Chapter 6: Ecology and Biodiversity[1]

Patricia N. Manley,[2] Dennis D. Murphy,[3] Seth Bigelow,[4] Sudeep Chandra,[5] and Lisa Crampton[6]

Introduction

The integrity of animal and plant communities serves as a critical measure of the effectiveness of policies designed to protect and restore ecosystem processes in the Lake Tahoe basin. The conservation of plants and animals in the Tahoe basin is utterly dependent on the conservation of its terrestrial and aquatic ecosystems; so, in many ways, the research agenda that follows builds on the other research described in this volume. Accordingly, successful integration of outcomes from research on water quality, air quality, and other natural attributes of the basin will contribute greatly to the recovery and persistence of biological diversity in the Tahoe basin.

A Lake Tahoe research agenda that considers biological diversity and ecological function is best based on data collected from across scientific disciplinary boundaries. In Tahoe's intensively managed forests, there is an immediate and keen interest in linking forest fuel treatments to changing soil conditions, vegetation composition and structure, and the status of wildlife populations at multiple trophic levels. That immediacy noted, the Lake Tahoe basin actually is home to remarkably few imperiled species; however, that could change in short order through well-intended land and resource management actions that lead to unanticipated species declines (Manley 2005). Little species-specific information is currently available to guide land use and resource planning should changed circumstances lead to new listings under federal or state endangered-species statutes.

A number of policies direct and define management objectives for biological diversity in the Lake Tahoe basin. The Lake Tahoe Environmental Improvement Program identifies multiple restoration actions that are expected to benefit wildlife. Documents supporting the Tahoe Regional Planning Compact (1969), namely the 1987 Regional Plan (see http://www.trpa.org), call out 20-year goals for wildlife and

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[2] Pacific Southwest Research Station, USDA Forest Service, Davis, CA 95618.

[3] University of Nevada, Reno, Department of Biology, Reno, NV 89557.

[4] Pacific Southwest Research Station, USDA Forest Service, Davis, CA 95618.

[5] University of Nevada, Reno, Department of Natural Resources and Environmental Sciences, Reno, NV 89557.

[6] University of Nevada, Reno, Department of Biology, Reno, NV 89557.

fish, and identify environmental thresholds, indicator measures of those thresholds (including species indicators), and species and communities of special concern. The National Forest Management Act (1976) directives pertain to plants and animals on the more than 70 percent of Tahoe basin lands under U.S. Department of Agriculture, Forest Service jurisdiction. The U.S. Department of the Interior, Fish and Wildlife Service implements focal activities associated with several wildlife, fish, and plant species on National Forest System lands in the basin. Provisions of the Migratory Bird Act pertain to the entirety of the Lake Tahoe basin. Stringent state lands and parks rules are enforced on both California and Nevada sides of the lake. And both federal and state wildlife agencies are able to implement prohibitive policies if a threatened or endangered species listing becomes necessary.

Despite a demonstrated concern, our understanding of nearly all aspects of Lake Tahoe's biodiversity—from species found in lakeside meadows, to those on alpine peaks above—is still rudimentary and would benefit greatly from implementation of the research agenda that follows. To varying degrees, management of all Tahoe basin ecosystems would be better informed by improved scientific knowledge about ecological characteristics, habitat associations, and species responses to management activities. Detailed status and management response information is available for very few species in the basin; and, in most management applications, it will be necessary to know the local status and responses to management given the unique configuration of wildlife habitats within the basin, and the basin's relative isolation from the larger forested landscape of the Sierra Nevada. To that end, this chapter identifies focal management issues, associated uncertainties, and key research questions that, if answered, would encourage effective, efficient, and accountable resource management designed to maintain and conserve biological diversity, ecological function, and ecosystem services. Research in the Lake Tahoe basin will be most effective when designed in a manner that both decreases resource risk and uncertainty by closing information gaps, and directly informs management. For example, a research program to address uncertainties about the effects of forest management on biological diversity might start with a description of site-scale response patterns of biological diversity to various environmental changes associated with forest management. This program also might take steps to apply those data to the development of management tools that:

- Apply that understanding to the basin as a whole to inform management about conditions throughout the Lake Tahoe basin.
- Identify system indicators that can be used to monitor progress toward management goals for forest ecosystems.

- Determine thresholds of species and community responses that can inform how and when management actions should respond to monitoring results.
- Provide evaluation tools that managers can use independently.
- Provide basic data to enhance management and policy development.

The ecology and biodiversity research agenda considers seven subthemes that represent various management activities and objectives: (1) old-growth and landscape management, (2) fire and fuels management, (3) special community management, (4) aquatic ecosystem restoration, (5) urbanization, (6) recreation, and (7) climate change. Within each subtheme, we provide a summary of issues and uncertainties and associated key research questions. The departure from historical conditions reflected in current ecosystem conditions in the basin presents many challenges to restoration. Most fundamental is the challenging fact that existing terrestrial and aquatic ecosystem conditions are unique in the history of the basin as are the current and projected future climate conditions. Thus, the objective of restoration is not to return these systems to an historical structure or composition, but rather to restore their biological diversity, function, and resilience. The key research questions span many types of information gaps including basic information gaps; effects and effectiveness of existing management approaches; models of past, current, and potential future conditions; and field and analysis tools to enhance the "toolbox" of methods available to managers to inform planning and decisionmaking.

The ecology and biodiversity research agenda highlights the interactions between native species and communities and natural and human-caused stressors that present the greatest ecological and social risk, and for which research can reduce management-related uncertainties. Conceptual models are provided that show the primary linkages between native species and communities as components of ecosystems and the factors that affect their condition, including human-caused stressors (figs. 6.1 and 6.2). The two conceptual models group subthemes that share most of the same components and drivers: terrestrial ecosystem subthemes (old-growth forests and fire and fuels management) (fig. 6.1), and primarily aquatic ecosystems subthemes (special communities and aquatic ecosystems) (fig. 6.2).

The subthemes identified in the ecology and biodiversity theme area represent focal elements for management planning and action in the Lake Tahoe basin (figs. 6.1 and 6.2). The core components are those shared by most biological systems (e.g., species composition and abundance, vegetation structure), with differences expressed in the specifics of the components (such as associated species). The primary drivers of the condition of components also are often shared, given that human activities are pervasive and affect many biological components. Secondary

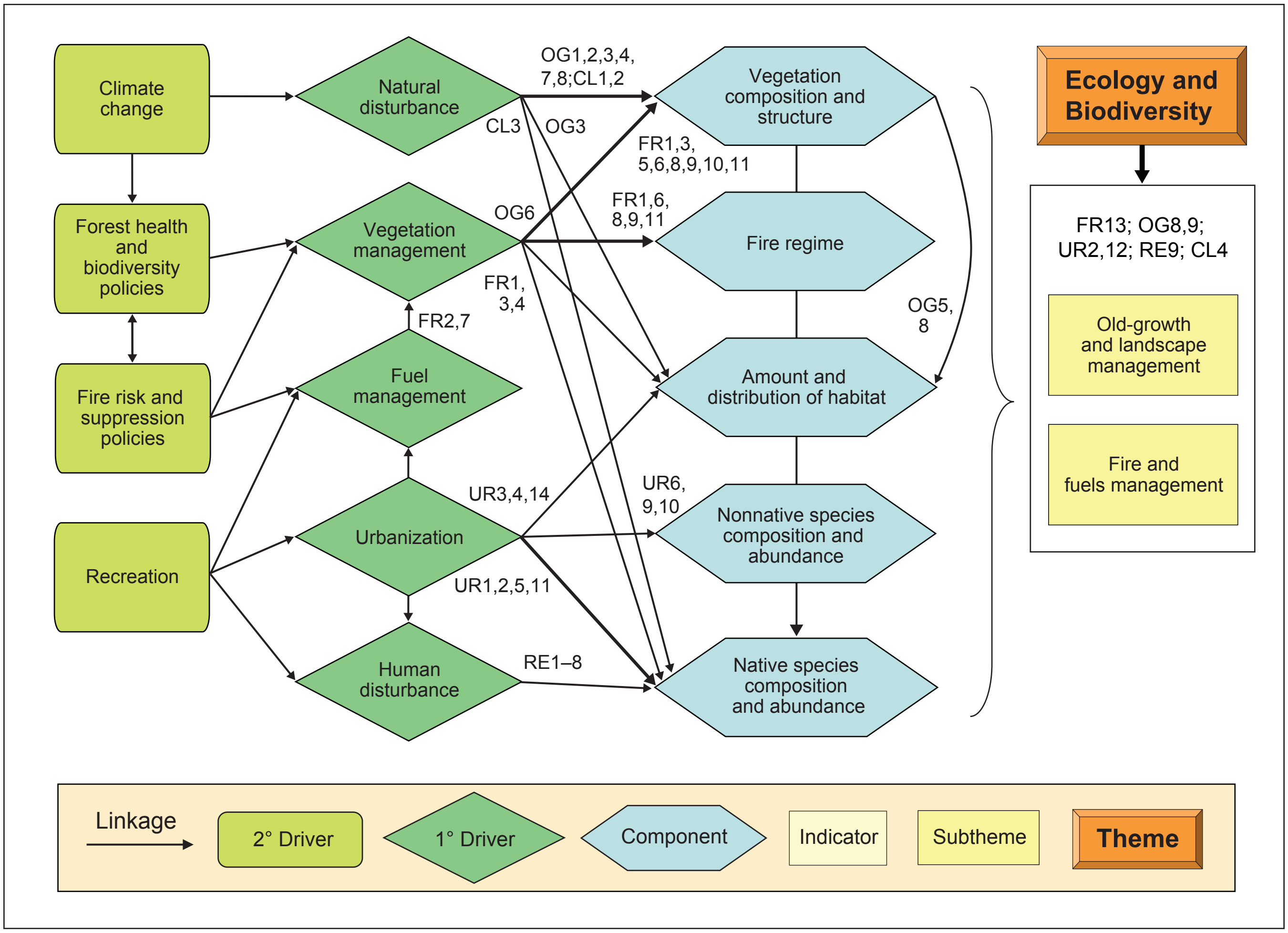

Figure 6.1—Conceptual model of the terrestrial ecosystem subthemes in the Ecology and Biodiversity theme. Identified are the primary components of terrestrial ecosystems in the Lake Tahoe basin, the natural and human-caused phenomena that affect their conditions, and the focus of research questions in the theme area, which are based on management concern and uncertainty. Thick arrows indicate especially important linkages between drivers and components. Research needs are indicated by alphanumeric symbols (e.g., CL3, OG3) and correspond to the descriptions presented later in the chapter.

drivers are typically external, broad-scale forces that act on human activities, such as regulations, policies, economic forces, and climate. It is important to recognize that stressors may have initial positive consequences for some species (e.g., habituation to human settlement by bears and geese) that then lead to undesirable secondary consequences (e.g., property damage or reduced diversity of native species).

The majority of uncertainties associated with terrestrial ecosystems pertain to the linkages between vegetation management and climate change (i.e., natural disturbances) and their effects on vegetation structure, composition, and associated fire hazards (fig. 6.1). A more limited set of questions pertain to the effects of forest fuels treatments on plant and animal communities, populations, and habitats. The

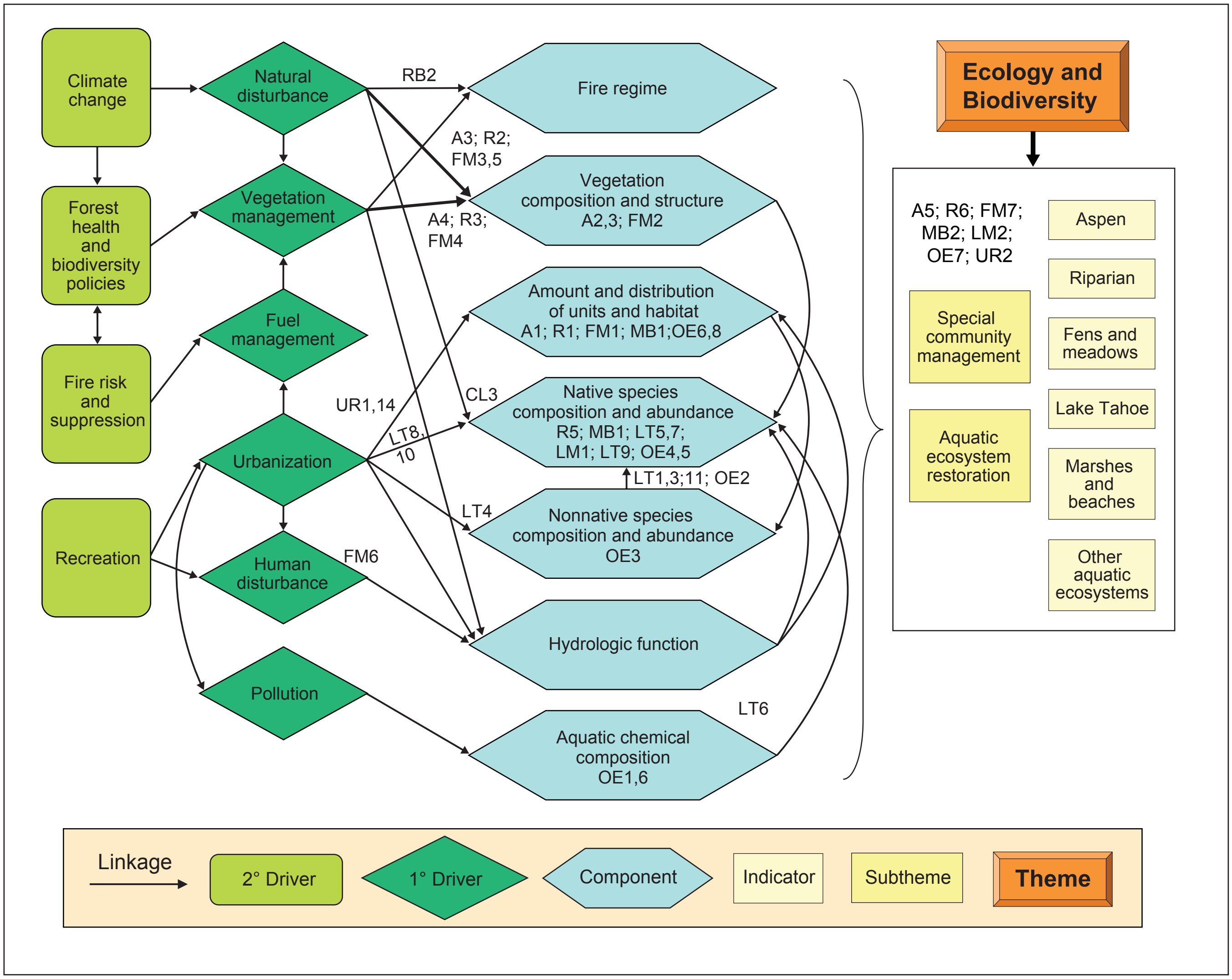

Figure 6.2—Conceptual model of the aquatic ecosystem subthemes in the Ecology and Biodiversity theme. Identified are the primary components of aquatic ecosystems in the Lake Tahoe basin, the natural and human-caused phenomena that affect their conditions, and the focus of research questions in the theme area, which are based on management concern and uncertainty. Thick arrows indicate especially important linkages between drivers and components. Research needs are indicated by alphanumeric symbols (e.g., R2, FM3) and correspond to the descriptions presented later in the chapter.

limited set of questions regarding biodiversity does not reflect lower uncertainty and risk, but rather it reflects the priorities of management, and the assumption that fuels treatments will not substantially alter the habitats of animals and herbaceous plants. Land and resource managers are interested in identifying key measures of conditions that can be used as indicators for progress toward desired conditions. These circumstances are not unique to the terrestrial ecosystems or the ecology and biodiversity theme; rather they recognize an area of substantial investment by management agencies at the present time.

The majority of uncertainties associated with the special communities and aquatic ecosystems are weighted toward basic information, as opposed to linkages between activities and the condition of components (fig. 6.2). This is a function of limited investment in research and monitoring in aquatic ecosystems other than Lake Tahoe itself; so it is generally thought that basic information on current conditions is the first step toward informing management. Not all special communities are identified, but the suite that is identified represents those of greatest management interest. In addition to the pursuit of basic information, greater understanding is needed about the linkages between natural disturbances, and the role of fire and fuels reduction on vegetation composition and structure, particularly in riparian and meadow habitats. As with terrestrial ecosystems, indicators would be selected for the purposes of assessing the condition of each of the special communities and aquatic ecosystems.

The research questions that are identified here constitute the highest priority information needs over the next 10 years, based on the combination of three considerations: (1) uncertainty based on lack of knowledge, (2) current risk based on the current condition of biophysical components, and (3) potential future risk based on current or future management activities or climate change. The questions represent those that, if addressed through research, would make a substantial contribution toward reducing uncertainty and risk in conservation and restoration efforts targeting biological diversity and ecological integrity in the Lake Tahoe basin. Some of the questions presented are more time sensitive than others, either as a function of their placement in a sequence of discovery or the ease of answering the question relative to the value of the contribution to reducing uncertainty and risk. The most time-sensitive questions within each subtheme are indicated in bold.

Old-Growth and Landscape Management

Past management activities, particularly historical logging, followed by fire suppression, substantively shaped the amount, distribution, and condition of old-growth forests in the Lake Tahoe basin today. Current management activities continue to affect the character and distribution of the basin's forest ecosystems. The combination of these anthropogenic and natural disturbances has determined the current distribution of seral conditions across the basin, including the distribution and abundance of the remaining old-growth forest patches (Manley et al. 2000). Forests in the Lake Tahoe basin now differ in a number of important aspects from their pre-Euro-American appearance. In the montane zone, the tree species composition and diameter distribution have changed greatly; there are far more small-diameter trees (e.g, < 30 cm diameter at breast height [DBH]) of shade-tolerant species (particularly white fir, *Abies concolor* (Gordon & Glend) Lindl ex Hildebr.) in the understory than there were formerly, and far fewer larger-diameter (e.g., ≥ 75 cm DBH), older trees (Barbour et al. 2002). Moreover, the proportion of the landscape in montane chaparral has diminished, having been converted to forest (Nagel and Taylor 2005). Both of these changes indicate a reduced proportion of the landscape in both early and late-successional stages relative to the pre-Euro-American Tahoe basin landscape. The majority of the landscape is single-aged, fire-suppressed, second-growth fir and pine, a condition that would not exist historically.

Knowledge Gaps

The departure from historical landscape conditions in the Tahoe basin resulting from timber harvest and fire suppression has contributed to a reduction in terrestrial biodiversity, as well as apparent increases in fire risk (Weatherspoon and Skinner 1996). Debate exists regarding the extent of old-growth forests that historically occurred in the basin. A better understanding of historical old-growth reference conditions could help in assessing how the basin has changed over time, what those changes represent in terms of accompanying plant and animal diversity, and what targets might be set for future conditions in terms of the extent and condition of old-growth forests in the basin (Manley et al. 2000).

Seth Bigelow

Old-growth mixed-conifer stand in the Upper Truckee watershed, Lake Tahoe basin (2006).

Central questions for Lake Tahoe basin forest managers pertain to how much of various forest conditions is desired, and how those conditions should be distributed spatially to ensure the persistence of associated species, functions, and services. A well-defined vision for desired conditions can be used to design forest management and speed the transition to desired conditions; alternatively, forest management lacking such a vision can impair progress toward desired conditions. Agency managers in the basin have identified species of special concern and interest. For example, species of special concern identified in the Pathway planning process that have an association with old-growth forests include northern goshawk (*Accipiter gentilis*), American marten (*Martes americana*), pileated woodpecker (*Dryocopus pileatus*), and California spotted owl (*Strix occidentalis*). Other species of concern associated with old-growth components include osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), and black bear (*Ursus americanus*). The population of brown-headed cowbird (*Molothrus ater*), another species of concern based on its potential ecological impact, is also affected by forest management practices. Coyote (*Canis latrans*) and black bear are species of high public interest in the basin (Manley et al. 2000); their populations are likely to change in response to forest management, and given their status as top carnivores in the basin, changes in their populations are likely to precipitate changes in wildlife community composition and structure (Crooks and Soule 1999).

There are many areas in the basin that cannot support certain forest structural conditions owing to physiographic constraints, such as slope, aspect, elevation, and soil depth, which affect vegetation growth rates and disturbance regimes (Taylor and Skinner 1998, Urban et al. 2000). Vegetation growth models can help define how those structural conditions will change over time across the basin, but a concrete understanding of how landscape configuration constrains the basin's vegetation communities is needed.

Disturbance fundamentally shapes forest structure and species composition in the Lake Tahoe basin. Current management activities with the greatest potential to affect old-growth forest vegetation conditions and landscape configuration are fuel treatments, fire suppression activities, and salvage logging. Wildfire, avalanches, and landslides are the most common natural disturbances shaping forest structure in the basin. Although we now understand the fundamentals about the role of fire in maintaining historical vegetation structure in the basin (Scholl and Taylor 2006, Taylor 2004, Taylor and Beaty 2005), relatively little is known about the role of avalanches and landslides, and their interactions with fire regime. Avalanches can break up landscape-level fuel continuity, and conversely, forested areas diminish avalanche risk (Kattelman 1996). A better understanding of the basin's natural disturbance regimes and their interactive effects would aid forest restoration efforts. Recreation activities, both motorized and nonmotorized, can greatly affect the occurrence and abundance of wildlife species and thereby the structure of animal communities. Thus, recreation represents an added source of disturbance to wildlife, and its management is relevant to achieving desired forest conditions.

Research has begun to examine how forest restoration planning should consider a changing climate regime (Harris et al. 2006). Most research suggests that by the year 2070, a mean increase of two to five degrees centigrade in June–August temperatures will manifest in the Western States (Running 2006). This dramatic temperature change, and attendant changes in the hydrologic cycle, will predispose the basin to more extensive and intense wildfires (Taylor and Beaty 2005, Westerling et al. 2006) and change the distribution and interactions among plant and animal species. This means that desired-condition decisions and associated management strategies now informed and shaped by historical reference conditions also could be informed by current and projected future climatic conditions and disturbance regimes.

These issues and uncertainties translate into the following broad management questions:

- What stand conditions should management create to ensure that forest health and resilience is restored in the future?
- How much and where should various stand conditions be located throughout the basin to ensure that populations and communities of native plant and animal species are maintained?
- What key measures of stand conditions and landscape configurations will be most effective and efficient in monitoring forest ecosystem health and informing forest management?

Research Needs

In the subsequent research needs sections, and figures 6.1 and 6.2, research questions are identified by combined text and numeric codes. Text codes are defined as follows: OG for old-growth and landscape management; FR for fire and fuels management; FM for fens and meadows; A for aspen; R for riparian areas; LM for lakeside, beach, and marsh; LT for Lake Tahoe aquatic ecosystems; OE for other aquatic ecosystems; UR for urbanization; RE for recreation; and CL for climate change. Numbers refer to the sequence of questions presented in each subtheme. Bold codes indicate the most time-critical research needs.

Following are the old-growth and landscape management research questions:

(**OG1**) What more can we learn about pre-Euro-American settlement (prior to 1850) characteristics of forests in the Lake Tahoe basin with respect to plant species composition; diameter distribution of trees, snags and logs; and proportional representation of seral stages? How did these characteristics differ according to topographic position (slope, aspect, and elevation), longitude, and soil substrate? What is the relationship between historical stand structure and composition, and existing map products depicting "potential natural vegetation?"

(**OG2**) Does the condition of the pre-Euro-American settlement forests in the Tahoe basin represent a satisfactory model for forest restoration (i.e., desired future condition), and if not, how should it be modified to account for factors such as climate change and irreversible changes in land use? What are the projected changes in range and elevation of dominant tree species within the Tahoe basin owing to climate change?

(**OG3**) How did the historical disturbance regime (e.g., fires, landslides, avalanches, insect outbreaks) differ spatially, in intensity and extent, within the Tahoe basin? How did these disturbances shape the structure and composition of the forest? Did upper and lower elevation zones exhibit different spatial patterns of disturbance and resulting structure?

(**OG4**) What animal species are most closely associated with old-growth forests in the basin, and what are the relative effects of different stand conditions and landscape configurations on the persistence of these species and biodiversity, with particular emphasis on special-status species? How do closely associated species use old-growth stands, compared to other available areas, for foraging, shelter, dispersal, and reproduction, and what are the most favorable amount and configuration of forested conditions to support forest biological diversity and special-status species?

(OG5) What were and are the effects of historical logging and fire suppression on forest-associated wildlife species, including composition, abundance, co-occurrence, and diversity?

(OG6) What are the likely spatial changes in range and elevation of sentinel animal and plant species (i.e., species that are sensitive indicators of change) within the Tahoe basin in response to climate change?

(**OG7**) What elements of old-growth forests are key to maintaining their biological diversity (including density of large trees, basal area, stand contiguity, tree age structure, or standing or fallen large woody debris)? What is an effective set of indicators of the physical and biological conditions of old-growth forests?

(**OG8**) What performance measures—including presence and abundance of plants and animals, and other ecological community metrics—can be used to assess the effectiveness of efforts to restore historical (or achieve desired) old-growth forest structure, composition, and function?

(**OG9**) What landscape features and locations (e.g., dispersal/migration corridors) play key roles in maintaining populations within the basin, and what species or measures can serve as indicators of the function of these key features?

Fire and Fuels Management

Fire was undoubtedly the most pervasive agent of ecological disturbance in the Lake Tahoe basin prior to its settlement by Euro-Americans in the latter half of the 1800s. Reconstructions of the presettlement fire regime from cross-dated fire scars in old stumps and logs have shown that the historical fire-return interval ranged from an average of about 11 years in Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) and white fir forests (Taylor 2004), to 28 years in montane chaparral stands (Nagel and Taylor 2005), to 76 years in high-elevation red fir (*Abies magnifica* A. Murr.) and western white pine (*Pinus monticola* Douglas ex D. Don) forests. Fires then consumed surface fuels, thinned forest stands, and produced openings in the forest where shade-sensitive tree species could regenerate. Although historical fires were likely predominantly of low severity, the presence of extensive patches of montane shrubs in some areas indicates that stand-replacing fires of higher severity also occurred (Nagel and Taylor 2005).

Forests that developed under fire suppression after extensive logging in the Tahoe basin during the middle and later 1800s are now very different than those historical forests. Tree densities, particularly in smaller size classes, are now much higher, and species composition has shifted to favor firs over pines (Barbour et al. 2002, Taylor 2004). The abundance of trees and lack of fire return has led to unnaturally high amounts of surface fuels (Barbour et al. 2002), and greater fuel continuity, contributing to high fire hazard and greater probability of stand replacement upon burning (Manley et al. 2000, McKelvey et al. 1996, Skinner and Chang 1996).

Knowledge Gaps

Reducing surface and ladder fuels using prescribed fire or mechanical treatments has been shown to substantially improve the resilience of forest stands to wildfire (Agee and Skinner 2005, Pollet and Omi 2002); however, because of the importance of tourism, forest proximity to populated areas, and concerns about protection of natural resources, fuel management in the Lake Tahoe basin presents unique challenges. Smoke and liability issues may limit the use of prescribed burning in many areas. As a result, fuels in these areas are often treated mechanically or by hand, rather than through burning. Unfortunately, the extent to which mechanical forest treatments can mimic the ecological role of fire is poorly understood for many forest attributes (Weatherspoon and Skinner 2002). Because much of the excess forest biomass in the basin is in the form of small trees of low value, mechanical removal may not be cost-effective. As a result, new implementation strategies for reducing fire hazard, such as mechanical mastication or chipping, have been initiated. These methods leave the fuels on site, but alter their vertical profile, and have been shown not to result in soil compaction or erosion—yet concerns about fire effects such as soil heating, if the material should burn, remain (Busse et al. 2005, Hatchet et al. 2006; also see chapter 5, "Soil Conservation").

Even in areas where prescribed burning is a viable management option, smoke management and the narrow window available for prescribed burns in many years severely limit the number of acres that can be treated. Most fires in the Lake Tahoe basin historically occurred in the late summer or fall (Taylor 2004), and managers have often opted to conduct prescribed burns at that time of year; however, recent research has found that early-season prescribed burns, which typically consume less fuel, may have some benefits for at least the first burn in areas with heavy fuel loading (Knapp et al. 2005). Not only was the recovery of understory plant species more robust following early-season burns, but tree mortality was lower in early-season burns than late-season burns (Thies et al. 2005), although not significantly (Schwilk et al. 2006). Fire disturbance may also promote the invasion of exotic species (Keeley et al. 2003), and Merriam et al. (2006) and Kerns et al. (2006) reported a greater abundance of exotic plant species after late-season burns.

Forest fuels treatments can change forest habitat attributes required by many wildlife species, including vertical layering of vegetation, age structure of trees, tree composition, spatial distribution of remaining trees, snag and log densities and characteristics, and understory cover and species composition. The intensity and extent of fuels treatments and their objectives (i.e., only fuels reduction or some balance of ecological outcomes) can greatly differ among agencies and projects; thus, the magnitude of effects of treatments on plants and animals is directly related

Peter Goin

Prescribed pile burning as a means to reduce excess forest fuel loads. Tahoe Pines, Lake Tahoe basin.

to the intensity and extent of treatments. Treatments designed with fuel reduction as the primary objective tend to simplify and homogenize forest structure and composition. Further, they may extend impacts associated with urbanization farther into the forest by functionally extending edge effects. Simplified forest structure as observed in urban forest remnants (Heckmann et al. 2008) exhibited reduced biological diversity and ecosystem resilience (Manley et al. 2006; Sanford et al., in press; Schlesinger et al. 2008). Long-term environmental changes associated with fuel treatments are less certain, and will differ based on the combination of overstory treatments and postharvest treatments (chipping, pile and burn, prescribed burns) applied.

The impact of fuel treatments on plant and animal populations in the Tahoe basin is not known because of the general lack of information on the distribution and status of wildlife and plant populations in the basin, and the unique combinations of understory treatment (including chipping), large extent of actions, and rapid implementation of treatments being employed in the basin. Populations of many forest-associated species, particularly those associated with the montane zone, could be at risk of habitat fragmentation and isolation as a result of forest alterations.

These issues and uncertainties suggest the following broad management questions:

- What vegetation management approaches will be most effective and efficient in meeting a variety of management objectives, including reducing fire hazard, restoring forest health, increasing the amount and integrity of old-growth forests, maintaining and conserving biological diversity, and restoring a more natural fire regime?
- What locations are the highest priority for management and what balance of objectives are most appropriate in each location and throughout the basin?
- What measures are most informative and efficient in determining the effectiveness of vegetation management approaches in meeting fire and fuels management objectives?

Research Needs

Following are fire and fuels management research questions:

(**FR1**) How do current fuel treatments and future treatment scenarios simultaneously affect fire hazard and other values such as scenic and recreational amenity, water yield and quality, soil erosion, old-growth characteristics, and plant and animal diversity (including less-abundant species, narrowly distributed species, and forest and aquatic associates)? What are the effects of spatial distributions of fuel treatments on primary ecological management objectives in the basin, including (a) connectivity of populations of species expected to be most sensitive to changes in forest structure and understory conditions; and (b) maintaining quality habitat for aquatic species?

(FR2) Are there fuel treatment solutions that are optimal with respect to the multiple forest management objectives that exist in the basin (see question FR1), including considerations of cost? (This question could be addressed within a multiobjective modeling framework; the quality of the answers would depend at least in part on data from the kinds of field studies outlined below and elsewhere in this plan.)

(**FR3**) How do sensitive and vulnerable animal species associated with montane forests and aquatic inclusions (e.g., ponds and streams) use treated (masticated versus prescription-burned) and untreated areas to meet various needs (e.g., reproduction, foraging, movement, and shelter)?

(**FR4**) What are the projected consequences of current and projected fuel treatments for landscape connectivity for sensitive and vulnerable animal species?

(FR5) How does intensity of tree canopy thinning affect a range of ecosystem attributes? Is there a relationship between residual canopy cover after fuel treatments, and subsequent rates of surface and ladder fuel development? Do canopy openings and soil disturbance from fuel treatments favor establishment of shade-intolerant pine species? Is there a relationship between residual canopy cover and wildlife habitat value?

(FR6) How do alternative understory fuel treatments (e.g., canopy thinning followed by biomass removal, mastication and mulching, or prescribed burning) affect the trajectory of forest succession, including understory plant and animal species composition, relative abundances, and ecological community states and transitions? Do these treatments differ in resultant opportunities for invasive plant establishment? (It is recommended that the definition of forest succession include tree, shrub, herb, and grass plant forms, and that measurements include rate of fuel reaccumulation so that fire hazard can be calculated.)

(FR7) Mastication followed by mulching is a dominant mode of treatment of understory fuels currently used in the Lake Tahoe basin. Is the longevity of fire hazard reduction produced by mastication treatments related to vegetation type, resprouting potential, microenvironment, or chip depth? What are the ecological consequences of mulching compared to other treatment options? Will multiple cycles of treatment with mastication result in the buildup of unacceptably high amounts of surface fuels?

(FR8) How do alternative techniques for prescribed burning that are currently in use in the Lake Tahoe basin (jackpot, piling, understory, and piling with understory burns) compare in terms of fuel consumption and fire hazard, soil heterogeneity, wildlife responses, and wildlife habitat?

(FR9) What are the ecological consequences of season of treatment (early or late) when applying fuel treatments, such as mastication, mulching and prescribed burning? Important response variables might include mortality of remnant trees, resprouting of shrubs, and germination of species that have seed banks, and effects on small mammals and birds.

(FR10) What is the relative importance of ozone damage, soil depth, periodic drought, insect attack, and stand density in determining spatial patterns and temporal dynamics of tree mortality and subsequent surface fuel accumulation? What is the optimal range of temporal and spatial dynamics of tree mortality based on current and future climate conditions?