sierra Nevada Bioregion: conservation priorities and strategies for safeguarding Sierra bird populations. Institute for Bird Populations and California Partners in Flight, Point Reyes Station, CA.

Siegel, R. B. & D. R. Kaschube. 2007. Landbird monitoring results from the Monitoring Avian Productivity and Survivorship (MAPS) program in the Sierra Nevada. The Institute for Bird Populations, Point Reyes Station, CA.

Siegel, R. B., R. L. Wilkerson & S. K. Heath. 2004. Landbird inventory for Devils Postpile National Monument. The Institute for Bird Populations, Point Reyes Station, CA.

Siegel, R. B., R. L. Wilkerson & M. G. Rose. 2010. Bird monitoring protocol for national parks in the Sierra Nevada Network. National Park Service, Fort Collins, CO. Natural Resource Report NPS/SIEN/NRR -- 2010/231.

Sierra Nevada Ecosystem Project. 1996a. Chapter 4, Fire and Fuels. In: *Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. I, Assessment Summaries and Management Strategies*. D. C. Erman (ed.). University of California, Davis, Centers for Water and Wildland Resources, Davis, CA.

Sierra Nevada Ecosystem Project. 1996b. Chapter 5, Plants and Terrestrial Wildlife. In *Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. I, Assessment Summaries and Management Strategies.* D. C. Erman (ed.). University of California, Davis, Centers for Water and Wildland Resources, Davis, CA.

Sierra Nevada Ecosystem Project. 1996c. Chapter 8 Watershed and Aquatic Biodiversity. In *Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. I, Assessment Summaries and Management Strategies*. UC Davis, Centers for Water and Wildland Resources, Davis, CA.

Simpson, B. A. 2002. California Exotic Plant Management Team's trip report of work conducted at Devils Postpile National Monument, August 7 - 14, 2002. California Exotic Plant Management Team.

Skancke, J., A. MacCoubrey, & L. Chow. In prep. Sierra Nevada Network rivers monitoring protocol. Sierra Nevada Network Inventory and Monitoring Program, National Park Service, Three Rivers, CA.

Skinner, C. N. & C.-R. Chang. 1996. Chapter 38 Fire regimes, past and present. In: *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II, Assessments and scientific basis for management options*. University of California, Centers for Water and Wildland Resources, Davis.

Slaughter, G.W. & J.R. Parmeter Jr. 1989. Annosus root disease in true firs in northern and central California national forests. In: *Proceedings of the symposium on Research and Management of Annosus Root Disease (Heterobasidion annosum) in Western North America*. W. J. Otrosina & R. F. Scharpf (eds.). pp. 70-77. USDA Forest Service General Technical Report PSW-116**.**

Smith, S. J. & R. S. Anderson. 1992. Late Wisconsin paleoecologic record from Swamp Lake, Yosemite National Park, California. *Quaternary Research* 38**:** 91-102.

Snyder, M. A., J. L. Bell, L. C. Sloan, P. B. Duffy & B. Govindasamy. 2002. Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulnerable region. *Geophysical Research Letters* 29(11).

Solomons, T.S. 1894. Among the sources of the San Joaquin. *Sierra Club Bulletin* 1(3): 61-84.

Somers, G. L., A. H. Chappelka, P. Rosseau & J. R. Renfro. 1998. Empirical evidence of growth decline related to visible ozone injury. *Forest Ecology and Management* 104(1-3)**:** 129-137.

Southall, B. L. 2005. Final Report of the National Oceanic and Atmospheric Administration (NOAA) International Symposium: Shipping noise and marine mammals: a forum for science, management, and technology. U.S. National Oceanic and Atmospheric Administration, Arlington, VA.

Southall, B. L. & A. Scholik-Schlomer. 2009. Potential application of vessel-quieting technology on large commercial vessels. U.S. National Oceanic and Atmospheric Administration, Silver Spring, MD.

Sparling, D. W., G. M. Fellers & L. McConnell. 2001a. Pesticides are involved with population declines of amphibians in the California Sierra Nevadas. *The Scientific World Journal* 1**:** 200-201.

Sparling, D. W., G. M. Fellers & L. L. McConnell. 2001b. Pesticides and amphibian population declines in California, USA. *Environmental Toxicology and Chemistry* 20(7)**:** 1591-1595.

Squires, J. R. & R. T. Reynolds. 1997. Northern Goshawk (*Accipiter gentilis*), The Birds of North American Online. http://bna.birds.cornell.edu/bna/species/298 (last accessed 11/16/2010).

Stebbins, R. C. 2003. *Peterson Field Guide to Western Amphibians and Reptiles*, 3rd Ed. Houghton-Mifflin Co., Boston, Mass.

Steel, Z. L., M. L. Bond, R. B. Siegel, and P. Pyle. 2012. Avifauna of Sierra Nevada Network parks: Assessing distribution, abundance, stressors, and conservation opportunities for 145 bird species. Natural Resource Report NPS/SIEN/NRR—2012/506. National Park Service, Fort Collins, Colorado.

Stephens, S. L. 2001. Fire history differences in adjacent Jeffrey pine and upper montane forests in the eastern Sierra Nevada. *International Journal of Wildland Fire* 10**:** 161-167.

Stephenson, N. L. 1987. Use of tree aggregations in forest ecology and management. *Environmental Management* 11**:** 1-5.

Stephenson, N. L. 1988. Climatic control of vegetation distribution: The role of the water balance with examples from North America and Sequoia National Park, California. PhD. Dissertation. Cornell University, Ithaca, NY.

Stephenson, N. L. 1994. Long-term dynamics of giant sequoia populations: Implications for managing a pioneer species. In *Proceedings of the symposium on giant sequoias: Their place in the ecosystem and society*. June 23-25, 1992, Visalia, CA. P. S. Aune (ed.). pp. 56-63. USDA Forest Service Visalia, CA. USDA Gen. Tech. Rep. PSW-151.

Stevens, R., W. McCambridge & C. Edminster. 1980. Risk rating guide for mountain pine beetle in Black Hills ponderosa pine. US Dept. of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. Research Note RM-385.

Stewart, I. T., D. R. Cayan & M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario. *Climatic Change* 62(1-3)**:** 217-232.

Stewart, I. T., D. R. Cayan & M. D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. *Journal of Climate* 18(8)**:** 1136-1155.

Stock, S. 2010. Wildlife biologist. El Portal, CA.

Stoddard, J. L. 1987. Microcrustacean communities of high-elevation lakes in the Sierra Nevada, California. *Journal of Plankton Research* 9**:** 631-650.

Stohlgren, T. J. & D. J. Parsons. 1987. Variation of wet deposition chemistry in Sequoia National Park, California. *Atmospheric Environment* 21(6)**:** 1369-1374.

Stuart, S. N., J. S. Chanson, N. A. Cox, B. E. Young, A. S. L. Rodrigues, D. L. Fischman & R. W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306**:** 1783-1786.

Sullivan, T. J., D. L. Peterson & C. L. Blanchard. 2001. Assessment of air quality and air pollutant impacts in Class I National Parks of California. National Park Service, Denver, CO.

Swetnam, T. W. 1993. Fire History and Climate Change in Giant Sequoia Groves. *Science* 262(5135)**:** 885-889.

Swetnam, T. W., C. H. Baisan, A. C. Caprio, R. Touchan & P. M. Brown. 1992. Tree-ring reconstruction of giant sequoia fire regimes. University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ. Coop. Agreement No. DOI 8018-1-0002.

Szewczak, J. M., S. M. Szewczak, M. L. Morrison & L. S. Hall. 1998. Bats of the White and Inyo Mountains of California and Nevada. *Great Basin Naturalist* 58(1)**:** 66-75.

Takemoto, B. K., A. Bytnerowicz & M. E. Fenn. 2001. Current and future effects of ozone and atmospheric nitrogen deposition on California's mixed conifer forests. *Forest Ecology and Management* 144(1-3)**:** 159-173.

Takemoto, B. K., B. E. Croes, S. M. Brown, N. M. Motallebi, F. D. Westerdahl, H. G. Margolis, B. T. Cahill, M. D. Mueller & J. R. Holmes. 1995. Acidic deposition in California: findings from a program of monitoring and effects research. *Water Air and Soil Pollution* 85**:** 261-272.

Tamm, C. O. 1989. Comparative and experimental approaches to the study of acid deposition effects on soils as substrate for forest growth. *Ambio* 18(3)**:** 184-191.

Tarnay, L. 2010. Air Resources Specialist, Yosemite National Park.

Taylor, A. H. & R. M. Beaty. 2005. Climatic influences on fire regimes in the northern Sierra Nevada mountains, Lake Tahoe Basin, Nevada, USA. *Journal of Biogeography* 32**:** 425-438.

Thorne, D. J., T. R. Kelsey, J. Honig & B. Morgan. 2006. The Development of 70-Year-Old Wieslander Vegetation Type Maps and an Assessment of Landscape Change in the Central Sierra Nevada. California Energy Commission, PIER Energy-Related Environmental Program. CEC-500-2006-107.

Thorne, J. H., B. J. Morgan & J. A. Kennedy. 2008. Vegetation Change Over Sixty Years in the Central Sierra Nevada, California, USA. *Madroño* 55(3)**:** 223-237.

Thorne, J. H., J. H. Viers, J. Price & D. M. Stoms. 2009. Spatial patterns of endemic plants in California. *Natural Areas Journal* 29**:** 344-366.

Tingley, M. W., W. B. Monahan, S. R. Beissinger & C. Moritz. 2009. Birds track their Grinnellian niche through a century of climate change. *PNAS* 106(2)**:** 19637-19643.

Tonsor, S. J. & S. Kalisz. 1991. Population-Level Techniques for Measuring Microevolutionary Change in Response to Air Pollution. Chapter 10 in: *Ecological Genetics and Air Pollution.* G. E. Taylor, Jr., L. F. Pitelka & M. T. Clegg (eds.). pp. 289-312. Springer-Verlag, New York, NY.

Trombulak, S. C. & C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14(1)**:** 18-30.

Truex, R. L. & W. J. Zielinski. 2005. Short-term effects of fire and fire surrogate treatments on fisher habitat in the Sierra Nevada. Joint Fire Science Program, Porterville, CA. JFSP 01C-3-3-02.

Trzcinski, M. K., L. Fahrig & G. Merriam. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. *Ecological Applications* 9(2)**:** 586-593.

Tyser, R. W. & C. A. Worley. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (U.S.A.). *Conservation Biology* 6(2)**:** 253-262.

U.S. Environmental Protection Agency. 2001. Functions and Values of Wetlands. U.S. Environmental Protection Agency. EPA 843-F-01-002c

U.S. Fish and Wildlife Service (USFWS). 2008. Birds of Conservation Concern 2008. US Fish and Wildlife Service, Arlington, VA.

Uhrin, A. V. & J. G. Holmquist. 2003. Effects of propeller scarring on macrofaunal use of the seagrass *Thalassia testudinum*. *Marine Ecology Progress Series* 250**:** 61-70.

Ursem, C., C. S. Evans, K. A. Ger, J. R. Richards & R. W. Derlet. 2009. Surface Water Quality along the Central John Muir Trail in the Sierra Nevada Mountains: Coliforms and Algae. *High Altitude Medicine & Biology* 10(4)**:** 349-355.

USDA Forest Service. 1991. Chapter 7.0 of the Final Environmental Impact Statement. (Appendix E: “Wild & Scenic Rivers Study, Description, and Evaluation” in support of the Forest Land and Resource Management Plan: Sierra National Forest). USDA Forest Service, Pacific Southwest Region.

USDA Forest Service. 2010. cal_fire_history_2010. Digital geodatabase of California’s fire history. USDA Forest Service, Sacramento, CA.

USDA Forest Service & The Nature Conservancy. 2010. FRID_InyoNatForest08_1. Digital geodatabase of the fire return interval departure for the Inyo National Forest through 2008. Accessible from: http://www.fs.fed.us/r5/rsl/clearinghouse/r5gis/frid/. USDA Forest Service and The Nature Conservancy, California chapter.

Van der Oost, R., J. Beyer & N. P. E. Vermeulen. 2003. Fish bioaccumulation and biomarkers in environmental risk assessment: a review. *Environmental Toxicology and Pharmacology* 13(2)**:** 57-149.

van Dijk, H. F. G. & J. G. M. Reolofs. 1988. Effects of excessive ammonium deposition on the nutritional status and condition of pine needles. *Physiologia Plantarum* 73(4)**:** 494-501.

Van Liew, W. 2012. Hydrogeologist, NPS Water Resources Division.

van Mantgem, P. J. & N. L. Stephenson. 2007. Apparent climatically induced increase of tree mortality rates in a temperate forest. *Ecology Letters* 10**:** 909-916.

van Mantgem, P. J., N. L. Stephenson, M. Keifer & J. Keeley. 2004. Effects of an introduced pathogen and fire exclusion on the demography of sugar pine. *Ecological Applications* 14(5)**:** 1590-1602.

van Wagtendonk, J. W. 1985. Fire suppression effects on fuels and succession in short-fire-interval wilderness ecosystems. In: *Proceedings -- Symposium and Workshop on Wilderness Fire, 15-18 November 1983*. J. E. Lotan, B. M. Kilgore, W. C. Fischer & R. W. Mutch (eds.). pp. 119-126.

Missoula, Montana. USDA Forest Service, Missoula, Montana. General Technical Report INT-182.

van Wagtendonk, J. W. 2004. Fire and landscapes: Patterns and processes. In: *Sierra Nevada Science Symposium*, pp. 69-78. USDA Forest Service, Kings Beach, California. Gen. Tech. Rep. PSW-GTR 193.

van Wagtendonk, J. W., K. A. van Wagtendonk, J. A. Meyer & K. J. Paintner. 2002. The use of geographic information for fire management planning in Yosemite National Park. *The George Wright Forum* 19(1)**:** 19-39.

Vankat, J. L. & J. Major. 1978. Vegetation changes in Sequoia National Park, California. *Journal of Biogeography* 5(377-402).

Veblen, T. T., T. Kitzberger, R. Villalba & J. Donnegan. 1999. Fire History in Northern Patagonia: The Roles of Humans and Climatic Variation. *Ecological Monographs* 69(1)**:** 22 pp.

Verner, J. & L. V. Ritter. 1983. Current status of the brown-headed cowbird in the Sierra National Forest. *Auk* 100(2)**:** 355-368.

Vitousek, P. M., J. D. Aber, R. H. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger & D. G. Tilman. 1997. Human alteration of the global nitrogen cycle: Source and consequences. *Ecological Applications* 7(3)**:** 737-750.

Vitousek, P. M., C. M. D'Antonio, L. L. Loope & R. Westbrooks. 1996. Biological Invasions as Global Environmental Change. *American Scientist* 84**:** 468-478.

Vogler, D. R. 1982. Ozone monitoring in the southern Sierra Nevada, 1976-1981. USDA Forest Service, Pacific Southwest Region, San Francisco, CA. Report No. 82-17.

Vredenburg, V. T. 2001. Exotic species and the decline of amphibians: Unintended consequences on a global scale. *American Zoologist* 41(6)**:** 1616.

Wake, D. B. 2007. Climate change implicated in amphibian and lizard declines. *Proceedings of the National Academy of Sciences of the United States of America* 104(20)**:** 8201-8202.

Wake, D. B. & V. T. Vredenburg. 2008. Are we in the midst of the sixth mass extinction? A view from the world of amphibians. *Proceedings of the National Academy of Sciences of the United States of America* 105**:** 11466-11473.

Ward, D. & J. N. M. Smith. 2000. Brown-headed cowbird parasitism results in a sink population in warbling vireos. *The Auk* 117(2)**:** 337-344.

Wehausen, J. D. 2003. DRAFT Recovery Plan for the Sierra Nevada Bighorn Sheep (*Ovis canadensis californiana*). U.S. Fish and Wildlife Service, Region 1, Portland, Oregon.

Weiss, S. B. 2010. From butterflies to bristlecones: microclimate and topoclimate range adjustments as a foundation for conservation in a changing macroclimate. In *Mountain Climate Research Conference*, pp. USDA Forest Service, Blue River, OR.

Wemple, B. C., F. J. Swanson & J. A. Jones. 2001. Forest roads and geomorphic process interactions, Cascade Range, Oregon. *Earth Surface Processes and Landforms* 26(2)**:** 191-204.

Werner, H. W. 2004. Vertebrate survey for Sequoia and Kings Canyon National Parks and Devils Postpile National Monument. U.S. National Park Service, Three Rivers, CA.

Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das & S. R. Shrestha. 2009. Climate Change, Growth, and California Wildfire. California Climate Change Center.

Westerling, A. L., A. Gershunov, T. J. Brown, D. R. Cayan & M. D. Dettinger. 2003. Climate and wildfire in the western United States. *Bulletin of the American Meteorological Society***:** 595-604.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan & T. W. Swetnam. 2006. Warming and earlier spring increases western U.S. forest wildfire activity. *Science* 313**:** 940-943.

Wettstein, W. & B. Schmid. 1999. Conservation of arthropod diversity in montane wetlands: effects of altitude, habitat quality and habitat fragmentation on butterflies and grasshoppers. *Journal of Applied Ecology* 36(3)**:** 363-373.

Wheeler, S. S., C. M. Barker, Y. Fang, M. V. Armijos, B. D. Carroll, S. Husted, W. O. Johnson & W. K. Reisen. 2009. Differential impact of West Nile virus on California birds. *The Condor* 111(1)**:** 1-20.

Wickman, B. E. 1992. Forest health in the Blue Mountains: the influence of insects and diseases. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW-GTR-295.

Wilkening, J. L., C. Ray, E. A. Beever & P. F. Brussard. 2011. Modeling contemporary range retraction in Great Basin pikas (*Ochotona princeps*) using data on microclimate and microhabitat. *Quaternary International* 235(1-2)**:** 77-88.

Willard, B. E. & J. W. Marr. 1970. Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colorado. *Biological Conservation* 2(4)**:** 257-265.

Willard, B. E. & J. W. Marr. 1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. *Biological Conservation* 3(3)**:** 181-190.

Williams, M. R. & J. M. Melack. 1997. Effects of prescribed burning and drought on the solute chemistry of mixed-conifer forest streams of the Sierra Nevada, California. *Biogeochemistry* 39(3)**:** 225-253.

Woodhams, D. C., V. T. Vredenburg, M. A. Simon, D. Billheimer, B. Shakhtour, Y. Shyr, C. J. Briggs, L. A. Rollins-Smith & R. N. Harris. 2007. Symbiotic bacteria contribute to innate immune defenses of the threatened mountain yellow-legged frog, *Rana muscosa*. *Biological Conservation* 138(3-4)**:** 390-398.

Worrall, J. J., L. Egeland, T. Eager, R. A. Mask, E. W. Johnson, P. A. Kemp & W. D. Shepperd. 2008. Rapid mortality of *Populus tremuloides* in southwestern Colorado, USA. *Forest Ecology and Management* 255(3-4)**:** 686-696.

Zabik, J. M. & J. N. Seiber. 1993. Atmospheric transport of organophosphate pesticides from California's Central Valley to the Sierra Nevada mountains. *Journal of Environmental Quality* 22**:** 80-90.

Zedler, J. B. & S. Kercher. 2004. Causes and consequences of invasive plants in wetlands: opportunities, opportunists, and outcomes. *Critical Reviews in Plant Sciences* 23(5)**:** 431-452.

Zedler, J. B. & S. Kercher. 2005. Wetland Resources: Status, Trends, Ecosystem Services, and Restorability. *Annual Review of Environment and Resources* 30**:** 39-74.

Zielinski, W. 2004. The status and conservation of mesocarnivores in the Sierra Nevada. In *Sierra Nevada Science Symposium*, pp. 185-193. USDA Forest Service, Kings Beach, CA. Gen. Tech. Rep. PSW-GTR 193.

Zielinski, W., T. Kucera & R. Barrett. 1995. Current distribution of the fisher, *Martes pennanti*, in California. *California Fish and Game* 81(3)**:** 104-112.

Zielinski, W., R. L. Truex, C. V. Ogan & K. Busse. 1997. Detection surveys for fishers and American martens in California, 1989-1994: summary and interpretations. In: *Martes: taxonomy, ecology, techniques, and management*. pp.372-392. Proceedings of the Second International Martes Symposium. G. Proulx, H. N. Bryant & P. M. Woodard (eds.). Edmonton, Alberta.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt & R. H. Barrett. 2004. Home range characteristics of fishers in California. *Journal of Mammalogy* 85(4)**:** 649-657.

Appendix A. Plant Species in Devils Postpile

Plant species list for DEPO. Total richness = 384 species. Survey: A = Arnett & Haultain (2005); E = California Exotic Plant Management Team exotic plant surveys (2002-2006); * non-native; + considered weedy or invasive by Gerlach et al. (2003).

Family	Genus, species	Common name	Survey
Apiaceae (10)	*Cymopterus terebinthinus var. californicus*		A
	Heracleum lanatum	cow parsnip	A
	Ligusticum grayi	Gray's lovage	A
	Lomatium torreyi	Torrey's lomatium	A
	Osmorhiza chilensis	mountain sweet-sicily	A
	Osmorhiza occidentalis		A
	Oxypolis occidentalis	cow bane	A
	Perideridia parishii ssp. latifolia		A
	Sium suave		A
	Sphenosciadium capitellatum	ranger's buttons	A
Apocynaceae (1)	*Apocynum androsaemifolium*	bitter dogbane	A
Asteraceae (53)	*Achillea millefolium*	yarrow	A
	Ageratina occidentalis		A
	Agoseris elata	tall agoseris	A
	Agoseris glauca var. monticola	short-beaked agoseris	A
	Agoseris retrorsa	spear-leaved agoseris	A
	Anaphalis margaritacea	pearly everlasting	A
	Antennaria corymbosa	meadow everlasting	A
	Antennaria rosea ssp. confinis		A
	Arnica chamissonis ssp. foliosa	meadow arnica	A
	Arnica mollis	cordilleran arnica	A
	Artemisia douglasiana	mugwort	A
	Artemisia ludoviciana ssp. incompta	silver wormwood	A
	Artemisia tridentata ssp. vaseyana	mountain sagebrush	A
	Aster breweri	Brewer's golden-aster	A
	Aster eatonii		A
	Aster foliaceus var. parryi		A
	Aster integrifolius		A
	Aster occidentalis var. occidentalis	western mountain aster	A
	Chaenactis alpigena	Southern Sierra chaenactis	A
	Chaenactis douglasii var. douglasii	dusty maidens	A
	Chrysothamnus nauseosus ssp. albicaulis	rubber rabbitbrush	A
	Chrysothamnus parryi ssp. monocephalus		A
	Cirsium andersonii	Anderson's thistle	A
	Cirsium scariosum	elk thistle	A
	Cirsium vulgare *+	bull thistle	A, E
	Ericameria bloomeri	Bloomer's goldenbush	A
	Erigeron breweri var. breweri		A

Family	Genus, species	Common name	Survey
	Erigeron coulteri	Coulter's daisy	A
	Erigeron elmeri	Elmer's daisy	A
	Erigeron peregrinus var. callianthemus	wandering daisy	A
	Erigeron peregrinus var. hirsutus	wandering daisy	A
	Eriophyllum lanatum var. integrifolium	Oregon sunshine	A
	Gnaphalium californicum	ladies' cottonrose	A
	Gnaphalium canescens ssp. Thermal		A
	Gnaphalium palustre	lowland cudweed	A
	Helenium bigelovii	Bigelow's sneezeweed	A
	Hieracium albiflorum	white-flowered hawkweed	A
	Hieracium horridum	shaggy hawkweed	A
	Hulsea brevifolia	short-leaved hulsea	A
	Hulsea vestita ssp. vestita	pumice hulsea	A
	Lactuca serriola *	prickly lettuce	A, E
	Microseris nutans	nodding microseris	A
	Senecio canus	wooly butterweed	A
	Senecio integerrimus var. exaltatus	single-stemmed butterweed	A
	Senecio scorzonella	Sierra butterweed	A
	Senecio triangularis	arrowhead butterweed	A
	Solidago canadensis ssp. elongata	Canada goldenrod	A
	Stephanomeria tenuifolia	wire lettuce	A
	Taraxacum officinale *	dandelion	A
	Tragopogon dubius *	Salsify	A, E
	Trimorpha lonchophylla	short-rayed daisy	A
	Wyethia mollis		A
	Madia exigua	threadstem madia	A
Betulaceae (1)	*Alnus incana ssp. tenuifolia*	mountain alder	A
Boraginaceae (8)	*Cryptantha torreyana*	Torrey's cryptantha	A
	Cryptantha affinis	common cryptantha	A
	Cryptantha echinella	prickly cryptantha	A
	Hackelia micrantha		A
	Hackelia mundula	pink stickseed	A
	Hackelia velutina	velvety stickseed	A
	Plagiobothrys hispidulus	harsh popcornflower	A
	Plagiobothrys hispidus		A
Brassicaceae (19)	*Arabis sp*		A
	Arabis holboellii var. pinetorum	Holboell's rock cress	A
	Arabis holboellii var. retrofracta	Holboell's rock cress	A
	Arabis platysperma var. howellii	flat-seeded rock cress	A
	Arabis platysperma var. platysperma	flat-seeded rock cress	A
	Arabis rectissima var. rectissima	bristly-leaved rock cress	A
	Arabis repanda var. repanda		A
	Arabis xdivaricarpa		A
	Barbarea orthoceras	American winter cress	A
	Cardamine breweri var. breweri	Brewer's bittercress	A
	Descurainia incana	mountain tansy mustard	A
	Draba albertina	Alaska whitlow-grass	A

Family	Genus, species	Common name	Survey
	Erysimum capitatum ssp. perenne	western wallflower	A
	Lepidium densiflorum var. macrocarpum		A
	Phoenicaulis cheiranthoides		A
	Rorippa cuvipes		A
	Rorippa curvisiliqua	western yellow-cress	A
	Rorippa nasturtium-aquaticum	watercress	A
	Streptanthus tortuosus var. orbiculatus	mountain jewelflower	A
Caprifoliaceae (5)	*Lonicera conjugialis*	double honeysuckle	A
	Lonicera involucrata var. involucrata	twinberry	A
	Sambucus mexicana	blue elderberry	A
	Symphoricarpos mollis	creeping snowberry	A
	Symphoricarpos rotundifolius var. rotundifolius		A
Caryophyllaceae (5)	*Sagina saginoides*	arctic pearlwort	A
	Silene menziesii		A
	Spergularia rubra *	purple sand-spurry	A
	Stellaria longipes var. longipes	long-stalked starwort	A
	Stellaria umbellata		A
Chenopodiaceae (1)	*Chemopodium sp*		A
Cornaceae (1)	*Cornus sericea ssp. sericea*	American dogwood	A
Crassulaceae (1)	*Sedum obtusatum ssp. obtusatum*	Sierra stonecrop	A
Cupressaceae (1)	*Juniperus occidentalis var. australis*	Sierra juniper	A
Cyperaceae (26)	*Carex abrupta*	abrupt-beaked sedge	A
	Carex athrostachya	slender-beaked sedge	A
	Carex heteroneura var. epapillosa		A
	Carex heteroneura var. heteroneura		A
	Carex hoodii	Hood's sedge	A
	Carx integra	smooth-beaked sedge	A
	Carex jonesii	Jones' sedge	A
	Carex lanuginosa	woolly sedge	A
	Carex lenticularis var. impressa		A
	Carex lenticularis var. lipocarpa		A
	Carex leporinella		A
	Carex mariposana	Mariposa sedge	A
	Carex microptera		A
	Carex multicostata		A
	Carex nebrascensis	Nebraska sedge	A
	Carex nervina		A
	Carex rossii	Ross' sedge	A
	Carex subfusca	rusty sedge	A
	Carex utriculata	beaked sedge	A
	Carex vesicaria		A
	Carex vesicaria var. vesicaria		A
	Carex whitneyi		A
	Cyperus squarrosus		A
	Eleocharis acicularis var. bella	needle spikerush	A

Family	Genus, species	Common name	Survey
	Eleocharis macrostachya	pale spikerush	A
	Scirpus microcarpus	small-fruited bulrush	A
Dennstaedtiaceae (1)	*Pteridium aquilinum var. pubescens*	bracken fern	A
Dryopteridaceae (2)	*Athyrium filix-femina var. cyclosorum*	lady fern	A
	Cystopteris fragilis	fragile fern	A
Equisetaceae (2)	*Equisetum arvense*	common horsetail	A
	Equisetum laevigatum	smooth scouring rush	A
Ericaceae (6)	*Arctostaphylos nevadensis*	pinemat manzanita	A
	Arctostaphylos patula	greenleaf manzanita	A
	Ledum glandulosum	western labrador tea	A
	Pterospora andromedea	pinedrops	A
	Pyrola picta	white-veined wintergreen	A
	Sarcodes sanguinea	snow plant	A
Fabaceae (11)	*Lotus crassifolius var. crassifolius*		A
	Lotus oblongifolius var. oblongifolius	narrow-leaved lotus	A
	Lotus purshianus var. purshianus	Spanish clover	A
	Lupinus albicaulis		A
	Lupinus latifolius var. columbianus	broad-leaved lupine	A
	Lupinus lepidus var. sellulus		A
	Lupinus polyphyllus var. burkei	large-leaved lupine	A
	Trifolium cyathiferum	bowl clover	A
	Trifolium longipes var. nevadense		A
	Trifolium monanthum var. monanthum	carpet clover	A
	Trifolium wormskioldii	mountain clover	A
Fagaceae (2)	*Chrysolepis sempervirens*	bush chinquapin	A
	Quercus vaccinifolia	huckleberry oak	A
Gentianaceae (3)	*Gentianopsis holopetala*	Sierra gentian	A
	Gentianopsis simplex	hiker's gentian	A
	Swertia radiata	monument plant	A
Geraniaceae (1)	*Geranium richardsonii*	Richardson's geranium	A
Grossulariaceae (5)	*Ribes cereum var. cereum*		A
	Ribes inerme var. inerme	white-stemmed currant	A
	Ribes nevadense	mountain pink currant	A
	Ribes roezlii var. roezlii	Sierra gooseberry	A
	Ribes viscossissinum		A
Hydrophyllaceae (6)	*Hesperochiron pumilus*	dwarf hesperochiron	A
	Nemophila spatulata	Sierra nemophila	A
	Phacelia eisenii	Eisin's phacelia	A
	Phacelia hastata ssp. compacta	silverleaf phacelia	A
	Phacelia hydrophylloides	waterleaf phacelia	A
	Phacelia mutabilis		A
Hypericaceae (2)	*Hypericum formosum var. scouleri*	Saint John's wort	A
	Hypericum anagalloides	tinker's penny	A
Iridaceae (1)	*Sisyrinchium idahoense var. occidentale*	Idaho blue-eyed grass	A
Juncaceae (8)	*Juncus nevadensis*	Sierra rush	A

Family	**Genus, species**	**Common name**	**Survey**
	Juncus balticus	Baltic rush	A
	Juncus drummondii	Drummond's rush	A
	Juncus orthophyllus		A
	Juncus parryi		A
	Juncus saximontanus		A
	Luzula comosa	hairy woodrush	A
	Luzula parviflora	small-flowered woodrush	A
Juncaginaceae (1)	*Triglochin maritima*	seaside arrow-grass	A
Lamiaceae (3)	*Agastache urticifolia*	horse mint	A
	Monardella odoratissima ssp. pallida	mountain mint	A
	Stachys albens	white hedge-nettle	A
Liliaceae (10)	*Calochortus leichtlinii*	leichtlin's sedge	A
	Lilium kelleyanum	Kelley's lilly	A
	Smilacina racemosa	western solomon's seal	A
	Smilacina stellata		A
	Triteleia ixioides ssp. anilina	golden brodiaea	A
	Veratrum californicum var. californicum	corn lily	A
	Zigadenus venenosus var. venenosus	death camas	A
	Allium validum	swamp onion	A
	Brodiaea elegans ssp. elegans	harvest brodiaea	A
	Fritillaria atropurpurea		A
Loasaceae (1)	*Mentzelia dispersa*	Nevada stickleaf	A
Malvaceae (1)	*Malva parviflora* *	Cheese weed	E
Onagraceae (17)	*Circaea alpina ssp. pacifica*	enchanter's nightshade	A
	Epilobium anagallidifolium		A
	Epilobium angustifolium ssp. circumvagum	fireweed	A
	Epilobium brachycarpum	panicled willow-herb	A
	Epilobium canum ssp. latifolium	California fuchsia	A
	Epilobium ciliatum ssp. ciliatum	northern willow-herb	A
	Epilobium ciliatum ssp. glandulosum	slender willow-herb	A
	Epilobium glaberrimum ssp. fastigiatum	glaucus willow-herb	A
	Epilobium glaberrimum ssp. glaberrimum	glaucus willow-herb	A
	Epilobium halleanum	Hall's willow-herb	A
	Epilobium hornemannii ssp. hornemannii	Horneman's willow-herb	A
	Epilopium lactiflorum		A
	Gayophytum decipiens		A
	Gayophytum diffusum ssp. parviflorum		A
	Gayophytum heterozygum		A
	Gayophytum humile	low gayophytum	A
	Gayophytum racemosum	black-foot gayophytum	A
Orchidaceae (3)	*Platanthera leucostachys*	white-flowered bog-orchid	A
	Corallorhiza maculata	spotted corralroot	A
	Spiranthes romanzoffiana	hooded ladies tresses	A

Family	Genus, species	Common name	Survey
Orobanchaceae (1)	*Orobanche fasciculata*	clustered broom-rape	A
Pinaceae (7)	*Pinus contorta ssp. murrayana*	lodgepole pine	A
	Pinus jeffreyi	jeffrey pine	A
	Abies concolor	white fir	A
	Abies magnifica var. magnifica	California red fir	A
	Pinus albicaulis	whitebark pine	A
	Pinus monticola	western white pine	A
	Tsuga mertensiana	mountain hemlock	A
Poaceae (45)	*Achantherum lemmonii*		A
	Achnatherum occidentalis ssp. californicum		A
	Achnatherum occidentalis ssp. occidentalis	western needlegrass	A
	Achnatherum occidentalis ssp. Pubescens		A
	Agrostis exarata	spike bent	A
	Agrostis idahoensis	Idaho redtop	A
	Agrostis scabra		A
	Agrostis thurberiana	Thurber bent	A
	Agrostis variabilis		A
	Bromus ciliatus	fringed brome	A
	Bromus laevipes		A
	Bromus suksdorfii		A
	Bromus tectorum *+	Cheatgrass	E
	Calamagrostis canadensis	bluejoint	A
	Calamagrostis stricta ssp. inexpansa	northern reedgrass	A
	Cinna bolanderi	Scribner woodreed	A
	Danthonia intermedia		A
	Deschampsia cespitosa ssp. cespitosa	tufted hairgrass	A
	Deschampsia danthonioides	annual hairgrass	A
	Deschampsia elongata	slender hairgrass	A
	Distichlis spicata	saltgrass	A
	Elymus elymoides ssp. californicus	squirreltail	A
	Elymus elymoides ssp. elymoides	squirreltail	A
	Elymus glaucus ssp. glaucus	blue wildrye	A
	Elymus trachycaulus ssp. trachycaulus	slender wheatgrass	A
	Glyceria elata	tall mannagrass	A
	Glyceria striata	fowl mannagrass	A
	Hordeum brachyantherum ssp. californicum		A
	Leymus triticoides		A
	Melica bulbosa		A
	Melica harfordii		A
	Melica stricta	rock melic	A
	Muhlenbergia andina	foxtail muhly	A
	Muhlenbergia filiformis	pull-up muhly	A
	Muhlenbergia richardsonis	mat muhly	A
	Phleum alpinum	mountain timothy	A

Family	Genus, species	Common name	Survey
	Phleum pretense *	cultivated timothy	A
	Poa annua *	annual bluegrass	A
	Poa bolanderi	Bolander's bluegrass	A
	Poa pratensis ssp. pratensis *	Kentucky bluegrass	A
	Poa secunda ssp. secunda	one-sided bluegrass	A
	Poa wheeleri	Wheeler's bluegrass	A
	Scribneria bolanderi		A
	Trisetum canescens	tall trisetum	A
	Trisetum spicatum	spike trisetum	A
Polemoniaceae (11)	*Allophyllum gilioides ssp. violaceum*	dense false gilyflower	A
	Allophyllum integrifolium		A
	Collomia linearis	narrow-leaved collomia	A
	Collomia tinctoria	yellow-staining collomia	A
	Gilia capillaris	smooth-leaved gilia	A
	Gilia leptalea	Bridges' gilia	A
	Ipomopsis aggregata ssp. formosissima		A
	Leptodactylon pungens	granite gilia	A
	Linanthus ciliatus	whisker brush	A
	Phlox gracilis	slender phlox	A
	Polemonium occidentale		A
Polygonaceae (13)	*Eriogonum nudum var. deductum*	tibinagua	A
	Eriogonum nudum var. nudum	tibinagua	A
	Eriogonum spergulinum var. reddingianum	spurry buckwheat	A
	Eriogonum umbellatum var. nevadense	sulfur flower	A
	Eriogonum umbellatum var. furcosum	sulfur flower	A
	Eriogonum wrightii var. subscaposum	bastard sage	A
	Oxyria digyna	mountain sorrel	A
	Polygonum bistortoides	western bistort	A
	Polygonum douglasii ssp. douglasii	Douglas' knotweed	A
	Polygonum douglasii ssp. johnstonii	Douglas' knotweed	A
	Polygonum polygaloides ssp. kelloggii	milkwort knotweed	A
	Rumex salicifolius var. salicifolius	willow dock	A
	Rumex salicifolius var. triangulivalvis	willow dock	A
Portulacaceae (6)	*Calyptridium monospermum*		A
	Calyptridium umbellatum	pussy paws	A
	Claytonia rubra ssp. rubra		A
	Lewisia nevadensis	Nevada lewisia	A
	Montia chamissoi	toad lily	A
	Lewisia triphylla		A
Potamogetonaceae (1)	*Potamogeton gramineus*	grass-leaved pondweed	A
Primulaceae (1)	*Dodecatheon jeffreyi*	Sierra shooting star	A
Pteridaceae (3)	*Aspidotis densa*	Indian's dream	A
	Cryptogramma acrostichoides	American parsley fern	A
	Pellaea breweri	Brewer's cliff-brake	A

Family	Genus, species	Common name	Survey
Ranunculaceae (10)	*Aconitum columbianum*	monkshood	A
	Aquilegia formosa	crimson columbine	A
	Delphinium glaucum	mountain larkspur	A
	Delphinium gracilentum	slender larkspur	A
	Delphinium nuttallianum	meadow larkspur	A
	Delphinium polycladon	high mountain larkspur	A
	Ranunculus alismifolius var. alismellus	water plantain oak	A
	Ranunculus cymbalaria var. saximontanus		A
	Thalictrum fendleri var. fendleri		A
	Thalictrum sparsiflorum		A
Rhamnaceae (2)	*Ceanothus cordulatus*	mountain whitethorn	A
	Rhamnus rubra	Sierra coffeeberry	A
Rosaceae (13)	*Amelanchier alnifolia var. semiintegrifolia*	service-berry	A
	Amelanchier utahensis		A
	Geum macrophyllum	bigleaf avens	A
	Holodiscus microphyllus var. microphyllus	rock spiraea	A
	Horkelia fusca ssp. parviflora		A
	Ivesia santolinoides	mousetail ivesia	A
	Potentilla diversifolia var. diversifolia		A
	Potentilla glandulosa ssp. nevadensis	sticky cinquefoil	A
	Potentilla gracilis var. fastigiata	slender cinquefoil	A
	Prunus emarginata	bitter cherry	A
	Rosa woodsii var. ultramontana	interior rose	A
	Sorbus californica	California mountain ash	A
	Spiraea densiflora	mountain spiraea	A
Rubiaceae (5)	*Galium aparine*	goose grass	A
	Galium bifolium	low mountain goosegrass	A
	Galium trifidum var. pusillum	trifid bedstraw	A
	Galium triflorum	sweet-scented bedstraw	A
	Kelloggia galioides	kellogia	A
Salicaceae (6)	*Populus balsamifera ssp. trichocarpa*	black cottonwood	A
	Populus tremuloides	quaking aspen	A
	Salix lemmonii	Lemmon's willow	A
	Salix lucida ssp. lasiandra	shining willow	A
	Salix jepsonii	Jepson's willow	A
	Salix scouleriana	Scouler's willow	A
Saxifragaceae (6)	*Heuchera rubescens var. alpicola*	pink alum root	A
	Heuchera rubescens var. rydbergiana		A
	Lithophragma glabrum	rock star	A
	Mitella breweri	Brewer's mitrewort	A
	Saxifraga nidifica var. nidifica	peak saxifrage	A
	Saxifraga odontoloma	brook saxifrage	A
Scrophulariaceae (28)	*Castilleja applegatei ssp. pinetorum*	indian paintbrush	A
	Castilleja miniata ssp. miniata	great red paintbrush	A

Family	Genus, species	Common name	Survey
	Castilleja parviflora		A
	Castilleja tenuis	hairy owl's clover	A
	Collinsia parviflora	blue-eyed mary	A
	Collinsia torreyi var. wrightii	Torrey's blue-eyed mary	A
	Mimulus sp.		A
	Mimulus breweri	Brewer's monkeyflower	A
	Mimulus guttatus	common large monkeyflower	A
	Mimulus laciniatus	cut-leaved monkeyflower	A
	Mimulus leptaleus	least-flowered monkeyflower	A
	Mimulus lewisii	great purple monkeyflower	A
	Mimulus moschatus	musk monkeyflower	A
	Mimulus pilosus	downy monkeyflower	A
	Mimulus primuloides ssp. primuloides	primrose monkeyflower	A
	Mimulus tilingii	larger mountain monkeyflower	A
	Pedicularis attollens	little elephant's head	A
	Pedicularis semibarbata	pine-woods lousewort	A
	Penstemon azureus var. azureus	azure beard-tounge	A
	Penstemon heterodoxus var. cephalophorus	Sierra beard-tounge	A
	Penstemon laetus var. laetus	gay beard-tounge	A
	Penstemon newberryi var. newberryi	mountain pride	A
	Penstemon rostriflorus		A
	Penstemon rydbergii var. oreocharis	meadow beard-tounge	A
	Veronica americana	American brooklime	A
	Veronica serpyllifolia ssp. humifusa	thyme-leaved speedwell	A
	Veronica wormskjoldii	American alpine speedwell	A
	Verbascum thapsus *+	Woolly mullein	E
Selaginellaceae (1)	*Selaginella watsonii*		A
Solanaceae (1)	*Solanum xanti*	purple nightshade	A
Typhaceae (2)	*Sparganium emersum ssp. emersum*		A
	Typha latifolia	broad-leaved cattail	A
Urticaceae (1)	*Urtica dioica ssp. holosericea*	hoary nettle	A
Valerianaceae (1)	*Valeriana californica*	California valerian	A
Violaceae (1)	*Viola macloskeyi*	Macloskey's violet	A
Viscaceae (1)	*Arceuthobium americanum*	lodgepole pine dwarf mistletoe	A

Appendix B. Vertebrate Species in Devils Postpile

Vertebrate species occurring in Devils Postpile National Monument from several surveys and research projects. Source of detection in the survey column: M = Medeiros, 1981; W = Werner, 2004; PR = Pierson & Rainey, 2009; D = Deinstadt, 1995; I = Siegel et al., 2004; P = Parker & Parker, 2001; H = Gates & Heath, 2003; O = PRBO surveys (Heath, 2005a; Heath, 2007; Richardson & Moss, 2010); DP = Devils Postpile NM staff (2009); N = listed on NPSpecies (NR Info) but no recorded detection. Those in BOLD not in NPSpecies (IRMA) lists.

* Considered nonnative even though it has arrived in the Sierra Nevada via range expansion; ** Detected just outside monument boundary; *** Probably present but not confirmed. **** May be present and not confirmed.

	Genus, species	Common Name	Survey	California Status
Birds (127)	*Buteo jamaicensis*	Red-tailed hawk	I, O	
	Accipiter striatus	Sharp-shinned hawk	N, O	CA sp of concern
	Accipiter cooperii	Cooper's hawk	P, O	CA sp of concern
	Circus cyaneus	Northern harrier	N	Sp of Special Concern
	Buteo lineatus	**Red-shouldered hawk**	DP, O	
	Accipiter gentilis	**Northern goshawk**	P, O	Sp of Special Concern
	Chordeiles minor	Common nighthawk	O	
	Aquila chrysaetos	Golden eagle	I, O	
	Haliaeetus leucocephalus	Bald eagle	P, O	Endangered
	Cathartes aura	Turkey vulture	O	
	Bubo virginianus	Great horned owl	P, O	
	Glaucidium californicum	**Northern pygmy-owl**	DP, O	
	Strix nebulosa	Great Gray Owl ****	M	Endangered
	Strix occidentalis	Spotted Owl ****	M	Sp of Special Concern
	Asio flammeus	Short-eared owl ****	N	
	Asio otus	Long-eared owl ****	N	Sp of Special Concern
	Falco sparverius	American kestrel	I	
	Ceryle alcyon	Belted kingfisher	P, O	
	Actitis macularia	Spotted sandpiper	W, I, O	
	Ardea heodias	Great blue heron	N	
	Larus californicus	California gull	W, P, O	
	Pelecanus erthrorhynchos	American white pelican	N	
	Phalacrocorax auitus	Double-crested comorant	N	
	Oreortyx pictus	Mountain quail	I, O	
	Rallus limicola	Virginia rail	I	
	Capella gallinago	Wilson's snipe	O	
	Zenaida macroura	Mourning dove	I, O	
	Dendragapus obscurus	Blue grouse	M	

	Genus, species	Common Name	Survey	California Status
	Fulica americana	American coot	N	
	Anas platyrhynchos	Mallard	I, O	
	Oxyura jamaicensis	Ruddy duck	O	
	Aythya collaris	Ring-necked duck ***	N	
	Mergus merganser	Common merganser	I, O	
	Anas strepera	**Gadwall**	D, O	
	Pandion haliaetus	Osprey	N, O	
	Cypseloides niger	Black swift	P, O	
	Chaetura vauxi	Vaux's swift	I	
	Aeronautes saxatalis	White-throated swift	I	
	Calypte anna	Anna's hummingbird	I, O	
	Stellula calliope	Calliope hummingbird	I, O	
	Selasphorus rufus	Rufous hummingbird	P, O	
	Selasphorus platycercus	Broad-tailed hummingbird	O	
	Melanerpes formicivorus	Acorn woodpecker	P	
	Picoides albolarvatus	White-headed woodpecker	W, I, O	
	Picoides pubescens	Downy woodpecker	I, O	
	Picoides villosus	Hairy woodpecker	I, O	
	Picoides arcticus	Black-backed woodpecker	I, O	
	Melanerpes lewis	Lewis's woodpecker	P	
	Sphyrapicus ruber	Red-breasted sapsucker	W, I, O	
	Sphyrapicus thyroideus	Williamson's sapsucker	W, P, O	
	Contopus sordidulus	Western wood-pewee	W, I	
	Corvus corax	Common raven	W, I	
	Cyanocitta stelleri	Steller's jay	W, I	
	Nucifraga columbiana	Clark's nutcracker	W, I	
	Parus gambeli	Mountain chickadee	W, I	
	Anthus rubescens	American pipit	M	
	Colaptes auratus	Northern flicker (Red-shafter flicker)	I, O	
	Contopus cooperi	Olive-sided flycatcher	I, O	Sp of Special Concern
	Empidonax oberholseri	Dusky flycatcher	I, O	
	Empidonax traillii	Willow flycatcher	P, O	Endangered
	Empidonax hammondii	Hammond's flycatcher	P, O	
	Empidonax wrightii	Gray flycatcher	P	
	Empidonax difficilis	Pacific-slope flycatcher	M	
	Sitta canadensis	Red-breasted nuthatch	W, I, O	
	Sitta carolinensis	White-breasted nuthatch	W, I	
	Sitta Pygmaea	Pygmy nuthhatch	DP, O	
	Cinclus mexicanus	American dipper	W, I	
	Regulus satrapa	Golden-crowned kinglet	W, I, O	
	Regulus calendula	Ruby-crowned kinglet **	P	
	Tudus migratorius	American robin	W, I	
	Vermivora celata	Orange-crowned warbler	W, P	

	Genus, species	Common Name	Survey	California Status
	Wilsonia pusilla	Wilson's warbler	W, I, O	
	Vermivora ruficapilla	Nashville warbler	I, O	
	Dendroica coronata	Yellow-rumped warbler	I, O	
	Dendroica occidentalis	Hermit warbler	I, O	
	Oporornis tolmiei	MacGillivray's warbler	I, O	
	Dendroica petechia	Yellow warbler	P, O	Sp of Special Concern
	Dendroica coronata auduboni	**Audubon's Warbler**	O	
	Piranga ludoviciana	Western tanager	W, I, O	
	Junco hyemalls	Dark-eyed junco, Oregon junco	W, I, O	
	Melospiza melodia	Song sparrow	W, I, O	
	Zonotrichia leucophys	White-crowned sparrow	W, I, O	
	Passerella iliaca	Fox sparrow	I, O	
	Melospiza lincolnii	Lincoln's sparrow	I, O	
	Passerculus sandwichensis	Savannah sparrow	P, O	
	Spizella breweri	Brewer's sparrow	P, O	
	Amphispiza bilineata	Black-throated sparrow	P, O	
	Spizella passerina	Chipping sparrow	O	
	Pooecetes gramineus	**Vesper sparrow**	DP, O	
	Stunella neglecta	Western meadowlark **	P	
	Euphagus cyanocephalus	Brewer's blackbird	W, I	
	Agelarius phoeniceus	Red-winged blackbird	I	
	Carpodacus cassinii	Cassin's finch	W, I	
	Carpodacus purpureus	Purple finch	I, O	
	Carduelis psaltria	Lesser goldfinch	P, O	
	Sayornis nigricans	**Black phoebe**	DP, O	
	Vireo gilvus	Warbling vireo	I, O	
	Vireo cassinii	Cassin's vireo	P, O	
	Vireo huttoni	Hutton's vireo ****	M	
	Tachycineta thalassina	Violet-green swallow	I, O	
	Petrochelidon pyrrhonota	Cliff swallow	I, O	
	Tachycineta bicolor	Tree swallow	P, O	
	Certhia americana	Brown creeper	I, O	
	Polioptila caerulea	Blue-gray gnatcatcher	O	
	Catherpes mexicanus	Canyon wren	M	
	Cistothorus palustris	Marsh wren	O	
	Salpinctes obsoletus	Rock wren	I	
	Troglodytes aedon	House wren	I, O	
	Thryomanes bewickii	Bewick's wren	N	
	Catharus guttatus	Hermit thrush	P, O	
	Catharus ustulatus	Swainson's thrush	O	
	Sialia currucoides	Mountain bluebird	I, O	
	Sialia mexicana	Western bluebird	N	
	Myadestes townsendi	Townsend's solitaire	I, O	

	Genus, species	Common Name	Survey	California Status
	Geothlypis trichas	Common yellowthroat	I, O	
	Pipilo chlorurus	Green-tailed towhee	I, O	
	Pipilo maculatus	Spotted towhee	P, O	
	Carduelis pinus	Pine siskin	I, O	
	Coccothraustes vespertinus	Evening Grosbeak	I, O	
	Pheucticus melanocephalus	Black-headed grosbeak	P, O	
	Pinicola enucleator	Pine Grosbeak	P, O	
	Passerina amoena	Lazuli bunting	P, O	
	Passerina cyanea	**Indigo bunting**	DP, O	
	Loxia curvirostra	Red crossbill	P, O	
	Bucephala albeola	Bufflehead **	P	
	Charadrius vociferus	Killdeer	O	
	Bombycilla cedrorum	**Cedar waxwing**	DP, O	
	Molothrus ater	Brown-headed cowbird*	I, O	
Mammals (37)	*Epesicus fuscus*	Big brown bat	PR	
	Eudezema maculatum	Spotted bat	PR	Sp of Special Concern
	Lasionycteris noctivagans	Silver-haired bat	PR	
	Lasiurus cinereus	Hoary bat	PR	
	Myotis evotis	Long-eared myotis bat	PR	
	Myotis lucifugus	Little brown bat	PR	
	Myotis volans	Long-legged myotis bat	PR	
	Myotis yumanensis	Yuma myotis bat	PR	
	Eumops perotis	Western mastiff bat	PR	Sp of Special Concern
	Tadarida brasiliensis	Brazilian free-tailed bat	PR	
	Antrozous pallidus	**Pallid bat** ***	PR	Sp of Special Concern
	Lasiurus blossevillii	**Western red bat** ***	PR	Sp of Special Concern
	Myotis thysanodes	**Fringed myotis bat** ***	PR	
	Canis latrans	Coyote	DP	
	Urocyon cinereoargenteus	Gray fox ***	DP	
	Vulpes vulpes	Red fox ***	DP	
	Puma concolor	Mountain lion	DP	
	Ursus americanus	Black bear	W	
	Procyon lotor	Raccoon	DP	
	Martes Americana	Marten	W	
	Mustela erminea	Ermine	DP	
	Mustelea frenata	Long-tailed weasel	DP	
	Bassariscus astutus	Ringtail	DP	
	Odocoileus hemionus	Mule deer	W	
	Marmota flaviventris	Yellow-bellied marmot	DP	
	Sorex monticolus	Montane shrew	DP	
	Sorex palustris	**Northern water shrew**	DP	
	Spermophilus beldingi	Belding's ground squirrel	W	

	Genus, species	Common Name	Survey	California Status
	Spermophilus lateralis	Golden-mantled ground squirrel	W	
	Tamias speciosus	Lodgepole chipmunk	W	
	Tamiasciurus douglasli	Douglas' squirrel	W	
	Thomomys monticola	Mountain pocket gopher	DP	
	Peromyscus boylii	Brush mouse	W	
	Peromyscus maniculatus	Deer mouse	W	
	Microtus longicaudus	Long-tailed vole	W	
	Neotoma cinerea	Bushy-tailed woodrat	DP	
	Erethizon dorsatum	Porcupine ***	DP	
Reptiles (8)	*Sceloporus graciosus*	Sagebrush lizard	W	
	Sceloporus occidentalis	Western fence lizard	W	
	Elgaria coerulea	Northern alligator lizard	W	
	Charina bottae	Rubber boa	DP	
	Masticophis lateralis	**Striped racer**	DP	
	Thamnophis elegans	Western terrestrial garter snake	DP	
	*Crotalus viridis ****	Western rattlesnake	DP	
	Eumeces gilberti	Gilbert's skink	DP	
Amphibians (1)	*Pseudacris regilla*	Pacific Treefrog	W	
Fish (4)	*Oncorhynchus mykiss*	rainbow trout	D	
	Oncorhynchus mykiss aguabonita	golden trout	D	
	Salmo trutta	brown trout	D	
	Salvelinus fontinalis	brook trout	D	

* Considered non-native even though it has arrived in the Sierra Nevada via range expansion
** Detected just outside monument boundary
*** Probably present but not confirmed
**** May be present and not confirmed
BOLD = not in NPSpecies (NR Info) lists

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National Park Service
U.S. Department of the Interior

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