Chapter 1.2—Integrative Approaches: Promoting Socioecological Resilience

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Introduction

This chapter begins by discussing current challenges for ecosystem management that emerged from multiple chapters of the full synthesis. It then considers integrative approaches to promote resilience, including general strategies that recognize the integrated nature of socioecological systems, the importance of promoting disturbance regimes upon which these systems have evolved, and opportunities to integrate social considerations into strategies (see chapter 1.1, "Introduction," for definitions of key terms). It continues by outlining an adaptive management approach to scale up current practices so that planning and implementation are more congruent with the scales at which processes affect ecosystems in the synthesis area. The following chapter 1.3, "Synopsis of Emergent Approaches," focuses on three important themes that are touched on in this chapter; these themes emerged largely from synthesizing findings from the forest ecology, fire, and wildlife chapters. Chapter 1.4, "Synopsis of Climate Change," summarizes how climate change relates to all the chapters in this synthesis and strategies to promote resilience to that stressor. Chapter 1.5, "Research Gaps: Adaptive Management to Cross-Cutting Issues," discusses a number of current adaptive management efforts and important topics that emerged as priorities for adaptive management and research. Altogether, the chapters in this section outline strategies to respond proactively to expected challenges in the synthesis area.

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The Challenge of Multiple Stressors

The challenges facing national forests in the synthesis area reflect long-standing natural processes including fire, decades of fire suppression and other practices that have altered ecosystems and increasingly, novel stressors associated with human activities within the region and even across the globe.

The challenges facing national forests in the synthesis area have grown much more complex as the forests themselves have changed and as external influences have evolved. These challenges reflect long-standing natural processes (including fire, drought, and insects), decades of fire suppression and other practices that have altered ecosystems (e.g., hydrologic modifications, habitat fragmentation, loss of biodiversity, etc.), and increasingly, novel stressors associated with human activities within the region and even across the globe (Folke 2006, Steffen et al. 2007). Incursions of nuisance plants and animals, diseases, and pollutants, combined with a legacy of human influences on climate, fire regimes, and species extinctions, are forming "novel ecosystems" (Hobbs et al. 2009), which do not have historical analogues upon which to base predictions or to serve as clear references for restoration. The remainder of this chapter focuses on several opportunities to promote system resilience to stressors.

There are many challenges to managing forests of the synthesis area in the 21st century, including an array of evolving, novel stressors:

- Dust from as far away as China may be causing snowpack to decline and polluting water bodies in alpine areas that have historically been regarded as relatively pristine wilderness (see chapter 8.1, "Air Quality").
- The barred owl (*Strix varia*) is invading forests at the expense of the California spotted owl, and there are no clear solutions to prevent this incursion (Gutierrez et al. 2007) (see chapter 7.2, "California Spotted Owl: Scientific Considerations for Forest Planning").
- The fisher is being poisoned by application of rodenticides by marijuana growers to protect their illicit crops (Gabriel et al. 2012) (see chapter 7.1, "The Forest Carnivores: Marten and Fisher").
- Populations of priority amphibians face combined effects of climate change, introduction of predatory fishes, disease, pesticides, disrupted flow regimes, and other habitat impacts (see chapter 6.4, "Lakes: Recent Research and Restoration Strategies").
- Climate change is projected to shift precipitation from snow to rain, which may reduce seasonal water availability in forest soils, and negatively affect aquatic systems and associated ecosystem services by altering channel stability and stream hydrographs, especially by reducing summer baseflows (see chapter 6.1, "Watershed and Stream Ecosystems").

- Climate-driven projections suggest that forests will become more susceptible to insect attack and disease caused by native and introduced pathogens (Evangelista et al. 2011, Sturrock et al. 2011). A complex interaction of climate change, altered fire regimes, and air pollution pose threats to forest resilience (see chapter 8.1). Research has already documented increased rates of insect attack, disease, and mortality in many Western forests that could portend vulnerability to substantial changes in forest structure, composition, and function (van Mantgem et al. 2009).
- Scientists report increasing frequency and extent of wildfires, along with the increasing occurrence of uncharacteristically severe wildfire in the synthesis area (Lenihan et al. 2003; Miller and Safford 2012; Miller et al. 2009, 2012; Westerling et al. 2011) (see chapter 4.1, "Fire and Fuels").

Land management agencies have a limited ability to prevent these impacts, but effective management actions can mitigate their effects. The new planning rule acknowledges the likelihood that some stressors may render it infeasible to maintain or restore ecological conditions to maintain a viable population of a species of conservation concern in a planning area. The existence of such stressors complicates management because it becomes harder to evaluate the effects of management actions without accounting for the stressor that cannot be controlled. Interactions between climate change, other stressors, and disturbances can induce positive feedbacks that threaten to push systems beyond key thresholds; these challenges should be considered as syndromes rather than as isolated problems (Rapport and Maffi 2011). Common indicators of such syndromes include losses of biodiversity, especially predators; simplifications of food webs; eutrophication of aquatic systems; and increasing prevalence of invasive species and diseases (Rapport and Singh 2006). Assessments, research studies, and management strategies that target these syndromes will be most effective if they consider multiple factors and their synergistic effects. Amphibians in lakes provide an example in the Sierra Nevada (see chapter 6.4) of how a response to a syndrome could include removing introduced fishes from lakes to help amphibians better withstand disease and climate change. Other strategies for assessing and responding to these syndrome impacts have been to develop highly integrated ecological indexes or state of the environment reports, which consider effects on both ecosystems and social systems, and emphasize opportunities for human actions to improve ecological health (Rapport and Singh 2006).

Conditions That May Reduce Socioecological Resilience

Periodic disturbance plays a fundamental role in the development of socioecological systems by facilitating reorganization and renewal (Cabell and Oelofse 2012, Folke 2006). However, people often regard such disturbances negatively because of their disruptive effects. Indeed, major shocks that push systems beyond critical thresholds can induce large and persistent loss in the flows of ecological services. Such shocks as well as more frequent stressors can reduce the ability of a system to recover from future disturbances.

Systems that remain in a condition with essentially the same function, structure, identity, and feedbacks may demonstrate resilient change, whereas those that move to a new configuration may be described as undergoing transformation or "regime shift" (Berkes and Ross 2012). However, real-world outcomes are unlikely to fall neatly into one category or the other, but rather are likely to fall along a continuum associated with changes in system function over time. For example, research within the synthesis area has been undertaken to try to determine where observed changes in high-elevation whitebark forests lie on such a continuum (see chapter 1.5).

Human actions have contributed to the potential for regime shifts that have negative impacts on livelihoods and societal development (Folke 2006). Stressors associated with anthropogenic activities, such as climate change, pollution, and species invasions, are critically important to consider from a socioecological perspective, although they are difficult to manage because they originate from outside local landscapes or do not recur frequently and predictably. Human alteration of fire regimes through suppression has promoted fires with behavior and effects that are outside the range of natural variation (Sugihara et al. 2006). The lasting legacy of fire suppression is an important stressor that can be directly addressed through management in the synthesis area, although reducing those accumulated fuels requires difficult tradeoffs among short- and long-term costs and risks to values held by different groups of people.

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Fire is a fundamental ecological process that often repeats in relatively predictable ways across a landscape. Native Americans in the synthesis area historically lived with fire and used it to promote ecological outcomes that supported their communities (fig. 1). Changes in forest fuel and habitat conditions over time can leave systems vulnerable to regime shifts (Agee 2002). If forests that have uncharacteristically large accumulations of living and dead fuels are not managed, when they inevitably burn there will be a loss of ecosystem services, including biodiversity and other social values (Franklin and Agee 2003). Consequently, various topical sections of this synthesis describe negative

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Figure 1—California black oaks demonstrate the importance of viewing social and ecological systems in an interconnected manner. Because these trees have been cultivated and used by Native Americans and other people, they have important roles in providing wildlife habitat, and their condition is fundamentally connected to fire regimes in the synthesis area.

consequences of large and severe fires on many socioecological values in the modern era. These impacts include the following:

1. High levels of tree mortality over large areas can forestall recovery of forested conditions and associated ecosystem services for long periods (decades to centuries) and may be a catalyst for regime shifts as climate change progresses. Even if these systems begin to regrow trees, they may be more vulnerable to effects of future fires (chapter 4.3, "Post-Wildfire Management")
2. Widespread tree mortality and persistent loss of trees may be associated with significant emissions of carbon, as forests are converted from carbon sinks into source areas for extended period (Dore et al. 2012) (chapter 2.1, "Forest Ecology").

3. Large patches of tree mortality may represent a loss of breeding habitat for species such as California spotted owl, fisher, and Pacific marten (chapters 7.1 and 7.2).
4. Intense, large, and long-lasting wildfires are likely to cause exceedances of air quality standards instituted to protect human health (Cisneros et al. 2010). It is much more difficult to control air quality and other impacts from those wildfires than from prescribed fires (chapter 8.1).
5. Although aquatic systems often demonstrate relatively high levels of resilience and important rejuvenating effects following wildfire, very large and severe wildfires may induce significant channel erosion and reorganization that can extirpate vulnerable aquatic populations, degrade downstream water quality, reduce storage capacity of downstream reservoirs, and elevate flood risks (chapters 4.3 and 6.1).

It is difficult to identify critical thresholds beyond which the resilience of social systems substantially erodes (see chapter 9.4, "Strategies for Job Creation Through National Forest Management"). However, fires can cause a range of impacts to social values, and much greater impacts are expected to result from fires that burn intensely, over large areas, and for long periods. It is also important to recognize that residential fire disasters can be avoided through treatments in the narrow "home ignition zone" surrounding dwellings (Cohen 2000, Reinhardt et al. 2008). However, large, intense and unmanageable wildland fires pose significant and costly challenges to agencies responsible for addressing short-term health and safety hazards, including smoke, flooding, and erosion. Such fires can induce the acute stresses of evacuation, as well as longer term impacts to individual health and community well-being (Hodgson 2007). Severe wildfires that cause widespread tree mortality affect socioeconomic values, including timber flows that contribute to local economies and maintain their infrastructure and markets for forest products. The nonmarket value of wildfire impacts are potentially very large but also challenging to assess owing to the size and diversity of resources that may be affected; the variability of responses across space and time (including the possibility that social preferences are likely to vary over time), and the infeasibility of valuing the cultural heritage of indigenous peoples (Venn and Calkin 2009). Furthermore, large fires threaten values held by people well beyond California, as residents of New England expressed willingness to pay substantial sums to treat and protect old-growth forests associated with spotted owls from high-intensity wildfire (Loomis and Gonzalez-Caban 1998).

Large and severe fires (fig. 2) may constitute a threat to resilience for some components of a socioecological system but not others. Recent syntheses have focused on the problem of "megafires," which some authors have described as having catastrophic damages in terms of human casualties and economic losses (San-Miguel-Ayanz et al. 2013). Adams (2013), writing from a perspective in Australia, suggested a size threshold for such megafires at 100 000 ha. Until the Rim Fire of 2013, none of the fires within the synthesis area had exceeded that size threshold. Although fire size alone can increase risks and challenges during an event, it is important to consider consequences rather than size alone (Reinhardt et al. 2008).

Because the concept of resiliency is scale-dependent and requires viewing outcomes along a continuum (see chapter 1.1), it is important to evaluate whether outcomes are "characteristic" by considering the spatial and temporal arrangement of a series of events in relation to the expected distribution of outcomes. Not all fires that result in widespread tree mortality should be viewed as causing a loss

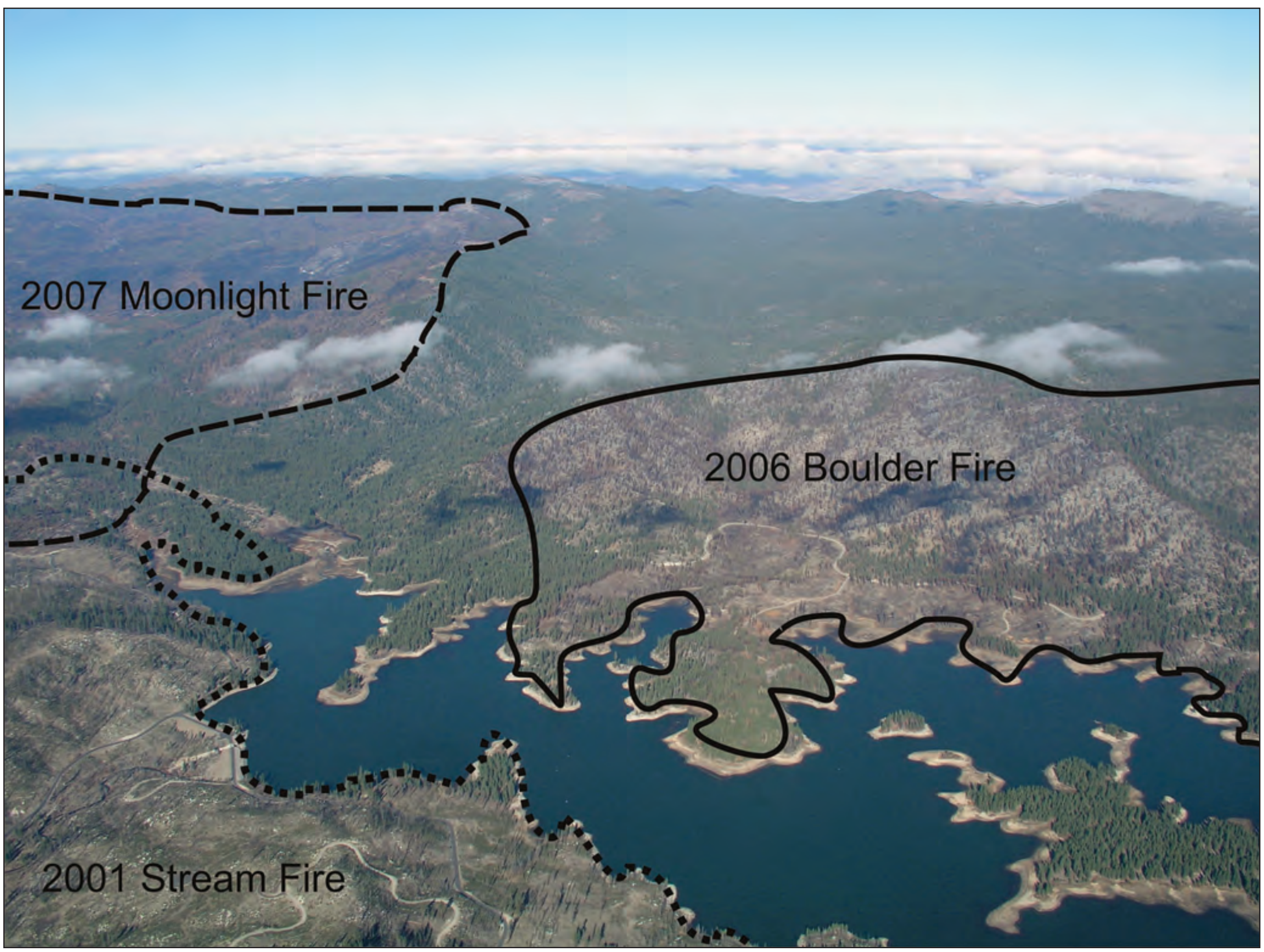

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Figure 2—Multiple fires have burned large patches with high severity in the watershed of Antelope Lake; such processes have potential for both short-term and long-lasting impacts to a wide range of social and ecological values. Fire boundaries illustrated by Brandon Collins.

The cumulative landscape impact of large areas of high-severity burns followed by reburns may also lead to transformations of ecosystems, including extended periods with reduced availability of mature forest. Long-term impacts to important ecological services are likely to be linked to the size of the high-severity patches, which influences recovery of both terrestrial and aquatic systems.

of ecological resilience; in some cases, trees may have invaded areas that were much more open or even dominated by nonforest vegetation under a fire regime that existed prior to fire suppression (see chapter 4.3). From a long-term landscape perspective, such fires may be seen as corrective. Yet, the cumulative landscape impact of large areas of high-severity burns followed by reburns may also lead to transformations of ecosystems, including extended periods with reduced availability of mature forest (see chapter 4.3). Consequently, long-term impacts to important ecological services are likely to be linked to the size of the high-severity patches, which influences recovery of both terrestrial and aquatic systems (Dunham et al. 2007, Lentile et al. 2007). Another concern associated with large patches of high-severity burn is the potential loss of genetic diversity, especially of trees that may have special resistance to nonfire disturbances such as insects and diseases.

The ultimate measure of resilience is how systems respond to major shocks, so it can be a difficult property to evaluate except in hindsight. However, there may be useful surrogates or indicators that point to vulnerabilities. Chapter 1.5 considers the need to evaluate impacts of fires of different severities, and concludes with further consideration of indicators of resilience. There will be important resources that decline in the absence of recurring fire. Some of these components may include yellow pines, sugar pine, and California black oak in frequent fire mixed-conifer forests (fig. 3 and chapter 4.2) and wildlife species that depend on habitat created and maintained by fire of different severities. In addition, valuable components such as large trees can become increasingly vulnerable to fire as duff accumulates in the absence of frequent fire (Hood 2010). A general approach for evaluating impacts of wildfire on social and ecological values is to measure ecological departure from historical range of variability (HRV) (Venn and Calkin 2009). Such an emphasis is consistent with the idea that both the curtailment of fire and uncharacteristically severe wildfires are undesirable. Moritz et al. (2013) discuss a conceptual approach to guide ecosystem management using boundaries associated with too much or too little fire based upon HRV and social preferences and cite examples of applications, including an analysis of risks of fire in chaparral communities to viability of steelhead populations in southern California.

Risks of Insufficient Treatment

North et al. (2012) pointed out that large areas of the Sierra Nevada are unlikely to receive needed forest treatments. Forgoing treatments can result in lasting impacts to ecosystems, human communities, and myriad ecosystem services. For example, deferring tree harvest for extended periods can not only impose social and economic impacts, but can also result in losses of key infrastructure needed to

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Figure 3—Large "legacy" pine trees loom over a California black oak and incense cedars in an area that has burned twice in the past 30 years within Yosemite National Park.

maintain capacity to conduct restoration treatments and preserve options for future forest management (see chapter 9.5, "Managing Forest Products for Community Benefit"). Furthermore, the global dimensions of economic and environmental issues mean that reducing harvests in local forests can have an unintended consequence of increasing environmental impacts much farther away (Berlik et al. 2002). For yellow pine and mixed-conifer forests, the likelihood of major disruptions in the long term may increase if effective treatments are not implemented, with effectiveness often being marked by the combination of targeted mechanical or hand removal of trees followed by treatment to reduce surface fuels, typically by fire (Agee and Skinner 2005, Safford et al. 2012c). For instance, computer modeling by Scheller et al. (2011) indicated that the threat of large, severe wildfires to habitat of fisher over large areas likely outweighs the expected short-term negative effects

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of fuels treatments on fisher population size. Moreover, the analysis noted that the benefits of treatment would be even greater if climate change makes wildfires larger and more severe (see chapter 1.4). In a similar vein, Roloff et al. (2012) completed a risk analysis of fuels treatments for northern spotted owls in southwest Oregon, which suggested that active management posed fewer risks than no management in fire-prone landscapes, although they cautioned that this strategy requires testing through field evaluation under an adaptive management framework. For these reasons, lack of treatment may exact a higher cost than first imagined, and the desire to avoid short-term risk from an institutional perspective must be weighed against the larger social risks that may be compounded through insufficient action.

Recognizing and Resolving Scale Mismatches

Research to understand socioeconomic and ecological processes is often restricted to a narrow range of influences, effects, localities, and timeframes that facilitate study (see table 1 for common spatial scales of ecological studies), but these constraints may not sufficiently reflect important processes that operate at larger scales. These types of scale mismatches have exacerbated debates over how best to manage national forests. In the Sierra Nevada, research has rarely been conducted in an interdisciplinary, cross-scale fashion that could enable better understanding of the dynamics and interactions of patterns over multiple scales of both space and time (Bissonette 1997). Many of the areas that have been designated for experimental approaches are relatively small (see table 1 in chapter 1.5). Likewise, there have been few attempts to craft a cohesive, interdisciplinary management strategy aimed at achieving multiple but seemingly disparate objectives. Forest management practices are often regulated by standards set for localized conditions at a single point in time, despite the fact that forest conditions continuously change in both space and time via stand development and disturbance processes. The integrated approach suggested in PSW-GTR-220 by North et al. (2009) took important steps forward in promoting a landscape strategy and collaboration across the disciplines of forest ecology, wildlife biology, and silviculture. The follow-up report, PSW-GTR-237, also edited by North (2012), extended those recommended considerations to include bark beetles, climate change, and various wildlife communities, and featured examples of collaboration and adaptive management experiments.

Integrated management strategies that consider effects at scales of 50 years or more, across local to large spatial scales, and across ecological and social dimensions, could help enhance socioecological resilience. Management approaches that seem suboptimal from a stand-level perspective may be favored when seen from a

Table 1—Minimum scales needed to evaluate ecological data that can be collected at various spatial scales to answer research and management questions

Typical minimum scale of data	Ecological attributes or processes
Plot (<1 to 4 ha) (<1 to 10 acres) to stand scale (40 ha or 100 acres)	• Vegetation structure, composition, and regeneration • Fire effects on plants, soils, insects, wildlife with small home ranges, etc. • Effects of some mechanical and prescribed fire treatments and wildfires • Soil structure and chemistry • Soil erosion • Wildlife with small home ranges, such as small mammals, birds, and amphibians • Use of habitat patches by species with large home ranges (i.e., nest patch and foraging patch) • Meadows • Air pollution effects • Tree genetics
Small landscape scale (40 to 400 ha or 100 to 1,000 acres), including headwater watersheds	• Linkages between terrestrial watersheds and aquatic systems • Stream water quantity and quality • Benthic macroinvertebrates • Sediment loads • Fire effects on stands to small watersheds • Fire history and stand structure reconstruction
Intermediate landscape scale (400 to 40 000 ha or 1,000 to 100,000 acres)	• Terrestrial wildlife with large home range dynamics (e.g., raptors, forest carnivores, and other large mammals) and fishes • Fire history and stand structure reconstruction • Fire severity patterns • Fuel treatment effectiveness to reduce large, high-intensity wildfires • Climatic influences on fire regimes and subbasin hydrology
Large landscape scale (40 000 ha or 100,000 acres and larger)	• Population dynamics of wildlife with large home ranges • Landscape genomics • Climatic influences on regional fire activity

Note: For non-ecological data, see the scale discussion in chapter 9.1, “Broader Context for Social, Economic, and Cultural Components.”

landscape perspective (or vice versa), because the effects of treating a stand may influence how the landscape as a whole responds to fire. For this reason, strategies that opportunistically target areas suggested by high fuel loads, low treatment costs, and reduced obstacles (such as regulations, additional planning requirements, or avoidance of potential litigation) can leave large parts of the landscape vulnerable to uncharacteristically severe wildfire under a management regime dominated by fire suppression. In a similar fashion, aquatic scientists have reinforced the importance of moving beyond reach-scale evaluations of conditions and projects to assessing how management shifts the cumulative distribution of stream conditions within a watershed over decades (Benda et al. 2003). The importance of a landscape perspective to promote forest resilience is detailed in the following chapter (1.3).

Strategies to Promote Socioecological Resilience

The introduction to this synthesis (chapter 1.1) defines socioecological resilience as "the capacity of systems to cope with, adapt to, and shape change; to persist and develop in the face of change; and to innovate and transform into new, more desirable configurations in response to disturbance." **This synthesis focuses in particular on the long-term challenges posed by wildfire and climate change because of their potential to affect the resilience of socioecological systems throughout the region.** This section considers several general strategies to address these kinds of challenges, beginning with several principles that emerge from a broad-scale perspective on ecological resilience.

Box 1.1-1

General Strategies for Addressing Challenges

- Recognize and address scale mismatches—the temporal and spatial scales of management systems may not be well matched to the scales of environmental variation (Cumming et al. 2006).
- Consider long-term (more than 50 years) risks in addition to short-term (fewer than 10 years) expected outcomes. Management focused on avoiding short-term risks is unlikely to sufficiently account for infrequent disturbances such as severe wildfires, nor for the progressive effects of climate change.
- Set adaptable objectives and revisit them, because there may be a lack of clear solutions, certain options may prove unrealistic, and new opportunities may become apparent as conditions change (Hobbs et al. 2010). In particular, the occurrence of large fires is likely to affect plans.
- Rely more on process-based indicators than static indicators of structure and composition, while recognizing that restoration of structure and process must be integrated.
- Integrate valuation tools, decisionmaking tools, modeling, monitoring, and, where appropriate, research to evaluate responses and better account for the risks and tradeoffs involved in management strategies. Although applications of such tools entail many caveats, technologies have advanced to facilitate concurrent analysis of many tradeoffs, such as effects on air quality, fire risk, wildlife habitat, water quality, water quantity, and cultural and economic values.

Promoting Heterogeneity, Emulating Natural Disturbances, and Restoring Processes

Actively promoting forest heterogeneity through silviculture and managed fire is an important restoration strategy, especially given the threat of climate change (see chapter 2.1). Current forest conditions are often relatively homogenous owing to past management practices and the absence of fire. Forests that developed under the influence of frequent, mostly low- and moderate-intensity fires exhibited very heterogeneous conditions that were likely produced by interacting effects of site productivity, topography, and fire history. These forests were common historically, but are now very limited because of fire suppression. Researchers have suggested actively promoting greater diversity in stand structure, age, species composition, and genetic backgrounds within those species as a hedging strategy to address uncertainty associated with climate change (Notaro et al. 2012). Treatments to reduce and promote variation in stem density and fuel loads should promote forest resilience to large disturbances associated with climate change, including droughts and insect and disease outbreaks (Fettig 2012, Littell et al. 2012, Safford et al. 2012b, Sturrock et al. 2011). To promote desired wildlife habitat and other forest restoration objectives, traditional uniform treatments could be modified to yield more variable density structure and canopy closure consistent with reference conditions (Knapp et al. 2012, North and Sherlock 2012, North and Stine 2012).

Treatments to reduce and promote variation in stem density and fuel loads should promote forest resilience to large disturbances associated with climate change, including droughts and insect and disease outbreaks.

North et al. (2012) suggested that the most practical strategy for treating large areas is to significantly expand managed fire, while recognizing the importance of structural treatments to facilitate such a strategy. This approach builds on the principle of natural disturbance-based management (North and Keeton 2008), and it is consistent with recent research concerning the importance of fire in riparian and aquatic ecosystems (see chapters 6.1, 6.2, and 6.3). A recent review of the Fire and Fire Surrogate study concluded that fire should be maintained whenever possible, because mechanical treatments did not serve as surrogates for fire for most variables (McIver et al. 2013). Arkle and Pilliod (2010) similarly concluded that using early-season prescribed fire in upland forests was unlikely to serve as a surrogate for the reference fire regime in maintaining integrity of riparian and stream systems. However, as Knapp et al. (2009) explained, in systems that have departed significantly from the reference fire regime, it may take a series of treatments (including out-of-season prescribed burns) to reduce fuel loads sufficiently before in-season fires will more predictably yield desired outcomes. Successful adaptive management strategies will anticipate wildfire disturbances and seek to direct them to achieve desired conditions. For areas with frequent fire regimes, Hirsch et al. (2001) called for "fire-smart" management strategies that acknowledge the inevitability of wildfire. This approach prompts consideration of how immediate risks associated with use of prescribed fire may be offset by potential to reduce future wildfire risks.

There are many areas where treatments to modify stand structures would help to facilitate returning fire as a primary disturbance mechanism (Miller and Urban 2000). Varying forest conditions with micro- and macro-topography can help increase heterogeneity and provide managers with a template for how and where to vary treatments. Recent studies provide information on how forest conditions and fire regimes varied according to topography when active fire regimes were operating historically (Beaty and Taylor 2001; Scholl and Taylor 2010; Taylor 2000; Taylor and Skinner 1998, 2003) and in landscapes where fire regimes have been partially restored (Lydersen and North 2012). Treatment strategies that build on the concept of emulating natural disturbance regimes would alter treatment type and intensity according to topographic position; for some landscapes in this synthesis area, such an approach might include reducing fuels preferentially on drier southern and western slopes, as compared to north slopes and canyon bottoms, and initially managing ridgetops for fuelbreaks (Weatherspoon and Skinner 1996).

Emphasizing process-based restoration and indicators—

Because a resilience-based restoration strategy places so much emphasis on the dynamism of systems, it demands greater attention to functional processes. Conditions and processes are so interconnected that restoration has to address both; however, restoration ecology has placed increasing emphasis on restoration of dynamic ecological processes versus static targets for structure and composition (Harris et al. 2006). For example, scientists in the field of stream restoration have called for less emphasis on in-stream structural approaches in favor of reestablishing disturbance regimes (fires and floods), vegetation dynamics, coarse woody debris recruitment, and lateral and longitudinal stream connectivity that build in-stream habitat (see Palmer et al. 2005 and chapter 6.1). In terrestrial forests that experience frequent fires, researchers contend that ecologically based restoration depends on successfully restoring mostly low- to moderate-intensity fire as a keystone process, while recognizing that fire regimes and stand structures must be restored in an integrated way (see chapter 4.1 and Allen et al. 2002). Therefore, structural indicators remain essential, but they have to be considered in light of dynamic processes, and there is a need for indicators and metrics that focus on process. It will be necessary to rely on modeling and monitoring to evaluate whether important habitat elements are likely to be sustained over time.

In addition to abiotic processes like fires and floods, it is also important to consider biotic processes as indicators of ecological resilience. For example, predation is an important process given the potential for trophic cascades when predators are lost (see chapter 7.1). Using an example from Lake Tahoe, Vander Zanden et al. (2003) demonstrated how consideration of long-term changes in food webs can guide restoration efforts, in particular by targeting systems where such changes have been less extensive.

Researchers studying aquatic systems have asserted that management systems have tended to rely too much on indicators of acceptable habitat conditions and water quality standards rather than embracing system dynamics and disturbance regimes (Rieman et al. 2003). Some decisionmaking systems may provide incentives to treat priority species and water quality as constraints, with an emphasis on avoiding short-term potentially negative impacts. However, approaches based upon promoting resilience need to sustain ecological values over the long run. Foundational components include the physical-chemical aspects of soil and water, which in turn support vegetation and habitat for terrestrial and aquatic organisms. Because foundational ecological processes, such as soil water storage, may not have explicit targets, there may be a tendency to undervalue, or even ignore them in decisionmaking. Yet, as noted in chapter 6.1, forest treatments have the potential to enhance system resilience to multiple stresses by increasing soil water availability. Such treatments, along with meadow restoration (see chapter 6.3), also have potential to enhance the yield, quality, and timing of downstream water flows and resulting ecosystem services. Another approach emphasized in promoting resilience of fluvial systems is to reestablish reference hydrologic regimes, including overbank flows in wet meadows (see chapter 6.3) and natural hydrograph patterns in regulated rivers (see chapter 6.1). The strategic orientation of PSW-GTR-220 (North et al. 2009) and PSW-GTR-237 (North 2012), which focus on restoring heterogeneity and landscape-scale ecological processes, can address aquatic resources by incorporating key hydrologic processes as treatment objectives rather than primarily as constraints.

Using fire regime metrics to evaluate performance—

By addressing system dynamics, process-based indicators avoid some of the shortcomings that may be posed by structural indicators, but they still pose a risk of oversimplification. Carefully selected fire regime metrics can be useful for setting priorities and evaluating performance, because they focus on a key disturbance process. Sugihara et al. (2006) identify seven important attributes for characterizing fire regimes, including fire return interval, seasonality, size, spatial complexity, fireline intensity, severity, and type. The total amount of area burned in any given year does not necessarily indicate failure or success, because there has been such a deficit of fire on the landscape since the onset of fire suppression. The proportion of area burned at low, moderate, and high severity and how the fires threaten human life and property are more important indicators. Area burned at low to moderate severity could be an important indicator of progress, whereas the extent of high-severity fire could be a useful indicator of a problem (Weatherspoon and Skinner 1996). In terms of achieving restoration goals, expectations for particular areas would need to be based on historical variation and/or contemporary reference sites, current conditions, and projections of climate change and future disturbance (Safford et al. 2012a). Fire return interval departure (FRID) analyses can help evaluate departures from reference conditions at a large scale. However, FRID analyses may not provide sufficient detail to apply these metrics at the project scale, and fire recurrence intervals alone are insufficient to drive treatment priorities (see chapter 4.1). For example, depending on values at risk and socioecological context, it may be more important to maintain a restored or minimally departed condition in one area than it would be to correct a significantly departed condition in another.

It is also important to consider the various dimensions of the fire regime other than simple averages of fire frequency, since the variation in fire regime characteristics within and among fires is a more important influence on landscape heterogeneity and biodiversity (Agee 2002). Individual low-severity burns are generally insufficient to restore reference structure and process after long fire-free periods (Collins et al. 2011, Miller and Urban 2000, Skinner 2005). Consequently, a metric like time since last fire may be useful as an initial look or as a short-term indicator of management performance, but it should not necessarily be construed as an indicator of a restored fire regime (see chapter 4.1). Unqualified measures of area burned or area treated would not be particularly useful indicators of restoration of ecological process. More multidimensional metrics are needed to evaluate effectiveness in reducing hazard or in restoring ecosystems.

Large areas affected by uncharacteristically severe fire may shift ecosystems into less desirable states that may persist for long periods, especially because climate change is also influencing those trajectories.

Managing long-term post-wildfire outcomes—
Uncharacteristically severe wildfires will continue to affect large areas of the synthesis area in coming decades. The Burned Area Emergency Response (BAER) program addresses short-term postfire impacts to life, property, and ecosystems, but a longer term strategy is important for promoting resilience of ecosystems within severely burned landscapes (see chapter 4.3). The Forest Service in California has recently developed a template to help guide national forests in planning for restoration and long-term management of post-wildfire landscapes. Postfire conditions offer opportunity to realign ecosystem structure, function, or composition with expected future climate. Large areas affected by uncharacteristically severe fire

may shift ecosystems into less desirable states that may persist for long periods, especially because climate change is also influencing those trajectories. Additional research and extensive monitoring are needed to ensure that treatments of those areas do not rely on untested approaches applied in a piecemeal fashion without consideration of landscape context and changing climate.

Social and Ecological Integration

The "triple bottom line" concept, which emphasizes social, economic, and ecological dimensions of sustainability (see chapter 9.1, "Broader Context for Social, Economic, and Cultural Components"), underscores the understanding that human and natural ecosystems are interdependent (see also chapter 4.2, "Fire and Tribal Cultural Resources"). Chapter 9.2, "Ecosystem Services," in particular notes the importance of understanding natural ecosystems as a foundation that generates finite streams of ecological services that benefit human societies and have limited substitutability. Findings from research (see section 9 in particular) suggest that an important part of a strategy to promote socioecological resilience is to explicitly consider social effects of forest management strategies on near and more distant human communities, as well as how community capacity can facilitate management to promote resilience. Researchers studying socioecological systems note that

Box 1.1-2

Summary of Approaches for Integrating Social Considerations Into Strategies

- Consider the integrated nature of socioecological systems; approaches that address issues from a narrow perspective are less likely to succeed in the long run than strategies that consider ecological, social, economic, and cultural components. Recognizing and measuring ecosystem services and other sociocultural values can help to consider impacts to communities and ecosystems as part of this approach.
- Use participatory and collaborative approaches to facilitate adaptive responses and social learning. Many of the topical sections of this synthesis note how scientists have moved toward such approaches as a way of promoting resilience, especially where management systems may be geographically and culturally distant from people who use the forests and their local knowledge systems (examples in chapter 9.6, "Collaboration in National Forest Management," include grazing management and incorporation of traditional ecological knowledge).

no single approach to governance, including broader and more active participation by local communities, will solve problems in managing socioecological systems (Ostrom 2007), because human-environment relationships are so complex and differ from one place to another. However, there is growing recognition that engagement, capacity building, and participation are often necessary components of strategies that promote resilience through social learning (Fernandez-Gimenez et al. 2008).

Recognizing ecosystem services and other sociocultural values—
The shift to thinking about integrated socioecological systems has spurred efforts to value ecosystem services (see chapter 9.2), because an ecosystem's capacity to generate such services is the foundation for social and economic development (Folke 2006b). Understanding changing demand for many ecosystem services at different scales is crucial for developing appropriate ecosystem management strategies (Grêt-Regamey et al. 2012). An important component of a resilience strategy may be to moderate societal expectations for ecological services rather than trying to provide a constant or ever-increasing supply. The Sierra Nevada encompasses watersheds that support millions of people and a large part of the global economy; therefore, potential impacts to water quality and quantity are of great importance locally, regionally, and even globally. Impacts of treatments and wildfires on these services are an important research topic (see chapter 6.1 as well as chapter 1.5).

The sociocultural value of ecosystems is not limited to direct uses by people, as it also extends beyond the Sierra Nevada and southern Cascade Range. Research has shown that people living far from the Sierra Nevada hold substantial values for the region's ecosystems and especially for their charismatic fish and wildlife (Loomis and Gonzalez-Caban 1998, Richardson and Loomis 2009). Ecosystems also support community identity and sense of place (see chapter 9.1). These values resist quantification and commodification but may be critical to maintaining the sustainability of socioecological systems (Berkes et al. 2006, Ostrom 2007).

Emphasizing values sustained by the forests may help facilitate communications with diverse members of the general public, local residents, landowners, and other groups. Studies have shown that science-based planning and communication are important for improving acceptability of proposed actions, such as wildfire risk reduction treatments, biomass utilization, and salvage logging (see chapter 9.5). Because local communities often play a role in management practices related to biodiversity enhancement, soil and water protection, and improving other ecosystem services, managing forest products on national forest lands to benefit those communities can in turn provide environmental benefits for forest and rangeland ecosystems across ownerships (see chapter 9.5).

Considering impacts to communities and ecosystems—
An integrated landscape-scale strategy can promote restoration in ways that benefit both local communities and ecosystems using specific approaches that are discussed within chapter 9.4. However, potential solutions may entail various tradeoffs between ecological and social impacts at multiple scales. For example, tools like stewardship contracts afford certain benefits and flexibility to promote ecological restoration, but under current policies, they can also incur potential impacts to communities by reducing payments to local governments. Redressing public policies that create disincentives for ecological restoration may be important in developing a successful long-term strategy.

An important issue raised in different topical sections of this synthesis concerns the potential to generate energy and fuel from forest biomass. This approach holds promise for simultaneously reducing greenhouse gas and smoke emissions, promoting renewable energy and U.S. energy security, and facilitating larger scale forest treatments in support of reduced fire hazard and ecological restoration. There has been considerable debate concerning whether forest biomass should be regarded as carbon-neutral, and assessments of the overall impact of emissions hinge on assumptions about fire regimes (Winford and Gaither 2012). However, there is consensus that the utilization of "waste" biomass debris that would otherwise release carbon quickly into the atmosphere (through decay or pile burning) is likely to be carbon friendly (Johnson 2009). Therefore, encouraging a shift from burning debris from harvest or fire hazard reductions in piles to burning in biomass facilities could yield significant environmental and economic benefits. Researchers have sought to estimate a sustainable supply of biomass that represents a byproduct of other management objectives, such as precommercial thinning and wildfire hazard reduction (Parker et al. 2010). However, development of biomass utilization in the Sierra Nevada requires consideration of an array of ecological, economic, and social factors, and the overall impact and acceptability of biomass initiatives depends heavily on local conditions (see chapter 9.5).

Encouraging a shift from burning debris from harvest or fire hazard reductions in piles to burning in biomass facilities could yield significant environmental and economic benefits.

Promoting collaboration and partnerships—
Consistent with an all-lands approach, working at the landscape scale will require greater coordination and partnerships with private landowners, nongovernmental organizations, and state and local governments. In addition, collaboration demands consideration of views and interests of stakeholders at broad scales, including people who may be farther away than those who have traditionally been included in planning. Although collaboration entails costs and complications, stakeholder input and participation from early stages can be crucial in outlining shared goals and objectives, facilitating shared learning and problem solving, and building

trust (Bartlett 2012). Although reaching consensus may not necessarily be a goal of planning, research from other areas, such as the yellow pine forests of northern Arizona, suggests that diverse stakeholder groups are able to reach consensus about managing very large landscapes (Hampton et al. 2011, Sisk et al. 2006), particularly because treatments need to initially target only a portion of the landscape to effectively reduce the risk of large, intense wildfires (Ager et al. 2007, Loehle 2004, Schmidt et al. 2008, Syphard et al. 2011). Achieving such agreement may be easier in high-relief areas where topography has a strong influence on effective treatment options and more difficult in areas with high-profile values (e.g., sequoia groves and habitat for wildlife species of concern). However, there are no guaranteed outcomes from adopting a collaborative process, and, as outlined in chapter 9.6, "Collaboration in National Forest Management," cross-boundary collaboration may be particularly challenging in some communities. That chapter also suggests that fire could be a rallying point, given that creating strategies to reduce fire risk across boundaries may enhance cooperation.

Science-based monitoring and feedback mechanisms that enable adaptive management practices are valuable for correcting course and building trust and cooperation (Cox et al. 2010, Fernandez-Gimenez et al. 2008). Such adaptive systems are important because there are significant gaps in scientific knowledge of the behaviors of these complex systems, as outlined in chapter 1.5. Furthermore, these approaches embed capacity to identify and benefit from new information discovered as a result of monitoring, shifts in social systems or values, shifts in ecological systems or dynamics, or a change in their interactions. A wide range of collaborative approaches to adaptive management, including participatory research and monitoring, and collaborations with tribal groups to investigate effects of reintroducing traditional burning practices, is discussed in chapter 9.6.

Institutionalized science-management partnerships are an approach to collaborative adaptive management that has been developed in the synthesis area. These partnerships have attempted to facilitate the dissemination of scientific information directly to resource managers, while providing researchers with a better understanding of contexts and constraints, including the challenges associated with climate change (Littell et al. 2012). Robust science-management partnerships may also provide the added benefit of building stakeholder trust and encouraging creative approaches to adaptive management. Regional examples of these science-management partnerships include the Tahoe Science Consortium, Southern Sierra Conservation Cooperative, Northern California Prescribed Fire Council, and California Fire Science Consortium.

Employing Adaptive Management Strategies

Phased Strategies for Long-Term Resilience

Considering management strategies in terms of phases may help reconcile short- and long-term priorities, reduce both short- and long-term risks, and facilitate adaptation to changing conditions. Attempts to restore a more natural disturbance regime of fire as an ecological process without first securing vulnerable communities and resources could have undesirable outcomes. Accordingly, a starting point for many landscapes has been to emphasize fire hazard reduction in areas of high value, such as the wildland-urban interface (WUI), as well as other areas where human-caused ignitions are likely to cause problems. Though such treatments can be effective, conditions on adjacent private lands in the WUI and the susceptibility of structures also determine effectiveness of wildfire defenses. As a result, involvement and cooperation of local communities is important in implementing treatments in a coordinated way across property boundaries (Weatherspoon and Skinner 1996).

Although WUI-focused approaches may do little to restore resilience to the larger landscape (Schmidt et al. 2008), they may expand windows of confidence in allowing fire to return. A major challenge is to go beyond localized fire hazard reduction and pursue a goal of restoring conditions where fire can be returned safely as a key process in the landscape. This goal is an integral part of a larger landscape resilience strategy. A near-term emphasis on reducing fire hazard in strategic areas can secure a margin of safety for pursuing longer term objectives. However, treatments driven by near- and long-term objectives do not necessarily need to be applied in a distinct sequence, but rather could be adapted to the needs, constraints, and opportunities of particular contexts. Accordingly, a strategic approach would likely blend more short-term defensive fire risk reduction as well as more restorative treatments for the long term. For example, resource managers may be able to take advantage of wildland fire opportunities without necessarily completing near-term strategic defensive treatments. In addition, strategically located treatments intended to reduce the potential for uncharacteristically severe wildfire would not necessarily need to be limited solely to achieving that objective. Rather, they could incorporate elements designed to promote future wildlife habitat, increase stand resilience to insects, diseases, and drought, and achieve other facets of the long-term goal (Weatherspoon and Skinner 1996). There are opportunities to enhance habitat for wildlife and other resources when seeking to reduce wildfire risk in developed areas (Eitzel et al. 2012); such an approach can be important because those areas may also harbor important biodiversity (Manley et al. 2006) and provide wildlife-related ecological services, including recreational opportunities.

A major challenge is to go beyond localized fire hazard reduction and pursue a goal of restoring conditions where fire can be returned safely as a key process in the landscape.

The hallmark of a strategic approach is the spatial and temporal arrangement of treatments to promote landscape resilience, rather than targeting the least costly locations or those that exhibit the worst fuels conditions. Although these strategies may be guided by local knowledge, geospatial decision support software, such as the Landscape Treatment Designer (Ager et al. 2012b), can be valuable in designing and evaluating such strategies.

Near-term phase: strategic treatments in a fraction of landscape to reduce fire hazard and promote resilience—
A near-term strategy would select areas for treatment to inhibit the potential for high-intensity wildfire to burn in uncharacteristically large patches. This approach sets up the landscape to achieve long-term goals. Treatments in this phase would represent a mix of approaches to promote conditions where wildfire can occur without unacceptably severe outcomes. Topography, vegetation, expected fire behavior, and resource concerns can guide development of treatment strategies (Skinner et al. 2006). Multiple landscape modeling studies suggest that if treatments are strategically placed, an initial target of treating 10 to 25 percent of the landscape within a period of 5 to 10 years can effectively reduce the likelihood of unacceptably large, high-intensity fires (Ager et al. 2007, 2010; Finney et al. 2007; Schmidt et al. 2008; Syphard et al. 2011). A strategy based on within-stand and across-landscape heterogeneity appears suited to deter the spread of high-intensity fire across the landscape while providing for a wide range of habitat conditions (Knapp et al. 2012, Weatherspoon and Skinner 1996). This phase may require a number of years to be completed, as some areas may require sequential treatments before they would achieve the desired condition (Skinner 2005). In some areas, strategic fuels treatment has been examined through the Fireshed planning effort (Bahro et al. 2007). This near-term strategic approach may reflect various strategies designed to impede wildfire spread similar to that modeled by Ager et al. (2013), including broad landscape protection as well as the restoration of dispersed fire barriers.

Managed fire will likely become increasingly important for promoting resilience in forest ecosystems particularly important in the many areas that are inaccessible to mechanical treatments to remove smaller trees.

Long-term phase: landscape-scale restoration of resilience and heterogeneity—
Objectives for this long-term phase would focus on expanding restoration work while sustaining a desired mosaic of ecological conditions through time. Integrating predictive habitat models with silvicultural and fire models would help to evaluate these spatial and temporal dynamics. A combination of corrective treatments to bring areas back into a desired condition and maintenance treatments would need to be applied. Tradeoffs between treating new areas and maintaining existing areas would need to be considered using models to account for costs of treatment, changing fire conditions, and other factors (Finney et al. 2007).

Corrective treatments and maintenance treatments may be distinguished more by their objectives than by their means of treatment. However, managed fire will likely become increasingly important for promoting resilience in forest ecosystems (North et al. 2012). As outlined in chapter 1.3, this approach would be particularly important in the many areas that are inaccessible to mechanical treatments to remove smaller trees.

As wildfires occur, they may alter the priorities for treatment across the landscape, and create new opportunities to influence ecological trajectories (fig. 2). As a consequence, greater integration with post-wildfire treatment plans, both before and after such fires occur, is another important facet of a resilience-based landscape strategy (see chapter 4.3). To be successful, adaptive strategies may require integration of land management plans and fire management plans to address short-term responses to wildfire as well as long-term objectives for large-scale fire restoration. Post-wildfire plans are important not only because fires are likely to be widespread agents of change, but also because wildfires can open windows of opportunity to learn and to take actions to promote future resilience (Littell et al. 2012).

Incentives for landscape-scale restoration—
Although strategic defense treatments can facilitate a larger restoration approach, they do not necessarily constitute restoration, because their intent is primarily to alter fire behavior to aid suppression activities and ameliorate wildfire impacts while working to produce conditions that reestablish fire as an ecological process. Hence, this approach relies strongly upon a resistance strategy (Millar et al. 2007).

Treatments would have to include some fire component to be considered fully restorative, even though mechanical treatments will in many cases be needed before fire can be safely applied. To encourage restoration, it would be appropriate to recognize and accord greater weight to treatments that come closer to facilitating reference fire regimes based upon frequency, seasonality, severity, and spatial pattern. Performance metrics based heavily on area treated will incentivize treating the easiest parts of the landscape in a concentrated fashion; therefore, they may hinder a strategic approach to promote resilience. Consequently, selection of appropriate performance metrics is a particularly important topic for management and science to consider (see chapter 1.5). Promoting more integrated accounting of ecological outcomes may help to facilitate actions that may generate significant gains over the long-term but involve shorter term risks and costs. As an example, one approach to integrate consideration of land management and air quality objectives has been to make decisions about prescribed burning through a more unified or joint institutional structure, as reported from a successful program in western Australia (Adams 2013).

Designing a landscape strategy requires carefully considering opportunities to promote wildlife, riparian, and aquatic habitat values rather than avoiding such priority areas. Applying the principle of emulating natural disturbance regimes would likely benefit riparian areas and habitat for species of concern over the long term, but this approach would benefit from testing within an adaptive management framework.

Economic considerations are particularly important in planning a landscape scale strategy because treatments of areas that have not been harvested for many decades may provide resources to restore parts of the landscape where harvest costs are likely to exceed biomass revenues (Hartsough 2003, North 2012). Although corrective treatments will remove merchantable trees, returns from maintenance treatments are likely to be much smaller. Consequently, opportunities to receive greater returns for smaller tree biomass will be important in accelerating the pace and extent of restoration treatments.

Demonstration landscapes—

Designing a landscape strategy requires carefully considering opportunities to promote wildlife, riparian, and aquatic habitat values rather than avoiding such priority areas. Applying the principle of emulating natural disturbance regimes would likely benefit riparian areas and habitat for species of concern over the long term, but this approach would benefit from testing within an adaptive management framework, including experimentation, modeling, intensive monitoring, and research on particular issues. Experimental approaches to landscape management, focusing on fire-related treatments in particular, have been tested on relatively small scales within experimental forests and other adaptive management areas in the synthesis area (see chapter 1.5). Larger demonstration areas could facilitate evaluation of treatment impacts on wildfire at the landscape scale and on a wide range of species with large home ranges, such as California spotted owls and fishers. The Dinkey Collaborative Forest Landscape Restoration Project has enabled observations of the effects of prescribed fire on fishers, but larger areas would be needed to address questions of connectivity for forest carnivores. The Northwest Forest Plan set up 10 adaptive management areas (AMAs), which ranged in size from around 37 000 ha (92,000 ac) to almost 200 000 ha (500,000 ac), to afford managers an opportunity to test new approaches at large scales and adjust standards and guides to local conditions. Scientists have noted that the plan's potential to facilitate large-scale experimentation has not been fulfilled owing to disagreements over what constitutes adaptive management and a perceived or real lack of sufficient flexibility to test different strategies (Rapp 2008, Stankey et al. 2003). Nevertheless, the Goosenest Adaptive Management Area (GAMA), located within this synthesis area, has demonstrated some on-the-ground progress (Rapp 2008). Whereas managers used the larger area to explore strategies pertaining to raptors, goshawks, and spotted owls, the GAMA Ecological Research study was undertaken to specifically test a variety of treatments designed to achieve the AMA's goal of accelerating late-successional conditions in young-growth forests. Explicitly designated demonstration areas, as described in chapter 1.3, could play an important role in facilitating the landscape-scale adaptive management needed to reconcile short-term risks with long-term gains. This type of active adaptive management approach would benefit from a robust partnership involving management, research, and stakeholder groups.

Riparian areas—

Landscape strategies that consider fire regime and topography interactions in designing treatments should be able to accommodate riparian area concerns (North 2012, Skinner et al. 2006). Management to promote resilience of small to medium stream reaches that historically burned frequently like adjacent uplands would facilitate similarly frequent, low- to moderate-intensity fire (see chapter 6.2, "Forested Riparian Areas"), rather than being set aside as unmanaged buffer zones that are more susceptible to high fire intensity. However, in riparian areas that function differently than uplands, other tactics are warranted because of higher soil moisture and stronger connectivity to aquatic systems. Experimental, scientifically informed harvesting and burning techniques could illuminate new ways to improve riparian conditions and improve understanding of treatment effects on water flow, water quality, soils, riparian and aquatic biota, and impacts from wildfire. This approach would require consideration of large woody debris loading, shading, stream channel stability, and nutrient inputs, among other factors (Burton 2005). As part of a long-term adaptive management strategy, experiments in riparian areas would help to address a significant research gap.

Special wildlife management areas—

Areas of special management have been designated for several wildlife species, for example, protected activity centers (PACs) for California spotted owl and den buffer areas for fisher. In these areas, restrictions on vegetation management have been linked to site location and hazard levels (wildland-urban interface versus wildlands), but they have generally made treatments more challenging to implement. In wildland settings, mechanical treatments have often been restricted or not allowed, and approved treatments (e.g., prescribed fire and hand removal of fuels) have often been limited to specific timeframes or prescriptions (see sidebar on limited operating periods in chapter 1.5). PACs were originally designated as an interim measure, but they have become long-term zones with little to no active management (Berigan et al. 2012). In some cases, their boundaries have been revised based on changes in conditions and long-term monitoring data (Berigan et al. 2012), but in other cases, unoccupied areas have remained set apart from the general forest matrix.

Because areas within primary habitat for species of concern may be at relatively high risk for uncharacteristically severe wildfire (Ager et al. 2012), treatments within such areas could aid their long-term conservation despite short-term risks of impacts (Scheller et al. 2011). It would be valuable to evaluate the effects of including or excluding core wildlife areas from treatment within landscape-scale plans. Extensive monitoring within demonstration landscapes could help to test tradeoffs between short-term risks and long-term gains for species conservation projected through modeling (see chapter 1.3). Another approach would be to use abandoned areas and margins of core areas as a surrogate to evaluate treatment effects on occupied habitats. Use of robust modeling tools as part of an adaptive management framework may highlight the ways in which landscape-scale strategies can promote long-term improvements in habitat. The focus needs to move beyond effects easily seen at the stand scale to effects that are not as easily seen at the landscape scale, but that can still be modeled and validated through monitoring. This approach may aid conservation and recovery of additional species of concern as research is better able to evaluate the quality and connectivity of their habitats.

Promoting future habitat and appropriate habitat connectivity—
Where landscapes appear to have deficits of priority species habitat compared to the likely HRV, plans could be developed to guide management activities to restore high-quality habitat (North 2012) following conservation approaches suggested by Thompson et al. (2011) and Spencer et al. (2011). Landscape-level restoration strategies could be developed to promote desired habitat conditions where they currently do not exist, using concepts and tools like the HRV, climate adaptation strategies, and scenario planning (Nydick and Sydoriak 2011, Peterson et al. 2011). Landscape strategies would include treatment designs that consider and promote habitat connectivity appropriate to the landscape, keeping in mind the potential undesirable effects of connectivity, such as unwanted spread of severe fire or invasive species. The maintenance of habitat connectivity would be an important consideration as treatments progress through the landscape and as forest conditions change with stand development. Landscape analysis tools that can evaluate multiple objectives are well suited to help resource managers evaluate these tradeoffs (see chapter 7.1 for examples).

Applying landscape-scale modeling—
Because experimentation is so costly, difficult, and slow, modeling will be an important component of developing and adjusting an adaptive management strategy. The "fireshed" modeling approach demonstrated the potential for spatial analyses to evaluate complex tradeoffs across large areas over many decades (Bahro et al. 2007). Although the term "fireshed" may imply an emphasis on fuels reduction, the intent of the approach is to focus thinking at the broader landscape scale at which fire operates rather than at a more limited project scale. In this sense,

fireshed is analogous to watershed except it is based on the scale at which fire operates informed by fire history, fire regimes, topography, vegetation, expected fire behavior, and the risk of problem fires (Bahro et al 2007). The objective of fireshed assessment would be to develop plans that limit the risk of large, high-intensity fires while considering a broad array of values—including watersheds, viewsheds, smokesheds, wildlife habitat quality and connectivity, ecosystem services, and other social and economic values—in an integrated approach at an appropriate landscape scale. Landscape-scale simulations suggest that these broad treatment strategies may benefit wildlife species (Scheller et al. 2011). Combining multiple tools may be necessary to assess treatment effects on the distribution of seral stages/structural types, associated habitat values, and connectivity through time at multiple scales. An example of an integrated approach applied the Forest Vegetation Simulator (FVS) tool to model effects at the smaller scale of fisher home ranges (Thompson et al. 2011), while designing fuels treatments based on landscape analyses (e.g., Fireshed, Flammap), local knowledge of prevailing winds, and the general direction of historical large wildfires. Modeling habitat for priority species at the landscape scale would allow projections of the future arrangement of dense patches, matrix, and openings based on treatments and wildfires under different management strategies. The complementary use of modeling and monitoring can examine potential air quality benefits of prescribed burning, managed wildfires, and other treatments to mitigate hazardous conditions during wildfires (see chapter 8.1). Chapter 9.6, "Collaboration in National Forest Management,") notes that participatory approaches to modeling and data visualization may be a useful way to engage stakeholders in sharing knowledge of the environment and considering management alternatives in relation to the particular geography of a landscape.

Although many species appear to either benefit from or be indifferent to fuels reduction treatments, other species associated with high canopy closure and high structural complexity may be negatively affected by conventional treatments. However, even these species persisted within landscapes that historically had considerable amounts of open forest conditions and early seral habitat created and maintained by frequent, low- and mixed-severity fires.

Monitoring effects on species of concern—
Although habitat modeling will be important to evaluate potential outcomes at large scales, species monitoring will also remain a significant part of an overall resilience strategy. Effects of treatments on current habitat conditions would need to be monitored to estimate how species of concern are likely to respond. Although many species appear to either benefit from or be indifferent to fuels reduction treatments (Stephens et al. 2012), other species associated with high canopy closure and high structural complexity may be negatively affected by conventional treatments. However, even these species persisted within landscapes that historically had considerable amounts of open forest conditions and early seral habitat created and maintained by frequent, low- and mixed-severity fires (Perry et al. 2011). Chapters 1.3 and 7.1 focus more on this issue. In particular, chapter 7.1 notes that tension

between achieving fire-related objectives and promoting habitat for fisher may be more significant when addressing the forest understory rather than the large trees in the overstory. Again, landscape management strategies that emphasize heterogeneity, in addition to robust monitoring in treated areas, may be able to account for and address the needs of different priority species.

Monitoring plans are expected to include both a coarse-filter approach to evaluate landscape-scale habitat patterns and ecological processes, and a fine-filter approach to ensure that at-risk species are being conserved. Integrating modeling with monitoring of field conditions can help to evaluate how ecosystems are changing at broad scales where experimentation may be impractical. Noon et al. (2012) recommended targeting a small number of species based on management objectives and the species' ecological roles, sensitivity to change, and conservation importance; however, they recognized that multiple species approaches, as described by Manley et al. (2004), are appropriate for species that can be detected using the same protocols (for example, breeding birds, small rodents, and mesocarnivores).

Management Implications

- Strategic placement and phasing across the landscape using a combination of prescribed fire, managed wildfire, and mechanical treatments can accomplish the following:
    - Shift disturbance regimes toward patterns that are more consistent with how ecosystems evolved and promote resilience to stressors such as climate change.
    - Reduce undesirable losses from the terrestrial, aquatic, and socioeconomic components of socioecological systems that can result from large, severe, and dangerous wildfires.
    - Promote important values for the long term, including habitat needs for species of concern, favorable water flows, traditional cultural resources, forest products and associated livelihoods and infrastructure, and other ecosystem services and social benefits.
- Measures of ecological departure from the HRV can be useful for evaluating effects of wildfire on socioecological values and to design and evaluate strategies to promote resilience.
- Approaches for reestablishing historical processes within aquatic ecosystems, in addition to terrestrial treatments, can include restoring incised channels in wet meadows, removing introduced fishes from lakes, and promoting more natural stream hydrographs below dams.

- Development and implementation of these approaches through collaborative, placed-based efforts can strengthen existing community capacities and reduce vulnerabilities to major disruptions.

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