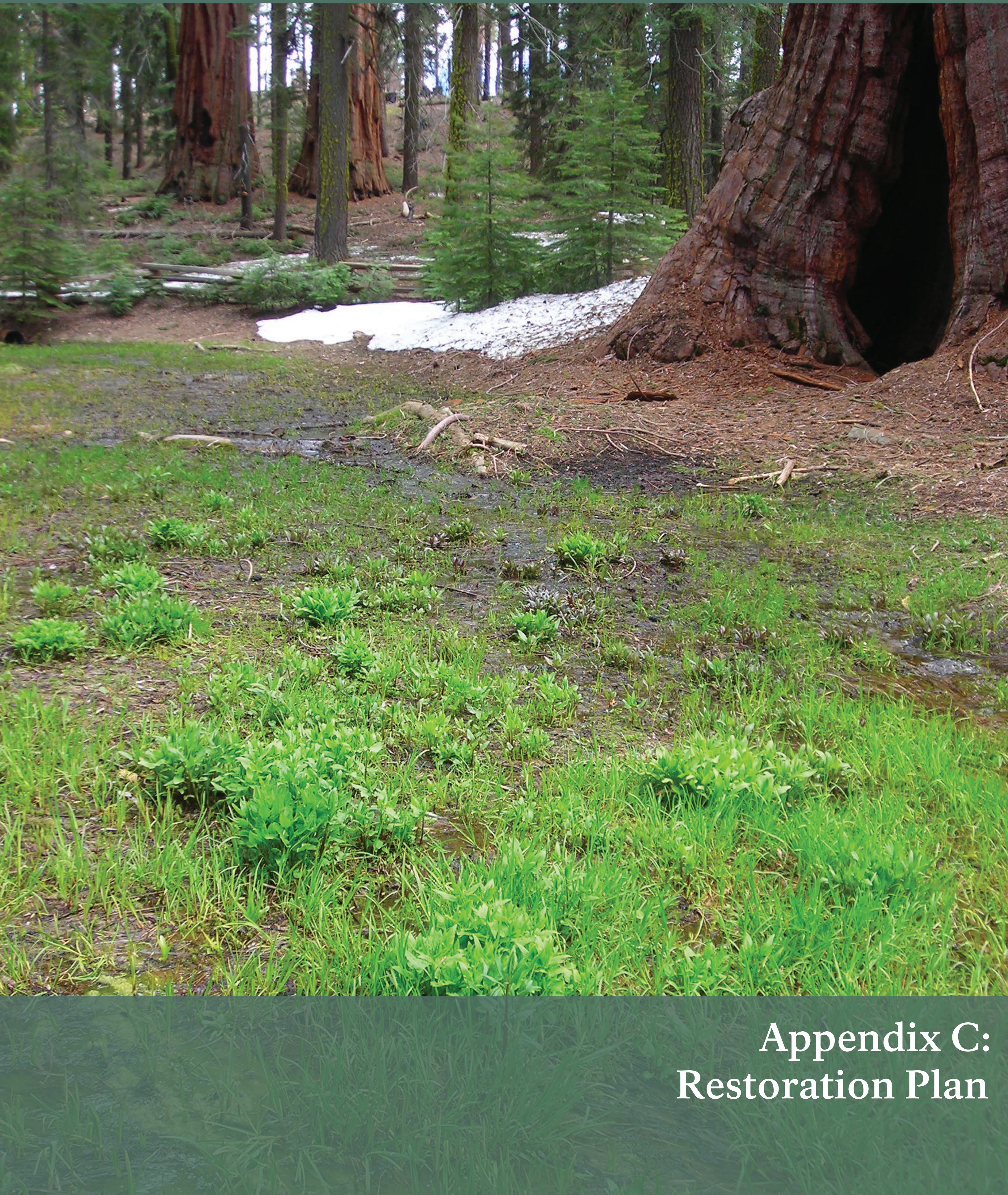
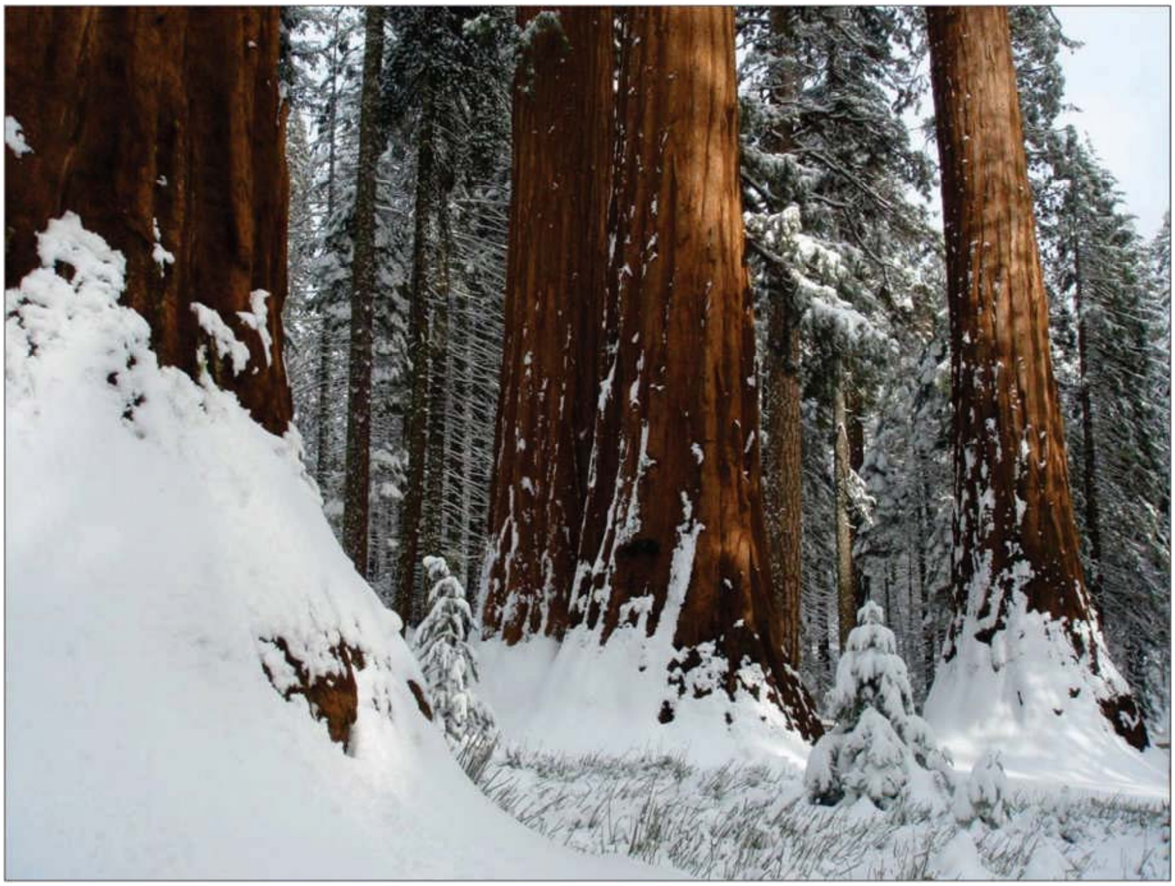


Appendix C: Restoration Plan

Ecological Restoration Planning for the Restoration of the Mariposa Grove of Giant Sequoias



2012

ECOLOGICAL RESTORATION PLANNING FOR THE RESTORATION OF THE MARIPOSA GROVE OF GIANT SEQUOIAS

DIVISION OF RESOURCES MANAGEMENT AND SCIENCE

YOSEMITE NATIONAL PARK

Written by

Monica Buhler and Sue Beatty

Reviewed by

Judi Weaser

Cover Photo:

Winter of 2010 in the upper portion of the Mariposa Grove (A. Colwell)

TABLE OF CONTENTS

INTRODUCTION

This report presents an ecological restoration plan to support the Restoration of the Mariposa Grove of Giant Sequoias Plan and Environmental Impact Statement (Mariposa Grove Plan). It provides a description of sites recommended for ecological restoration in the Mariposa Grove area, incorporating the most recent natural resource condition assessments and analyses of the Grove. This report also addresses cultural resources, American Indian consultations and park infrastructure and operations. We also present best management practices and general guidelines for ecological restoration and project implementation in the Mariposa Grove.

Several studies frequently cited in this document provide baseline information on hydrology, vegetation, wildlife, visitor use and cultural resources that direct ecological restoration efforts and priorities. Kuhn (2011) completed a landscape and population analysis of the giant sequoias in the Mariposa Grove, providing quantitative and qualitative information about the distribution and age class of all giant sequoias occurring in the grove. Kuhn and Roche (2011) assessed hydrologic conditions in the grove and identified point source and landscape level concerns, along with proposed mitigations. Buhler (2011) assessed current vegetation conditions and distribution in the grove, fire history and other vegetation management. Colwell (2010) completed a comprehensive plant survey that identified the occurrence and distribution of sensitive plant species and non-native plants, and compiled a plant list for the area. Repath (2011) completed a wetland delineation to identify the spatial distribution and condition of wetlands in the Mariposa Grove. Finally, Stock (2011) assessed wildlife populations occurring in the Mariposa Grove, focusing on special status species. A cultural resource summary completed by Bane (2011) provides information on cultural resources in the grove, both historic and prehistoric. These studies help managers propose resource based and informed recommendations on the most effective ecological restoration of the Mariposa Grove.

Many of the proposed ecological restoration guidelines and actions are based on the experience and success of the Giant Forest restoration in Sequoia and Kings Canyon National Parks. This provides us with confidence that recommended restoration tools and methods are likely to succeed.

Ecological Restoration Planning for the Restoration of the Mariposa Grove of Giant Sequoias

By Monica Buhler and Sue Beatty

The Mariposa Grove of Giant Sequoias

The Mariposa Grove of Giant Sequoias is one of the most significant natural and cultural resources in Yosemite National Park. In 1864, Congress passed a bill granting the Yosemite Valley and the Mariposa Grove of Big Trees to the State of California. President Lincoln signed this innovative law, which required California to manage this new park for "public use, resort, and recreation." Protection of the grove was crucial in this time period as logging of other giant sequoia groves was ongoing. There are three groves of giant sequoias in Yosemite National Park: the Mariposa Grove, Merced Grove, and Tuolumne Grove. The Mariposa Grove is the largest, containing 86% of the park's mapped adult giant sequoias and estimated to receive more than one million visitors annually.

Over the years, policies and programs aimed at protecting giant sequoia in the national parks and forests of the Sierra Nevada, including Yosemite, have evolved from the protection of individual trees to the preservation of entire groves. Understanding of the giant sequoia life cycle and ecology is still evolving but several key points are important to consider for effective restoration and management. (York et al. in press).

- Giant sequoias are relatively rare and only occur in disjunct groves on the western slope of the Sierra Nevada, numbering 65 to 75 (depending on whether adjacent groves are lumped or split) covering approximately 14,600 ha.
- Despite the difficulty of using giant sequoia wood, loggers cut 34% of the original sequoia acreage between 1856 and the mid-1950s.
- Trees may live as long as 3,200 years
- Past shifts in the distribution of giant sequoia groves are thought to be driven by changes in climate. Today's distribution appears to be constrained by cold temperatures at upper elevations and insufficient water at lower elevations.
- Giant sequoias typically occur in mixed conifer forests and may be the dominant species in terms of basal area, but are relatively uncommon in terms of density of individuals.

- Trees have several adaptations to fire (e.g. thick and non-resinous bark, serotinous cones, scorch-resistant foliage, epicormic sprouting).
- Its life history strategy is a combination of pioneer (i.e. light seeds, rapid post-disturbance colonization, rapid growth) and late-seral species (longevity, large size) strategies. It is perhaps best classified as a "long-lived pioneer, "ideal for regenerating, recruiting, and persisting within the context of a low and moderate severity fire regime.

Giant sequoia germination, establishment and persistence are largely driven by fire and hydrology, and both of these processes are profoundly altered in the Mariposa Grove. Giant sequoias are extraordinary records of fire history because of their resistance to rot, ability to heal quickly from fire damage and extreme longevity. Swetnam et al. (1990) reconstructed a 1,438 year long fire history of the Mariposa Grove and found that frequency of fires ranged from annually (although very patchy), to the longest fire-free period of 15 years; with an average range of every 5-8 (6.5) years. Fire suppression policy beginning in the late 1800's led to an approximately 100 year fire-free period, until prescribed burning began in 1971. The absence of fire along with 40 years of prescribed burning has shaped current forest structure in and around the grove, as well as the current number and distribution of younger giant sequoias. Giant sequoia populations only occur where hydrologic conditions provide ample surface and subsurface water to maintain moist, but not saturated, soils (Rundel 1962). Recent assessments of hydrologic conditions in the Grove indicate that current infrastructure has altered surface flow, water storage and soil conditions in the Mariposa Grove, which is likely to affect the existing and future population of giant sequoias. The ecological restoration of fire and hydrology should be the central focus to ensure success.

THE NEED FOR ECOLOGICAL RESTORATION

Giant sequoia groves are sites of exceptional ecological importance and are therefore priorities for ecological restoration. While the area of the Mariposa Grove is small (less than 900 acres) over 20% of wildlife and plant species occurring in Yosemite National Park occur in or utilize the grove. This report describes potential ecological restoration actions for currently impacted areas in the Mariposa Grove area, including developed areas that require restoration if infrastructure is moved or removed, as well as undeveloped areas that have directly or indirectly been altered by human activities.

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed and is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability (SER 2004). When preserving and restoring any ecosystem we often focus on reference conditions that describe a range of ecosystem conditions (i.e. structure, composition and function) occurring in a defined area for a particular time period prior to Euro-American settlement (Stephenson 1999). This is problematic when so many unknowns seem to overwhelm the knowledge we do have. However, we do have an extensive knowledge base that allows us to draw informed conclusions about conditions and trends and can make recommendations to improve conditions. The most successful ecological restoration focuses on key processes (particularly fire and hydrology), and how to restore their function and to maximize the resilience and resistance of an ecosystem (Stephenson 1999, Whisenant 1999).

Through ecological restoration in the Mariposa Grove, we strive to restore and maintain natural processes, primarily fire and hydrology, which sustain the giant sequoia ecosystem and provide conditions ideal for the perpetuation of native flora and fauna. Ecological restoration is also needed to restore natural conditions if infrastructure is removed, updated, or relocated.

Important cultural resources are numerous in the Mariposa Grove area, including the adult giant sequoias themselves and the following programmatic guidance and collaboration with cultural resource staff will ensure protection during ecological restoration implementation. Archeological sites are fragile, non-renewable resources and contain important information potential about past life ways and represent tangible heritage resources for park-associated American Indian peoples, as well as the visiting public. Where archeological sites are subject to ongoing impacts through social trails or visitor use, these areas will be carefully assessed for stabilization needs. Social trails will be removed and visitor use in these areas will be discouraged, using techniques that retain the data potential of the resource while encouraging native vegetation establishment and persistence. Where ecological restoration actions have the potential to affect cultural resources, the actions will be designed to avoid impacts wherever feasible. If avoidance is not possible, archeological site treatments such as controlled testing, and data recovery excavations where necessary, will be employed to reduce the level of impact and thereby avoid adverse effects. All treatments for pre-contact archeological sites will involve close consultation with park-associated American Indian tribes and groups to ensure these treatments incorporate native concerns, issues and perspectives.

This plan identifies both passive and active ecological restoration actions to restore natural structure and processes as well as protecting cultural resources. Passive restoration actions may include fencing and signing sensitive areas, which will halt human impacts and allow natural processes to repair damage. Active restoration actions include removing infrastructure (roads, asphalt, and underground utility lines), soil decompaction, revegetation, prescribed burning, removing hydrologic impediments and removal of formal and informal trails out of sensitive areas. These actions will accelerate ecosystem recovery and promote the health and longevity of the giant sequoia population.

ECOLOGICAL RESTORATION GOALS AND OBJECTIVES

The long-term preservation of giant sequoias is dependent on mitigating and minimizing the influences of human activities. In the past 40 years, managers across the Sierra Nevada have sought to remove infrastructure (such as the large restoration project in the Giant Forest of Sequoia National Park) and to restore the fire regime and hydrologic connectivity to giant sequoia groves. This ecosystem approach is centered on three key management goals (Piirto and Rogers 1999):

- Protect naturally occurring groves from human impacts (e.g. infrastructure, logging) and disturbances outside a natural range of variability (i.e. stand replacing fire).
- Preserve the groves by allowing and promoting natural ecosystem processes to prevail
- Actively restore impaired ecosystem functions, particularly fire and hydrology

The overarching goal of ecological restoration in the Mariposa Grove is to promote giant sequoia germination and establishment and ensure the persistence and longevity of the giant sequoia population. In order to achieve this goal, a combination of restoration actions will provide the best avenue for achieving the following ecological restoration objectives:

- Protect, maintain and enhance environmental conditions and ecosystem function required to sustain the population of giant sequoias
    - Ensure germination and recruitment through frequent surface fires
    - Create and maintain canopy gaps to facilitate giant sequoia germination and recruitment
    - Conduct prescribed burning outside of the Mariposa Grove to reduce the risk of a catastrophic fire originating outside of the grove
    - Protect individual trees and seedling habitat from structural damage sustained by roads, trails, utilities and visitor trampling
- Protect, maintain and restore natural hydrologic function in the Mariposa Grove of Giant Sequoias

  - Remove or modify infrastructure that impacts sheet flow hydrology
  - Where roads and trails remain, remove inside ditches, outslope cutbank areas and replace or install culverts to facilitate surface flow
  - Protect and restore wetlands
- Restore areas impacted by the removal, alteration or relocation of infrastructure to natural conditions
- Maintain and manage structure and composition of native vegetation within the range of natural variability and so that if functions dynamically in a long-term time frame (50-100 years)
  - Continue prescribed burning and modify as needed to reach target forest conditions
  - Minimize hazard tree removal to retain large snags for wildlife habitat
  - Continue invasive plant removal in and around the grove

By removing infrastructure from groves, protecting the roots of giant sequoias from the impacts of roads, trails, and foot traffic, removing impediments to natural surface and subsurface water flow, and restoring a natural fire regime (augmented by prescribed fire as necessary), we can effectively preserve, protect, and restore these unique ecosystems. Management must also focus on understanding and managing for the effects of anthropogenic factors such as air pollution and greenhouse gas driven climatic change.

Best Management Practices and Resource Protection Zones

Multiple actions will be taken across all alternatives to protect and restore ecological processes and the giant sequoia population. In order to minimize impacts to natural and cultural resources when implementing project actions, several mitigations and best management practices to ensure protection of resources in the grove during project implementation are listed below. Many of these guidelines are based on the successful ecological restoration project in Giant Forest, Sequoia National Park (USDI 1995).

General practices

- Limit future impacts in the natural and cultural resource protection zones: 300 feet from wetlands or streams, 50 feet from rare plant populations and 200 feet from adult giant sequoias, 100 feet from juvenile and 50 feet from seedlings and saplings and wildlife buffers. Current actions will occur in these zones to accomplish ecological restoration goals.
- All equipment used in the grove should have a low compaction factor and may include excavator, dozer, backhoe, loader, skid steer and dump truck.
- Ensure that local impact does not degrade the surrounding area, specifically giant sequoia, wetland, or riparian ecosystems or any primary ecological processes, by limiting size and development of staging and construction areas
- Minimize any impacts to giant sequoias including the bole, roots, root zone and seedling habitat
- Minimize impacts to hydrology and reduce erosion potential
- Minimize impacts to wetlands and processes (hydrology) that sustain them
- Minimize impacts to wildlife by monitoring and arranging (i.e. modify time of day, season etc.) construction or maintenance activities
- Ensure that any soil used from outside of the Grove is checked for pathogens (e.g. root rot) to limit the spread of tree diseases
- Ensure that all equipment and materials are weed seed free
- Protect rare or sensitive plant and animal species from direct and indirect impact
- Protect restoration areas from further impacts with fencing or appropriate deterrents
- Establish vegetation monitoring plots (both qualitative and quantitative) and photo-document project implementation and results

Wildlife

Based on all available anecdotal and scientific evidence, 78 amphibian, reptile, mammal, and bird species occur in the Mariposa Grove and South Entrance project areas. Of these 78 species, 13 are special status species, including 7 bird species (northern goshawk, golden eagle, peregrine falcon, bald eagle, great gray owl, California spotted owl, and olive-sided flycatcher) and 6 mammal species (pallid bat, spotted bat, western red bat, western mastiff bat, Sierra Nevada mountain beaver, and Pacific fisher).

Snags are an essential habitat element for the majority of special status species documented using the Mariposa Grove. Removal of snags may indirectly result in decreased rates of reproduction and increased rates of mortality for fisher (USDA Forest Service 2001) and spotted owls use cavities in snags for nesting and raising young. The following management recommendations protect key habitat features for fisher, bats, and owls.

- Minimize hazard tree removal and protect and restore vegetation and wildlife habitat
    - Retain and recruit large diameter snags (Freel 1991, Buskirk and Powell 1994) and large diameter (greater than 24" dbh) live conifer and oak trees with decadence such as broken tops or cavities (Freel 1991).
    - Retain and recruit large woody debris, including large diameter (at least 15 in dbh by 15 ft long) down logs (Freel 1991, Buskirk and Powell 1994) and complex structure near the ground (e.g., down logs, large down branches, root masses, live branches) (Buskirk and Powell 1994).
- If hazard tree removal cannot be avoided
    - Remove snags only under consultation with the park biologist and park forester.
    - Prior to removal, a wildlife biologist will examine any trees and snags for nesting, denning, or roosting wildlife
- Avoid disturbing basal hollows (created by repeated fires), deep bark furrows, and cavities and crevices of tree crowns important for bats and other wildlife (Pierson et al. 2006).
- FISHER: Park biologists will continue to work closely with fisher researchers working in and around the park to establish whether fisher are actively foraging or denning near the project area, and may set additional protection measures as deemed necessary, to avoid disturbance during construction or restoration-related activities.
- OWLS: Conduct surveys in the spring (beginning March 15) to determine if spotted owls are nesting and foraging in the vicinity of the construction/restoration area. If owls are present, construction project manager should work with biologist to determine appropriate measures to avoid disturbance, such as no construction activities between 30 minutes before dusk and after dawn, and a 400 meter buffer of no disturbance (light or noise) around nest trees from March 15 through August 31.
- BATS: If a project targets any trees for removal during the winter, a biologist should survey for roosting bats in the preceding fall (September and October). If the biologist suspects hibernation in a tree, do not remove that tree until mid-April to mid-May. If a project targets any trees for removal during the summer, a biologist should survey for roosting bats within one-week prior to removal to determine if a bat maternal colony occurs in the tree.
- WILDLIFE USE: In construction zones, carnivore cameras, owl and bird surveys, and bat acoustic surveys will be installed as needed to inform proper mitigation actions that would reduce impacts to wildlife.

Soil conditions

Where soils are heavily compacted and are covered with asphalt, soil conditions may be such that reestablishment of vegetation is unlikely without further treatment. Demetry (1997) found that soil impacts most frequently observed in Giant Forest were soil compaction, loss of organic matter, topsoil erosion and loss or alteration of natural soil structure. Soil compaction was highest under pavement (Demetry 1997).

Soil conditions in restoration areas of the Mariposa Grove will be tested for compaction, texture and chemical properties such as organic matter content and nitrogen, and amendments or treatment will be applied accordingly. Listed below is a range of soil treatments available to improve the potential for plant establishment, particularly giant sequoias.

- Measure depth of compaction with a penetrometer and decompact to that depth (typically 6-10 inches), (Demetry 1997)
- Decompact soils by hand or with heavy equipment (dozer or skid steer with rippers) under moderately moist conditions (may require 1 week of irrigation if work is completed in late summer or fall)
- Avoid large roots during decompaction; a rototiller or hand decompaction may be more appropriate in these areas
- Add locally gathered duff to provide seeds and organic matter
- If available, add local native soil and topsoil
- If determined that soil conditions are not conducive to plant reestablishment, amendments such as peat moss, kelp or other natural fertilizers may be used.
- To provide nutrients to the soil, open up cones on adult giant sequioas and prepare a seedbed, woody debris may be scattered and burned over the area. If woody debris is not available for burning, fuel may be burned at a single location and the ashes mixed into the topsoil of the restoraiton area

Surface topography

Depending on the degree of alteration in landform, a variety of recontouring and topography restoration actions may be implemented and are listed below:

- Regrade with existing soil: Where extensive recontouring to natural topography is required (e.g. road cuts) we will attempt to accomplish this through re-balancing cut and fill.

- Fill: Where additional material is needed, soils of the same type from the Mariposa Grove area is preferable but may need to be imported from South Entrance or other nearby locations
- Topsoil retention: Wherever removal or compaction to topsoil will occur, the top 12 inches of soil will be salvaged, stockpiled and replaced on the surface. To preserve microbial communities and limit erosion and the establishment of weeds, all soil piles will be mulched or covered with erosion blankets
- Final grade will be uneven to provide microhabitat for seed germination and establishment

Site preparation

After decompacting soils, particularly on sloped areas, potential for erosion can be high. Following is a list of available erosion control measures.

- Duff: Locally gathered litter and woody debris will be spread over disturbed areas for erosion control as well as provide a source of seeds and organic matter.
- Rice straw: If sufficient quantities of duff are not available, rice straw mulch (relatively inert and not a source of non-native seeds) may be used.
- Erosion control blankets and/or wattles: Erosion control blankets and/or wattles will only be used on steep slopes (3:1 or greater) and in unprotected drainages. Coconut fiber or rice straw will be used.
- Stones, boulders, limbs and logs: In conjunction with any other erosion control methods, these materials (gathered from adjacent areas) may be placed on the surface to provide microclimate for plants and slow water flow.

Revegetation

There is a range of actions available to revegetate an area with native plants and a combination will provide the most successful restoration. For any revegetation activities within the grove, only locally gathered plant material will be used to retain genetic integrity.

- Natural regeneration**:** Rely on natural regeneration from adjacent seed sources and duff
- Seed collection, seed increase and direct seeding: Plant the area with local native seed. It may not be practical to collect enough seed for direct seeding of the acreage involved. Increasing seed can provide necessary quantities. This process requires three years.
- Seed or cutting collection and nursery propagation: Local native seeds and cuttings are gathered and planted in a nursery setting to provide established plants for planting in restoration areas. Plants are placed in a way to mimic natural distribution – not landscaping. This requires 1-3 years.

- Plant salvage and transplanting: In cases where plants may be damaged or destroyed when infrastructure is removed, repaired or relocated, plants can be salvaged and replanted when the area is recontoured to more natural conditions, or in an adjacent restoration site. Salvaged plants will be stored on site and protected with shade cloth and irrigated as necessary.
- Giant sequoias: nearly all restoration sites lie within the seed rain area of adult giant sequoias so the need for propagating giant sequoias in a nursery setting and planting these trees is not likely to be necessary for germination and recruitment. Rather, sites will be prepared to facilitate germination including burning woody debris to provide nutrients and a heat source to open cones on the trees. If seed dispersal does not occur (e.g. adequate heat is not created), some hand spreading of locally collected giant sequoia seeds may occur.

Canopy gaps

Canopy gaps are integral to successful giant sequoia recruitment. The Giant Forest Restoration Project focused on creating and maintaining gaps as part of the restoration because according to their assessments of existing recruitment and gaps, neither was adequate. However, based on our assessment of the giant sequoia population in the Mariposa Grove, we found that many gaps exist in the Mariposa Grove and recruitment is relatively high when compared to other groves (Kuhn 2011). Based on this assessment, we will continue to rely on fire to create and maintain these canopy gaps and capitalize on the gaps created by existing infrastructure (e.g. parking areas) as areas for giant sequoia recruitment.

Ecological Restoration Actions Common to All

Several restoration actions common to all action alternatives provide an avenue into restoring processes and some structural components to giant sequoia ecosystem. These actions are organized by topic below.

Prescribed burning and invasive plant removal are both on-going activities occurring in the grove and will continue. Invasive plant removal will follow the guidelines of the Invasive Plant Management Plan. Prescribed burning for resource benefits will follow the Fire Management Plan but prioritizing burning outside of the grove is key for effective restoration. Management of the scenic values of the grove will be managed following the 2010 Scenic Vista Management Plan.

FIRE

Frequent surface fires produce optimum conditions for giant sequoia reproduction and persistence by: 1. removing thick layers of dead and downed woody debris; 2. providing nutrients to the active seed by exposing bare mineral soil with a thin layer of ash; 3. maintaining an open canopy and creating canopy gaps that provide sunlight exposure and reduce competition; and, 4. heating the cones causing a release of large numbers of seeds (USDI 2004). Prior to fire suppression policy, frequent fires regularly consumed accumulated woody debris, a critical role in nutrient cycling, and burned smaller trees, maintaining a more open forest and often creating canopy gaps from pockets of higher intensity fire (Hartesveldt and Harvey 1967, Harvey et al. 1980). These canopy openings are required for successful regeneration of shade intolerant species such as giant sequoia (Hartesveldt and Harvey 1967, Harvey et al. 1980). In the absence of frequent fire, increased density of shade-tolerant conifers (primarily white fir and incense cedar) coupled with unprecedented levels of accumulated fuels leave these forests susceptible to stand replacing fires (Webster and Halpern 2010).

While summarized plot data for the Mariposa Grove are not statistically conclusive, trends indicate that prescribed fire is very effective at reducing density of trees less than 30 inches in diameter while causing limited mortality in trees larger than 30 inches in diameter. However, species composition data indicate a proportional increase in white fir, including larger trees, while pine (sugar and ponderosa) is decreasing. This decline in large trees is occurring at a landscape level in Yosemite National Park as well as across the Sierra Nevada range (Lutz et al. 2009).

Although we may be approaching target forest structural conditions (in terms of density) *within* the boundaries of the Mariposa Grove, all forests surrounding the grove have not burned in over 100 years and are far outside target conditions, leaving the grove vulnerable to high intensity fires originating outside of the grove. We are uncertain if current burning is sufficient to influence the resilience or likelihood that the giant sequoia grove will withstand a large, landscape wildfire. Burning and/or fuel treatments around the Mariposa Grove are essential to protect this important habitat and should be at the forefront of our objectives for restoration.

In continuing to manage fire in and around the Mariposa Grove, it is important to consider the dynamic nature of fire as well as vegetation response and to emphasize that variation in fire frequency, size and intensity, as well as looking at a landscape level, is key for restoring and maintaining the giant sequoias in the Mariposa Grove.

Following is a list of proposed actions to restore and maintain fire as a primary disturbance process.

- Conduct prescribed fire (adjusting season, intensity and frequency) to reach target conditions outlined in the Yosemite Fire Management Plan focusing on heterogeneity
    - Increase size of burn units to minimize hazard tree cutting and impacts from line construction
    - Create and maintain canopy gaps to facilitate giant sequoia and pine recruitment
    - Continue to monitor forest structure and modify fire prescription to promote pine and giant sequoia germination and establishment
    - Maintain a mosaic forest structure that provides some dense canopy in the vicinity of large trees for Pacific fisher habitat (Buskirk and Powell 1994) but also opens up forest canopy and reduces the chance of large scale stand replacing fire.
    - Retain forest structure with multi-layered vegetation (vertical within-stand diversity), (Freel 1991).
- Conduct prescribed fires or fuel treatments outside of grove and around the South Entrance (requires collaboration with USFS) within five years of implementation of the Mariposa Grove Restoration Plan to reduce the risk of catastrophic fire originating outside of the grove. This is a priority for Yosemite's Prescribed Fire Program. Rather than restrict treatment to a particular area buffer, focus on the landscape level is essential to protect the Mariposa Grove and any investment into restoration.

HYDROLOGY

As with most giant sequoia groves, in-depth hydrologic studies in the Mariposa Grove are lacking. Thus, we are unable to quantify changes to hydrologic conditions in the Grove and are limited to the assessment of current conditions in relation to inferences on likely conditions in the past and from hydrologic studies in other giant sequoia groves.

Existing studies in giant sequoia ecosystems suggest that optimal hydrologic conditions include adequate soil-moisture for recruitment of successive giant sequoia cohorts (Rundel 1972), seed germination (Weatherspoon 1986), and seedling survival and growth (Hartesveldt and Harvey 1967). Anderson (1995) qualified that available water was topographically driven, and giant sequoias positioned in topographic lows would be less likely to experience drought stress due to surface and shallow soil water inputs from catchment hillslopes. York et al. (in press) described that changes in climatic water deficit—water balance and drought stress—may be as important as altered fire regimes on giant sequoia ecosystems.

Hydrologic alterations in the Mariposa Grove include surface flow impacts, channelization, soil compaction, and hardened surfaces. Channelization of surface runoff within the Grove accelerates drainage and reduces the volume and timing of water available for infiltration, soil moisture, and subsequent uptake by giant sequoias. In addition, the channelized flow can transport chemical pollutants directly to aquatic ecosystems. Soil compaction affects hydrologic conditions of the unsaturated zone by altering soil structure, at both the surface and within the soil profile. Similar to the presence of hardscape features within the Grove, compaction of the soil surface reduces infiltration rates and thereby augments surface runoff. Surface compaction inhibits successful seed germination of giant sequoia seedlings (Hartesveldt et al. 1975, Demetry 1997), and can alter soil structure and associated porosity. Thus, soil compaction may affect the sustainability of the Grove by limiting water infiltration, seed germination, and root development of giant sequoia.

The lower portion of the main Rattlesnake Creek channel (roughly 0.5 miles upstream from the bridge crossing at the lower Grove parking area to the watershed outlet) is notably entrenched. As there is not a defined headcut, the source of this anomaly remains undetermined. However, both the outer loop trail and the water supply pipeline do cross this channel roughly 200 feet downstream from the upper extent of the entrenched channel. Signs of recovery (streambank and floodplain formation) were observed but rates of sediment accretion are likely low and reconnections with the floodplain will likely take decades.

- Facilitate surface water infiltration into soil subsurface horizons
    - Reduce soil compaction within the grove watershed, and especially within the rooting zone of all existing giant sequoia trees and in areas of likely recruitment (i.e., forest canopy gaps)
    - Remove or redesign roadways and trail systems such that they are out-sloped eliminating the need for culverts and drainage ditches.
    - Mulch denuded areas to reduce erosion potential and increase water holding capacity
    - Investigate Rattlesnake Creek channel entrenchment and replace or repair trail crossing or other impediments to flow (may include a bridge)

WETLANDS

The Mariposa Grove and its wetlands are not only unique because of the presence of giant sequoias but also because of the great diversity of habitats, plants and wildlife. Wetlands in the Grove form an almost continuous, dendritic network and make up a significant portion (12.3%) of the watershed. These wetlands provide important hydrologic support for the Merced Watershed. Hydrologic functions provided by such wetlands include aquifer recharge, storm runoff abatement, sediment retention, prevention of erosion through streambank stabilization, and stream/river temperature moderation.

Mariposa Grove wetlands have very high biotic functions and values. This area contains a rich mosaic of old growth forest (with trees of all age classes, standing snags and large downed trees), streams and wetlands. These habitats support a great variety of plant and wildlife species, including a number of special status species. Area wetlands have high native plant productivity, cover, and diversity. In addition, several fens, which have a limited distribution in the Sierra Nevada, are present.

Overlaying the position of giant sequoias in the Grove with delineated wetlands, roughly 82% of giant sequoias are located within 200 feet of delineated wetlands (Kuhn 2011). This supports conclusions by Halpin (1995) on the importance of topographic flow accumulation, and further signifies the importance of soil water availability within the rooting zone for giant sequoia.

Roughly 0.42 miles of paved road surfaces are located within wetlands, as determined by spatial overlay the of wetland extent on the road network within the Grove area. In these locations, the compacted road prisms may influence wetland function within the Grove; Forman and Alexander (1998) reported the hydroperiod (i.e., the timing and extent of inundated and saturated conditions) of wetland habitats is amplified on upslope side of the road and depressed downslope side. In other locations along the Grove Road, emergent wetland communities have formed in drainage ditches at the base of road cut-slopes. Wetland formation in these areas is most likely due to the interception of shallow percolating soil water by the compacted road prism and associated cut-slopes (Wemple 1998).

In cases where roads, infrastructure or trails are removed and opportunities for wetland restoration exist the following restoration action are proposed:

- Recontour to facilitate sheet flow, high groundwater levels and wetland plant establishment
- Seed or plant with local native wetland plant species
- Ensure that natural hydrologic conditions are present to sustain wetland hydrology
- Reduce erosion potential

- Refer to adjacent wetlands for plant species, functions and values
- Prevent and remove invasive plant species (specifically velvet grass)
- Install fencing or other deterrents to decrease human impacts

INFRASTRUCTURE

Although infrastructure in the Mariposa Grove today is significantly different from the past, it still has profound impacts to ecosystem functions. Currently, there are just over ten miles (16.1 km) of trail and 5.21 miles (8.4km) of paved roads (includes grove road, road to Wawona Point and the old road from Grizzly Giant toward Goat Meadow) that provide many access points in the Mariposa Grove. In addition, the parking area and shuttle/tram transfer areas cover approximately three acres in the lower portion of the grove. Buildings in the grove include the museum, restrooms with flush toilets and a pit toilet in the upper grove; a cell tower, repeater, and generators at Wawona Point; a vault toilet at the Grizzly Giant; and a bathroom, gift shop and fueling station in the lower grove. Utilities to support this infrastructure include a water line, sewer lines from the upper grove restrooms, a water tank in the middle grove and a generator near the gift shop. It is also likely that many abandoned utility lines that once supported the hotel and tent cabins in the upper grove remain. The impacts from construction and use of roads, parking lots, trails, buildings, sewer systems, and water lines can have small to large impacts on trees and may take years, decades, or centuries to potentially lead to tree mortality. These impacts may weaken trees and contribute to tree death and failure by introducing root rot, compacting soil, depleting organic matter, and increasing soil erosion (Hartesveldt 1962, Demetry 1997). The Mariposa Grove Plan outlines several common to all actions that will allow for some ecological restoration and are described below.

The grove road and parking area has the most profound impact on giant sequoias and other natural resources in the Mariposa Grove. Sixty eight percent of adult giant sequoias are within an estimated adult rooting zone distance (200 feet or 61meters) of the grove road (Kuhn 2011). Direct observations such as cut roots, disturbed and compacted soils, bole damage, and altered hydrology adjacent to the road lead to the conclusion that roads are likely having a negative impact on giant sequoias. In addition, inadequate culverts, road cuts, and the impervious road surface alter surface water flow and connectively to subsurface water (Entrix 2007). The road causes fragmentation of wetlands and many plant communities (including giant sequoia forest) in numerous places and eliminates potential giant sequoia seedling habitat.

The Grove Road and Culverts

Entrix (2007) delineated and assessed the existing road drainage network and reported conditions for sixty-three culverts within the drainage area of the Grove. The function of the majority of these culverts (41 of 63 observed culverts; or 65%) was either diminished or compromised entirely due to inadequate capacity, incorrect orientation, or by the accumulation of sediment and debris (Entrix 2007). In addition, runoff from an area totaling 88.5 acres, roughly 12 percent of the Grove drainage area, is intercepted and rerouted out of the of the Grove drainage area, and is no longer available for uptake by giant sequoia trees.

In order to improve the hydrologic conditions, additional, larger and better-placed culverts could mitigate many of the observed impacts. Once culverts are enhanced and replaced, work to restore the contours adjacent to existing culverts would help reduce the impacts and likelihood of further downcutting, channeling and ponding. The surface, width and other components of the road will vary between alternatives but culvert replacement and improvements are common to all. To mitigate the road and culvert impacts on hydrology the following restoration actions are proposed:

- Install larger (wider), at grade, better placed, additional culverts to facilitate sheet flow rather than channelized flow
- Remove inside ditches and out-slope hillside above the road to facilitate sheet flow
- Narrow road
- Fill in ditches associated with culverts with native soil
- Apply woody debris, native mulch, and plant material (willows using hydrodrilling techniques) to divert and disperse runoff, reduce erosion, promote deposition and limit scour
- If appropriate, place rocks to disperse outflow energy and prevent downcutting
- Recontour slope and landform to natural conditions where possible to encourage sheet flow
- Revegetate with native species (plant or seed) to slow water velocity, reduce erosion and encourage sheet flow and sediment deposition
- Protect and document cultural resources

Removal/Reduction of Upper Loop Road

The removal or reduction of the north and west sections the upper Grove Loop road will reduce the extent of impervious surfaces, allow for recontouring topography to more natural conditions and provide potential giant sequoia seedling habitat. This work would occur when soils are moist and water table is lower, in mid-summer to fall over a period of 12 weeks.

Planting will occur in the fall and plants will be watered as needed. The following restoration actions are recommended:

- Salvage any soil or vegetation impacted by asphalt or infrastructure removal
- Remove all asphalt and other non-native material
- Decompact soils with equipment (skid steer or dozer with rippers)
- Recontour to natural slope topography and establish narrow trail where impacts to hydrology are minimal (excavator, dozer, ski steer, loader)
- Amend soils based on soil assessments
- Mulch, seed and revegetate impacted area
    - Plant any salvaged plants
    - Collect and broadcast local native herbaceous seed
    - Grow out native plants sparsely planted to mimic natural vegetation (not like a landscaped park)
    - water plants as necessary
- Protect and document cultural resources
- Protect restoration areas from further impacts with fencing or appropriate deterrents
- Establish vegetation monitoring plots and photo-points (qualitative and quantitative)
- Install groundwater monitoring wells to assess subsurface water levels

Removal of Gift Shop and Parking areas

The removal and/or reduction of the extent of the parking area and the removal of the gift shop and parking area will reduce the acreage of impervious surfaces, allow for recontouring topography to more natural conditions and provide potential giant sequoia seedling habitat. This work would occur when soils are moist but when water table is lower, in summer to fall over a period of up to 12 weeks. Planting will occur in the fall and plants will be watered as needed. The following restoration actions are recommended:

- Salvage any soil or vegetation impacted by infrastructure removal
- Remove all asphalt and other non-native material
- Recontour to natural slope topography
- Decompact soils with equipment
- Amend soils based on soil assessments
- Mulch, seed and re-vegetate impacted area
    - Collect, increase and broadcast local native herbaceous seed
    - Grow out native plants and sparsely plant to mimic natural vegetation (not like a landscaped park)

    - Water plants as necessary
- Protect and document cultural resources
- Protect restoration areas from further impacts with fencing or appropriate deterrents
- Establish vegetation monitoring plots and photo-points (qualitative and quantitative)

TRAILS

Trails typically have less impact than roads although many trails in the grove are wide (up to 8 feet) and do impact hydrology, wetlands and giant sequoias. In addition, the high concentration of trails in the grove requires maintenance and hazard tree management (for safety as well as prescribed fire), thus impacting a large portion of the grove area. The current trail system and lack of barriers around most adult trees allows for extensive direct human disturbances (includes social trails) to many giant sequoias that can have a number of negative ecological impacts. To mitigate trail impacts or remove sections of trail and restore to natural conditions, the following actions are proposed:

- Replace two sections of trail with boardwalk to reduce impacts to wetlands
- Out-slope the uphill side of trails and remove any inside ditches or impediments to hydrology
- Install fence, plants or other barriers where necessary to maintain minimal trail width
- Remove remnant asphalt on the western portion of the Outer Loop Trail (in wilderness)
- Remove trail segments (nature trail, southern trail in upper loop road area and redundant trail linking the grove road and outer loop trail west of the museum) and restore to natural conditions. In wilderness areas, this work will be completed with hand tools and in non-wilderness areas, a skid steer or mini excavator may be used. This work would occur in late summer or fall when conditions are dryer over 8 weeks.
    - Remove the linear feature by recontouring natural slope topography
    - Mulch and seed with local native plant species.

UTILITIES

A pipeline from Biledo Spring, located in the adjacent Rainier watershed, provides domestic drinking water for the Grove and South Entrance. Long-term evaluation of the reliability of this water supply is needed if augmented water demands are required to support additional infrastructure (i.e., conversion from vault to flush restroom facilities) for the Grove or the South Entrance Station.

Yosemite Utilities staff pressure tested these lines in January 2012 to determine the location and volumes of water leaked from the aged infrastructure. From this assessment, the total pipeline loss was estimated at 39,504 gallons per day (or 44.28 acre-feet per year); all of this loss occurs within the upper Grove area between the uppermost water tank and the Mariposa Tree, and likely percolates into the upper Grove wetland. An additional 500-1500 gallons per day (0.6-1.7 acre-feet per year), depending upon level of use, leak into the wetland from water percolation through the upper Grove leach field. Leaks reported by Hartesveldt (1962) centered on the uppermost water tank, and were repaired by previous maintenance efforts. Although this large amount of water likely augments groundwater levels and available water for giant sequoias in the area, these long-lived trees are unlikely to be adversely affected in the long term by the repair of these leaks. Some young sapling giant sequoias established on the water line may be adversely affected with the repair but we do not want to create or maintain unsustainable (artificial) conditions for giant sequoias for long-term management.

- Slipline the entire length of the pipe (4" Cast Iron) with a 2" HDPE (plastic) pipe to repair the leak and minimize surface impacts. Where access to the line is necessary, use currently impacted areas (e.g. roadbed) and avoid giant sequoia roots or rare plant populations.
- Crush, fill (slurry), or remove all abandoned underground utilities
- Salvage any soil or vegetation impacted by repair or removal
- Recontour area to natural landform
- Decompact, mulch, seed and revegetate impacted area
- Monitor giant sequoias and wetland vegetation affected by the current leak

HISTORIC DUMPS

There are a number of historic dumpsites throughout the Mariposa Grove. In some cases, evidence of the dump is apparent on the surface, which is characterized by compacted soils, absence of vegetation and scattered metal and other debris. Depending on archeological significance of these sites, some surface or subsurface debris will be removed and the area restored to more natural conditions. To accomplish this, extensive documentation may be required and we must ensure that no hazardous materials, such as asbestos, are present. Cultural resource staff will recommend mitigations to ensure proper documentation of the site prior to any removal.

- Document cultural resources
- Ensure that materials are not hazardous
- Depending on cultural resource documentation, remove surface (possibly subsurface) debris and any non-native material
- Recontour area to natural topography

- Decompact soils
- Mulch, seed and/or plant the area to facilitate plant recovery

VISITOR USE

Trampling by foot traffic and the resulting soil compaction negatively affect the shallow roots of giant sequoias (Hartesveldt 1962, Hartesveldt et al. 1975). Soil compaction decreases soil porosity (which affects root respiration), decreases water storage, increases erosion of topsoil (loss of organic matter and nutrients) and affects continued root growth (Hartesveldt 1962, Demetry and Manly 2001). A decrease in root growth as well as actual physical damage to roots decreases the trees ability to obtain nutrients and water, exacerbated by decreases in mycorrhizal fungi and beneficial soil microbial populations unable to survive in compacted soils (Demetry and Manly 2001). Damage to the shallow root system and associated reductions in nutrient and water uptake can weaken both the structure and health of the tree, making it more susceptible to other pathogens or physical damage. Fences, removing infrastructure and rerouting trails and roads away from giant sequoia roots, has mitigated many of these impacts but often can divert attention to a previously undisturbed giant sequoia.

- Protect easily accessible giant sequoias. Some trees may require fencing. In addition, rather than fence every tree, well-placed trails and improved education delivering a consistent message is necessary for effective protection of the entire grove population.

MONITORING AND LONG-TERM MAINTENANCE AND MANAGEMENT

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed and is typically very successful. However, successful ecological restoration should include continued protection and management of the project site into the indefinite future (Clewell et al. 2005). Frequently, ecological restoration projects are not funded for subsequent management that may be required to prevent recurrent degradation of restored ecosystems. To ensure success and to facilitate learning (sometimes from mistakes), it is critical to include monitoring and utilize adaptive management in ecological restoration planning.

Monitoring can help to determine the efficacy of the restoration efforts and provide guidance for future restoration projects in similar environments. Monitoring methods may include vegetation transects, quadrats or ocular estimations, groundwater monitoring wells, and photo point establishment.

The Mariposa Grove of Giant Sequoias comprises the largest grove of giant sequoias in Yosemite National park and is a complex and dynamic ecosystem. Any alterations can effect cascading changes to the complex physical, chemical and biological interactions and conditions. Monitoring the efficacy of restoration efforts and the conditions stemming from those actions can feed into adaptive management and help avoid unwanted results. Ecological restoration is a long-term process of initiating autogenic repair but when the degree of degradation is high, further intervention may be necessary. Future ecological restoration actions and monitoring will also be guided by ongoing and future research as understanding of the causal factors for ecosystem damage increases.

Long-term monitoring coupled with investigative research studies could facilitate an in-depth understanding of past and present hydrologic conditions in the Grove and inform management of potential approaches to enhance the sustainability of the Grove over time. Such efforts are especially important considering potential environmental changes associated with climate change. Research needs to enhance our understanding and management of giant sequoia sustainability in the Grove, include:

Future monitoring of restoration actions will be dependent on Park staff to secure funding through proposal processes.

Maintenance of restoration sites is also required to ensure plant recovery and successful giant sequoia recruitment. General management and maintenance recommendations should follow an ecosystem approach centered on the following.

- Minimize anthropogenic disturbance and infrastructure near all giant sequoias and wetlands
- Maintain natural resource protection buffers for wetlands and streams, rare plant populations, giant sequoias and wildlife
- Facilitate surface water infiltration into soil subsurface horizons
    - Minimize hardscaping within the grove watershed
    - Minimize soil compaction within the grove watershed, and especially within the rooting zone of all existing giant sequoia trees and in areas of likely recruitment (i.e., forest canopy gaps)
    - Minimize induced channelization of runoff.

- Minimize vehicular traffic in the Grove
- Continue an active prescribed fire program
- Maintain, protect and enhance wetland extent and condition
- Minimize the need for hazard tree removal to protect and restore vegetation and wildlife habitat
- Continue non-native plant survey and treatment to control infestations and limit spread
- Protect easily accessible giant sequoias. Rather than fence every tree, well-placed trails and improved education delivering a consistent message is necessary for effective protection of the entire grove population.

DATA GAPS

Future studies needed to fill information gaps

- Complete giant sequoia survey to map and measure all trees in the grove.
- Use data collected in (1) to construct a population model that can be compared to expected population structure
- Conduct an analysis of fire history and giant sequoia mortality, survival, and recruitment to more fully understand the relationships
- Measure gap size and distribution to determine if current fire intensity and patterns are congruent with giant sequoia regeneration and wildlife habitat requirements
- Long-term monitoring and research to increase understanding of the water regime in the grove and to facilitate management actions to sustain the grove over time in light of changing snow line due to climate change.

LITERATURE CITED

Buskirk, S.W., and R.A. Powell, 1994. Habitat ecology of American martens and fishers. In S.W. Buskirk, A.S. Harestad, M.G. Raphael, and R.A. Powell (Eds.), Marten, sables, and fishers: biology and conservation (PP. 297-315). Ithica, NY: Cornell University Press.

Clewell, Andre, J. Rieger & J. Munro. 2005. Society for Ecological Restoration International: Guidelines for Developing and Managing Ecological Restoration Projects, 2nd Edition. http://www.ser.org/content/guidelines_ecological_restoration.asp

Demetry, A. and D. M. Duriscoe. 1996. Fire-caused canopy gaps as a model for the ecological restoration of Giant Forest Village. Report to Sequoia and Kings Canyon National Parks.

Demetry, A. 1997. Assessment of soil conditions in the Giant Forest area, Sequoia National Park. Final report to National Park Service, Denver Service Center.

Demetry, A., and J. Manley. 2001. Ecological Restoration in a Giant Sequoia Grove. Crossing Boundaries in Park Management: Proceedings of the 11th Conference on Research and Resource Management in Parks and on Public Lands. The George Wright Society, Hancock, Michigan.

Entrix. 2007. Mariposa Grove Hydrology, Yosemite National Park. Unpublished report for Yosemite National Park, CA.

Freel, M. 1991. A literature review for management of the marten and fisher on National Forests in California: USDA Forest Service Pacific Southwest Region.

Hall, J.E. 1997. Vegetation Management Plan; Yosemite National Park. USDOI National Park Service, U.S. Government Printing Office.

Halpin, P.N. 1995. Forest pattern in the giant sequoia-mixed conifer forest of the Sierra Nevada. PhD Dissertation, Department of Environmental Sciences, University of Virginia. 276 pp.

Hartesveldt, R. J. 1962. The effects of human impact upon Sequoia gigantea and its environment in the Mariposa Grove, Yosemite National Park, California. Doctoral Dissertation, University of Michigan.

Hartesveldt, R. J. 1965. An investigation of the effect of direct human impact and of advanced plant succession on Sequoia gigantean in Sequoia and Kings Canyon National Parks, California. Contract No. 14-10-0434-1421. Final Contract Report for the Regional Director, Western Region, U.S. National Park Service, San Francisco, California.

Hartesveldt, R. J. and H. T. Harvey. 1967. The fire ecology of sequoia regeneration. Tall Timbers Fire Ecology Conference #7 Proceedings

Harvey, H. T., H. S. Shellhammer, and R. E. Stecker. 1980. Giant sequoia ecology: fire and reproduction. U.S. Department of the Interior, National Park Service, Washington, D.C.

Harvey, H. T. 1986. Evolution and history of giant sequoia. In: Witherspoon, C. P.; Iwamoto, Y. R.; Piirto, D. D., technical coordinators. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, California. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture.

Kuhn, B. 2011. Mariposa Grove Landscape Analysis. Yosemite National Park. Unpublished report.

Kuhn, T. and J. Roche. 2011. Mariposa Grove hydrological condition assessment. Yosemite National Park. Unpublished report.

Leisz, D.R. 1994. Remarks for a Giant Sequoia Symposium. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, California.

Mitsch W. J. and J. G. Grosselink. 2007. Wetlands. 4th edition. John Wiley & Sons Inc. Hoboken, NJ.

Parsons, D. J. and H. T. Nichols. 1986. Management of giant sequoia in the National Parks of the Sierra Nevada, California. In: Witherspoon, C. P.; Iwamoto, Y. R.; Piirto, D. D., technical coordinators. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, California. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture.

Pierson, E.D., W.D. Rainey, and L.S. Chow. 2006. Bat use of the giant sequoia groves in Yosemite National Park, project report prepared for The Yosemite Fund, Yosemite, California.

Piirto, D. D. and R. R. Rogers. 1999. An ecological foundation for management of National Forest Giant Sequoia Ecosystems. R5-EM-TP-005. United States Department of Agriculture, Forest Service. Piirto, D. D., R. R. Rogers and M.C. Bethke. 1997. Communicating the role of science in the management of giant sequoia groves. Presented at: National Silviculture Workshop, Warren.

Repath, Charles. 2011. Delineation of Wetlands and Waters of the United States occurring in and around the Mariposa Grove of Giant Sequoias. Yosemite National Park. Unpublished report.

Reynolds, R. D. 1959. Effect of natural fires and aboriginal burning upon the forests of the central Sierra Nevada. unpublished Thesis M A, University of California, Berkeley.

Rundel, P. W. 1969. The distribution and ecology of the giant sequoia ecosystem in the Sierra Nevada, California. Doctoral Dissertation, Duke University.

Rundel, P.W. 1971. Community structure and stability in the giant sequoia groves of the Sierra Nevada, California. The American Midland Naturalist 85(2):478-492.

Society for Ecological Restoration (SER) International Science & Policy Working Group. 2004. The SER International Primer on Ecological Restoration. www.ser.org & Tucson: Society for Ecological Restoration International.

Stock, S. 2011. Mariposa Grove and South Entrance wildlife assessment. Yosemite National Park. Unpublished report.

Stephenson, N. D. 1999. Reference conditions for giant sequoia restoration: structure, process and precision. Ecological Applications 9(4): 1253-1265.

Swetnam, T. W., R. Touchan, C. H. Baisan, A. C. Caprio, and P. M. Brown. 1990. Giant sequoia fire history in Mariposa Grove, Yosemite National Park.

Swetnam, T. W. 1993. Fire history and climate change in giant sequoia groves. Science 262: 885-889.

Weatherspoon, C. P. 1986. Silvics of giant sequoia. In: Witherspoon, C. P.; Iwamoto, Y. R.; Piirto, D. D., technical coordinators. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, California. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture.

Webster, K. M., and C. B. Halpern. 2010. Long-term vegetation responses to reintroduction and repeated use of fire in mixed-conifer forests of the Sierra Nevada. Ecosphere 1(5).

York, R. A., Z. Thomas, and J. Restaino. 2009. Influence of Ash Substrate Proximity on Growth and Survival of Planted Mixed-Conifer Seedlings. Western Journal of Applied Forestry 24:117-123.

York, R. A., N. L. Stephenson, M. Meyer, S. Hanna, T. Caprio and J. J. Battles. In press. Appendix to: Natural resources condition assessment. Sequoia and Kings Canyon National Parks.

United States Department of the Interior (USDI);

1995. Giant Forest Guidelines for Ecological Restoration. Appendix B of the Interim Management Plan/Environment Assessment – Giant Forest. Sequoia and Kings National Parks, CA.

1996. Interim Management Plan/Environmental Assessment – Finding of no significant impact – Giant Forest. Sequoia and Kings National Parks, CA.

2004. Yosemite National Park Fire Management Plan and Environmental Impact Statement. Yosemite National Park, CA.