Chapter 1.5—Research Gaps: Adaptive Management to Cross-Cutting Issues

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Summary of Cross-Cutting Research Gaps

- High-elevation forests, including the upper montane and subalpine zones, warrant increased attention and research owing to the projected effects of climate change. These forests provide important habitat and biodiversity values, and they face novel threats from shifts in precipitation patterns and increased likelihood of uncharacteristically severe wildfire.
- Forested riparian areas are highly valued, yet they have not been a focus for restoration research. Conducting experimental projects over extended periods and across the synthesis area, in combination with large-scale modeling, would help to guide practices to restore riparian areas and downstream aquatic resources.
- Long-term effects of wildfire, with and without various pre- and postfire treatments, remain a significant research gap for many socioecological values. Increased understanding of long-term effects of repeated fires across upland, riparian, and aquatic systems would help to promote socioecological resilience.
- Key questions remain concerning removal of burned trees and woody debris as part of post-wildfire treatments, given limited understanding of fuelbed succession following fires of different intensities. Both social and ecological research are needed to evaluate the outcomes of accepting or influencing ecological trajectories of severely burned areas through salvage and other kinds of treatments.

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- There is a great need for more integrated research that evaluates how ecological restoration efforts affect important socioeconomic and cultural values. Although science suggests that there are opportunities for forest treatments to enhance water supply and mitigate some of the potential effects of climate change, research is lacking in the Sierra Nevada on the longevity of treatment effects on water yield and the extent to which water quality can be maintained or enhanced.
- Benchmarks and performance criteria can be valuable tools for evaluating progress toward meeting broad restoration goals, and there are large efforts to develop integrated indexes of ecosystem health that consider ecological and social conditions. However, at a broad strategic landscape level, it can be problematic to emphasize quantitative targets. More research and joint consideration by managers and scientists of these types of benchmarks and criteria would help to inform management goals and strategies.

Building on Adaptive Management Efforts

A number of studies undertaken by the Forest Service within the synthesis area have been designed and implemented to better understand both more immediate and long-term effects of treatments, including the Blacks Mountain Ecological Research Project (Oliver 2000); Goosenest Adaptive Management Area Project (Ritchie 2005); Long-Term Soil Productivity Study (Powers 2006); National Fire and Fire Surrogate Study (McIver and Fettig 2010); the Teakettle Experiment (North 2002); the Kings River Experimental Watersheds (KREW) (Hunsaker and Eagan 2003); the Plumas-Lassen Administrative Study, which includes the Meadow Valley study area; and the Sierra Nevada Adaptive Management Project (SNAMP), a joint project spearheaded by the University of California (fig. 1 and table 1). These studies have generally had difficulty maintaining funding after initial implementation, so the resulting information from the studies has been limited to responses over relatively short time periods. In a few situations, researchers have been able to study some long-term questions by taking advantage of a well-designed study that had been dormant or abandoned for some time but had been well archived by the original researchers (Dolph et al. 1995, Knapp et al. 2012). These examples provide a valuable precedent for future research.

Progress made on previous research topics will help to inform development of landscape strategies. Synthesis of research on the effects of forest fire hazard reduction treatments suggests that the threat of high-intensity fire can be significantly reduced with relatively benign impact on most wildlife species at project scales

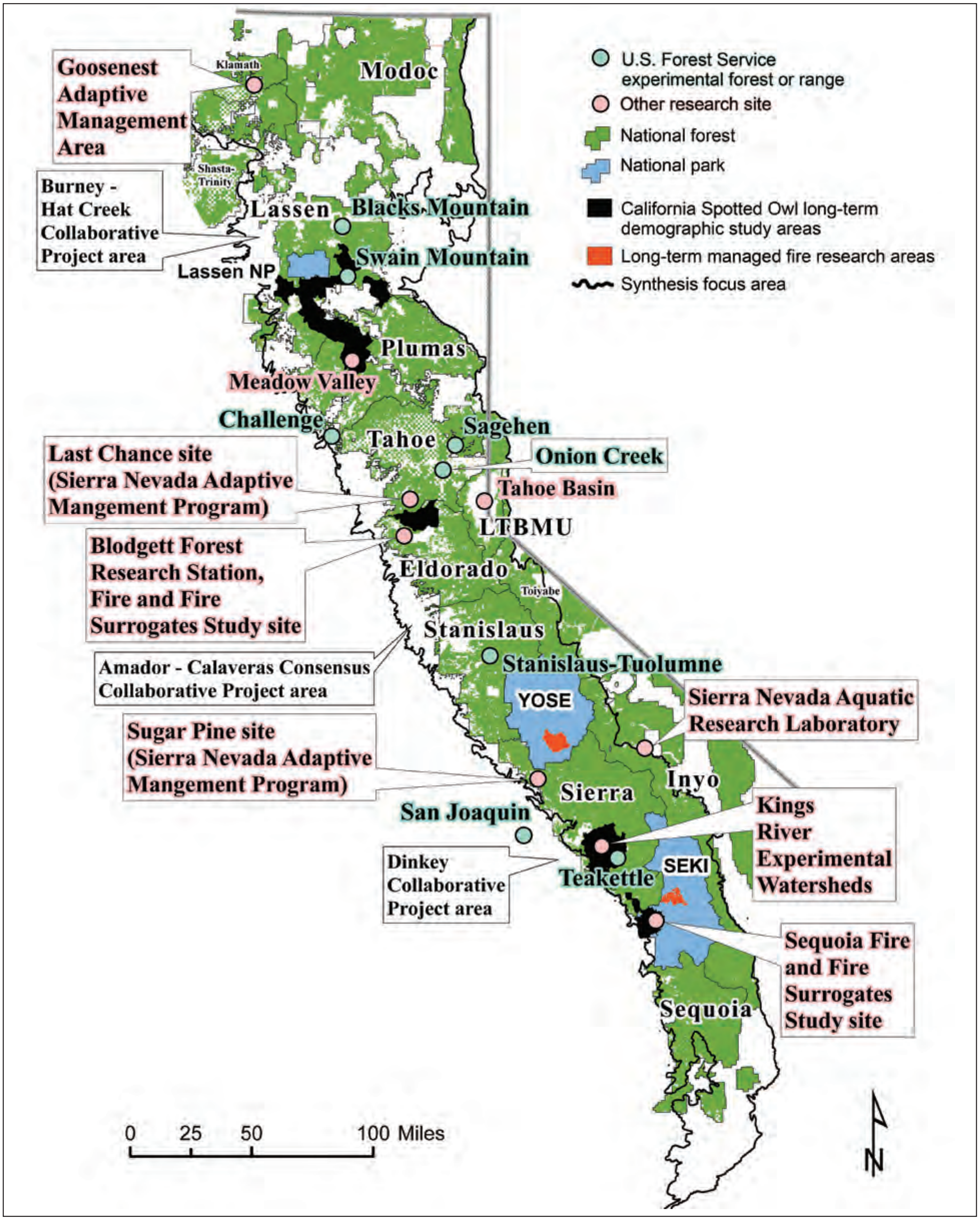

Figure 1—Map of experimental areas in the Sierra Nevada and southern Cascade Range, highlighting various adaptive management projects featured in this synthesis. LTBMU = Lake Tahoe Basin Management Unit. YOSE = Yosemite National Park. SEKI = Sequoia-Kings Canyon National Parks. NP = national park. Map by Ross Gerrard.

Table 1—USDA Forest Service experimental forests and adaptive management areas within the Sierra Nevada and southern Cascade Range synthesis area

Research area	Acres	Hectares
Blacks Mountain Experimental Forest	9,180	3715
Challenge Experimental Forest	3,573	1446
Goosenest Adaptive Management Area	172,000	70 000
Goosenest Ecological Research Study Area (also the southern Cascade Range Site of the National Fire and Fire Surrogates Study)	3,000	1200
Kings River Experimental Watersheds	46,604	18 860
Onion Creek Experimental Forest	2,965	1200
Sagehen Experimental Forest	20,016	8100
Stanislaus-Tuolumne Experimental Forest	1,500	607
Swain Mountain Experimental Forest	6,158	2492
Teakettle Experimental Forest	3,212	1300

Treatment areas within these studies have often not been large enough to make strong inferences about species with large home ranges, address patterns of habitat suitability and connectivity at the landscape scale, and evaluate the synergistic effects of treatments and wildfires on wildlife. Additionally, these research projects generally have not been in place long enough to evaluate long-term effects.

(Stephens et al. 2012). However, many of the less common species have not been a focus of study primarily because of statistical limitations with studying small populations or large home ranges. Most research associated with priority species, such as California spotted owl, has been on the small mammals that are their prey. Treatment areas within these studies have often not been large enough to make strong inferences about species with large home ranges, address patterns of habitat suitability and connectivity at the landscape scale, and evaluate the synergistic effects of treatments and wildfires on wildlife. Additionally, these research projects generally have not been in place long enough to evaluate long-term effects. Adaptive management studies must overcome the challenge of maintaining long-term capacity and resources in order to promote social learning and system resilience.

Many experimental forests and other areas dedicated to adaptive management experiments offer opportunities to improve understanding of how to design strategies to restore forests. A number of other large projects have been supported through the Collaborative Forest Landscape Restoration Program, including the Dinkey Landscape Restoration Project, the Amador Calaveras Consensus Group Cornerstone Project, and the Burney-Hat Creeks Basin Project. In particular, the Dinkey project is examining effects on fishers, and it has already yielded insights regarding approaches to promote successful collaboration (Bartlett 2012). A number of these projects are discussed throughout chapters of this synthesis; the following examples highlight projects in Forest Service experimental forests and adaptive management areas (fig. 1 and table 1).

The Teakettle Experiment improved understanding of the ecological effects of widely used forest treatments, such as understory and overstory thinning with and without prescribed fire (North 2002). Dozens of studies examined how these treatments affected different ecosystem components. Collectively, the research suggested that in fire-suppressed mixed-conifer forest prior to treatment, many ecological processes were impeded by competition for limited soil moisture and uncharacteristically high fuel and duff loading (North and Chen 2005). After treatment, patchy heterogeneity of forest conditions was associated with the greatest increases in species diversity and restoration of ecosystem functions (Ma et al. 2010, North et al. 2007, Wayman and North 2007). The researchers concluded that fire was essential to restoring many ecological processes but that understory thinning could play an important role in facilitating greater variability in burn effects and post-treatment forest heterogeneity (North 2006).

The objectives of several other experimental areas were to test particular hypotheses. For example, the Challenge and Blacks Mountain Experimental Forests are included in the Long-Term Soil Productivity (LTSP) study, which looks at effects of different treatments on long-term soil productivity (see chapter 5.1, "Soils"). Currents efforts on the Sagehen Experimental Forest are looking at the ecological effects of strategically placed treatments on a landscape. In addition, the Sagehen fuels reduction project was planned to protect and restore forest landscape heterogeneity, reduce fuels, and maintain and restore habitat for the Pacific marten. The consideration of habitat for a rare forest carnivore, early in a collaborative planning process, was viewed as key to the favorable prognosis for this project. Monitoring of martens and forest conditions as the treatments are implemented and beyond will help evaluate whether the expected outcomes develop.

The high-diversity treatment at Blacks Mountain Experimental Forest (BMEF) is one of the most established efforts to study heterogeneity in forest structure and fuels through variable-density thinning based on species composition and other factors. The primary objective of the BMEF study was to compare differences in ecological effects between stands treated for high structural diversity and stands treated for low structural diversity (Oliver 2000). Comparisons between the two types of treatments at the BMEF showed a large difference in short-term financial returns; the high-diversity treatment yielded less revenue because it maintained most large legacy trees, whereas the low-diversity alternative was based on a prescription that cut most larger trees while maintaining intermediate-sized trees (Hartsough 2003). However, both types of treatments reduced fire behavior considerably when affected by an otherwise severe wildfire (Ritchie et al. 2007, Symons et al. 2008). Although an analysis of carbon outcomes of alternative treatments in the study area has not been done, Pacific Southwest Research Station researchers have data available to do so.

Treatments in the Stanislaus-Tuolumne Experimental Forest were designed to mimic historical reference conditions, including density, species composition, and age distribution (Knapp et al. 2012). To achieve these objectives, treatments based on stand conditions described by original detailed data and old maps have extended into some riparian areas and moved away from diameter caps in favor of selecting trees for removal to achieve the desired structure and spatial pattern. Future analyses of these treatments will facilitate a number of important comparisons of the effects of creating different stand structures to achieve both restoration and fire hazard reduction objectives, including a comparison of timber volume and economic returns between variable-density thinning and a more conventional even density thin. An extension of this research is examining effects of the experimental treatments on water yield.

The Goosenest Ecological Study Project (including its associated Fire and Fire Surrogate Study) was focused on finding ways to accelerate late-successional conditions through mechanical thinning and prescribed fire, including a comparison of a treatment that emphasized retention of pine trees and an alternative that emphasized retention of any large trees including firs; the study assessed treatment effects on fire hazard, vegetation, soils, small mammals, beetles, and birds.

Research Gaps

Appendix E of the Sierra Nevada Forest Plan Amendment (SNFPA) provided a list of priority questions for monitoring and research to support adaptive management. Several of those priorities have yielded outcomes highlighted in this synthesis, including but not limited to the following:

- Effects of fuel treatments on wildfire risk reduction (chapter 4.1, “Fire and Fuels”);
- Continuation of watershed research at the Kings River Experimental Watershed (chapter 6.1, “Watershed and Stream Ecosystems”);
- Expansion of aquatic invertebrate monitoring (chapter 6.1);
- Study of grazing effects on amphibians (chapter 6.3, “Wet Meadows”);
- Expanded monitoring of fishers, particularly in the southern Sierra (chapter 7.1, “The Forest Carnivores: Marten and Fisher”); and
- Continuation of the owl demographic study (chapter 7.2, “California Spotted Owl: Scientific Considerations for Forest Planning”).

Other topics recommended in SNFPA appendix E are likely to have been under-addressed. In addition, some important areas discussed in this synthesis, such as social and economic components of resilience, were not emphasized in that document. Revisiting and revising the list of questions from SNFPA appendix E would help to develop a long-term strategy for research to address management challenges. The various chapters of this synthesis highlight gaps in knowledge from their respective disciplines and focal areas. The topics that follow emerged as important concerns across multiple chapters. In addition, chapter 1.3, "Synopsis of Emerging Approaches," highlights the importance of adaptive management to evaluate the effects of treating large landscape areas to achieve integrated resource objectives, including promotion of wildlife species of concern, promotion of water quality, and reduction of wildfire risks. The premise that a strategic landscape approach can promote resilience by avoiding potential traps of stand-scale perspectives and constraints is a particularly important hypothesis to test through simulation modeling and an adaptive management framework. Another topic that is related to understanding interactions between treatments and wildlife species of special concern is the issue of limited operating periods (see box 1.5-1).

Changes in Upper Montane and Subalpine Forests

The management recommendations for the mixed-conifer forests presented in North et al. (2009) were not intended to extend to higher elevation forests with less frequent fire regimes. Considerations for red fir forests, which fall into that category, are discussed in chapter 2.1, "Forest Ecology." Pacific marten (*Martes caurina*), which depend on relatively high-elevation forests, are thought to be particularly vulnerable to habitat loss as a result of climate change (Purcell et al. 2012, Wasserman et al. 2012).

Projected warming and shifts in precipitation from snow-dominated to rain-dominated, as well as associated increases in the incidence of severe wildfire, could result in disturbance effects that push systems in this red fir transition zone beyond important ecological thresholds.

The zone of transition from wet mixed-conifer forests into red fir (*Abies magnifica*) is a particularly important focal area for forest management in the synthesis area. Multiple sections of this synthesis note that red fir forests are an important subject for research because they are broadly distributed in the region; they support important values, such as habitat for priority species and water supply; and they have not been extensively researched. Projected warming and shifts in precipitation from snow-dominated to rain-dominated, as well as associated increases in the incidence of severe wildfire, could result in disturbance effects that push systems in this transition zone beyond important ecological thresholds. Trujillo et al. (2012) noted that forest productivity and composition in the elevation zone between 1800 and 2100 m in the Sierra Nevada appears particularly sensitive to changes in snowpack. Streams in this zone are expected to experience increases in and changes in seasonal timing of peak flows, and the freezing level in winter storms, which coincides with the moist mixed conifer/red fir transition, is expected to rise (Herbst and Cooper 2010, Safford et al. 2012a). As temperatures warm, trees in this zone are less likely to go dormant in winter, so their evapotranspiration will increase and

Box 1.5-1

Limited Operating Periods

Limited operating periods (LOPs) are typically seasonal restrictions on certain activities that are thought to disturb wildlife. Although special management zones typically impose spatial constraints on treatments, sets of LOPs impose additional temporal constraints. As a result, science that improves understanding of species' habitat associations does not resolve the LOP constraint. Although noise is often a primary concern, burning also generates heat and gases that could be harmful under certain conditions, such as when denning animals are unable to relocate (Dickinson et al. 2010). Many LOPs designated for raptors and carnivores of concern in the Sierra Nevada Forest Plan Amendment extend for 6 or 7 months through spring and summer, whereas LOPs for sensitive amphibians and wintering bald eagles run from fall through winter and into spring. Restrictions on spring burning in particular could constrain management especially in a near-term phase designed to render landscapes more resilient to fire. Paradoxically, LOPs may conflict with larger strategic recommendations to benefit wildlife species; for example, spring burning may have less effect on predicted fisher resting habitat than fall burning (see chapter 7.1, "The Forest Carnivores: Marten and Fisher"), yet spring burning is difficult to implement under the current LOP around fisher dens. Out-of-season burning may be a critical tool to reduce accumulated fuels, especially while trying to accommodate air quality constraints. Future listings of species under the Endangered Species Act could reduce management options to implement restorative landscape treatments; this possibility presents another incentive to transition toward the long-term phase outlined in chapter 1.2, " Integrative Approaches: Promoting Socioecological Resilience."

Limited operating periods constitute an important opportunity for research to address a practical management challenge. Synthesizing existing information and conducting additional research on effects of treatment operations on particular species of concern would help to narrow restrictions to the most ecologically relevant conditions (considering treatment effects and interactions with weather and animal development). Research to refine smoke modeling could also help to gauge potential impacts more precisely.

likely reduce soil moisture and stream discharge (Bales et al. 2011). In addition, competitive interactions between martens and fishers may increase with decline in snowpack, which is projected to continue in the northern Sierra Nevada (Safford et al. 2012a). Major changes in subalpine forest structure have occurred over the last century, and increasing tree densities may promote higher continuity of fuels, which could increase the future role of more intense fire, and greater density-related stress, which could increase forest susceptibility to outbreaks of insects and disease (Dolanc et al. 2012). Continued monitoring and research are needed to evaluate whether declines in whitebark pine (*Pinus albicaulis*) forests in California represent change that is indicative of a resilient ecosystem, or instead a "catastrophic" outcome (or transformation) resulting from the synergy of climate change, native insect pests, and novel stressors (Millar et al. 2012).

Restoration of Forested Riparian Areas

Forested riparian areas are highly valued yet have not been a focus for restoration research. Chapter 6.2, "Forested Riparian Areas," suggests that more active use of mechanical thinning and prescribed fire would help to restore riparian ecosystems in the synthesis area, but effects on water quality, riparian soils, and priority riparian and aquatic species (including Sierra yellow-legged frog, mountain yellow legged-frog, and Yosemite toad) may warrant special consideration in experimental studies. However, for the Sierra Nevada, few research experiments on prescribed fire have been conducted in riparian areas, and only one recent wildfire study has been published for stream riparian areas (see chapter 6.1.) In the Tahoe basin, there have been studies on pile burning in streamside zones (see chapter 5.1, "Soils") and pending research on silvicultural treatments in aspen stands, which are commonly found in riparian areas. The KREW study will provide new data from one experimental area in the southern Sierra Nevada over the next few years. Meanwhile, work as part of SNAMP will provide additional information on hydrologic effects in the central Sierra Nevada. Conducting experimental projects over extended periods (at least 10 years) and across the synthesis area, in combination with large-scale modeling, would help to guide practices to restore riparian areas and downstream aquatic resources.

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Effects of Wildfires, Particularly Long Term

Long-term effects of wildfire and treatments both pre- and post-wildfire remain a significant research gap (see chapter 4.3, "Post-Wildfire Management"). Safford et al. (2012b) noted that the effectiveness of fuels treatments in reducing wildfire severity in frequent-fire forest types has been well established. There remains a need to evaluate effects of fires (along with effectiveness of forest treatments) in other ecosystem types, including riparian and montane hardwood forests. The Fire and Fire Surrogates Study (McIver and Fettig 2010, McIver et al. 2013), which includes three research sites within the assessment area, was designed for this purpose and would continue to provide important information if these sites were again emphasized. Moreover, the effects of fires (and postfire treatments), especially in large severe patches over long periods, are not well understood.

Research on the effects of severe wildfire on aquatic systems has been quite limited in the Sierra Nevada (see chapter 6.2). Researchers have noted the importance of identifying thresholds at which high-severity burns have negative impacts on aquatic organisms (Minshall 2003). Given the particular importance of water quality as an ecosystem service, the potential impacts of increasingly severe wildfire on aquatic systems are an important research gap (see chapter 4.3). One particular threat from wildfires that has been recognized in the Sierra Nevada is sedimentation of reservoirs, which can degrade water quality in the short term and reduce storage capacity in the long term (Moody and Martin 2004, 2009).

A recent study by Buchalski et al. (2013) surveyed nightly echolocation activity of bats in riparian and upland areas one year after the McNally fire in the southern Sierra Nevada. They concluded that some species were selecting burned areas for foraging; a finding which reinforces the value of fire-created habitat heterogeneity for biodiversity. However, it did not examine roosting habitat, which could be more sensitive to effects of severe wildfire, especially for species that roost in large trees and snags, such as pallid bats (*Antrozous pallidus*) (Baker et al. 2008).

Recent wildfires, such as the 2012 Chips Fire on the Plumas and Lassen National Forests, present opportunities to learn how severe wildfires affect spotted owls and their habitat, because there is a decade-long monitoring dataset in the burned area. The Chips Fire burned through large areas previously burned by the 2000 Storrie Fire. The availability of data from existing plots in the Storrie Fire area will allow study of the effects of the reburn (see chapter 4.3). Among other objectives, these types of studies could help to evaluate the extent to which down woody fuel loads remaining from the Storrie Fire may have affected severity of the reburn. The Reading Fire 2012 within the southern Cascade Range portion of the synthesis area presented an opportunity to evaluate impacts of fire to sensitive wildlife species such as the Pacific marten, northern goshawk, California spotted owl, and native trout.

Effects of Post-Wildfire Treatments

Key questions remain concerning treatment of burned trees and woody debris in high-severity burn patches, given limited understanding of fuelbed succession following fires of different intensity. These questions are especially important given that the warming climate appears to be lengthening the fire season (Westerling et al. 2006), with associated increases in fire activity expected (Lenihan et al. 2003). Chapter 4.3 identifies a number of important gaps in socioecological research, including effects on channel processes (fig. 2), use of dead trees by wildlife such as black-backed woodpecker (*Picoides arcticus*), and outcomes of accepting or influencing ecological trajectories of severely burned areas through salvage, replanting and other kinds of treatments. In particular, novel approaches may be needed to encourage regeneration of conifers and hardwoods where widespread patches of high-severity burn may inhibit recovery of desired conditions.

Figure 2—Aerial view of the Lion Fire of 2011, which was managed for resource benefits.

Science suggests that there are opportunities for forest treatments to enhance water supply and mitigate some of the potential effects of climate change, although research is lacking in the Sierra Nevada for how much and how long restoration treatments are likely to influence water yield and water quality.

Effects of Restoration Treatments on Ecological Services and Other Social Values

A common thread throughout this synthesis is the need for more integrated research that evaluates how ecological restoration efforts affect important socioeconomic and cultural values (see chapter 9.2, "Ecosystem Services"). Chapters 4.2, "Fire and Tribal Cultural Resources; 4.3, "Post-Wildfire Management;" and 6.3, "Wet Meadows," all highlight the gap in understanding effects on ecosystem services associated with wildlife, culturally important plants, and water resources. Science suggests that there are opportunities for forest treatments to enhance water supply and mitigate some of the potential effects of climate change, although research is lacking in the Sierra Nevada for how much and how long restoration treatments are likely to influence water yield and water quality (see chapter 6.1). The use of geospatial modeling tools to prioritize landscape treatment strategies (see chapter 1.1) can explicitly integrate social values by mapping overlap between the use, provision, and vulnerability of ecosystem services to disturbances (Beier et al. 2008).

Performance Criteria

Benchmarks and performance criteria can be valuable tools for evaluating progress toward meeting broad restoration goals. However, at a broad strategic landscape level, it can be problematic to emphasize fixed quantitative targets. For one reason, such targets may lead to raising standards inappropriately high for some areas, reducing expectations for others, with an overall tendency to reduce heterogeneity in the landscape (Bisson et al. 2009). As a result, resilience-based approaches tend to de-emphasize fixed production targets in favor of plans to reduce vulnerability and strengthen capacity to respond and adapt. The properties of a socioecological system that confer resilience can change over time, with spatial configuration, and depending on the people involved, so the selection of useful surrogates or metrics needs to be similarly diverse and dynamic (Carpenter et al. 2005). By considering various policy constraints on management and other contextual factors, evaluation systems may yield more informative findings that promote social learning (for example, availability of burn windows, see chapter 9.3, "Sociocultural Perspectives on Threats, Risks, and Health"). As an example of how metrics could be used, Fire Return Interval Departure metrics can serve as an initial measure of restoring fire as an ecological process, but they should be considered within a broader context of the reference fire regime (Sugihara et al. 2006) and the larger socioecological system in terms of vulnerability and desired conditions (see chapter 4.1). In addition, the choice of metrics should be reviewed and may need to be revised as the system evolves and presents new opportunities and constraints.

Accordingly, restoration designed to promote broader societal interests will strive to include a mix of ecological and social criteria for evaluating success (see chapter 9.4, "Strategies for Job Creation Through Forest Management," for examples of socioeconomic indicators). There are many efforts to develop integrated indexes of ecosystem health that consider ecological and social conditions (Rapport and Maffi 2011, Rapport and Singh 2006) (see also chapter 9.2). Although efforts to quantify social criteria, such as cultural significance and community well-being, also entail a risk of being too reductionist (Higgs 1997), such indicators can provide valuable guides for identifying potential vulnerabilities and opportunities that may help promote resilience in socioecological systems (Cabell and Oelofse 2012). A key consideration is to incorporate feedback loops to evaluate whether the indicators appear to be working as intended and revise them especially to account for confounding factors.

Chapter 1.3, "Synopsis of Emergent Approaches," considers the hypothesis that treatments initially implemented across a relatively small proportion of a landscape in a short number of years could avert the most undesirable effects of wildfires while avoiding deleterious impacts to priority wildlife species. This example identifies a guideline that could be tested for particular landscapes in an adaptive management framework involving managers, stakeholders, and researchers. This type of reflective approach would engage the public and communities in evaluating the particular ecological and social characteristics of their landscapes, identifying vulnerabilities and appropriate indicators, and strengthening capacity to adapt to future disturbances and stressors by promoting a long-term view towards risks (see chapter 9.3).

Management Implications

- There are a number of important and potentially controversial topics for which science suggests that treatment approaches might be warranted, but further study in an adaptive management framework would be helpful to evaluate social and ecological tradeoffs and suitable contexts, including:
    - treatment of red fir forests,
    - treatment of riparian areas, and
    - removal of burned trees following severe wildfires.
- Management plans might be particularly well-informed through adaptive management or targeted research to evaluate effects of treatments and unmanaged wildfires on wildlife habitat, water supply, and other high-value ecological services.

- Collaborative review by scientists and managers of past efforts to implement adaptive management, including monitoring plans in the SNFPA appendix, could help to inform management plans.

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