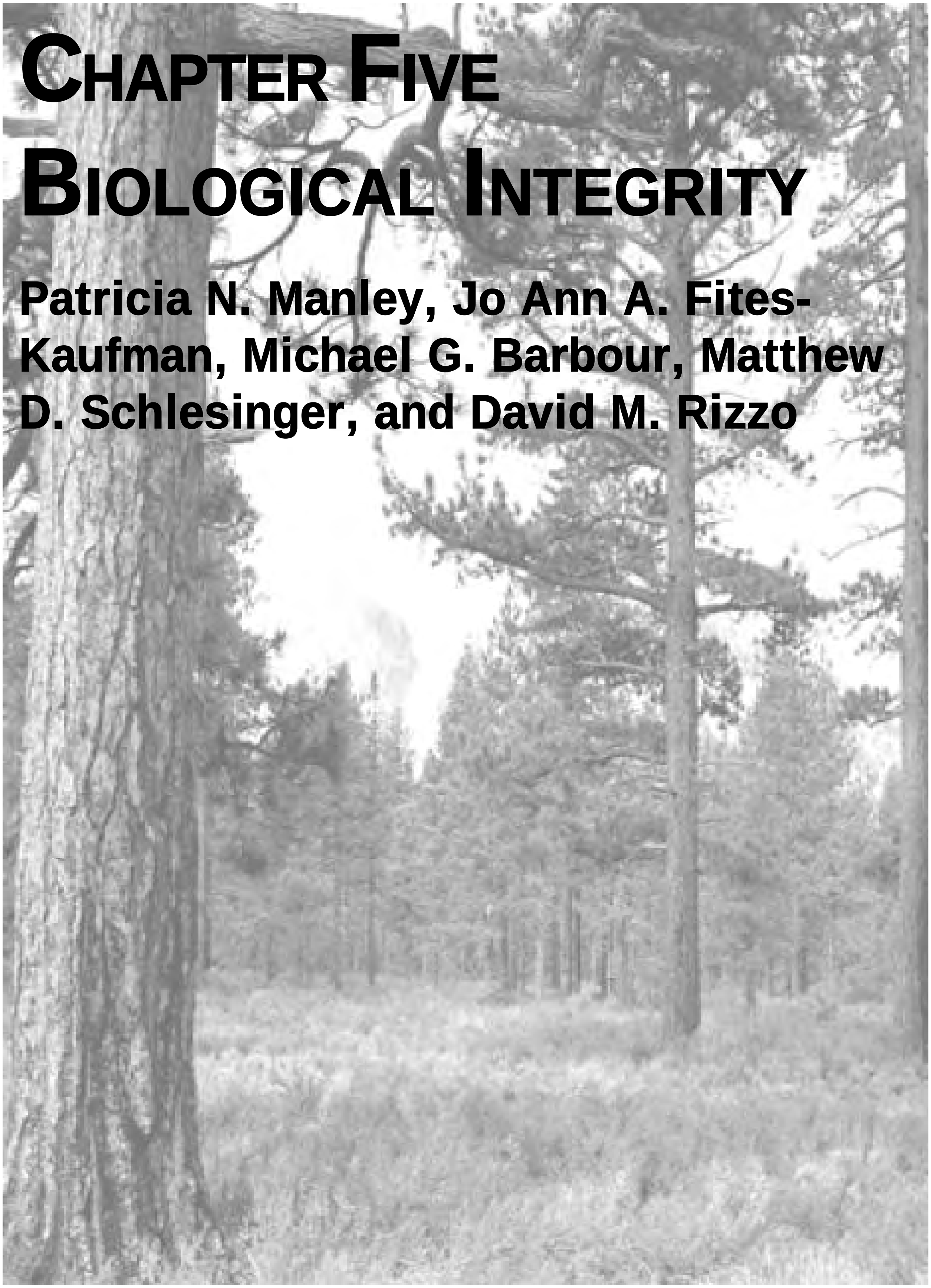

CHAPTER FIVE
BIOLOGICAL INTEGRITY

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Introduction

"As the wind howled outside my window, heralding the onset of winter, the local band of coyotes sang their evening chorus as they roamed the rich hunting grounds where the wet meadow and forest meet in the backyards of my neighbors. Drifting off into a cozy slumber, pleased with myself for living in a place where I can experience the pulse of the natural world, where coyotes and bears visit my backyard, I bolted out of bed, realizing I had forgotten to bring my cat inside for the night!"

So says a long-time Lake Tahoe resident. The Tahoe basin offers many natural splendors to its residents and visitors, several of which appear in the opening quote. Natural experiences in the basin are defined not only by characteristic landscape features, such as Lake Tahoe and the majestic mountain ranges surrounding the basin, but also by less dominant features, such as frequent sightings of wildlife from one's doorstep, the ability to enjoy beautiful forests and meadows, and the sound of coyotes howling in the night. Even the fact that coyotes occasionally prey on domestic cats left outside at night is something that most residents accept as part of living in an ecosystem that still supports a diversity of living creatures. Many of the natural features that have come to be expected as part of the "Tahoe experience" are a reflection of and depend on the biological integrity of ecosystems in the basin.

Biological integrity is "the capability of a landscape or ecosystem to support and maintain a balanced, integrated, adaptive community of organisms comparable to that of natural habitat of the region" (Karr and Dudley 1981). Biological diversity and the ecological and evolutionary processes inherent in natural systems are essential elements of biological integrity and ecological sustainability (Angermeier and Karr 1994; Hunsaker et al. in preparation). Biological diversity refers to the variety of living organisms in an area, encompassing a hierarchy of biological organization—genes, populations, species, communities, ecosystems, and biomes (Angermeier and Karr 1994; Noss and Cooperrider 1994). We can view biological diversity as building blocks and natural processes as architects and engineers determining how the blocks are shaped and arranged, together resulting in biological integrity.

Approaches to the conservation of biological integrity focus both on the needs of individual species and on conserving entire ecosystems and their fundamental processes. As the science of conservation matures, it is increasingly recognized that both approaches not only have merit but that attention to communities and ecosystems, as well as to species and populations, is important to the success of large-scale conservation efforts (Noss 1990), such as the conservation of biological integrity in the Lake Tahoe basin. Our assessment addresses both levels of biological organization.

The biological integrity of ecosystems in the basin has been altered and perhaps permanently compromised by human land use over the past 150 years (see Chapter 2). Three facets of biological integrity have experienced substantial changes over the past 150 years, and they form the central topics of this assessment of biological integrity: community structure and composition, fire as an ecosystem process, and species composition and population characteristics. The topics addressed in this chapter do not constitute a comprehensive treatment of the considerations in conserving and restoring biological integrity; rather, they are a combination of points of greatest concern and factors significantly affecting biological diversity and integrity in the basin.

Communities are composed of species that occur together in space and time, whereas ecosystems include interactions of biological components (plants, animals, and fungi) with all the physical and chemical components of the immediate environment (Begon et al. 1990). Although we can define communities conceptually, in practice they are difficult to identify and classify. Communities are dynamic collections of species in which each species responds independently to environmental variation (Whittaker 1975; Krebs 1978; Levin 1992). However, classification schemes facilitate taking stock of the quantity, quality, location, and diversity of communities. Common descriptors of communities include species richness, disturbance regimes, and the composition, age, and physical structure of the community. The distribution, abundance, and diversity of community types are also informative descriptors. Aquatic ecosystems usually are differentiated by both their physical and biological features and include a wide variety of flowing and standing water systems (Moyle and Ellison 1991). Physical features of aquatic ecosystems commonly include their size, shape, depth, volume, gradient, shade cover, temperature, water chemistry, and substrates.

Fire is recognized as a keystone process in Sierra Nevada ecosystems. Fire is a natural part of the Sierran environment, and it significantly influences the distribution and abundance of native plant and animal species, as well as the physical structure of vegetation communities. The arid summers typical of Mediterranean-type climates, such as California's, cause dead plant material on the ground to dry rapidly. Lightning strikes frequently in late summer and fall. If these events are not followed by rain, if there is sufficient dry fuel on the ground to carry flame, if the air is dry enough, and if wind conditions are right, then a surface fire results. In the Lake Tahoe basin, sediment cores from Lake Tahoe (Davis 1997) and nearby Osgood Swamp (Adams 1967) show that charcoal was continually deposited in the Lake Tahoe basin and vicinity in the past, indicating frequent fires. This historical pattern of fire represents a combination of wildfire and prescribed burning conducted by the Washoe tribe to manage vegetation, similar to many other Native American tribes (Anderson and Moratto 1996).

Characteristics of species and populations are considered primary attributes of biological diversity (Noss 1990). Although it is generally accepted that biological diversity in the basin has been altered in the past 150 years, the degree of alteration and its implications for species persistence have not been described previously. Populations typically are described by their distribution, species frequency of occurrence, and abundance (Noss 1990). Species can be described further in terms of their life history characteristics, habitat associations, and exotic or endemic status.

Factors Influencing Biological Integrity in the Basin

Factors influencing biological integrity become relevant when attempting to understand its current condition, how this condition came to pass, and how it may change in the future. The primary factors influencing biota are divided into physical and biological factors and are discussed below.

Physical Factors

A myriad of physical factors affect species, communities, and ecosystems. Some of the most influential physical factors include such major environmental gradients as elevation, precipitation, and latitude (Schluter and Ricklefs 1993). All of these gradients affect the productivity of an area and have been shown in numerous studies to have significant relationships with biological diversity and the distributions of species and communities (Rosenzweig 1995). In the basin, elevation and precipitation vary greatly for such a small geographic area and may exert a stronger influence than expected. Variation in precipitation is largely a function of basin's location in a transition zone between Mediterranean and continental climates. The Sierra Nevada and Carson Range crests, which flank Lake Tahoe west and east and create its basin, and provide the elevational variation that demarcates the transition between the two very different climatic regimes.

Biological Factors

Innumerable biological factors influence biological diversity and integrity in most systems. It is difficult, and perhaps inappropriate, to attempt to identify a few key factors that shape biological systems. Here, we discuss a limited set of biological factors that are of interest in the basin and are known to significantly influence biological diversity and integrity: fire and succession, interspecies interactions, and biogeographic dynamics.

Fire and Succession—Paleoecologists such as Axelrod (1986) believe that a fire-prone climate has existed in California for at least the past four to six million years; therefore, we can assume that Californian vegetation has evolved with fire, not only tolerating it but also, in the case of many species, requiring it to stimulate certain phases of their life cycle. In terms of community structure, fire is a dominant agent (along with human activities) that stimulates and alters secondary succession in vegetative communities in the Sierra Nevada. For example, researchers have shown how particular herb, shrub, and tree species in mixed conifer forests reproduce, regenerate, and grow better in the presence of periodic low to moderate intensity fires than in the absence of these fires (Rundel et al. 1988; Barbour and Minnich 2000). Further evidence is provided by Skinner and Chang (1996), who reported that white fir (*Abies concolor*) is more often dominant in forests with less frequent fires, whereas Jeffrey pine (*Pinus jeffreyi*) and lodgepole pine (*Pinus contorta*) are more often dominant in forests with higher fire frequency in upper montane and subalpine environments. Shifts in species composition as the result of fire exclusion is apparent in the Lake Tahoe basin.

Interspecific Interactions—The biological processes of competition among species for food and other resources and predation of one species on another are known to shape the composition and structure of communities, as well as to influence species distributions and local abundance (Begon et al. 1990). Changes in species composition have occurred throughout the Sierra Nevada in the last 100 years (Graber 1996), and the basin is no exception. Losses of large predators, such as the grizzly bear (*Ursus arctos*), change the food chain dynamics within communities significantly. The loss of top predators may affect many other species along the food chain (e.g., "trophic cascades"; Paine 1980; Power et al. 1985; Power 1990). In addition, many exotic species now occur in the basin, and some are aggressive competitors that can outcompete native species. Finally, as discussed above, fire suppression activities have influenced environmental conditions and shifted the competitive advantage among conifer tree species.

Biogeographic Dynamics—The basin is in a transition zone between two zoogeographic provinces, where the flora and fauna change substantially in response to a shift from the Mediterranean climate of California to the more continental climate of the Great Basin (Wallace 1860; Udvardy 1969). In the basin, the east-west distributions of many species, particularly the less mobile terrestrial and aquatic species, overlap but do not extend beyond the basin, suggesting that the basin lies along what is known as a biogeographic line (Wallace 1860; Carlquist 1965; Brown and Gibson 1983). The species composition of the basin represents a combination of taxa from both biogeographic regions, resulting in a higher taxonomic diversity, particularly within genera, than would be expected for an area of this size.

A Historical Context for Biological Integrity

Our ability to rigorously define the "integrity" or "health" of a basin, watershed, or ecosystem or even of a single population of an individual tree species is rudimentary for several reasons. First, it's difficult to measure ecosystem integrity with a single simple number. Human health can sometimes be represented by a single number—body temperature—but some diseases do not affect body temperature. Even if we could summarize present ecosystem status with one number, that number could be interpreted only by comparing it to some standard of "good health." Healthy human temperature is 98.6°F, but what is the standard of good health against which we can judge the biological integrity of the Lake Tahoe basin?

One possible means of answering that question is to reconstruct the landscape or ecosystem as it was prior to the onset of any anthropogenic (human-induced) disturbances thought to affect biological integrity. An understanding of the role of disturbance in ecological communities is critical in any attempt to manage for the sustainability of ecosystems, communities, and populations in the basin. Many biological and physical processes, such as fire, floods, and storms, are considered natural disturbances, and these processes have played an integral part in the evolutionary and ecological history of all communities (White and Harrod 1997). Anthropogenic disturbances, such as recreation, fire suppression, livestock grazing, pollution, tree cutting, and habitat alterations, such as fragmentation, degradation, and loss, are increasingly pervasive. The characteristics and interactions of anthropogenic disturbances influence the structure and composition of ecosystems (White and Harrod 1997) by affecting the probabilities of extinction and colonization and subsequent patterns of biological diversity in a landscape (Meffe and Carroll 1994). In the basin, anthropogenic disturbances have been superimposed on natural disturbance regimes for many centuries, creating complex patterns of influence on biological integrity.

The primary anthropogenic disturbances operating in the basin over the past 150 years varied in their time of onset. For instance, ranching, timber harvesting, and fragmentation began in the 1860s, fire suppression management began in the 1920s, and the release of pollutants in high concentrations began in the 1950s. Dramatic increases in anthropogenic disturbance began after 1844, the year John Fremont became the first Euro-American explorer to glimpse Lake Tahoe. Within a few years of his discovery, the basin became a landmark on an important route east and west for hundreds of travelers each year; the period of anthropogenic influence had begun.

Anthropogenic disturbances have been so pervasive in the basin that a control area unaffected by them does not exist. For the purposes of understanding changes resulting from these disturbances, we are relegated to reconstructing historic conditions to provide a context for interpreting current conditions and potential future trends. How accurately can we reconstruct the basin's ecosystem and landscape conditions? Several types of direct and indirect evidence are available to us. First, existing landscapes with intact natural disturbance regimes and minimal human disturbance can serve as references to demonstrate the ecological potential of landscapes disturbed by humans. Such a landscape with a natural fire regime, no history of logging or pollution, and only modest impacts from domesticated livestock is known to occur in Baja California. We were able to draw on its characteristics to improve our estimate of the nature of the basin's old-growth forest ecosystems before it came into contact with Euro-Americans.

A second source of evidence for the composition and condition of ecosystems in the basin undisturbed by humans is historical records, such as early vegetation maps, land surveys, records of log purchases (log-scaling) from known logging areas, photographs, newspaper accounts, books, and journal entries of early settlers or travelers that describe the landscape. For example, foresters Leiberg (1902) and Sudworth (1900) mapped vegetation and gathered data on forest plots generating quantitative descriptions of precontact vegetation. McKelvey and Johnston (1992) have summarized such data for Sierra Nevada forests in general. In the 1930s the US Geologic Survey initiated a major state-wide effort to quantify vegetation. These data were gathered so early in the period of fire suppression management that they provide our best glimpse of the presuppression landscape. Data from the Sierra gathered in that survey recently have been summarized by Bouldin (1999) and compared to modern data from the same forests. Early ecologists, such as Orr (1949), helped document animal species in the basin. We draw most heavily from historical data sources to describe changes in landscape conditions and species composition and abundance over the past 150 years.

A third source of evidence for the character of landscapes undisturbed by humans is the prehistoric archaeological/anthropological record. There are a number of historic Washoe village sites in the basin, and research has clarified some of the relationships between Washoe culture and the natural environment, such as the use of fire, availability and use of natural resources, attitude toward nature, and ability to manage vegetation. Records of the occupancy of the Washoe tribe in the basin are impressive. More than 60 prehistoric sites have been documented, indicating a long-term population size of 1,000 to 3,000. The cultural identity of the tribe remains strong today; knowledgeable elders describe traditional land management practices and the structure and composition of biota in the basin (Downs 1966; d'Azevedo 1986; Nevers 1976; Strong 1984; Lindström, Chapter 2, this volume). Other sources of prehistoric information include charcoal deposits in the bottom sediments of small lakes that can be used to date the incidence and frequency of extensive forest fires. Also, submerged stumps in Lake Tahoe can be aged to identify periods of warm dry weather (presumably corresponding to lower lake levels). We draw on some of these sources of data to better understand precontact community structure, fire regimes, and species composition in the basin.

Historical data are inevitably incomplete in some manner, and yet the period used to describe historical conditions can greatly influence the resulting depiction. Many ecologists have correctly warned against selecting a single year, or even a cluster of years, to serve as a snapshot of historic conditions (Norton 1992; SNEP 1996; Millar 1997; Botkin 1990). What is needed is a collection of many years, enough to encompass what has been called the historic range of variation (HRV). For long-lived trees, the HRV should be somewhere between 200 and 300 consecutive years because only this span is long enough to capture the effects of episodic droughts, insect outbreaks, catastrophic crown fires, and fluctuations in the size of indigenous human populations (Millar 1997). Tree ring records and aged stumps growing below Lake Tahoe's current surface level, for example, show that the period from 1750 to 1850 was warm and dry, whereas the periods before and after that were wet and cool. As for references for flora and fauna, under natural disturbance regimes changes in species composition generally happen gradually over multiple decades, if not hundreds of years. However, under the influence of anthropogenic disturbances, dramatic changes can occur in very short periods, suggesting that species composition characteristics of a century or two before contact with Euro-Americans would be an appropriate period for describing species composition. The period from 1600 to 1850, then, is long enough to capture the HRV of major climatic fluctuations and of the biotic response to those fluctuations.

Our Assessment of Biological Integrity in the Basin

The identification of pivotal ecosystems, communities, and species contributing to biological diversity and integrity in the basin serves to highlight areas where conservation efforts can make the greatest contribution to sustaining ecosystems. The first step in building a conservation and restoration plan is identifying the strongest and weakest points in the system, followed by conserving the strong points and restoring the weak points. The components of the system we identify and the issues we address in this chapter highlight these strong and weak points to help focus conservation efforts on protecting and restoring biological integrity in the Lake Tahoe basin.

In this chapter we discuss old-growth forests as a terrestrial community type of interest and concern in the basin and the ability to define desired future conditions for old-growth forests (Issue 1). We then address the need to improve our understanding of the dynamics of fire in the basin—to determine how the likelihood of fire varies geographically, to assess the relative importance of weather, fuels, and ignitions in contributing to the likelihood of fire, and to describe the probable effects of a high severity fire on urban areas, air quality, lake clarity, biological integrity, and human life and property in the basin (Issue 2). We also address the extent to which prescribed burning reduces fire risk, improves wildlife habitat, mimics the process of historic fire, and affects nutrient loading into the lake (Issue 3). We present a conceptual model of forest health with the intent of improving understanding of the primary factors affecting forest health (Issue 4). We describe the status of the aquatic ecosystems that occur in the basin and identify which types are most degraded or vulnerable and in need of conservation and restoration (Issue 5). Finally, we identify a limited number of unique and diverse ecological communities and ecosystems that contribute significantly to the biological diversity of the basin (Issue 6).

We assess the current and potential future conditions of species and populations of plants, animals, and fungi in the Lake Tahoe basin and identify species of ecological concern and cultural interest (Issue 7). Species of concern include those whose populations are recognized as imperiled or vulnerable to declines and species capable of negatively affecting other species. Species of cultural interest include those that are the target of consumptive and nonconsumptive uses and interests. We identify conservation, monitoring, and research activities regarding these species that would benefit biological diversity in the basin.

Issue 1: Define Desired Future Conditions for Old-Growth Forests in the Lake Tahoe Basin

With contributions from Susan Lindström, Elise Kelley, and Peter E. Maloney

Precontact Status and Trends

Almost all vegetation in the basin is different than it was in precontact time 150 years ago, but the degree and direction of difference are not uniform. From the narrow perspective of human existence, some of the differences have enhanced the quality of life, but from an ecosystem-centered perspective, none of the differences has been beneficial. A measure of how changes in the basin have negatively affected the basin is in the reduction of complexity of the vegetation, biodiversity, resistance to stand-replacing crown fires, the area of meadows and wetlands that serve as a buffer and filter between land and lake, lake clarity, air purity, and soil stability. The extent of this reduction and what it means to ecosystem function and resilience will always be open to question.

The trends—that is, the rate and direction of change—have not been constant over the past 150 years. For example, extensive clear-cutting of the forests ended at the turn of the century. At that time approximately 60 percent of the basin had been clear-cut but not uniformly: much more than 60 percent of low elevation pine forests were harvested, whereas less than that fraction of higher elevation fir forests were cut, and very little of the subalpine forest was entered. Harvesting continued to the present but at much reduced, more local, and selective harvest scales and intensities. The forest biomass trend has been toward recovery, rather than loss, during the past century (although the distribution of the increasing biomass has gone into young trees of small diameter, in contrast to the preexisting forests that had most of the biomass in the largest trees of greatest diameter). Grazing intensities of livestock on meadows and in forests have declined similarly in this century, and the trend is one of vegetation recovery. (However, hydrological recovery of meadows requires correcting past channel erosion, a process that takes so much time that we can conclude there has yet been no measurable recovery.) But, this century has also experienced fire suppression management with consequent trends of increasing fuel buildup and increasing density of stands, trends that have delayed the usual pathway of succession toward old-growth status. In this case, trends toward lower biodiversity and lower resistance to crown fire have continued and intensified to the present. The trend toward fragmentation in the landscape has been increasing in the last 50 years of this century, as the number of roads and homes has increased.

Given the historical record of extensive logging, grazing, and other forms of landscape alteration in the basin and given the length of time it takes degraded vegetation to recover, it comes as no great surprise to know that very little mature vegetation of any kind—forest, meadow, or wetland—exists in the basin. Only five percent of forested land, for example, is in old-growth status.

According to TRPA Resolution 82-11 (which defined threshold carrying capacities for the basin), five percent is not a desired future condition. The management objective is to Provide for promotion and perpetuation of late successional/old growth forests . . . across elevational ranges [and including such associations as Jeffrey pine, red fir, and subalpine forest].” The resolution goes on to propose that the percent of Jeffrey pine and red fir forests to be in old-growth status shall be 75 to 85 percent.

A definition of future desired conditions is important because that vision will drive management plans and actions for the next several decades. To help frame this particular vision, we will summarize the existing condition of old-growth and recovering forests in the basin, their areal extent and pattern of distribution, how these modern forests differ from precontact forests, and what management approach might best achieve TRPA's proposed standard.

What are the traits of modern relictual stands of old-growth forest in the basin that make them unique from the surrounding matrix of more disturbed (seral) forest vegetation?

The traits of old-growth stands are always relative to the kind of forest that can be supported by the local environment. An old-growth forest at very high elevations with short cool summers and shallow soils will not exhibit the same density of trees or the same number of large trees as an old-growth forest at lower elevations. It was for this reason that Franklin and Fites-Kaufman (1996) relativized their old-growth definitions for the entire Sierra Nevada.

There is a west-to-east gradient of declining precipitation in the basin, such that the average annual precipitation on the northeast shore is about half that on the southwest shore (see Chapter 1 of this document and James 1971, Kittel 1998, Rogers 1974). The basin consists of four climatic subunits: low-elevation west shore (Carnelian Bay through South Lake Tahoe to the state line, <2,250 m), which experiences 75 to 100 cm annual precipitation, high-elevation west shore (>2,250 m), 100 to 150 cm, low-elevation east shore (from the state line just northeast of South Lake Tahoe along the east shore and west to Carnelian Bay), 50 to 65 cm, and high-elevation east shore, 65 to 90 cm. Two-thirds of annual precipitation falls from December through March, and more than 80 percent of it falls as snow. Mean snowpack depth and duration increase with elevation such that April 1 snow depth in subalpine mountain hemlock forests (2,300 to 2,900 m elevation) averages 5.0 m depth, mean seasonal snowpack depth is 3.5 m, and snowpack duration is 200 to 250 days (Nachlinger and Berg 1988). Along the shore of Lake Tahoe, snowpack averages only 0.5 m depth, and snowpack duration is less than 130 days (Rogers 1974). Summer thunderstorms occur when subtropical monsoons occasionally extend north from the Gulf of California, but their contribution to total precipitation is trivial. Potential evapotranspiration, as calculated by the Thornthwaite method, is 48 cm. (Actual evapotranspiration is only 27 cm because soil moisture available for plant uptake is depleted by mid-July (Rogers 1974).) The precipitation to evaporation ratio, then, ranges from 1.3 in the drier parts of the basin to 2.2 in wetter locations or at higher elevations. Such values indicate a favorable environment for forest vegetation (Barbour et al. 1998).

Mean daily minimum winter temperature at lake elevation is about -6° C, mean daily maximum summer temperature exceeds 30° C, and length of the frost-free growing season is about 75 days. At higher forested elevations, length of the growing season drops to 60 days, and maximum summer temperatures are cooler.

The geologic substrate along the eastern, southern, and western shores is typically granite. Bedrock along the north shore is volcanic material about 10 million years old. Most soils are shallow Entisols or Inceptisols. Common forested soil series include Cagwin, Jabu, Jorge, Meeks, and Toem (Rogers 1974). In general, soils become more skeletal and undeveloped with increasing elevation. Much of the western and southern shores has been scoured by glaciers, resulting in a modern mosaic of rock outcrops, shallow soils, and deeper soils on glacial morains. The morains tend to support much different vegetation than the brushfields that dominate thinner soils.

In terms of vegetation, there are lower montane, upper montane, and subalpine zones (Table 5-1 and Figure 5-1). Each zone contains a mix of forest, meadow, and chaparral types of vegetation (Smith 1973). Elevational limits for the three types are approximately lake level to 2,200 m (<7,000 ft), 2,200 to 2,600 m (7,000 to8,500 ft), and greater than 2,600 m (>8,500 ft), respectively.

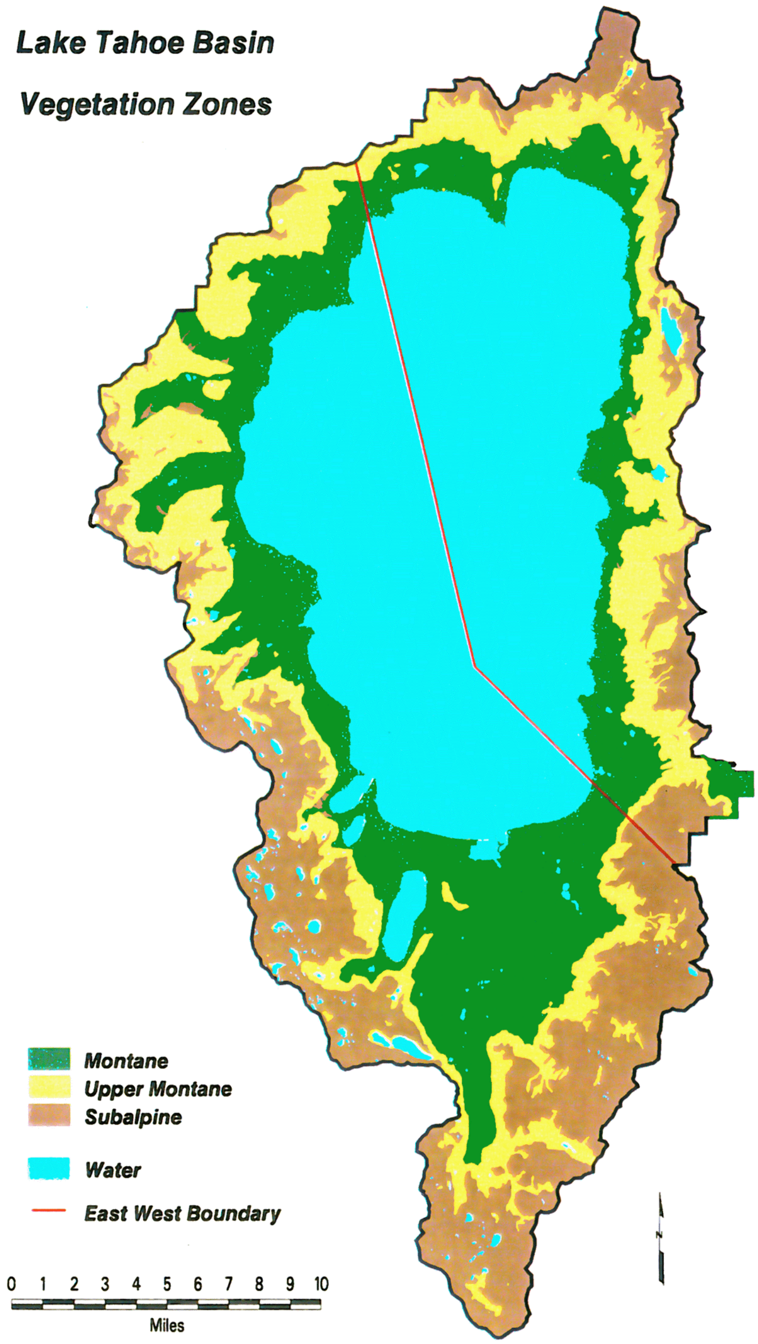


Figure 5-1—Major vegetation zones in the basin.

Table 5-1—Areas (in acres) of major vegetation types within the Tahoe basin.

Elevation Zone and Vegetation Type	West Side	East Side
Lower montane (<7,000 ft elev)		
Jeffrey pine forest	4,300	2,600
Mixed conifer forest	12,300	7,000
White fir forest	9,400	4,900
Lodgepole pine forest	5,100	1,400
Aspen/cottonwood riparian forest	200	600
Montane chaparral	4,800	800
Meadow	4,000	900
Barren	18,700	3,807
Upper montane (7,000-8,500 ft elev)		
Jeffrey pine forest	7,800	6,300
Red fir forest	9,600	900
White fir forest	7,400	5,300
Lodgepole pine forest	4,200	6,200
Aspen woodland	600	500
Montane chaparral	1,600	900
Meadow	7,200	2,600
Barren	24,100	5,700
Subalpine (>8,500 ft elev)		
Mixed subalpine woodland	19,800	5,600
Montane chaparral	300	400
Meadow	1,900	0
Barren	600	800

The most common forest types in the lower montane are Jeffrey pine forest, mixed-conifer forest, and white fir forest. Jeffrey pine forest is thoroughly dominated by *Pinus jeffreyi*, but common associates include *Abies concolor* (white fir) and *Calocedrus decurrens* (incense cedar). Mixed conifer forest is dominated by a complex mix of the same three species—plus *Pinus lambertiana* (sugar pine)—in which no one species consistently contributes more than half of the total number of trees or canopy cover. White fir forest is dominated by *A. concolor*, but a common associate is *A. magnifica* (red fir).

The most common forest type in the upper montane is red fir forest, overwhelmingly dominated by *A. magnifica*. Associated species include *P. monticola* (western white pine), *P. contorta* (lodgepole pine), and *A. concolor*. This forest has less cover by shrubs and herbs than the lower montane forests, possibly because the depth of snowpack and the length of time that snow remains on the ground are far greater than for any other forest in the basin.

A lodgepole forest type occurs in locally wet areas at the edge of meadows in the upper montane zone, and it can extend down into the lower montane where cold air drainage flows at night. Aspen stands also may occupy wet riparian areas or slopes disturbed in the past by wind-throw or avalanche in this elevational zone. Aspen also occurs in similar habitats within the lower montane zone, but to a lesser extent. Lodgepole and aspen types combined occupy a total of only 8,100 ha (20,000 acres); thus, they are not major forest types.

The most common forest type in the subalpine is mixed subalpine woodland, with *Pinus albicaulis* (white bark pine), *Tsuga mertensiana* (mountain hemlock), and species from the upper montane, such as *A. magnifica*, *P. contorta*, and *P. monticola*.

Thus, we have five major forest types in the basin; these types have been technically called "series" and described by Sawyer and Keeler-Wolf (1996). If we layer distinctly different east and west climates onto these five forest types, we have 10 types. In every case, the eastern variant has a lower density of trees and a lower canopy cover than the western variant. Subalpine forests have been least affected by stressors of the past 150 years because there has been virtually no entry for logging and the fire return interval is so long that a century of fire suppression has not yet missed a single fire cycle (see the discussion of issue two later in this chapter). Even those subalpine forests that have been disturbed show very little indication of cumulative change in the past century because the rate of succession at such an elevation is very slow. We think that a large portion of subalpine forest area is in an old-growth state and condition today not materially different than those of precontact time. Consequently, this section concentrates on three lower montane forest and one upper montane forest that exhibit the effects of disturbance much more extensively than do subalpine forests.

Two major nonforest vegetation types in the basin are meadow and montane chaparral. Their combined area is approximately 8500 ha (21,000 acres), significantly less than the forested landscape (Table 5-2).

Methods of Forest Sampling and Description

We first examined 1978 vegetation maps of the basin that had been prepared by the USDA Forest Service from aerial photographs combined with on-the-ground verification. The maps consisted of polygons of homogeneous vegetation at a scale of 1:24,000. Every forest polygon on the map carried three attributes: the name of the leading one-to-three dominant tree species, the average canopy size of

Table 5-2—Site and vegetation characteristics for 38 old-growth stands in the Tahoe basin.

Trait	Range or Mean
Longitude (degrees W/range)	120°13'/119°51'
Latitude (degrees N/range)	39°17'/38°47'
Elevation (meters/range)	1,794/2,406
Slope (%/range)	8/62
Litter cover (%)	75
Rock + log cover (%)	11
Overstory tree cover (%)	33
Understory tree cover (%)	20
Overstory tree density (per ha)	88
Understory tree density (per ha)	262
Sapling density (per ha)	626
Total tree basal area (m^2 ha^{-1})	45
Shrub cover (%)	20
Shrub species per transect	4.6
Herb cover (%)	<1
Herb species per transect	8.4

categories), and the density of trees (four categories) (Johnson 1995). Minimum polygon size is five ha and the largest polygons are 65 ha.

We highlighted approximately 400 potential old-growth polygons in which the leading dominants were characteristic of lower and upper montane forests on zonal habitats (thus excluding subalpine overstory trees (five woodland and riparian forest), overstory trees had large canopies greater than 7 m (24 ft; categories 4 and 5), and overstory trees were at moderate to high cover (>40 percent; categories N and G). We then visited the polygons by road and trail over two summers and selected 38 of them. We rejected 90 percent of the polygons because they had been entered and thinned since 1978 (stumps and skid trails were present), they had been mistyped as to leading dominants, size, or density, the homogeneous portion of stand area was less than 5 ha, or they had fewer than four trees per 1,000 m² of greater than 40 cm diameter at breast height (dbh). We also decided that we would reject any stand so decimated by drought and disease from 1987 to 1992 that it exhibited greater than 30 percent mortality, but none of the sites had such a high mortality, so we never exercised this criterion.

The polygons we accepted, in other words, did not represent a random subsample of available polygons; instead they were a complete census of all acceptable polygons.

Within an acceptable polygon, we chose a random starting point and a random compass bearing for a 300 m long transect. The location of the starting point was defined with GPS coordinates and later was marked on the polygon map. Distances and directions from the nearest road, trailhead, or prominent local feature to the starting point were also recorded.

Trees along the transect were sampled by the point-centered quarter method, generally considered to be one of the most efficient and accurate methods for quantifying trees (Mueller-Dombois and Ellenberg 1974; Engeman et al. 1994). Ten points were visited along the transect, located regularly every 30 m. Eight nearest trees to the point were measured as to distance from the point and their dbh and identity recorded. Four of the trees were overstory trees, defined as having greater than 40 cm dbh; four were understory trees, defined as having one to 40 cm dbh.

Along each transect, cores were taken from a minimum of three overstory trees each of Jeffrey pine and white fir of 40 cm dbh; these cores were later shaved and their rings counted under magnification to determine tree age at breast height (abh). In addition, one sapling of each species present, which was 1 cm dbh, was cut down at the base, and a segment of base wood was taken for later cleaning and ring counting. In this way, we determined the minimum age of understory trees and how many years to add to abh to get actual tree age for 40 cm dbh individuals. The density of trees (saplings) less than 1 cm dbh (including those shorter than breast height) was determined from quadrats (see below).

Each point formed the center of a 25 m² circular quadrat. Within that quadrat, all shrubs and herbs were identified to species and their canopy cover separately estimated. Saplings also were counted by species and were defined as being taller than 15 cm but having less than 1 cm dbh (or, of course, including those not even reaching breast height). Tree data were summarized in terms of absolute and relative basal area, density, and frequency. All three relative values then were added and divided by three to obtain an "importance percentage" (Mueller-Dombois and Ellenberg 1974). Shrub and herb data were summarized in terms of absolute and relative cover and frequency. The two relative values then were added and divided by two to obtain importance percentage.

We also estimated ground cover of litter, rocks, and logs (material greater than 25 cm diameter) by taking four samples at the cardinal points along the circumference of the quadrat. When litter was present, its depth was measured.

At the fifth point of the transect we counted and quantified standing snags and coarse woody debris according to USDA Forest Service and Park Service protocols (US Park Service 1992). That is, heights and diameters of standing dead trees and lengths and diameters of downed logs were measured within standard radii of the point (11 and 25 m). Log dimensions were transformed into volume estimates, then volume into biomass using

Smalian's formula, specific density values, and decay factors (Johnson 1995). Snag density was summarized by diameter class for all species combined.

Finally, at three random points along the transect we took three pairs of distance measures for overstory trees and three for understory trees in order to test our presumption of random tree distribution. The point-centered quarter method will generate biased estimates of density if trees are not randomly distributed. We used the T-squared method of detecting nonrandom pattern (Ludwig and Reynolds 1988) and took the required additional distance measures at three of the ten points. After all 38 polygons had been sampled and samples had been grouped by community type (series), we combined the distance measures to generate a single T-squared value for overstory trees and a single value for understory trees of each forest type.

We also assessed the distribution and abundance of old-growth forests by interpreting recent aerial photographs and other remotely sensed data, coupled with periodic ground-truthing. This approach allowed us to be more comprehensive in our survey, but at the expense of not being able to quantify the vegetation in much detail. Our criteria for labeling any polygon as old-growth in this method included total tree cover and the presence of some minimum number of crowns greater than a minimum diameter (which we correlated with trunk diameters of a minimum diameter).

We emphasize that the two procedures we used for locating old-growth stands deliberately eliminated from consideration any slow-growing low-productivity stands on poor soils that had very open canopies and any stands that had suffered very high recent mortality (greater than 30 percent).

Some of the same 38 vegetation sampling transects were used for quantifying disease incidence. Only lower montane stands were included; thus, red fir forest stands were not included. Twenty-two stands were visited in the summer of 1997. In each case, a circular plot 15 m in radius was established around each of the 10 points of the transect. We recorded disease incidence on all trees greater than 20 cm dbh within the plots and separated the data into three size classes of trees: 20 to 50 cm dbh, 51 to 100 cm dbh, and greater than 100 cm dbh. Individual trees, diseased or not, were counted by species. Trees were noted as alive or dead; if dead, year of death was estimated. Live trees also were measured for live-crown ratio (span of height of crown as a fraction of total tree height).

Pest signs and symptoms were searched for in the crown, trunk, and trunk base (e.g., Furniss and Carolin 1977; Hansen and Lewis 1997; Scharpf 1993). Signs included the presence of fungal fruiting bodies, mistletoe plants, and the presence of insects. Symptoms included the formation of witch's brooms (typically caused by mistletoe, some rusts, and *Elytroderma* sp.), chlorosis of foliage, reduced live crown ratio, reduced density of foliage, resinosis, and branch dieback. A synthetic index, which we called "crown vigor," included qualitative assessments of crown position, live crown ratio, color and density of needles, and amount of leader and branch growth. The index ranged from 1.0 (good) to 3.0 (poor).

On living trees, bark beetle attacks were confirmed by the presence of boring dust or pitch tubes. Bark was removed from dead trees to identify characteristic galleries of various bark beetle taxa (Furniss and Carolin 1977). Recently dead trees (1-3 yr old) were dissected to determine possible mortality agents. Fruiting bodies and the architecture of decayed wood can be used to determine pathogenic species. Tree death, of course, is rarely caused by a single agent. A succession of organisms, as well as abiotic stress—such as drought—all contribute to tree death (Ferrell et al. 1994; Filip and Goheen 1982; Worrall and Harrington 1988). However, proximate and ultimate causes of death could sometimes be teased apart. For example, trees killed secondarily by bark beetles would exhibit very little resin around the galleries; saprobic fungal colonization could be distinguished from pathogenic colonization by degrees of callus production and resin excretion; saprobic fungal colonization of trees already dead is usually confined to the outer sapwood, whereas pathogenic infections of living trees extend into the heartwood.

Disease Incidence and Mortality

The 38 stands were located throughout the basin (Figure 5-2). They ranged in size from five to 50 ha and averaged 25 ha. As summarized in Table 5-2, the transects were at elevations of less than 2,400 m (less than 7,500 ft). All aspects were represented, and their slopes ranged from eight to 62 percent. Dominant tree taxa included Jeffrey pine, white fir, and red fir. Tree cover (overstory plus understory) averaged 53 percent, whereas shrub and herb cover were much lower, averaging 20 percent for shrubs and less than one percent for herbs. Density of overstory trees (greater than 40 cm dbh) averaged 88 ha^{-1}, density of understory trees (one to 40 cm dbh) averaged 262 ha^{-1}, and density of saplings averaged 626 ha^{-1}. Mean basal area (45 m^2 ha^{-1}) was low, relative to wetter westside forests (Ansley and Battles 19989).

Species richness was high overall: seven species of trees, 28 species of shrubs, and 78 species of herbs. Within an individual polygon or transect, however, there was an average of only four species of trees, five species of shrubs, and eight species of herbs (Table 5-3). There was considerable species turnover from one transect to another, six shrub taxa and 30 herb taxa occurring only once.

Saplings one cm dbh of four taxa had a weighted average age of 61 years (range = 25 to 110 years; n = 72), and there was no statistically significant difference among the species at the P = 0.05 confidence level. Ring counts of 40 cm dbh individuals of the same taxa had a weighted aver-age of 117 rings (abh; range = 41 to 306; n = 201). Again, there was no significant difference among the taxa. If sapling age is added to ring counts abh, then trees 40 cm dbh had a weighted average age of 178 years. Thus, our three age cohorts were 20 to 60 years, 61 to 178 years, and greater than 178 years.

Table 5-3—Major pathogens, parasites, and insects of conifers on 38 old-growth stands in the Tahoe basin.

Host	Pest
White fir (*Abies concolor*)	Dwarf mistletoe (*Arceuthobium abietinum f.* sp. *concoloris*)
	Broom rust (*Melamsporella caryophyllacearum*)
	Annosus root disease (*Heterobasidion annosum*)
	Trunk rot (*Echinodontium tinctorium*)
	Bark beetle (*Scolytus ventralis*)
Red fir (*A. magnifica*)	Dwarf mistletoe (*Arceuthobium abietinum*)
	Broom rust (*Melamsporella caryophllacearum*)
	Annosus root disease (*Heterobasidion annosum*)
	Bark beetle (*Scolytus ventralis*)
Incense cedar (*Calocedrus decurrens*)	Broom rust (*Gymnosporangium libocedri*)
	Trunk rot (*Oligoporus amarus*)
Jeffrey pine (*Pinus jeffreyi*)	Dwarf mistletoe (*Arceuthobium campylopodium*)
	Root disease (*Phaeolus schweinitzii*)
	Needle cast (*Elytroderma deformans*)
	Bark beetle (*Dendroctonus jeffreyi*)
	Bark beetle (*D. valens*)
	Bark beetle (Ips species)
Sugar pine (*Pinus lambertiana*)	Bark beetle (*Dendroctonus ponderosae*)
	Bark beetle (Ips species)
	Blister rust (*Cronartium ribicola*)

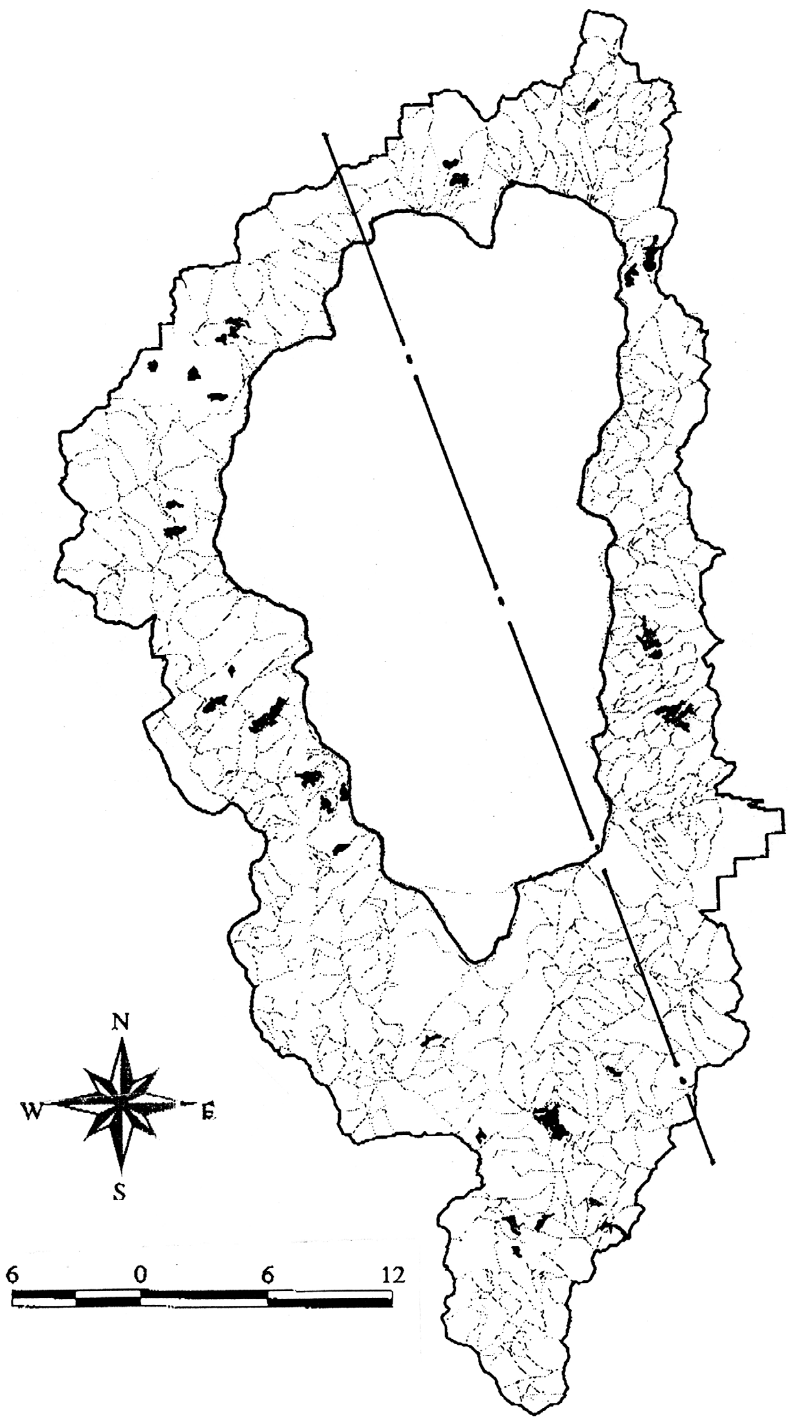


Figure 5-2—Location of 38 old-growth stands.

We did not age the largest and oldest overstory trees, but summaries of life spans in Burns and Honkala (1990) and Sudworth (1967) indicate that individuals in these taxa may commonly attain ages of 300 to 450 years.

Some 24 common pest organisms on our basin transects are summarized by host tree species in Table 5-3. In the most general of categories, the disease organisms fall into the categories of bark beetles, mistletoes, rusts, root rots, and trunk rots.

The most widespread (in terms of presence on the 22 transects) were bark beetles: *Scolytus ventralis* on *Abies concolor* (100 percent presence) and *Dendroctonus jeffreyi* on *Pinus jeffreyi* (68 percent presence). All other pathogens ranged from five to 36 percent presence. With regard to occurrence on individual trees (Table 5-4), bark beetles were associated with nearly 100 percent of dead trees of all species. For example, *Scolytus ventralis* was associated with 96 percent of dead white fir and *Dendroctonus jeffreyi* was associated with 91 percent of all dead Jeffrey pine. Live trees had much lower infection percentages: only 10 percent of white fir and one percent of Jeffrey pine.

The percentage of individuals infected with other pathogens was generally low, with considerable variation from stand to stand. Dwarf mistletoe (*Arceuthobium* species) on Jeffrey pine was found in 41 percent of the stands, but only an average of six percent of the trees was infected, even with the inclusion of one stand that had 56 percent infection. Dwarf mistletoe on white fir was found in 24 percent of the stands but only on two percent of the individuals. There was no significant difference in

Table 5-4—Incidence of major pests in old-growth stands. Incidence is the percent of (living + dead) trees because infection levels did not differ, except for *Dendroctonus jeffreyi* on Jeffrey pine (1 percent of living trees, 91 percent of dead trees) and for *Scolytus ventralis* on white fir (10 percent of living trees, 96 percent of dead trees). Dj = *Dendroctonus jeffreyi*, Dv = *D. valens*, Dp = *D. ponderosae*.

Host	Pest	Incidence
White fir	Dwarf mistletoe	2
	Broom rust	<1
	Annosus root disease	1
	Root disease	<1
	Trunk rot	<1
	Bark beetle	30
Red fir	Dwarf mistletoe	<1
	Broom rust	<1
	Annosus root disease	<1
	Trunk rot	<1
	Bark beetle	54
Incense cedar	Broom rust	10
	Trunk rot	11
Jeffrey pine	Dwarf mistletoe	6
	Root disease	<1
	Needle cast	6
	Dj bark beetle	17
	Dv bark beetle	<1
	Ips bark beetle	1
Sugar pine	Dp bark beetle	3
	Ips bark beetle	2
	Blister rust	<1

infection percentage for mistletoes when live and dead trees were compared. There was a low incidence of root disease, the most common pathogen being annosus root rot (*Heterobasidion annosum*) on white fir, an average of one percent of trees being infected. No incidence of this pathogen was observed in pine or incense cedar. Rusts were similarly low in occurrence: four to ten percent of *Calocedrus decurrens* trees were infected with the rust *Gymnosporangium libocedri* and 11 percent were infected with *Oligoporus amarus*. Less than one percent of sugar pines was infected with *Cronartium ribicola* (white pine blister rust). Crown vigor index for sugar pine, as a consequence, was best among the tree taxa (1.08, where 1.00 is the lowest value possible and indicates excellent health). None of the other tree taxa had indices of greater than 1.44, however, indicating that all tree species were in relatively good health.

Standing dead trees averaged 39 per hectare, which represented 21 percent of all trees, living and dead, that were greater than 20 cm dbh. (If we included all trees greater than one cm dbh, mortality was higher, but it still was lower than the commonly used figure of 30 percent mortality as an average for the basin as a whole, including seral and old-growth stands.) Approximately half the dead trees were queater than 40 cm dbh, and 16 percent were greater than 76 cm dbh. Most of the dead trees were white fir (62 percent) or Jeffrey pine (32 percent); red fir, incense cedar, and sugar pine made up the remaining six percent. All of the dead trees exhibited evidence of insect infestation intense enough to have contributed to or caused death. Most, however, had been infected by multiple pathogens and insects, so we could not identify a sole cause of death.

Stand Structure and Composition

We assigned all 38 samples into the four series: Jeffrey pine series (seven sites), white fir series (14 sites), red fir series (six sites), and mixed conifer series (11 sites).

Statistical analysis (ANOVA) showed that the four series differed in regard to mean elevation, but not with respect to aspect, total tree cover, total shrub cover, estimated depth of snowpack on April first, nor estimated melt date of that snowpack (Royce 1977).

We also showed that the pattern of distribution of overstory trees, understory trees, and saplings, relative to environmental gradients, were not consistent within most species. That is, the three age groups probably were responding to different environments: the overstory was a result of environmental gradients that existed more than 200 years ago, the understory to environmental gradients 100 years ago, and the saplings to environmental gradients of the most recent half a century. Additional evidence for this conclusion is that species importance usually changed from overstory through understory to sapling cohorts within any one stand. The only series that did not show any change in species importance was the red fir series. In all other series, species balance shifted away from pine and toward fir in younger and younger strata.

Tree density was highest in the white fir series (108 overstory plus 431 understory trees per hectare), basal area was highest in the red fir series (59 m^2), and both density and basal area were lowest in the Jeffrey pine series (63 overstory plus 222 understory trees per hectare and 31 m^2 ha^{-1}). Sapling density was lowest in mixed-conifer stands (425 per hectare) and highest in red fir stands (601 per hectare), but these differences were not significantly different.

The density of trees greater than 76 cm dbh was highest in red fir forest (50 ha^{-1}) and lowest in Jeffrey pine forest (24 ha^{-1}). The overall range of density for such trees among all 38 stands was eight to 89 trees ha^{-1}. As a percentage of overstory trees there was no significant difference among the four series in trees greater than 76 cm dbh: white fir was lowest at 13 percent, Jeffrey pine next at 14 percent, mixed conifer was next at 18 percent, and red fir was highest at 19 percent.

Jeffrey pine stands had the simplest overstory in terms of species composition: Jeffrey pine, white fir, and incense cedar in a density ratio of 2.3 to 1 to 0.05, with virtually no other species (Table 5-5). However, the understory and sapling layers were much more diverse. Jeffrey pine declined dramatically in importance percentage from the

Table 5-5—Selected traits of the Jeffrey pine series (n = 7). DEN = density per hectare, BA = basal area in $m^2 ha^{-1}$, FR = frequency (%), IP = importance percentage, 76 to 100 = density of trees 76-100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	**DEN**	**BA**	**FR**	**IP**	**TOT DEN**	**TOT BA**	**76-100**	**>100**
Overstory					63	27	15	9
Pinus jeffreyi	43	20	91	68				
P. lambertiana	0	0	0	0				
Abies concolor	19	6	59	29				
A. magnifica	<1	<1	1	1				
C. decurrens	1	1	4	2				
Others	<1	<1	1	1				
Understory					222	4		
P. jeffreyi 40	1	55	34					
P. lambertiana	3	<1	10	<1				
A. concolor	137	3	89	58				
A. magnifica	<1	<1	3	1				
C. decurrens	39	<1	16	7				
Others	3	<1	3	1				
Saplings					434			
P. jeffreyi 11		3	6					
P. lambertiana	0		0	0				
A. concolor	183		21	54				
A. magnifica	6		1	3				
C. decurrens	234		7	38				
Others	0		0	0				

oldest cohort (overstory, 68) to the understory cohort (34) to the sapling cohort (six)—an order magnitude of 10. At the same time, white fir increased in importance over the same three cohorts from 29 to 54 percent and incense cedar increased from two to 38 percent.

In the mixed-conifer series, Jeffrey pine and white fir shared dominance and three other species were equal associates at considerably lower densities, basal areas, and frequencies (Table 5-6). "Other" conifer taxa encountered lodgepole pine and western white pine. As with stands in the Jeffrey pine series, the importance percentage of Jeffrey pine declined with younger and younger cohorts (29-15-3), while that of white fir increased (33-55-78). Incense cedar also increased but not so much as in the Jeffrey pine series (5-20-11). Red fir showed a strong and unexpected increase in importance (4-17-80).

The white fir series was strongly dominated by white fir and red fir. Jeffrey pine often was present but contributed only about a quarter to a seventh the density of white fir (Table 5-7). The contribution of other conifer taxa was lower than in the mixed-conifer series. The importance percentage of Jeffrey pine declined with increasingly younger cohorts (14-7-1), but the importance of other conifers—including white fir—did not show any consistent pattern of change.

Finally, the red fir series was more completely dominated by a single species than

Table 5-6—Selected traits of the mixed-conifer series (n = 11). DEN = absolute density per hectare, BA = absolute basal area in m^2 ha^{-1}, FR = frequency (%), IP = importance percentage, 76-100 = density of trees 76 to 100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	**DEN**	**BA**	**FR**	**IP**	**TOT DEN**	**TOT BA**	**76-100**	**>100**
Overstory					67	40	13	17
Pinus jeffreyi	19	12	67	29				
P. lambertiana	6	8	31	14				
Abies concolor	27	11	76	33				
A. magnifica	4	2	15	6				
C. decurrens	5	5	24	10				
Others	6	2	24	8				
Understory					211	5		
P. jeffreyi 20	1	35	15					
P. lambertiana	4	<1	9	3				
A. concolor	135	4	90	55				
A. magnifica	17	<1	23	9				
C. decurrens	20	<1	19	8				
Others	15	<1	21	11				
Saplings					425			
P. jeffreyi 7		2	3					
P. lambertiana	0		0	0				
A. concolor	327		26	78				
A. magnifica	80		5	16				
C. decurrens	11		3	5				
Others	0		0	0				

Table 5-7—Selected traits of the white fir series (n = 14). DEN = absolute density per hectare, BA = absolute basal area in m^2 ha^{-1}, FR = frequency (percent), IP = importance percentage, 76-100 = density of trees 76 to 100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	**DEN**	**BA**	**FR**	**IP**	**TOT DEN**	**TOT BA**	**76-100**	**>100**
Overstory					108	41	22	12
Pinus jeffreyi	10	6	25	14				
P. lambertiana	<1	<1	1	1				
Abies concolor	74	28	88	63				
A. magnifica	21	5	36	16				
C. decurrens	1	1	4	1				
Others	2	1	7	5				
Understory					431	8		
P. jeffreyi 10	<1	16	7					
P. lambertiana	<1	<1	1	<1				
A. concolor	315	7	91	64				
A. magnifica	75	1	41	21				
C. decurrens	10	<1	7	3				
Others	21	<1	9	5				
Saplings					543			
P. jeffreyi 3		1	1					
P. lambertiana	0		0	0				
A. concolor	489		32	83				
A. magnifica	46		7	13				
C. decurrens	0		0	0				
Others	11		2	4				

any other series (importance percentage of red fir = 76 in the overstory). Lodgepole pine and western white pine had relatively high importance percentages in this series. Red fir showed a modest decline in importance in younger and younger cohorts, while white fir increased four-fold (7-15-28). No other taxa exhibited any consistent pattern of change (Table 5-8).

Pattern analysis, via the T-squared test, showed that overstory trees in each of the four series were distributed randomly. However, understory trees were clumped in all but the mixed-conifer series. Simulation testing by Engeman et al. (1994) have shown that moderate clumping underestimates tree density by 15 percent. Consequently, we can be sure that understory tree densities are at least as high as we show in tables 5-5 through 5-8, and they could be up to 15 percent higher.

Coarse Woody Debris

Forest floor surfaces of the four series were not statistically different in terms of percent cover by shrubs, herbs, rock, litter, or coarse woody debris (Table 5-9). Litter depth averaged five cm and litter covered 80 percent of the ground; rocks and coarse debris covered 11 percent of the ground.

Table 5-8—Selected traits of the red fir series (n = 14). DEN = absolute density per hectare, BA = absolute basal area in m^2 ha^{-1}, FR = frequency (%), IP = importance percentage, 76 to 100 = density of trees 76-100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	DEN	BA	FR	IP	TOT DEN	TOT BA	76-100	>100
Overstory					107	53	25	25
Pinus jeffreyi	3	2	15	6				
P. lambertiana	1	<1	3	2				
Abies concolor	6	1	20	7				
A. magnifica	86	47	100	76				
C. decurrens	0	0	0	0				
Others	11	3	28	10				
Understory					217	6		
P. jeffreyi 1	<1	5	2					
P. lambertiana	0	0	0	0				
A. concolor	34	1	33	15				
A. magnifica	155	4	100	67				
C. decurrens	0	0	0	0				
Others	27	1	38	16				
Saplings					601			
P. jeffreyi 7		2	2					
P. lambertiana	0		0	0				
A. concolor	167		13	28				
A. magnifica	380		27	59				
C. decurrens	0		0	0				
Others	47		7	11				

Table 5-9—Forest floor attributes of the four series. Litter depth (LD) is in centimeters, coarse woody debris (CWD) is in tons per acre for all material >25 cm diameter. Snag density per hectare is by diameter breast height class (in centimeters).

	Cover (%)						Snag density		
Series	**Shrub**	**Herb**	**Litter**	**Rock+log**	**LD**	**CWD**	**<76**	**76-100**	**>100**
Jeffrey pine	27	2	75	15	3.8	15	97	8	4
Mixed conifer	21	2	77	12	4.2	11	28	3	6
White fir	17	4	84	9	6.1	46	80	5	3
Red fir	16	1	86	0	3.4	24	31	6	9

Fuel loads of coarse woody debris (greater than 25 cm diameter) were high, averaging 26 tons per acre (58 metric tons per hectare; Table 5-9). This amount is well within values for mixed-conifer, white fir, and red fir stands from throughout the northern Sierra Nevada, which range from one to 46 tons per acre of coarse woody debris (Blonski and Schramel 1981). We did not measure fine debris smaller than 25 cm diameter, but according to tables in Blonski and Schramel (1981), such debris would contribute another 60 percent biomass. For our stands, that would be an additional 15 to 16 tons per acre. A few stands had exceptional fuel loads; one white fir stand had 73 tons per acre of coarse woody debris, and another white fir stand had 70. There was no statistically significant difference in the amount of coarse woody debris among the four series, but there was a definite trend: Jeffrey pine and mixed-conifer stands had about half the biomass of white and red fir stands.

Snags of all diameters averaged 70 per hectare, equivalent to 16 percent of total (live plus dead) tree density (Table 5-9). Snag density was lowest for the red fir series (46 per ha, 12 percent of all trees) and highest for the Jeffrey pine series (109, 28 percent of all trees). Perhaps this cline of mortality reflects the relative severity of the 1987-1992 drought at lower elevations. Most of the snags were less than 76 cm dbh in all series, but mixed-conifer and red fir series showed the highest percentages of snags greater than 76 cm (25 and 33 percent, respectively) whereas Jeffrey pine and white fir series had only 10 percent of their snags with greater than 75 cm dbh. These data could be taken to indicate that young and small trees were more at risk than old and large trees during the drought period.

How does the present condition of old-growth forest differ from precontact time and what are the reasons for that difference?

Historic Reconstructions

We have no quantitative summary of precontact forest in the basin, nor, for that matter, for anywhere in the Californias. Two kinds of indirect evidence, however, can be used to reconstruct the precontact vegetation.

One type of indirect evidence is the density, size distribution, and species identity of stumps still remaining from clear-cuts of old-growth forest accomplished in the late 1800s. Alan Taylor (1998) examined 17 such sites on the east side of the basin, harvested between 1875 and 1902. Relatively cool and dry conditions preserved stumps down to a diameter of 10 cm. It is possible that fir stumps disintegrated faster; if so, this method could have biased Taylor's reconstructions in favor of pine. Half-hectare samples were taken of 11 Jeffrey pine and six red fir stands, the data consisting of stump diameter, location, and species identification.

An abstraction of Taylor's results give us precontact Jeffrey pine stands with 68 trees per hectare and a basal area of 26 m^2 ha^{-1} and an importance percentage for Jeffrey pine of 79, for white fir of 19, and for red fir of two. These values are remarkably similar to those from the overstory of modern old-growth Jeffrey pine stands in the basin (Table 5-5). Today's overstory density is 63 trees per hectare, and it has a basal area of 27 m^2 ha^{-1}. Total tree density today is higher (285; four times Taylor's reconstruction of precontact density), but surely part of the difference is because our modern data include trees as small as one cm dbh, whereas Taylor counted stumps greater than only 10 cm dbh.

Taylor's precontact red fir stands had 160 trees per hectare and a basal area of 57 m^2 ha^{-1}; red fir had an importance value of 66, western white pine 29, and lodgepole pine five. Modern red fir stands (Table 5-8) have much less of an overstory tree density of 103 trees per hectare but only a slightly lower overstory basal area of 53 m^2 ha^{-1}. Total tree density today is much higher (324; twice the precontact density), but that could be due to the fact that our modern data include trees less than 10 cm dbh.

Lindström and Waechter (1995, 1996) sampled five north shore Jeffrey pine clear-cuts and obtained much smaller stump counts, averaging only 13 per hectare. They also sampled one east shore white fir clear-cut and counted 43 per hectare. We think these values are either underestimates or anomalies, given the much higher density of trees in modern Baja California forests that have never experienced fire suppression management (see below). Possibly stump decay was much faster in these wetter sites than where Taylor did his work.

Lindström, who has made a thorough search of 19th century scaling records in the basin, concluded that average maximum trunk diameters then were 130 cm and that clear-cuts yielded predominantly Jeffrey pine, lodgepole pine, white fir, and incense cedar in declining order (see Chapter 2).

Another view of the basin soon after contact time comes from surveys conducted by the General Land Office (GLO) in the last quarter of the 19th century. Surveyors annotated their routes through uncut forests by identifying overstory trees as to species and dbh at particular intervals along section lines or in four directions from section corners. J. A. Fites has summarized hundreds of trees recorded in GLO notes from lower and upper montane and subalpine zones for our report (figures 5-3, 5-4, and 5-5). The relative abundance of "fir" (a combination of white and red fir) to "yellow pine" (a combination of Jeffrey pine and ponderosa pine) in the lower montane is surprisingly close to 1:1 from these GLO notes, in contrast to Alan Taylor's stump counts (1:4) and in contrast to the common assumption that the ratio of fir to pine the previous century was low—certainly lower than it is today.

Anecdotal accounts by the two early foresters Lieberg (1902) and Sterling (1904) ratify the GLO's picture rather than Taylor's. They wrote that white fir accounted for 25 to 40 percent of lower montane stands in precontact time but 60 to 75 percent of secondary forests. Sugar pine and Jeffrey pine in contrast, they wrote, were not regenerating in sufficient abundance (only two to three percent of second growth stands) to recapture their past abundance (20 to 25 percent for each in precontact stands). To summarize their precontact estimates: white fir = 25 to 40 (mean = 32), sugar pine = 20 to 25 (mean = 22), Jeffrey pine = 20 to 25 (mean = 22), others (incense cedar, Douglas fir, lodgepole pine) = 24; that is, the fir to pine ratio must have been about 32 to 22, or 1.5 to 1. Second-growth stands at that time were heavily dominated by fir, at a ratio of 30 to 1.

The GLO records indicate that the upper montane zone was fir-dominated then, just as it remains today, the ratio of fir to pine being approximately two to one (Figure 5-4).

The subalpine zone was very high in fir (no doubt almost all red fir) and low in mountain hemlock, western white pine, and whitebark pine. One possible explanation for such a high ratio of fir is that few locations in the basin are high enough to exhibit dominance by whitebark and hence were rarely encountered in the surveys. Another explanation could be improper species identification, in which surveyors recorded many mountain hemlocks as firs by mistake.

The size distribution of trees in the three zones is relatively flat in the montane and subalpine zones (Figure 5-5). Such a size and age pattern is not the classic inverse-J shape expected of self-maintaining, multiple-age old-growth forest. However, the patterns do summarize a complex age structure and architecture, and they are similar to size and age distributions for modern old-growth subalpine tree populations (Major and Taylor 1988; Nachlinger and Berg 1988) and even for some lower montane old-growth mixed conifer stands (Ansley and Battles 1998). Distributions today for the basin's montane zones are very different; they show highest densities in the smallest and youngest cohorts, less than 16 inches dbh (less than 40 cm dbh; refer to tables 5-5 through 5-8). These small-trunked cohorts are the ones that exhibited a doubling to quadrupling of densities over the past 150 years.

Comparison to Modern Baja California Forests

A second type of evidence for reconstructing precontact basin forests comes from modern mixed-conifer forests in the Sierra San Pedro Martir (SPM) of Baja California, an ecological analog to the basin (Minnich 1986; Minnich et al. 1995, 1999). The SPM is the southernmost portion of the Peninsular Ranges, which extend from southern California across the international border for 250 km. Forests of Jeffrey pine, lodgepole pine, sugar pine, white fir, and incense cedar dominate a rolling plateau at 1,900 to 2,500 m elevation. Mean annual precipitation is 65 cm, more than half of which is snow. Fire suppression management has never been practiced in SPM. Fire scar studies

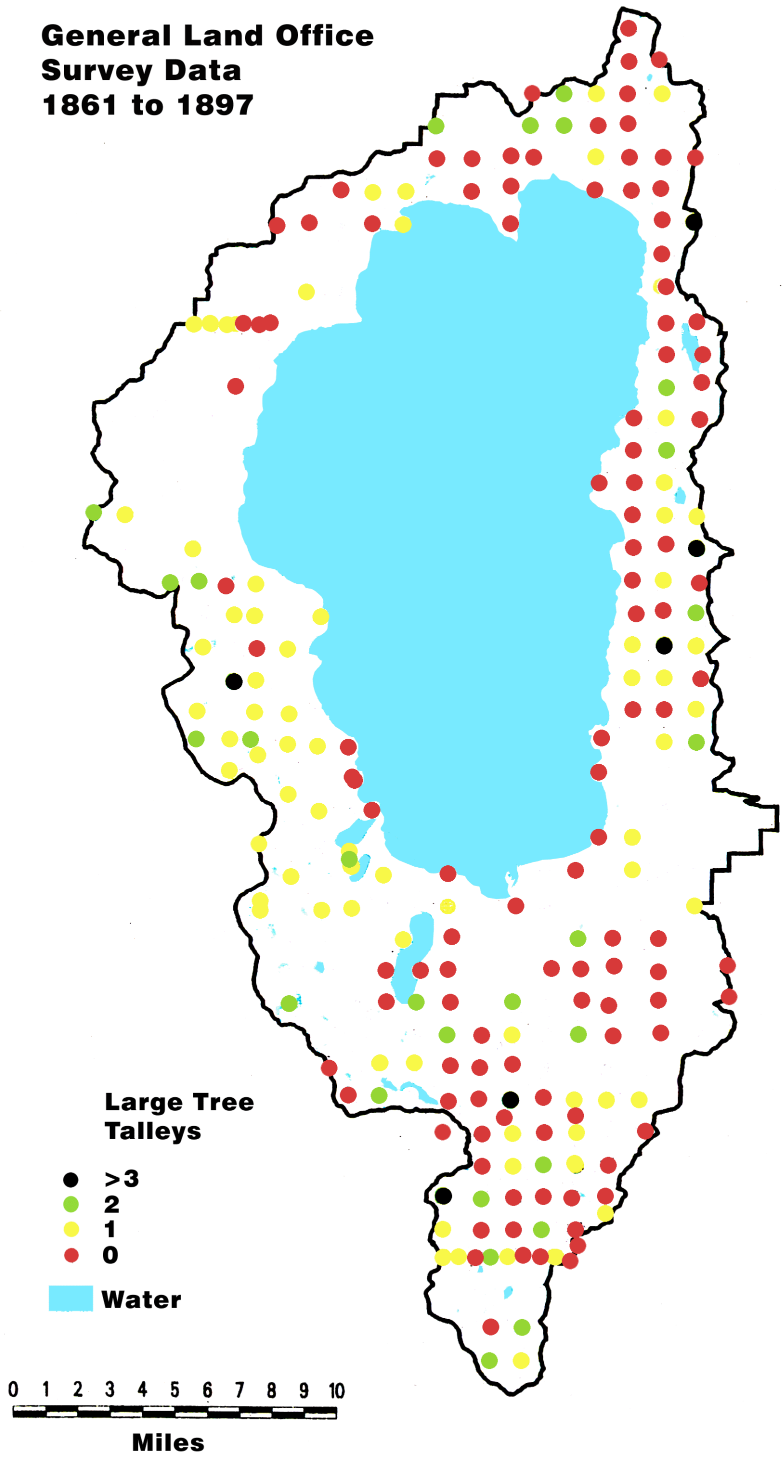


Figure 5-3—Location of areas surveyed by the General Land Office from 1861 to 1897. Dots show section corners at which the nearest trees in four quadrants around the corner totaled 0-4 with dbh >36 inches.

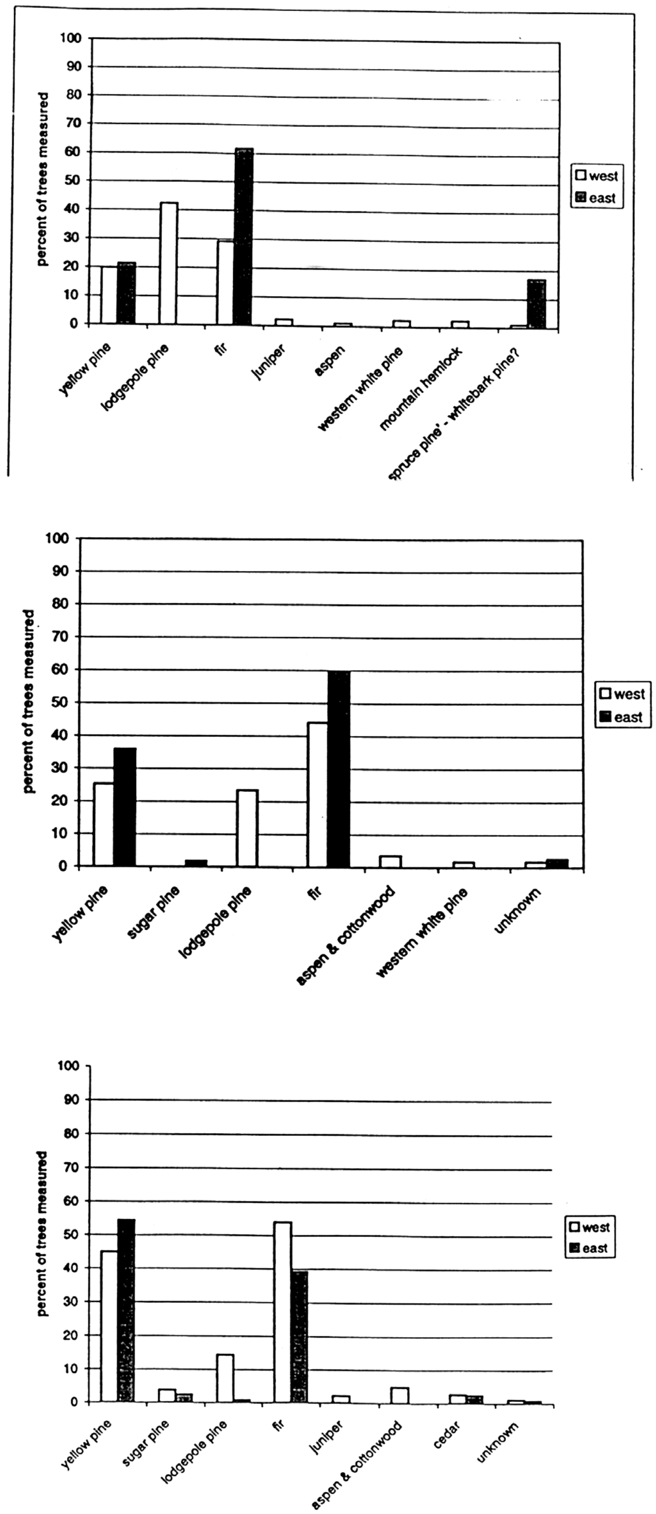


Figure 5-4—Species composition in the basin ca 1880, as recorded by the General Land Office survey. Top is subalpine zone woodland species, middle is upper montane, bottom is lower montane. From J. A. Fites, unpublished data.

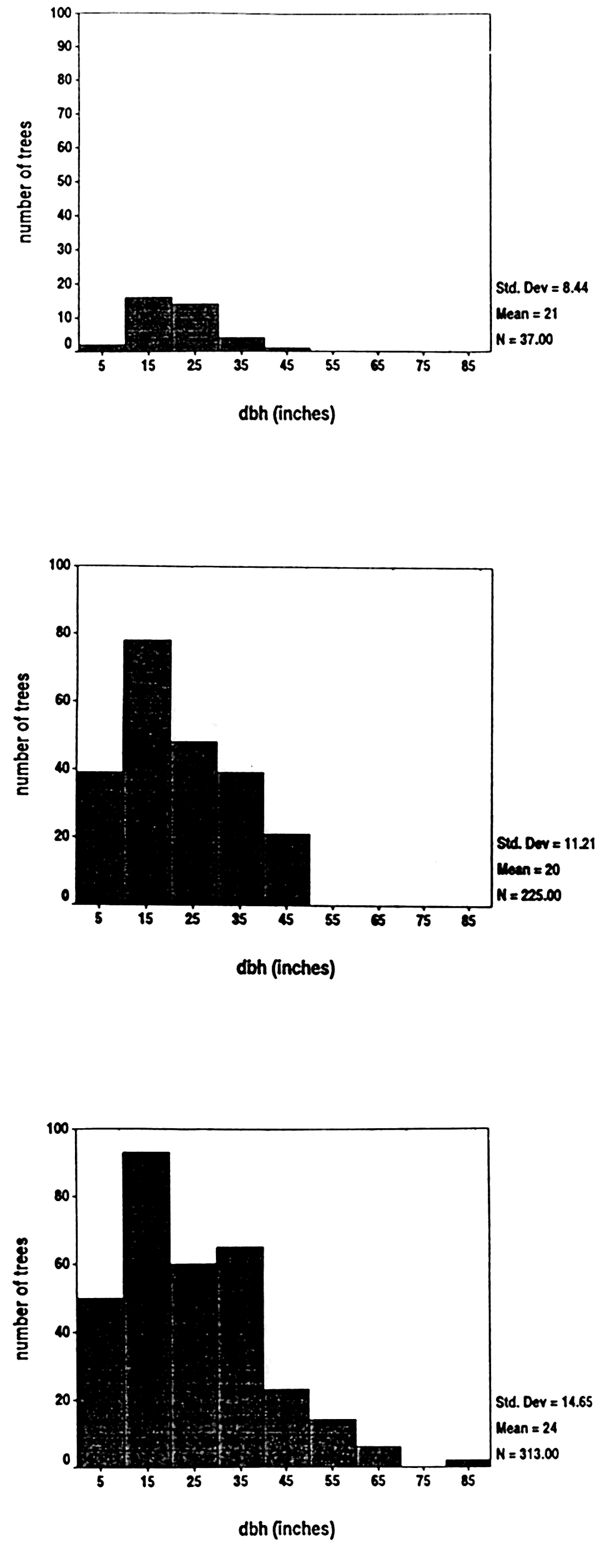


Figure 5-5—Diameter at breast height distribution of all trees encountered in the basin ca 1880 by the General Land Office survey. Top is subalpine zone, middle is upper montane, bottom is lower montane. From J. A. Fites, unpublished data.

indicate a mean fire return interval of 26 years over the past 400 years, with no evidence of any increase (that is, no evidence of fire suppression) during that time.

Minnich and his colleagues quantified twenty-one forest stands comparable to those of the Tahoe basin, using the same point-centered quarter technique tha we used. Tree density (trees greater than three cm dbh) ranged from 78 ha^{-1} in Jeffrey pine forest to 156 ha^{-1} for white fir forest. (A single Jeffrey pine-white fir stand sampled independently by Savage [1997] had a density of 162 ha^{-1}.)

The size-class distribution was flat and complex, similar to the GLO records for basin forests. Mixed conifer, white fir, and Jeffrey pine stands showed either equal densities in 10 to 30, 31 to 60, 61 to 90, and greater than 91 cm dbh classes or somewhat higher densities in the 31 to 91 cm dbh classes. The stands, in other words, exhibited the same size and age complex structure as uncut stands of the basin in the late 1800s (Figure 5-5). If we estimate that half the 61 to 91 cm dbh class represents trees greater than 76 cm dbh, then these forests had 20 to 25 trees ha^{-1} of size greater than 76 cm dbh (17 to 28 percent of all trees). Basal area ranged from a low of 21 m^2 ha^{-1} in Jeffrey pine stands to 34 m^2 ha^{-1} in white fir stands.

These SPM data are remarkably similar to overstory data for modern Tahoe forests. Overstory tree density in Jeffrey pine forests in the basin is 63 ha^{-1} and in white fir 108 ha^{-1}; overstory basal area in basin Jeffrey pine forests is 27 m^2 ha^{-1} and in white fir 41 m^2 ha^{-1}; and some 24 to 34 trees ha^{-1} are greater than 76 cm dbh in the same two series, accounting for just over 30 percent of all trees. The quantitative values of the two forests are within 25 percent of each other. On the other hand, if we include trees down to one cm dbh, then Tahoe old-growth forests have four times the density of SPM forests.

Unlike the Tahoe area, SPM understory and sapling species composition showed no trends toward increasing importance of white fir and incense cedar nor decreasing importance of Jeffrey pine.

We can conclude that the overstories of modern Tahoe Jeffrey pine and white fir old-growth forests closely resemble (within 25 percent) precontact old-growth forests in terms of species composition, density, and basal area. The modern forests differ from precontact forests in understory tree species composition and density: they have four times the density, the importance of white fir and incense cedar are two to three times higher, and the importance of Jeffrey pine is 50 percent less. We have less information on precontact red fir forests; the modern overstory appears to closely resemble precontact red fir forests, while the modern understory is about twice as dense as it once was, with a modestly larger importance of *A. concolor*.

How does the disease incidence of modern old-growth Tahoe forests compare with seral Tahoe forests and those in SPM?

We quantified disease incidence within 14 seral conifer stands in the basin and within 16 old-growth stands in SPM for the purpose of assessing modern forest health.

Tree mortality was approximately equal, in terms of percent of all trees dead (21 to 22 percent) for old-growth and seral Tahoe forests (Table 5-10). There was considerable variation from stand to stand, ranging from a low of six percent to a high of 41 percent. Most of the standing dead trees had died during the drought of 1987-1992. The age pattern of mortality was somewhat different, a larger percentage of dead trees coming from understory trees (70 percent) in seral forests than in old-growth forests (50 percent). White fir made up more than half of all mortality in all stands, but mortality was somewhat higher in seral stands (78 percent) than in old-growth stands (62 percent). Seral forests also had four to five times more infestation of dwarf mistletoe on both white fir and Jeffrey pine and of rust on incense cedar (Table 5-10). Bark beetle infestation was similar for seral and old-growth stands.

While much of the 1990s tree mortality in the basin can be indirectly attributed to the short-term effects of drought and the long-term effects of a century of fire suppression (which increased tree density and competition), the final cause of death has been due to a suite of insects and pathogens. For each of the major conifer species, overall pest incidence is lower in old-growth stands than in seral

Table 5-10—Mortality and the incidence of the most important pests in 17 old-growth and 14 seral stands of the Tahoe basin and in 16 old-growth stands of the Sierra San Pedro Martir (SPM). Incidence is expressed as a percentage of all trees, living + dead. Mortality (Mt) is expressed as a percentage of all trees, living + dead. Host species: Pj = *Pinus jeffreyi*, Ac = *Abies concolor*, Pl = *Pinus lambertiana*, Cd = *Calocedrus decurrens*. Technical names of diseases are in Table 4. T = trace, <1%.

Forest type/Mt	Host	Dwarf mistletoe	True mistletoe	Bark beetle	Annosus root rot	White pine blister rust	Cedar rust	Heartrot	Total
Old-growth/21	Pj	6		17					23
Seral 29		21		18					39
SPM 12		0*		12					12
Old-growth Ac	3	0	30	1				T	34
Seral		11	0	35	3			T	49
SPM		0	60	28	2			T	90
Old-growth Pl			3		0			3	
Seral				5		3			8
SPM				1		0**			1
Old-growth Cd						9	11	20	
Seral							34	1	35
SPM (this host not surveyed)									

stands (for example, 23 percent versus 39 percent total pest incidence for Jeffrey pine in old-growth and seral stands; 34 percent and 49 percent for white fir), but these differences were not large enough to be statistically significant.

Epidemic levels of several bark beetle species are the most important pests causing tree death in the past 10 years. The high level of mortality in the basin was not out of the norm for forests statewide; similar levels have been reported for the Modoc Plateau, the southern Cascades, the entire eastside of the Sierra Nevada, and mountains in southern California (Smith et al. 1994; Ferrell et al. 1994; Dale 1996).

There are few records of mortality prior to Euroamerican contact, but we can use the SPM forests as a surrogate for precontact basin forests. SPM forests had experienced the same 1987-1992 drought as Tahoe forests, yet mortality was much about halved. Tree mortality in SPM accounted for only 12 percent of all trees (range of variation from stand to stand = four to 15 percent). The overwhelming majority of snags (90 percent) were overstory trees greater than 50 cm dbh, whereas 60 percent of basin snags were less than 50 cm dbh.

A more localized sample of SPM mortality by Savage (1997) had only four percent mortality, in contrast to 14 percent mortality in similar Jeffrey pine forests in the Transverse Range north of the international border in southern California. Her analysis of SPM snags indicated that most had died prior to the 1987-1992 drought, whereas the great majority of snags in the Transverse Range had died between 1984 and 1991. Apparently, recurring surface fires in SPM keep tree density so low that episodic droughts do not increase competition for soil moisture. The different patterns suggest that fire is responsible for most stand thinning in SPM and that insects have replaced fire as thinning agents in the basin (Minnich et al. 1999).

Our analysis of 16 SPM stands showed that some of the same pathogens, parasites, and insects of Tahoe forests were present (tables 5-3, 5-4, and 5-10). Major exceptions were that dwarf mistletoe was absent in SPM, but true mistletoe (*Phoradendron pauciflorum*) was present and very abundant on white fir; also, white pine blister rust was absent in SPM. Jeffrey pine trees showed much lower combined incidence of bark beetles, mistletoe, and root and trunk rots in SPM than Tahoe (12 percent versus 23 percent). However, white fir had a much higher combined incidence in SPM, largely because of parasitism by true mistletoe (91 percent at SPM versus 33 percent dwarf mistletoe infection in the Tahoe basin). The combined disease incidence on sugar pine was virtually the same in both locations. Thus there is no consistent pattern of pest differences between SPM and Tahoe forests. However, we can conclude that SPM forests are healthier because mortality there has been almost half that of Tahoe during the past decade.

What is the present condition of seral (non-old-growth) forests in the basin?

The condition of Tahoe basin seral stands is significantly different than that of old-growth stands (Table 5-10). In comparison to more open old-growth forests of SPM, seral stands appear even more different; disease incidence is 325 percent higher, mortality is 167 percent higher, and tree density is 400 percent higher.

Old-growth forests can readily be compared to modern seral forests in the basin by reference to 774 plots quantified by the USDA Forest Service in the 1980s and 1990s as part of the Forest Inventory Analysis system (FIA Johnson 1995). By "seral," we mean any forest that has been previously entered, whether harvested individually, selectively, or entirely. Some FIA plots, therefore, do have old and large trees, and a few could be classified as old-growth, but we would not have selected most FIA plots for our old-growth group because of the presence of scattered stumps.

A summary of tree density and basal area for all five forest series, including east and west variants (tables 5-11 and 5-12) shows that for every series, except the subalpine mixed-conifer woodland, the west variant had at least a 30 percent greater tree density and greater basal area for all trees greater than 10 cm dbh (and at least 50 percent greater for trees greater than 91 cm dbh). Average total tree density for all FIA sites was 994 per hectare (no difference whether subalpine stands were or were not included), compared to average tree density for our 38 old-growth sites of 350 per hectare. Density of seral basin forests, therefore, was [(994-350)/350 = 184percent] greater than old-growth basin forests. Density of trees greater than 91 cm dbh in seral forests was seven per hectare, compared with old-growth density of 16 per hectare for trees greater than 100 cm dbh (Table 5-11).

In theory, restoring Tahoe forests to their precontact densities should mitigate most serious pest outbreaks in the future. However, thinning and prescribed burning can increase pest incidence and mortality. For example, thinning may damage residual trees and can increase the incidence of annosus root rot by exposing freshly cut stumps to airborne spores.

Table 5-11—Mean, minimum, and absolute minimum values for density of living trees >76, 91, and 100 cm dbh ha^{-1} in four series. Data come from this document, FIA Tahoe plots, and recommendations by Fites and Potter and their colleagues (F&P). Absolute minimum is defined in text.

	Trees >76				Trees > 100		Trees >91
Series	**Our mean**	**Our min**	**F&P min**	**F&P ab.min**	**Our mean**	**Our min**	**FIA seral mean**
Jeffrey pine	24	12	13	5	9	1	4
Mixed conifer	30	22	27	12	17	8	14
White fir	34	11	35	15	12	1	3
Red fir	50	44	42	18	25	11	6

Table 5-12—Area (hectares) of old-growth forests in the Tahoe basin estimated from the interpretation of remotely sensed images. Criteria for the inclusion of any polygon as old-growth include the >2 trees per acre with dbh >30 inches and four different percentages of canopy cover. Areas (hectares) are summarized separately for three forest zones (lower montane, upper montane, subalpine) and into western and eastern portions of the basin.

	West			East			
Old-growth criteria	**Lower**	**Upper**	**Subalpine**	**Lower**	**Upper**	**Subalpine**	**Total**
Tree canopy							
>60% cover	569	76	23	6	119	21	814
40-60%	439	377	58	141	280	14	1,309
25-40%	230	166	15	169	19	0	599
10-25%	87	170	87	19	15	7	385
Total	1,325	789	183	335	433	42	3,107

What is the distributional pattern of relictual old-growth forest now and what should it be in the near future? What sustainable mix of seral and old-growth forests is possible?

Old-growth stands in the basin occupy a very small percent of the landscape. Our field check of 400 potential old-growth polygons revealed only 38 to actually be unentered old-growth stands. On the one hand, if we presume that this field survey was exhaustive, then the total old-growth area of lower and upper montane forest is 38 x 25 ha = 1,030 ha. If, on the other hand, we interpret remotely sensed images more generally for overstories that meet some less quantitative criteria of old-growth status (let's choose greater than 40 percent cover), the potential total old-growth area in the lower and upper montane zones combined is 2,007 ha. Subalpine old-growth (choosing greater than 25 percent canopy cover) would add another 131 ha.

The area of lower montane plus upper montane forests, including all seral phases is 38,340 ha; subalpine forest area would add another 10,280 ha (Table 5-1). Taking the largest estimate for today's old-growth area, (2,007 plus 131), it totals four percent of all conifer forest area in the basin.

What percentage of basin forest land was in old-growth status prior to Euroamerican contact? The best estimate might come from an examination of old-growth landscapes in Sierran national parks. Franklin and Fites-Kaufman (1996) analyzed Lassen Volcanic, Yosemite, Sequoia, and Kings Canyon National Parks and concluded that 55 percent of the modern forested landscape was in old-growth status; the rest was seral. As logging had never occurred in those parks, they deduced that 55 percent of the landscape had been old-growth in precontact time. (In contrast to national forests, adjacent Forest Service lands had been open to logging, and these exhibited 13 percent cover by old-growth forests.) Applying the 55 percent "rule" to the Tahoe basin gives 26,740 ha. So, today's 2,138 ha of old-growth represents eight percent of the preexisting old-growth area.

The distributional pattern of remaining old-growth stands is scattered. There are no clumps of contiguous or nearly contiguous stands that form nuclei about which managers might build out from over time. Several areas do stand out as having loose clusters of stands (Figure 5-2): six stands on the east side between Logan House Creek (north) to Highway 207 (south), four stands in the northeast just north of Marlette Lake, four stands on the west side just north of Emerald Bay, and five stands in the extreme south in the Upper Truckee watershed.

An image of the location of old-growth stands from the interpretation of remotely sensed data (Figure 5-6) shows additional loose clusters. Looking only at the darkest colored areas (stands with greater than 60 percent canopy cover), there are more than 20 clusters, each greater than 200 ha,

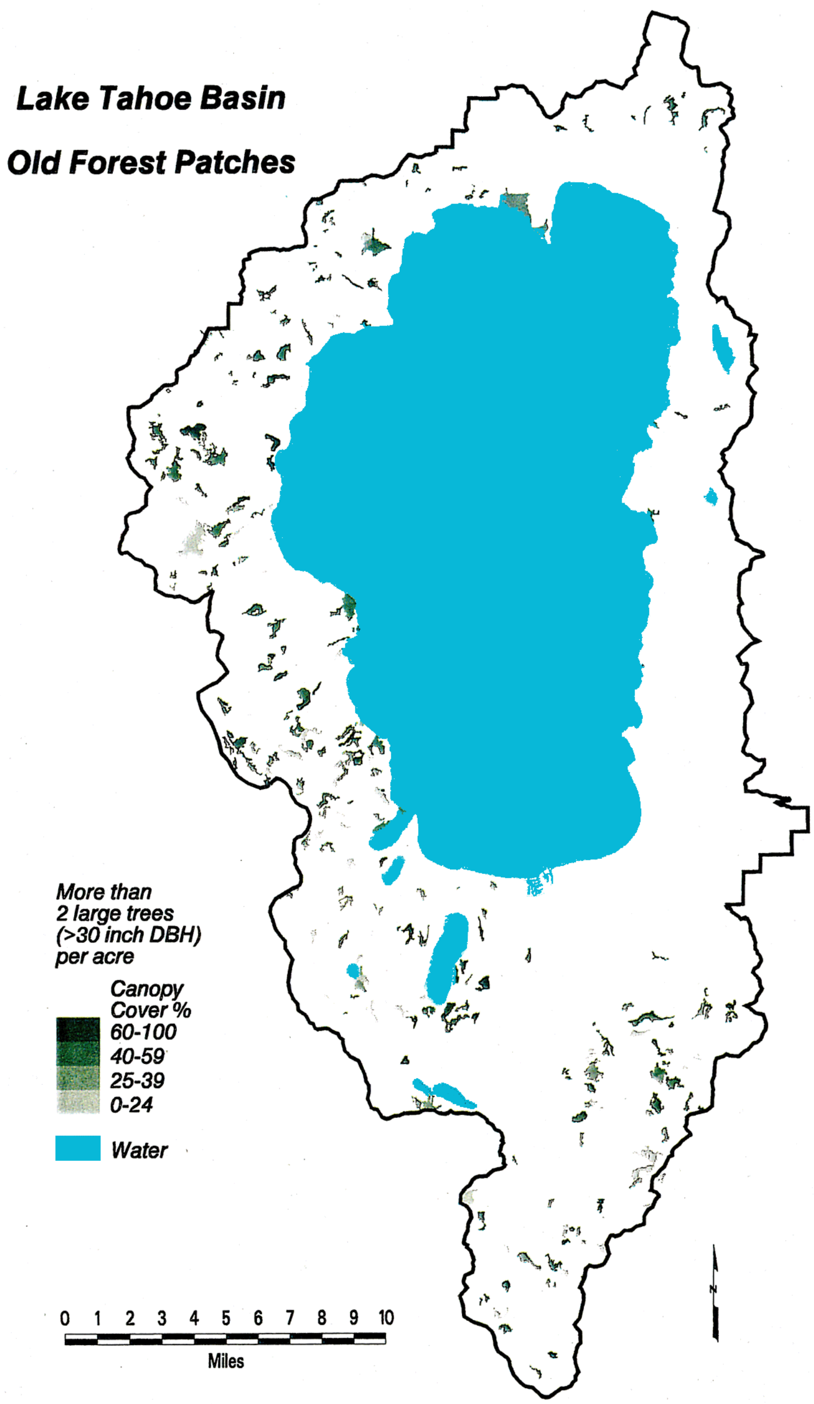


Figure 5-6—Clusters of old-growth stands identified from remotely sensed images and using the criterion of polygons having >2 trees per acre, >30 inches dbh, and various amounts of total canopy cover. About 20 clusters with cover >40 percent (darker green) are scattered in the north, west, and south parts of the basin.

located to the north, west, and south of the lake.

We suggest that these clusters be visited and their "neighborhood" forest vegetation be evaluated as to its potential to be moved toward old-growth status. Such traits as size of the old-growth core, slope stability, distance from structures and roads, and homogeneity of the neighborhood could be used to rate the suitability of each cluster for active management. A few of the highest rating clusters then would be identified for management and monitoring. Then, as funds, consensus, and abilities improve, the management area could be expanded, either by enlarging the area of the original clusters or by extending management to other clusters.

What should the ultimate distribution and extent of old-growth forest be? Should it be managed all the way to TRPA's Resolution 82-11 of 75 percent of forested land? Should it be returned to the precontact extent of 55 percent? Forest ecologist Jared Verner (1980) proposed that 40 percent of the Sierran landscape be old-growth, based on considerations of optimal habitat requirements for birds and other wildlife. Or should old-growth in the basin simply be increased a modest amount, to mirror the 13 percent typical of Forest Service lands (Franklin and Fites-Kaufman 1996)? We certainly can conclude that there are strong ecological reasons to make it larger than the present four percent, but there is not much consensus on how much larger.

Issue 2: The Current Likelihood of Fire; the Relative Importance of Weather, Fuels, and Ignitions in Contributing to the Likelihood of Fire; and Effects of a High Severity Fire on Urban Areas, Air Quality, Lake Clarity, and Biotic Health

With contributions from Sue Husari, Don Carlton, and Steve Beckwitt

In the Sierra Nevada, most fires prior to European settlement were thought to be of low to moderate intensity, with extensive areas (>100 acres) of high tree mortality uncommon (Skinner and Chang 1996). Fires typically spread along the surface, torching or consuming taller vegetation or tree crowns in small to medium patches. Litter, herbs, shrubs, and tree saplings were consumed, but most mature trees had a thick enough insulating bark to withstand the heat. Sometimes the upslope-facing side of a tree would be scarred because debris had accumulated there and temperatures were hotter. Once scarred, such trees often were scarred again in the same area by subsequent fires because of the lack of thick bark and accumulations of pitch. The wood of these trees thus bears a fire history record for several hundred years or longer. It is through the examination of such wood records (the science of dendrochronology) that we can determine the fire return intervals (number of years between fires for the same place) that occurred historically. Some fire scar records for the Sierra Nevada stretch back nearly 2000 years because of the long length of life of the scarred trees (Swetnam 1992).

The frequency of these surface fires appears to be determined mainly by the availability of fuel. Both the presence of fuel and the dryness of the fuel determine availability of fuel. At higher elevations of the Sierra Nevada, such as the red fir zone of the basin, fuels are often present, but, because of the short fire season, fuels are not always flammable for long periods. At lower elevations the weather is always suitably arid by late summer. Lightning strikes saturate the landscape at both lower and higher elevations, although patterns can vary locally due to topography. But if too few years have passed between the last surface fire and the lightning strike, then too little fuel is available to carry the flame. As growing conditions improve—because of increasing annual precipitation or locally wetter sites, a longer growing season, and productive soils—the speed with which fuel accumulates increases, and thus the minimum time between fires becomes shorter (Minnich et al. 1995).

By the 1920s, fire protection was a primary concern. Tahoe has now completed 75 years of fire suppression management, during which there normally would have been three to five fire cycles in the mixed-confer and pine zones. One consequence has been an increase in the amount of fuel on the forest floor and increased density of understory vegetation. Fire played an important role in thinning historic forests, and reducing surface fuels. Today fires are likely to be more intense because of the accumulation of surface fuels and understory. The amount of fuels available to burn at any given time in a given area is referred to as fire hazard. Our very successful program of fire suppression of low to moderate intensity fires has made the occurrence of high intensity fires more likely than ever. In upper montane and subalpine zones, fewer fire cycles have been missed; consequently, the effects of fire suppression are less evident in these zones.

In the Lake Tahoe basin, there have been many additional changes in vegetation from the time of settlement, which are the result of activities other than fire suppression. Extensive harvest in the late 1800s and early 1900s (Elliott-Fisk et al. 1997; Lindström, Chapter 2, this volume; Raymond 1992) resulted in an overall young forest. There is concern that these changes have contributed to an increased likelihood of severe fire. Younger forests are more susceptible to mortality from fires. This is due to the lower height and size of small trees. Their bark is thinner, and their crowns are lower to the ground, making them more susceptible to lethal heating by flames of a low height. With much of the basin in a younger state, a large proportion of it would burn severely, with high rates of mortality.

In addition to instituting fire suppression measures that may have increased fire hazard through fuel accumulation, humans have increased the number and changed the distribution of ignitions. Fire risk typically is defined as the probability that an ignition will occur and ignite fuel. Human caused fires are the source of most of the acres burned by wildland fire in the Lake Tahoe basin. People tend to ignite fires that escape and get larger than do lightning fires. Some of the fires that people ignite are on severe fire days, which are dry, windy, and hot; lightning fires often are ignited under conditions of higher humidities and cooler temperatures and during events that are usually forecasted, allowing fire managers to gear up for the subsequent fires.

These two human activities—creating younger forests by harvesting older trees and suppressing fires that otherwise would have burned off accumulated fuel—have increased the likelihood of severe fire in the basin. The Lake Tahoe basin is high elevation, with a relatively short fire season compared to other parts of the Sierra Nevada, two factors that greatly decrease the likelihood of fire. In addition, fire suppression is excellent in the basin, as demonstrated by the lack of large fires since the early 1900s. However, the likely consequences of fire in the basin are particularly great because of the importance and status of lake clarity and the high density and value of human development. There is a need to quantify the likelihood of fire in the basin, to assess the potential tools that would be most effective in reducing risk and hazard, and to set priorities about how best to reduce the likelihood of fire.

The potential effects of unplanned fire on vegetation in the basin are also important to consider. Vegetation in the basin provides important ecosystem and social values that would be at risk if a large, high severity fire occurred. Vegetation provides cover for the soil, filtering nutrients and sediment that might flow into the lake, reducing water quality. Vegetation also provides wildlife habitat and is an important component of the scenic beauty of the basin. For this assessment, we modeled the likelihood of unplanned fire occurrence in the basin and likely effects of fires on ecosystem and social/economic resources.

Definition of Terms

For clarity it is important to define some terms that are used throughout this section that people often use in varied ways. These terms include risk, fire risk, high severity fire, large fire, fire or fuel hazard, and likelihood of fire. The term "fire risk" has a very specific meaning in fire literature and is described as the likelihood that an ignition will occur. We use the term in this sense. "Fuel hazard" refers to the amount of fuel available to burn at any given time in a given area. Both the total quantity of fuel and the dryness of the fuel determine the amount of available fuel. High quantities of fuels may be present at a location, but if the fuel is wet or moist, then it is not available for combustion. Fire hazard and fire risk combine to determine the likelihood of fire. "High severity fire" refers to fires where a large proportion of the overstory vegetation is killed (i. e., >70 percent mortality of overstory trees). In the basin, any fire greater than 10 acres may have detrimental consequences. Fires of this size can cause extensive damage because of the high density and value of human development and importance of lake clarity. The term "risk" is used often by many people in a very general sense to refer to the likelihood of a high severity or large fire. To ensure clarity, we emphasize use of the more specific terms "fire risk," "fuel hazard," and "likelihood of fire" and use "risk" only in the general sense when considering the likelihood of a high severity fire or large fire that may jeopardize valued resources.

The following questions are addressed under this issue:

- What is the likelihood of large or severe fires in the Lake Tahoe basin under different weather conditions?
- What are the likely weather conditions associated with a high severity fire or a large fire?
- What is the relative importance of fuels, weather, and ignitions in contributing to the likelihood of large or high severity fires?
- What are the likely effects of a high severity or large unplanned fire on soil erosion, air quality, lake clarity, biotic health, old growth, and urban areas?
- How will susceptibility to fire change in the future when snags fall to the ground?
- Where are the key areas to restore or manage to reduce the likelihood of unplanned large or severe fires?

What is the likelihood of large fires in the Lake Tahoe basin under different weather conditions?

The likelihood of large fires is often quantified by analyzing historical patterns of large fires, such as was done for the Sierra Nevada Ecosystem Study Project (McKelvey and Busse 1996). In the Lake Tahoe basin, this approach is not directly applicable because fires have been few in the last 90 years. Therefore, an indirect approach was applied, using a combination of information sources, individually and together, to develop a fire susceptibility index (see Appendix A for computations). The sources of information included history of fires, recent ignition patterns, fuel conditions, weather patterns, suppression resources and effectiveness, and the spatial overlap of ignitions, fuels, weather, and topography.

The fire occurrence analysis determines the probability of an area igniting. It is based on historic data obtained from USFS files and from its Personal Computer Historical Analysis (PCHA) program. The PCHA databases contain daily weather records and individual fire report data. Data were obtained from the Tahoe and Eldorado national forests (NF) for the area within 10 miles of the Lake Tahoe basin and the Lake Tahoe Basin Management Unit (LTBMU). Forest lands on the Toiyabe National Forest, east of the LTBMU, were not included in the assessment because we were unable to obtain data in time for the assessment.

Various data sources were evaluated to provide a historical perspective on fire occurrence in the study area. These data were used only to provide a framework to evaluate the frequency and sizes of wildland fires in the study area. The Eldorado NF PCHA database had data for 1911 to 1939 and for 1960 to 1996; the Tahoe NF database had incomplete data for 1947 to 1959 and a complete data set for 1960 to 1996. Other sources from the Tahoe NF provided fire occurrence data from 1908 to 1996. Data from the LTBMU database was used to describe fire occurrence from 1973 to 1996. The USFS provided digital fire occurrence data for the LTBMU from 1973 to 1997. Very few fires greater than 100 acres have occurred in the basin, since fires have been recorded (approximately 1908).

No wildland fire greater than 2,000 acres has occurred in the basin since 1908 (Table 5-13). The largest fire since 1908 was 1,013 acres in 1918. Between 1974 and 1996, only nine fires larger than 10 acres have occurred in the basin, with the largest consuming 160 acres (Table 5-14). Humans caused all but one of these fires.

There are several reasons why very few large fires have occurred in the basin. First, fire detection and suppression is excellent. Reporting is very good, and average response time is among the shortest in the Sierra Nevada (Husari 1999). Although the basin has one of the highest

Table 5-13—Fire occurrence for wildland fires greater than 100 acres in the Lake Tahoe and adjacent forest lands (within 10 miles of the Tahoe and Eldorado national forests) from 1908 to 1939.

Current Admin Unit	Date of Year	Size	Location
LTBMU	1908	160 acres	Twn 16N Range 17E Section 14
Tahoe NF	1910	185 acres	Twn 15N Range 17E Section 32
LTBMU	1911	100 acres	Twn 16N Range 18E Section 19
LTBMU	1918	1,013 acres	Twn 14N Range 17E Section 18
LTBMU	September 15, 1917	480 acres	Twn 14N Range 16E Section 36
LTBMU	April 6, 1919	600 acres	Twn 12N Range 18E Section 2
LTBMU	1924	320 acres	Twn 16N Range 18E Section 35
LTBMU	August 13, 1924	180 acres	Twn 12N Range 17E Section 19
Tahoe NF	1926	612 acres	Twn 17N Range 16E Section 32
Tahoe NF	1926	526 acres	Twn 17N Range 16E Section 29
LTBMU	1928	335 acres	Twn 16N Range 16E Section 35
Tahoe NF	1928	1,355 acres	Twn 17N Range 17E Section 13
Tahoe NF	1928	259 acres	Twn 17N Range 18E Section 19
Eldorado NF	October 28, 1929	325 acres	Twn 12N Range 16E Section 22
LTBMU	October 28, 1935	120 acres	Twn 12N Range 18E Section 17

Table 5-14—Fire occurrence in the Lake Tahoe and adjacent (within 10 miles on the Tahoe and Eldorado national forests) forest lands from 1973 to 1996.

Study Fire ID	Current Admin Unit	Ignition Date	Size	Cause	Location
1	LTBMU	September 13, 1974	12 acres	Burning Bldg.	Twn 16N Rge 18E Sec 19
2	Eldorado NF	June 12, 1975	20 acres	Lightning	Twn 10N Rge 16E Sec 25
3	Tahoe NF	August 9, 1977	1,305 acres	Lightning	Twn 18N Rge 17E Sec 28
4	Tahoe NF	August 24, 1978	500 acres	Arson	Twn 17N Rge 17E Sec 6
5	LTBMU	June 26, 1979	23 acres	Smoking	Twn 13N Rge 17E Sec 28
6	Eldorado NF	September 16, 1979	7,024 acres	Campfire	Twn 11N Rge 11E Sec 31
7	Tahoe NF	September 24, 1979	35 acres	Arson	Twn 17N Rge 16E Sec 7
8	Eldorado NF	August 8, 1981	3,600 acres	Burning Vehicle	Twn 11N Rge 16E Sec 21
9	LTBMU	November 1, 1984	19 acres	Debris Burning	Twn 12N Rge 18E Sec 21
10	LTBMU	November 2, 1984	107 acres	Debris Burning	Twn 14N Rge 18E Sec 3
11	Eldorado NF	August 7, 1985	19 acres	Campfire	Twn 11N Rge 17E Sec 13
12	Eldorado NF	October 29, 1986	420 acres	Debris Burning	Twn 13N Rge 13E Sec 13
13	LTBMU	May 25, 1987	25 acres	Lightning	Twn 9N Rge 17E Sec 10
14	Eldorado NF	August 28, 1988	12 acres	Lightning	Twn 11N Rge 17E Sec 15
15	Tahoe NF	June 3, 1989	10 acres	Misc	Twn 14N Rge 15E Sec 5
16	Tahoe NF	August 11, 1994	1,300 acres	Equipment Use	Twn 18N Rge 17E Sec 29
17	LTBMU	September 9, 1994	34 acres	Misc	Twn 12N Rge 17E Sec 27
18	Eldorado NF	November 3, 1995	104 acres	Debris Burning	Twn 10N Rge 15E Sec 17
19	LTBMU	November 5, 1995	105 acres	Debris Burning	Twn 14N Rge 17E Sec 29
20	LTBMU	November 8, 1995	40 acres	Debris Burning	Twn 14N Rge 17E Sec 27
21	LTBMU	June 23, 1996	160 acres	Child. /Matches	Twn 12N Rge 18E Sec 9
22	Eldorado NF	August 12, 1996	40 acres	Lightning	Twn 8N Rge 16E Sec 1

ignition rates in the Sierra Nevada, the highest levels are concentrated around urban areas (Figure 5-7), where response time is most rapid. Data from 1973 to the present indicate that wildland fire control keeps fire to less than 10 acres 99. 5 percent of the time (Table 5-15).

Fires ignited by lightning are common in the basin in late summer, but these fires often remain limited in area because of associated rainfall and limited fuels at high elevations where lightning strikes are most common, or because suppression is highly effective. Twenty-three percent (figures 5-8, 5-9) of the terrestrial area in the basin has very limited (sparse vegetation) or no fuels (rock). A large proportion of the upland areas has sparse vegetation. Most of the heavier fuels that are likely to burn occur in a narrow band that coincides with the lower elevations and areas of heavy human access. The large expanse of Lake Tahoe breaks up continuity of fuels at low elevations. Because the basin is high elevation, the fire season is relatively short, reducing the likelihood of fire in most years.

The conditions that would most likely result in a fire greater than 10 acres are a human-caused ignition at lower elevations, along the lakeshore during a drought year. Fires move more rapidly and are more intense when they are moving upslope. During drought years, fuels are more flammable and likely to ignite and support rapid fire spread due to low moisture levels. Fires are more common outside of the basin, but topography and wind patterns indicate that there is a very limited likelihood that they would enter into the basin. Analysis of weather data, shows that only two percent of the time are east winds present (Table 5-16), that would carry a fire downslope into the basin that started outside the

Table 5-15—Occurrence of all wildland fires in the Lake Tahoe basin from 1973 to 1996.

	0-. 24 ac.	. 25-9. 9 ac	10 - 99 ac.	100-299 ac.	300+ ac.	Totals
Fires	1721 92. 28%	135 7. 24%	6 0. 32%	3 0. 16%	0 0%	1865
Acres	176	150	153	372	0	851

Table 5-16—Wind data from the Meyer Weather Station during fire season (July through September) from 1961 to 1996.

	No.	% of Time	90th %ile SC	20' Wind Speed (mph) Moderate	High	Extreme
N	895	27%	10	8	12	14
NE	173	5%	10	8	11	14
E	59	2%	10	7	13	15
SE	149	4%	14	9	14	26
S	668	20%	15	11	16	17
SW	680	20%	15	10	16	20
W	291	9%	11	8	12	15
NW	411	12%	10	8	11	14

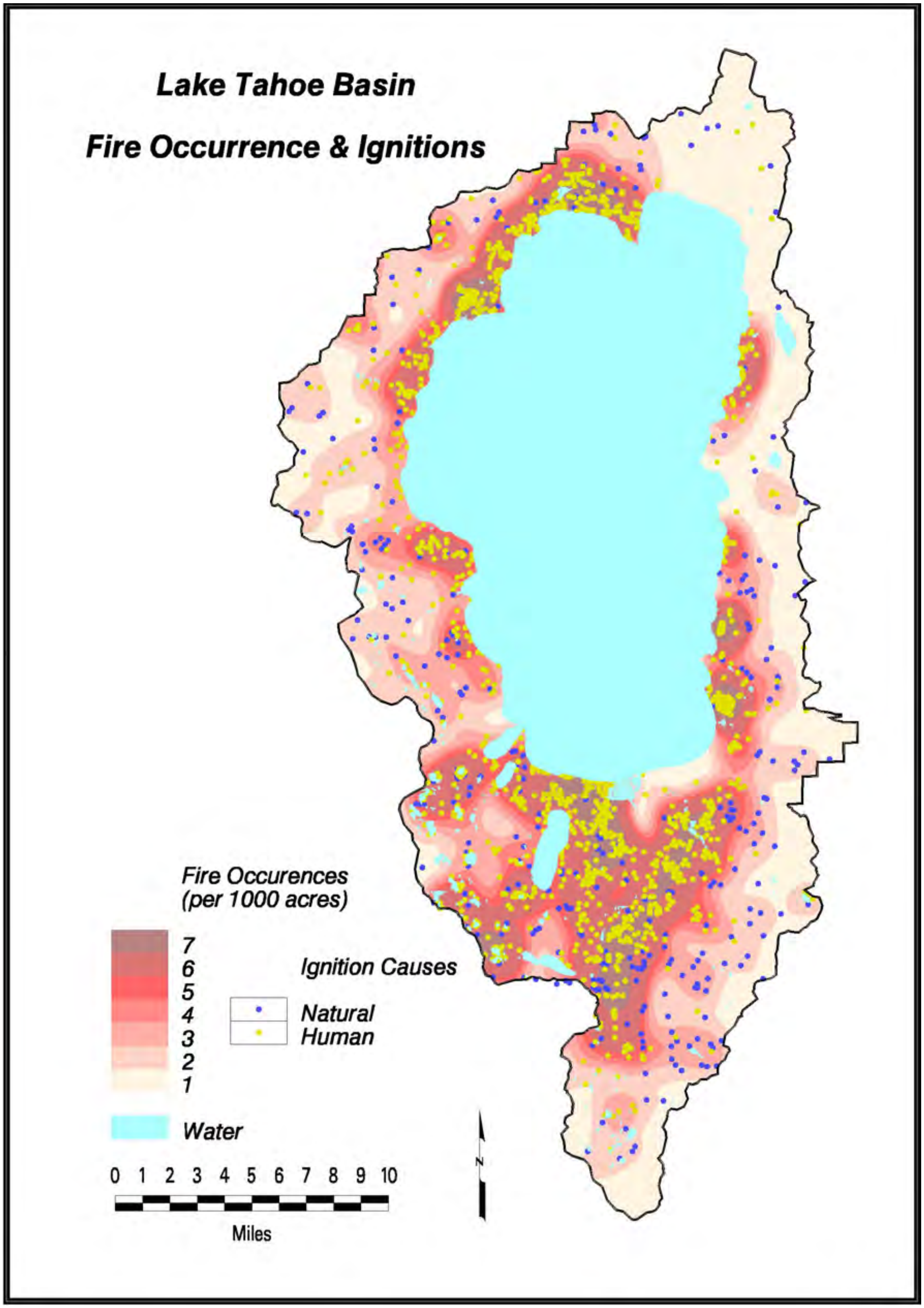


Figure 5-7—Spatial patterns of fire occurrences in the Lake Tahoe basin with human ignitions overlaid on top.

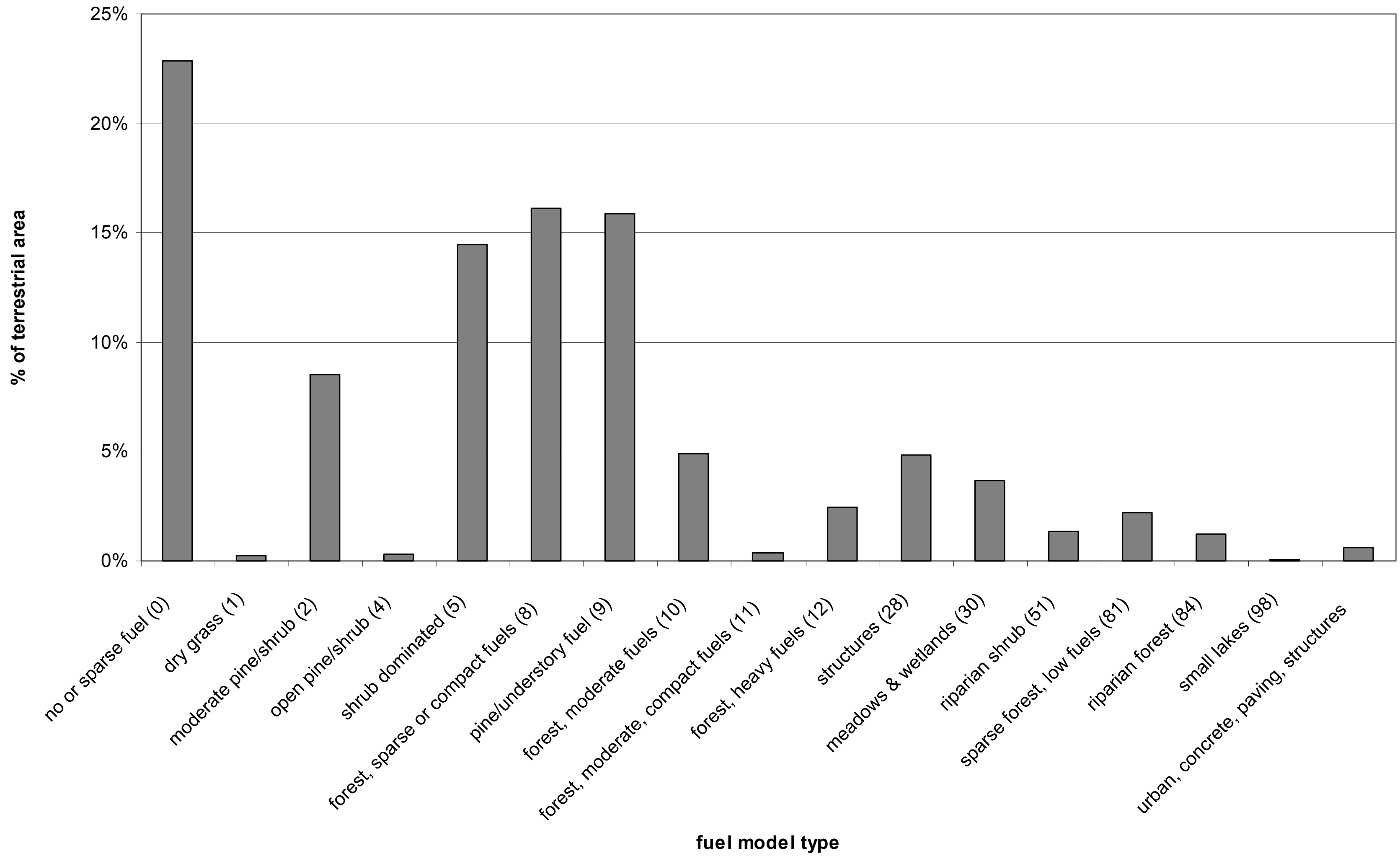


Figure 5-8—Proportion of area in different fuel types in the Lake Tahoe basin.

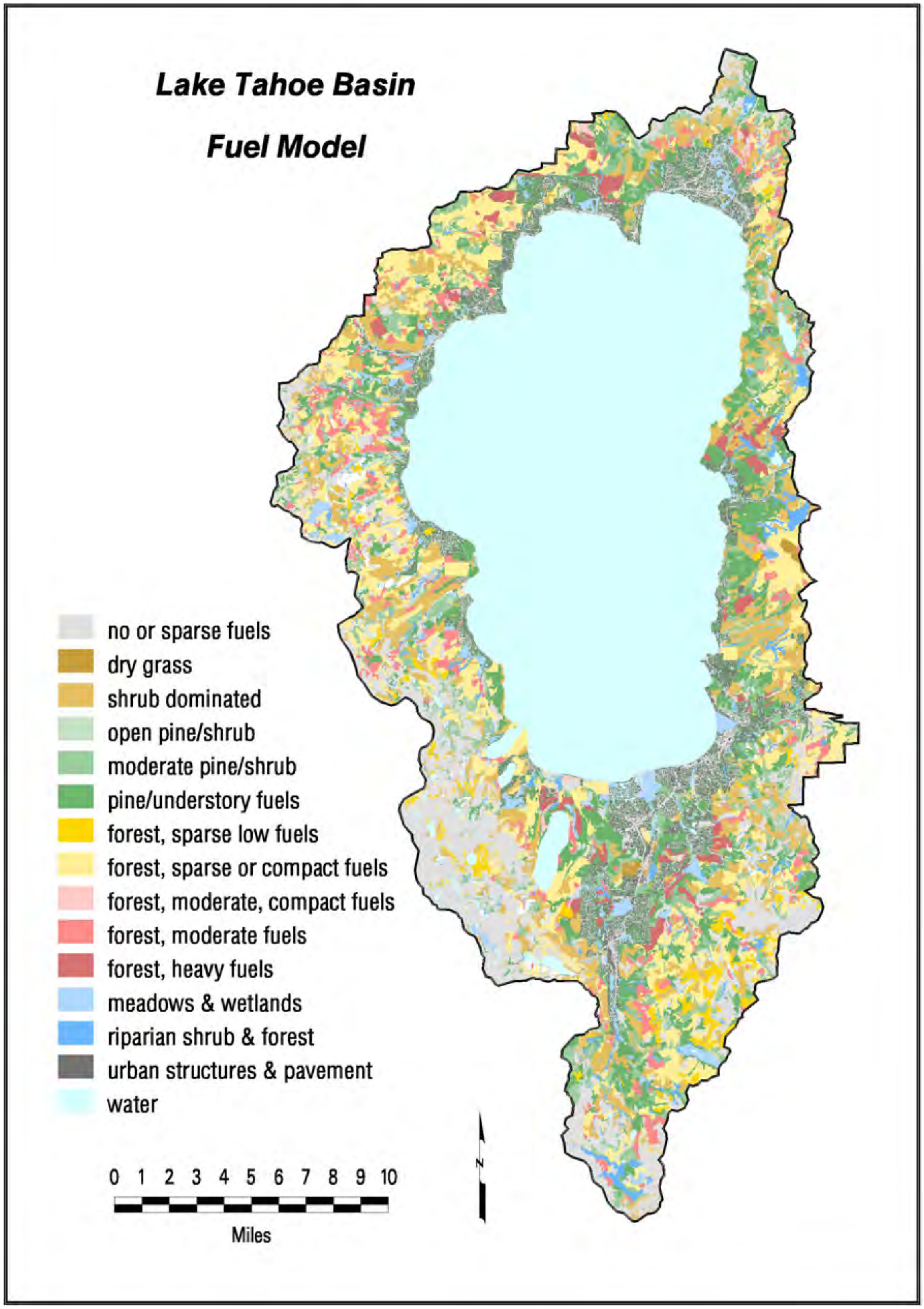


Figure 5-9—Spatial patterns of fuel model types in the Lake Tahoe basin.

basin to the east. On much of the south and west shores, there is a high proportion of rocky, low fuel areas at the top of the basin that would slow or stop fires from entering from the south or west. Diurnal wind patterns (upslope and downslope) are generally depressed in the basin because of the cold temperature of Lake Tahoe. This large body of water reduces temperature differentials between low and high elevations that produce diurnal wind patterns.

What are the likely weather conditions associated with a high severity fire or a large fire?

Two aspects of weather are important to the likelihood of high severity or large fires. One is weather that occurs during fire season, which influences fuel moistures in fine fuels (litter and small diameter branches). Fine fuels with low moistures are more easily ignited and have higher fire spread rates. The second important aspect of weather is climate, such as drought patterns. Climate, especially the annual precipitation level, influences fuel moistures in live vegetation and large fuels in addition to fine fuels. The climate in the Lake Tahoe basin is Mediterranean, which means that there are consistently dry periods every summer, with the period of dryness as the primary climate variation. We address both of these aspects of weather and their contribution to the likelihood of high severity or large fires.

Weather

Weather data from the Meyer Weather Station on the south shore was the primary source of information for analyzing fire weather. Temperature, relative humidity, and wind are the primary weather components important to fire behavior. For fire behavior analysis, weather data during the fire season is typically summarized by percentiles. For this assessment, we summarized data into the following percentiles and classes: moderate, 75th percentile; high, 93rd percentile (90 to 96 percent); and extreme, 98th percentile (97 to 100). We summarized the average, maximum, and minimum values for temperature, relative humidity, and wind for each of these different percentile classes (Table 5-17). These three classes represent different likely spread rates of fire. It is the combination of weather conditions that produce a given level of expected fire behavior, not any single component.

We analyzed weather associated with fires 10 acres or larger in the basin, occurring between 1973 and 1996. Five of these fires had no weather data for the day of the fire discovery at the Meyer Weather Station. The Meyer Station is operated during the typical fire season (June through September). One of the fires occurred in May, and four others occurred in November. For the remaining fires, the wind speed, spread component, and energy release component for the day the fire was discovered were compared to the 90th percentile values for these three variables.

The 90th percentile values are as follows: 20-foot wind speed at 13 mph, spread component at 13, and energy release component of 53 (see Appendix A for more detail on analysis). Of the sixteen fires examined, nine of the fires (60 percent) occurred on days when one or more of these three variables were at or above the 90th percentile values. When conditions are equal to or greater than the 90th percentile values, the weather conditions become aligned so that if an ignition were to occur where fuels are available for fire spread, then the likelihood for significant fire is high. A fire occurring in these weather conditions, with sufficient available fuels, results in rates of spread (greater than 25 chains/hour) that is an escape threshold in fire behavior and suppression analysis.

On average, there are 10 days each year when 90th percentile weather conditions occur. The actual number of days each year varies widely though. During wet years, there may be only one day with dry enough conditions. Most days occur during hot dry years.

All of this weather analysis is based on the Meyer Weather Station. We do not know how well this single weather station represents the weather in other parts of the basin. At least one other weather station on the north shore of Lake Tahoe would increase our ability to model likely fire weather and behavior. One other consideration of the Meyer Weather Station is that it is somewhat protected from wind. Therefore, windspeed data from the Meyer Weather Station used here to characterize different fire weather may be lower than what actually occurs throughout the basin.

Table 5-17—Weather at the Meyer Weather Station for three major fire weather classes: moderate (75th percentile), high (93rd percentile), and extreme (98th percentile). The average, maximum, and minimum values for environmental conditions are shown on the days when the spread component was at its median value for each weather class. The median spread component for the moderate weather class was 7 and for the high weather class was 15. For the extreme weather class, the median spread component was 30. Abbreviations are defined as follows: HERB—herbaceous, PPT AMT—precipitation (hundredths of an inch), DB—dry bulb temperature (degrees Fahrenheit), RH—relative humidity, FM—fuel moisture (percent), IC—NFDRS (National Fire Danger Rating System) ignition component, ERC—NFDRS energy release component, BI—NFDRS burn index.

Weather Class and Values	2pm	2pm	WIND	MAX	MIN	MAX	MIN	PPT	1HR	10 HR	100 HR	1000 HR	HERB	WOODY				
	DB	RH	SPD	DB	DB	RH	RH	AMT	FM	FM	FM	FM	FM	FM	IC	SC	ERC	BI
Moderate																		
Maximum	92	70	14	95	78	100	68	0. 37	13. 1	29. 0	27. 1	28. 2	200	178	46	7	72	54
Average	76	43	8	79	39	91	27		6. 5	7. 0	12. 9	13. 7	107	95	23	7	45	42
Minimum	49	5	5	54	21	10	4		2. 2	3. 0	5. 8	8. 4	64	35	5	7	5	16
High																		
Maximum	86	54	20	88	62	100	46	0. 01	9. 8	17	17. 5	16. 6	131	119	67	15	78	77
Average	75	29	14	80	42	78	22		5. 2	7. 1	11. 3	12. 8	100	85	41	15	50	63
Minimum	53	10	11	58	30	45	10		2. 2	4. 0	6. 1	7. 4	56	50	14	15	33	52
Extreme																		
Maximum	84	55	40	89	58	100	42	0. 01	7. 5	11. 0	15. 7	26. 2	200	150	85	46	67	108
Average	76	26	21	78	43	69	19		4. 7	6. 9	11. 4	13. 3	103	83	56	25	49	79
Minimum	58	9	15	0	0	0	0		2. 4	3. 0	6. 9	9. 3	71	37	30	20	16	42

Climate

Longer-term weather patterns, namely drought, influence the likelihood of fire. McKelvey and Busse (1996) analyzed the relationships between drought and large fires for the Sierra Nevada, using the Keetch-Byram drought intensity index (KBDI) (Keetch and Byram 1968). Days with KBDI values greater than 500 (out of a maximum of 800) were considered drought days. McKelvey and Busse (1996) concluded that nearly all extreme fire years occurred during hot dry periods, although not all hot dry years were extreme fire years. They found that the number of average drought days per decade was negatively correlated with elevation. Based on regressions of drought days as a function of elevation, 30 drought days occurred at 6,200 feet elevation between 1979 and 1989, at lake level. At 7,500 feet in elevation, approximately 18 drought days occurred. Although drought days are less common at higher elevations in the Sierra Nevada, they still occur regularly.

The highest likelihood of drought days is during drought years, when snowpacks are lightest. McKelvey and Busse (1996) found that fire acreage in the Sierra Nevada was negatively correlated with seasonal rainfall (March through October). The largest number of acres burned in the Sierra Nevada coincide with critical or dry years in the Sacramento and San Joaquin River Valleys, as defined by the California Department of Water Resources (Husari 1999). Their data from the cooperative snow surveys show that since 1906, 31 years out of 92 (34 percent) have been considered dry (Figure 5-10).

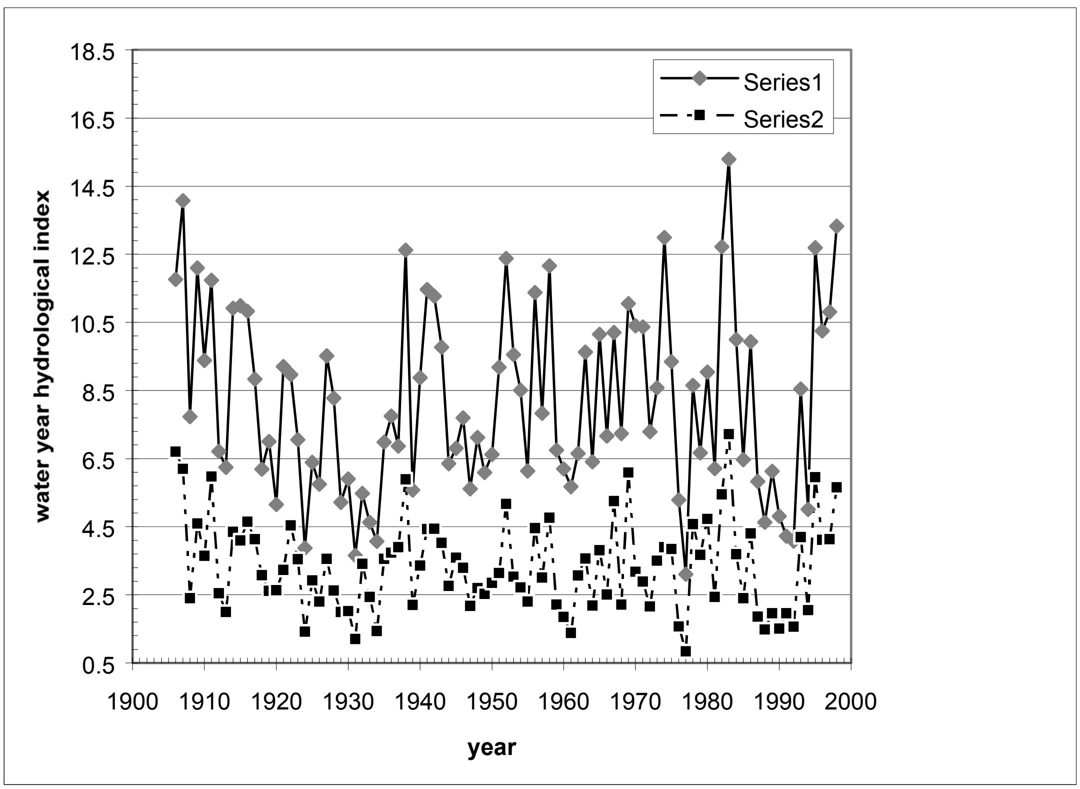


Figure 5-10—Water year (October 1 to September 30) hydrological indices, based on measured unimpaired runoff from the Department of Water Resources California Cooperative Snow Surveys. Series 1 is for the Sacramento Valley basins, with dry years classified as below 6.5. Series 2 represents the San Joaquin basin, with dry years classified as below 2.5.

Over longer periods, droughts have been far more common in the recent past. The period of 1937 through 1986 was the third wettest half-century in the past 1,000 years and the fourth wettest in the last 4,000 years (Graumlich 1993; Stine 1996). The occurrence of submerged stumps in Lake Tahoe indicates that these drier conditions have influenced the basin significantly (Elliott-Fisk et al. 1997; Lindström, Chapter 2, this volume). Swetnam (1992) found that fire activity in giant sequoia groves over a 2,000-year period was influenced by both temperature and moisture. Fires were more frequent during warmer periods, which is a situation that Swetnam attributes to the increased length of the fire season. Moisture was more related to synchrony of fires across the giant sequoia distribution. During moist periods, occasional dry years burned larger areas, presumably because of higher fuel accumulation rates from the moister conditions, whereas during dry periods fires were smaller, likely due to lower fuel accumulation rates. In New Mexico and Arizona, Swetnam and Betancourt (1992) found that variation in regional fire activity was associated with El Niño/Southern Oscillation patterns.

These longer-term weather patterns that can influence the amount of wildland fire depend on future climate trends. While we did not attempt to model future climate trends and their effect on the likelihood of fire, it is clear that climate is not constant and that changes in climate influence the likelihood of fire. Furthermore, it is likely that droughts will occur in the future to an unknown degree and frequency and that the greatest likelihood of large or severe fires will be associated with these droughts. It appears that the climate generally is warming and that past warm periods have been associated with dryness (Stine 1996). Therefore the trend appears to be one toward climate conditions with an increasing likelihood of large or severe fires. In simulations of forest pattern, fire, and climate change in the southern Sierra Nevada, Miller and Urban (1999) found that a warmer drier climate tended to produce more frequent fires. In higher elevation zones, comparable to much of the Lake Tahoe basin, the trends are more complicated because of the possible changes in biomass or fuels and the effects of snowpack changes on fuel-bed depth and bulk density. A longer growing season may increase biomass accumulation and thus fuel loading in the upper montane (i.e., red fir) and subalpine forests of the basin. Lighter snowpacks may compact these fuels less; thus increase the fire hazard overall. In the drier parts of the basin, such as the east shore, the changes may be the opposite. Biomass and thus fuel accumulations in the drier pine forests may decrease with warmer and drier conditions, resulting in reduced fuel hazard. There are uncertainties of the interaction of other disturbances, such as insect and disease outbreaks, with fire and climate. There may be increases in frequency and severity of insect and disease outbreaks (Ferrell 1996) that would increase fuel loading.

What is the relative importance of fuels, weather, and ignitions in contributing to the likelihood of large or high severity fires?

Fuels, ignitions, and weather conducive to fire simultaneously contribute to the likelihood of large or high severity fires. As mentioned previously, ignition rates are high in the basin, particularly in the urban interface areas. These ignitions occur in the portion of the basin with the greatest amount of fuel: the low elevation rim around the lake in the pine and mixed-conifer zone. The weather is rarely a factor in fire suppression because of the high elevation environment and relatively short fire season.

Fire behavior simulations were conducted using FARSITE for several randomly selected watersheds around the basin to evaluate the relative importance of fuels and weather and the likely fire effects. The parameters and conditions used in the modeling are described in more detail in Appendix B. The random selections were conducted with the constraint that at least one watershed occurred in each of the major portions of the basin, representing the major variation in fuel conditions and topographic orientations (i.e. north shore, east shore, and south shore). These behavior runs indicate that under all but the most extreme conditions (less than two percent of the fire season) fire suppression is effective in limiting the size of fires to less than 1,000 acres.

Although fire behavior was not modeled for extreme weather conditions, the topography and fuels in the basin make it highly unlikely that fires would exceed one or two subwatersheds in size. The basin has a complex topography, composed of many smaller subwatersheds that break up the continuity of slopes. Based on weather data from the Meyer Weather Station, 88 percent of the time wind direction is from the N, NW, W, SW or S (Table 5-16). Such wind orientations would tend to funnel fires within drainages, limiting their spread to just one or several subwatersheds. On the west shore, the upper ends of drainages are bounded by large rocky areas and the lower end of drainages by Lake Tahoe. On the east shore, the upper ends of drainages are bounded with sparse vegetation. Fires burning under the strongest winds (from the SW, W, or SE) have the greatest opportunity to become larger in the area south and especially north of Lake Tahoe. In these areas, topography lines up better (drainage orientation) with wind direction, and these areas contain more area with continuous fuel.

Fuels are composed of four basic components: ground fuels, surface fuels, ladder fuels, and crown fuels. Ground fuels are composed of litter and duff. Surface fuels are defined as the downed wood (twigs, branches, and logs) found on the ground. (In the remaining discussion, ground fuels are referred to as a component of surface fuels.) Ladder fuels are composed of the live vegetation that is low growing and in the forest understory, such as shrubs or smaller trees. Crown fuels are composed of tree foliage in the crowns of trees.

Fuel characteristics include the types of fuel (downed wood, shrub grass or tree or combinations of these), the amount of fuels (tons per acre), the sizes of fuels; and the arrangement (i.e., depth and compactness) (Anderson 1982). We modeled fuel types based on vegetation cover, dominant vegetation type (i.e., shrub, tree, grass, meadow, and riparian forest), dominant tree species, recent tree mortality survey locations, tree size (i.e., mature, seedling, and pole), treatment (thin and burn), and land use (TRPA land use layer) (figures 5-11 and 5-12). The sources of information included an updated existing vegetation layer based on the USFS 1978 photo-interpreted layer, a potential natural vegetation layer from the USFS, and the TRPA land use layer. Data from these layers were converted to 30-meter cell grid layers. The decision tree was programmed into Arc-Info Macro Language (ESRI 1998) to generate the fuel layer for uplands. Ground-truthing of the fuel loadings and configuration were conducted in a randomly selected subset of the photo-interpreted polygons (Fites-Kaufman and Weixelman, in preparation).

Urban areas and urban/wildland intermix areas were more difficult to model because of the fine-scale variation in vegetation, buildings and unvegetated areas (i. e. , pavement) and lack of spatial data at that scale. Further, the fuels inventory of randomly selected, undeveloped lots within urban areas conducted during 1998 indicated that fuels were highly variable. At present, there are no fire behavior models that can show how fire spreads from wildland to buildings, or that can test if some buildings can survive fire better than others.

Satellite imagery (landsat thematic mapper) was used to map two different fuel patterns in urban and urban/intermix areas. The urban and intermix zones were first identified on the existing vegetation map. In these areas, we examined the NDVI composition, which is an index of greenness. Based on visual examination of the NDVI patterns, we modeled three different categories of urban and urban/intermix areas separately (Figure 5-12). The first was of sparse vegetation, making up approximately 30 percent of the area. The second was of moderate vegetation, making up more than 30 percent of the area. The third was in the heavily developed areas, most of it in paved or bare ground around structures. For each of these three categories varied proportions of three different fuel models were randomly applied to 30-meter pixels (Table 5-18). The fuel types were assigned randomly because the resolution of the source data and precision of identifying individual fuel types precluded exact mapping. The fuel mapping provides a first approximation of general patterns. Detailed ground-based mapping would be required for more detailed

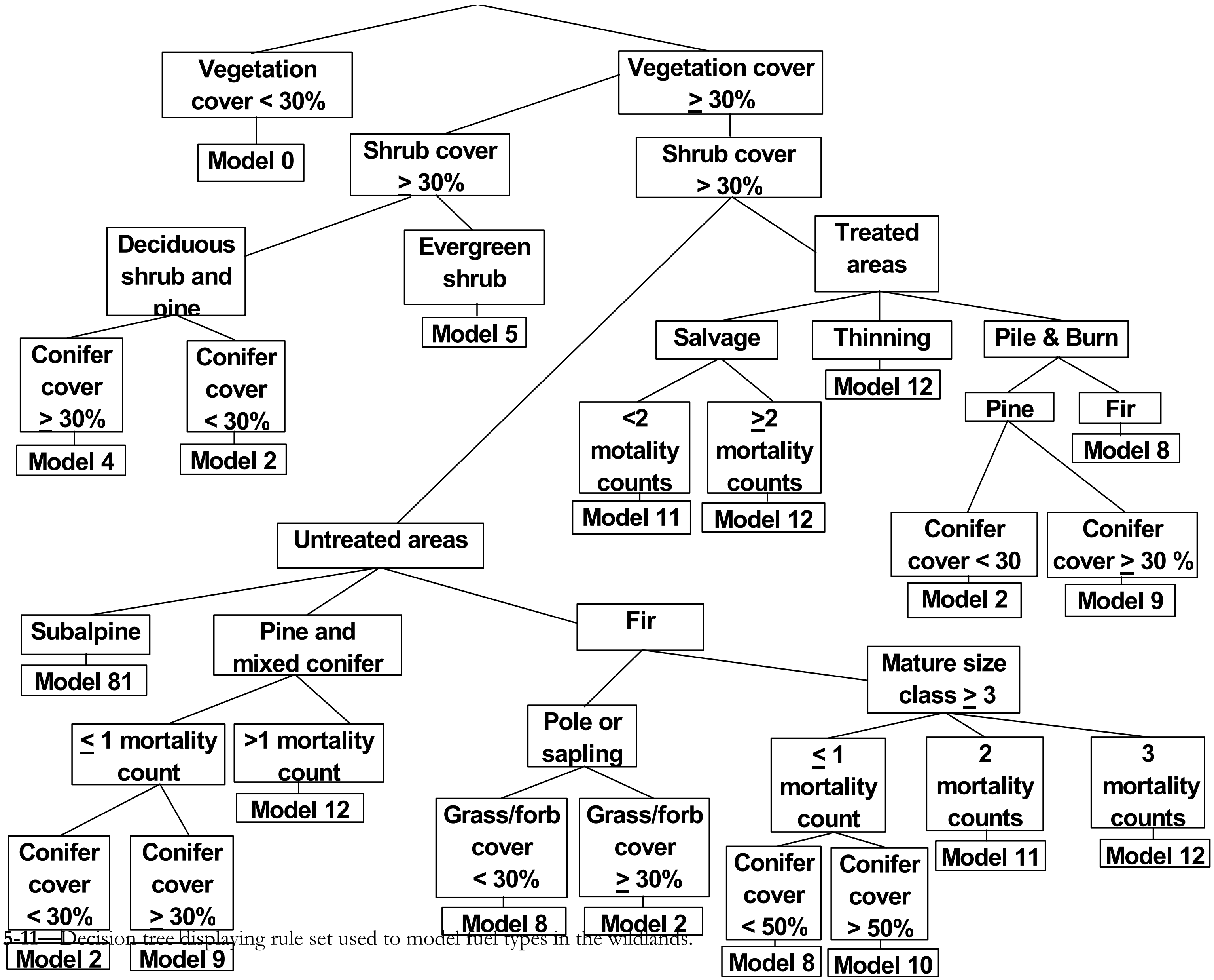


Figure 5-11—Decision tree displaying rule set used to model fuel types in the wildlands.

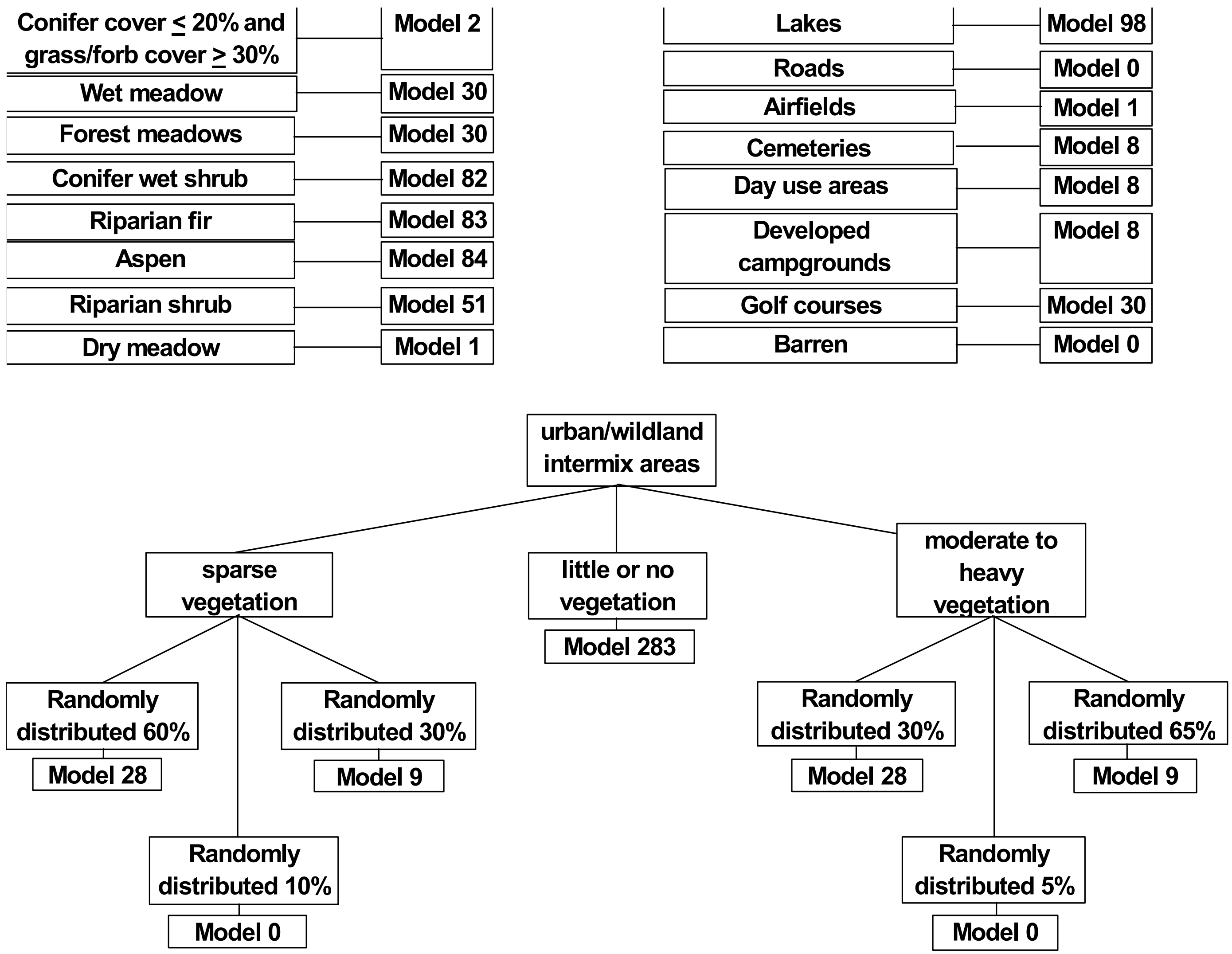


Figure 5-12—Decision tree displaying rule set used to model fuel types in the urban/wildland intermix zones and riparian or nonforested wildland areas. Randomly distributed cells were assigned to the different fuel types within a given urban/wildland intermix zone type using the random function in ArcInfo.

Table 5-18—Rules for assigning fuel model types to three different classes of urban and urban/wildland intermix zones.

	Percentage of Area Randomly Assigned to Fuel Model Type (by urban/wildland class)		
Fuel Model Types	**Moderate to high vegetation amounts**	**Low vegetation amounts**	**Little or no vegetation**
Structure model (model 28)	30	60	100
Vegetation model (model 9)	65	30	
Bare ground, pavement or concrete (model 0)	5	10	

and locationally specific urban/wildland intermix fuel model assignments. Major roads, golf courses, and airfields were modeled separately.

Fuels in the basin are characterized by variations in elevation, soil depth, precipitation, and vegetation. Glaciation in the west and south portions of the basin contributed to large expanses of scoured rocky expanses and rocky soils. These areas often are sparsely vegetated, and 23 percent of the upland areas have little or no fuel (Figure 5-9). An additional 16 percent has compact and relatively low fuel levels (model 8), which typically results in low to moderate intensities of fire and rates of fire spread. In the high elevation environment of the basin, heavy snowpacks are prevalent in much of the basin every year. This snowpack compacts fuels, reducing the likelihood of active burning even when fuel loading is high because a low surface area to fuel ratio. This results in a low oxygen to fuel ratio. Fires burn only when both oxygen and fuels are present in the right proportion. Compact fuels tend to burn more as slow smoldering fires, which are more easily suppressed.

Another 15 percent of the basin is composed of montane chaparral, with an evergreen shrub-dominated fuel type (model 5). Huckleberry oak and manzanita are the most common shrubs in this fuel type. These shrubs are often resistant to fire, except when foliar moisture is very low, such as during droughts and hot weather (Husari 1999). Concentrations of heavier fuels in the basin are often discontinuous due to small patches of rock and meadows and changes in vegetation.

Although fires have been and are likely to continue to be small in the basin, the severity of any fire can be high. Vegetation patterns and fuels are most important in contributing to likely high severity of unplanned wildland fires in the basin. In modeling fire behavior in all but extreme weather conditions, there is usually more variation in fire behavior among different fuel types than there is among different weather conditions for the same fuel type. Urban areas tend to have a lot of nearby vegetation, and many buildings are constructed of wood, leading to ready consumption by fire. In the wildland, trees are often young and small. Smaller trees are less resistant to fire because their bark is thinner and their crowns are lower to the ground (nearer flames). These smaller trees are more likely to die as a result, even when fire intensities are modest. However, in the most extreme weather conditions differences in fire behavior among different fuel types lessen.

In summary, weather, fuels, and ignitions all contribute to the likelihood of large or severe fires. Although weather conditions usually limit large or severe fires in the basin, some weather conditions can result in large or severe fires, particularly in hot and dry years. Fuel hazard is not particularly great in the Tahoe basin, but the small stature of vegetation and the high proportion of urban/wildland interface increase the likelihood that fires will be severe. Importantly, ignition densities are high in the urban/wildland interface. Although high levels of suppression forces and relatively cool, wet weather conditions limit the number and sizes of fires from these ignitions, reducing the number of ignitions would substantially reduce the likelihood of fire.

What are the likely effects of a high severity or large unplanned fire on soil erosion, air quality, lake clarity, biotic health, old growth, and urban areas?

Randomly selected watersheds around the basin were modeled for fire behavior using FARSITE (Finney 1998) to evaluate some of the likely effects of unplanned fires on wildlands and urban areas (see Appendix B for detail). In addition, the model FLAMMAP (Finney 1999) was run for four different sets of weather conditions for the entire basin. FARSITE simulates the spread of a fire burning on a landscape, with weather and wind varying diurnally and based on historic weather station data. Fire suppression also can be modeled. Outputs of the model can be used to determine likely fire size, intensity (heat per unit area, flamelength), and rate of spread. FARSITE also can be used to predict likely effects on vegetation during the fire when the flamelengths are combined with vegetation data using a mortality model. FLAMMAP provides similar fire behavior outputs as FARSITE but treats every point on the landscape separately. It does not predict the behavior of a fire, but displays the likely fire behavior characteristics and potential effects on vegetation for the entire landscape for any given weather conditions.

The effects of a large or high severity unplanned fire on soil erosion and lake clarity were not modeled. The modeling and integration chapter provides more detail on the integration of models that would be required to make such an assessment. The effect of a large or high-severity unplanned fire on urban areas also was not modeled directly. Urban fire modeling requires separate models and a higher level of detail on fuel patterns than were available. An in-depth inventory of urban fuels would be required at a high resolution, but some indirect inferences can be drawn from the FARSITE and FLAMMAP runs.

The FARSITE model was used on several randomly selected watersheds that represent the east, south, west, and north shores of the basin (Figure 5-13). Ward Creek watershed was selected purposely because of the erosion and nutrient models that have been and are being conducted in the watershed. The FARSITE model was run for high (93 percentile) weather conditions (see Question 2) with and without suppression. Although there are many effective suppression resources in the basin, the runs without suppression provide insight into some of the worst-case scenarios. The model was run for two burning periods (48 hours). Fires were started in locations in each selected watershed where the density of ignitions have been the greatest; usually at the interface between the urban and wildland areas.

Every run showed spotting and crowning of fire, but, with simulated direct attack, fire suppression tactics were controlled to a small size (42 to 546 acres). The largest simulated fire was on the north shore, where it reached 546 acres, due to the orientation of wind with the slope in that area. Without simulated suppression, flamelengths were high enough to reach the crowns and surface fuels were heavy enough to carry fire in the crowns in part of the fire perimeter (Table 5-19). However, only a portion of each area burned as a crown fire (Figure 5-13). Surface fires dominated (55 to 87 percent) the simulated fires. This corresponds well with observed behavior of actual fires in the basin (Bahro 1999). The maps of crown versus surface fire likely underestimate the area that would exhibit high tree mortality, which also would have occurred in some of the area modeled as a surface fire. If mortality had been included, total mortality would be greater.

Tree mortality is a function of bark thickness, the insulating ability of the bark of a given species, and the proximity of tree crowns to the flames (Agee 1993). Younger trees have thinner bark and crowns that are closer to the ground, making them more susceptible to mortality from fire than larger and taller trees. Jeffrey pine, ponderosa pine, and incense cedar are more resistant to fire than white fir and red fir. Lodgepole pine has thin bark and is readily killed by fire. In the previous section on vegetation, we discussed the finding that mixed-conifer and pine old-growth stands have many small, young, understory trees, and these are likely to be

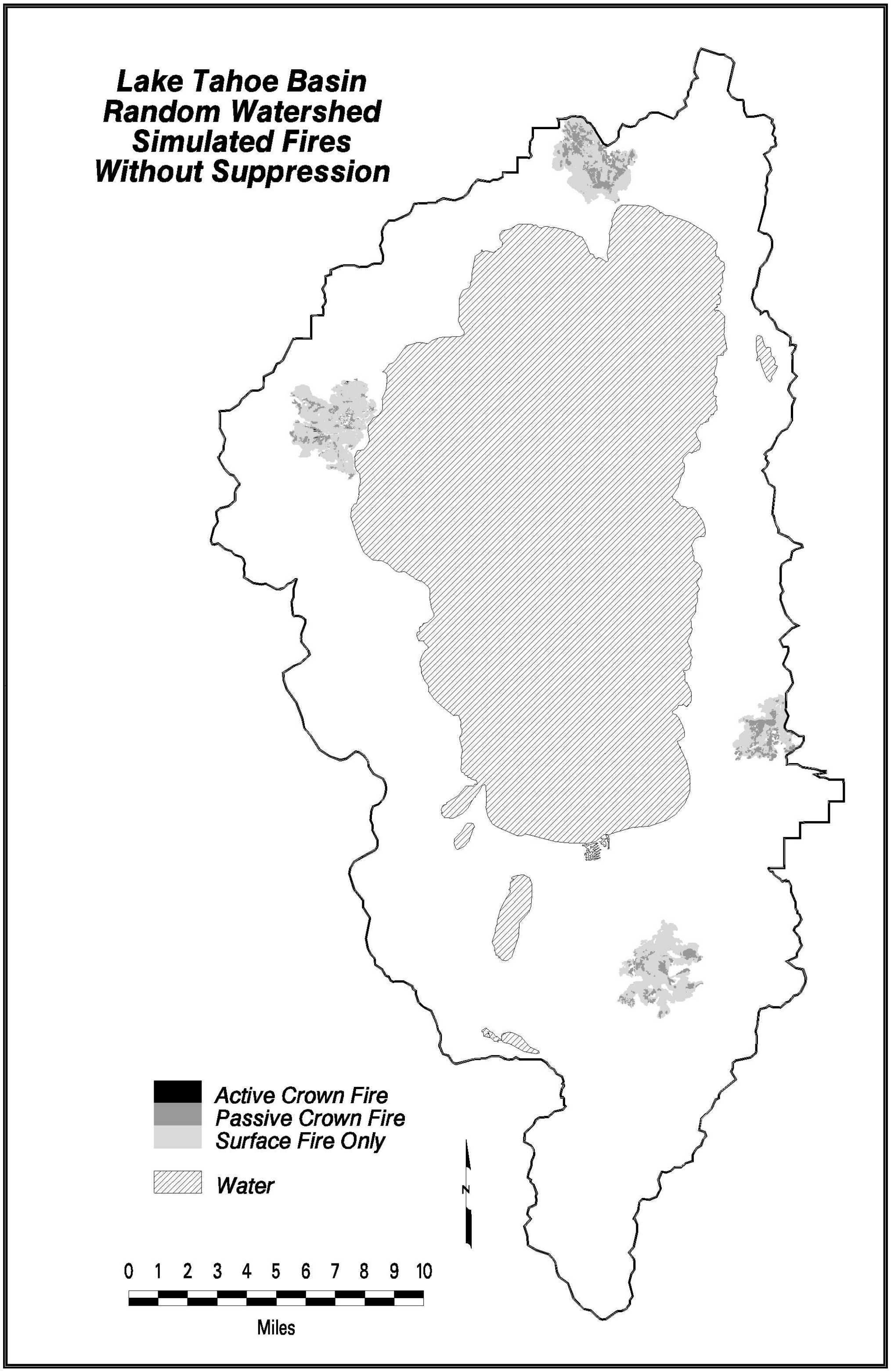


Figure 5-13a—Spatial patterns of simulated fire behavior (from FARSITE), for selected watersheds in the basin, without fire suppression. Models were run with the 93rd percentile weather, with ignitions located at the highest point of fire occurrence in the watershed.

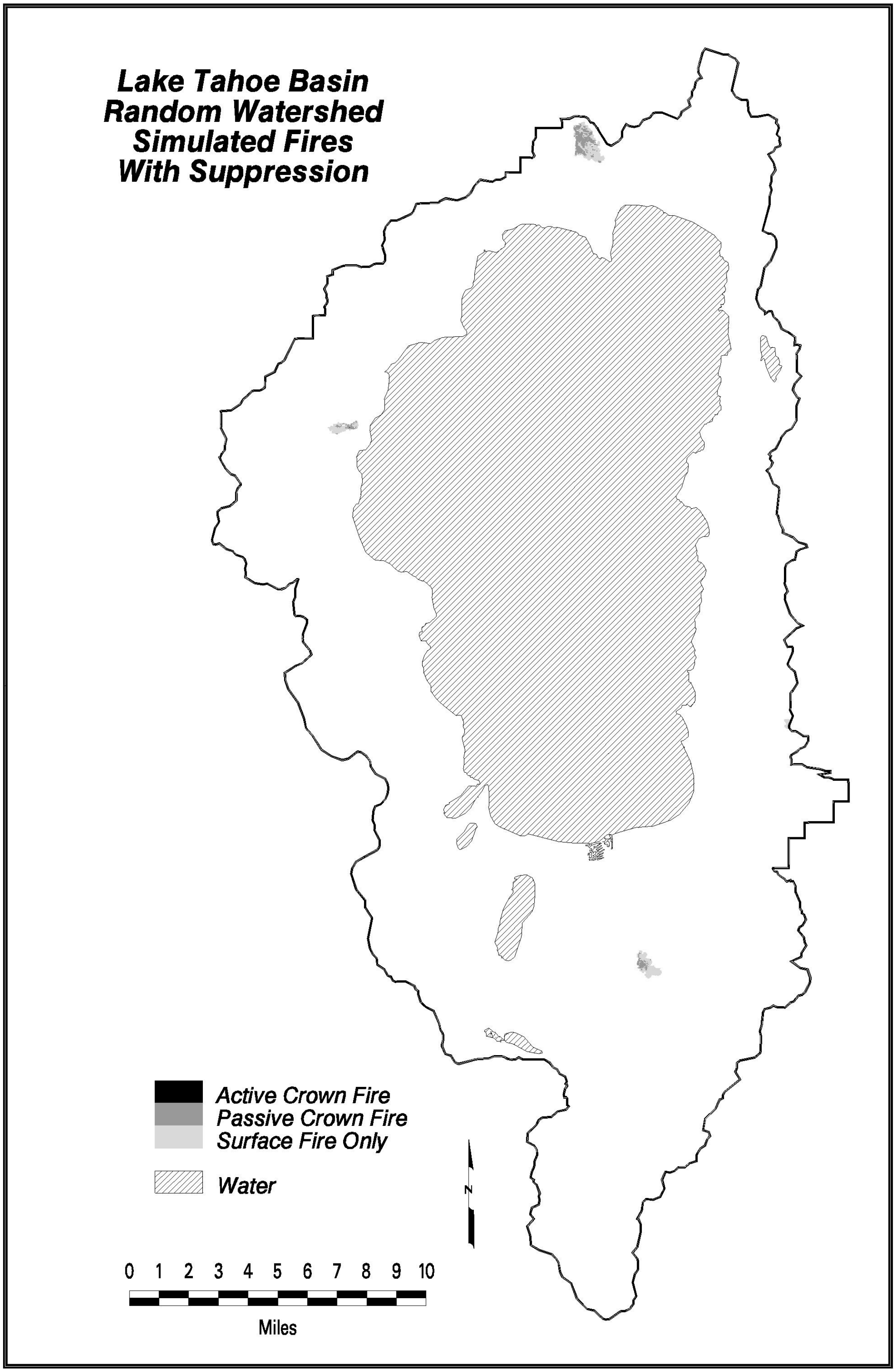


Figure 5-13b—Spatial patterns of simulated fire behavior (from FARSITE), for selected watersheds in the basin, with fire suppression. Models were run with the 93rd percentile weather, with ignitions located at the highest point of fire occurrence in the watershed.

Table 5-19—Potential fire behavior from simulated fires under high weather conditions (93rd percentile), with and without fire suppression for selected watersheds in the Lake Tahoe basin. Fires were modeled for two burning periods (48 hours).

Watershed and Fire Behavior Class	With fire suppression		Without fire suppression	
	Acres	% burn area	acres	% burn area
Ward				
Surface fire	123	76	3162	87
Passive crown fire	38	24	482	13
Active crown fire	0	0	6	0
Total	161		3650	
Trout				
Surface fire	195	77	2485	83
Passive crown fire	59	23	504	17
Active crown fire	0	0	0	0
Total	254		2989	
Edge				
Surface fire	36	86	1220	69
Passive crown fire	6	14	544	31
Active crown fire	0	0	0	0
Total	42		1764	
Griff				
Surface fire	300	55	2137	70
Passive crown fire	246	45	928	30
Active crown fire	0	2	0	0
Total	546		3065	

killed in an unplanned surface fire and carry flames into larger old trees.

The FLAMMAP runs for the high (93rd percentile), and extreme (98th percentile) weather sets (see Question 2) show that potential flamelengths vary considerably around the basin (Figures 5-14a-d). Higher elevation areas and much of the upper montane areas on the west and south shores do not have high flamelengths because of the sparse, discontinuous, or compact fuels (Figure 5-15). Flamelengths and consequent fire effects are likely to be most severe in the mixed conifer and pine zones at lower elevations and on the east shore where pine forest mortality has been prevalent.

As mentioned previously, fire behavior in urban areas was not modeled directly because insufficient detail about available fuels and lack of fire behavior models for these situations. However, some inferences can be made on likely fire effects. As described in the previous subsection, the urban areas were classified into three different categories: little or no vegetation and high proportion of paved and bare area, low amounts of vegetation and moderate proportion of paved and bare areas, and moderate to high amounts of forest intermixed with structures. The latter category is the one most likely to experience severe effects of an unplanned wildfire. The mix of forests and structures can result in increased rates of spread. This outcome is highly variable, however, depending on the amount of surface and ladder fuels, debris surrounding houses, and house building materials. In our inventory of fuels in undeveloped urban lots, we found that many had low surface and ladder fuel levels, while others had high levels. Fuels from structures and

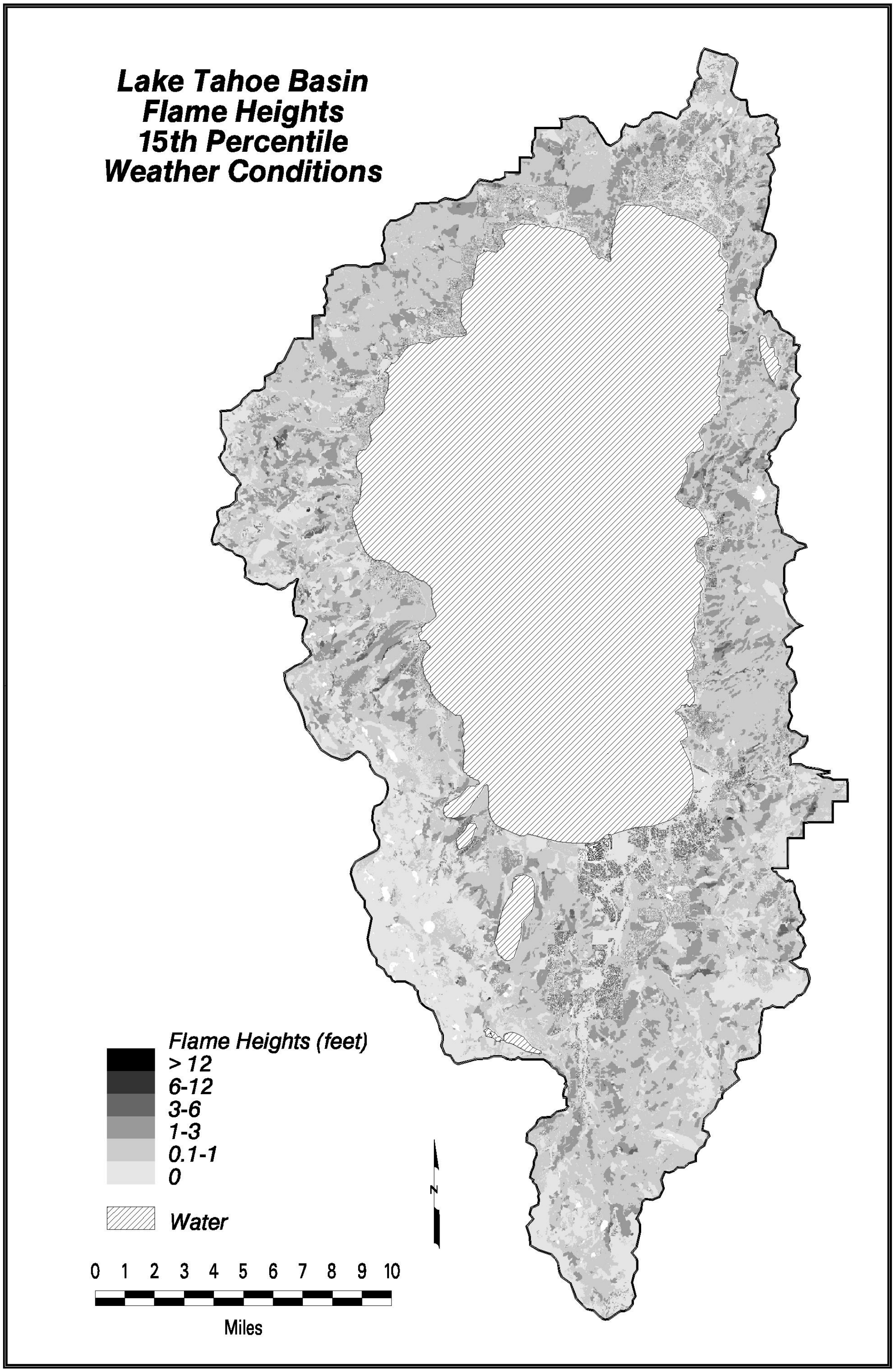


Figure 5-14a—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 15th percentile weather set in the Lake Tahoe basin.

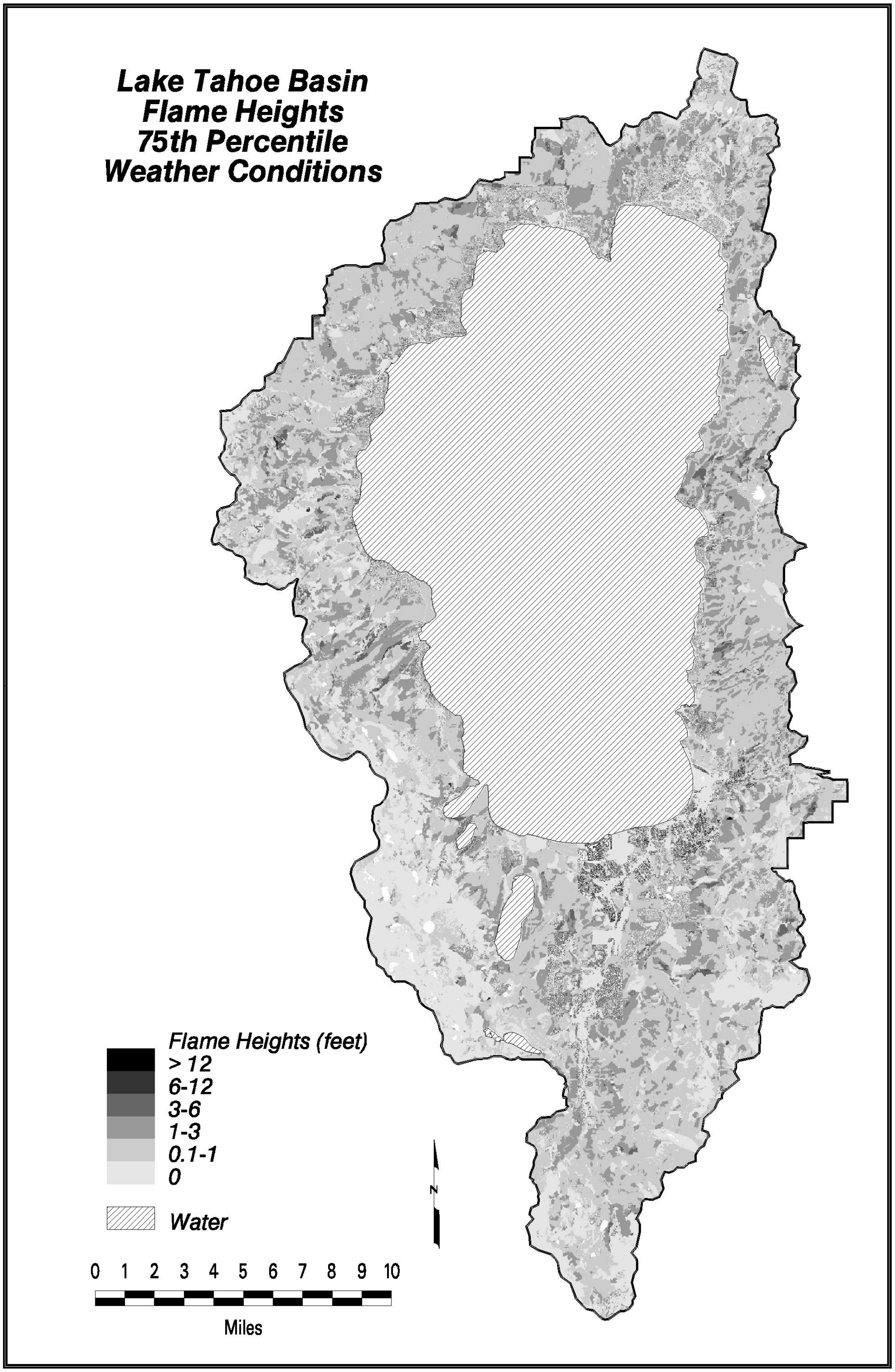


Figure 5-14b—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 75th percentile weather set in the Lake Tahoe basin.

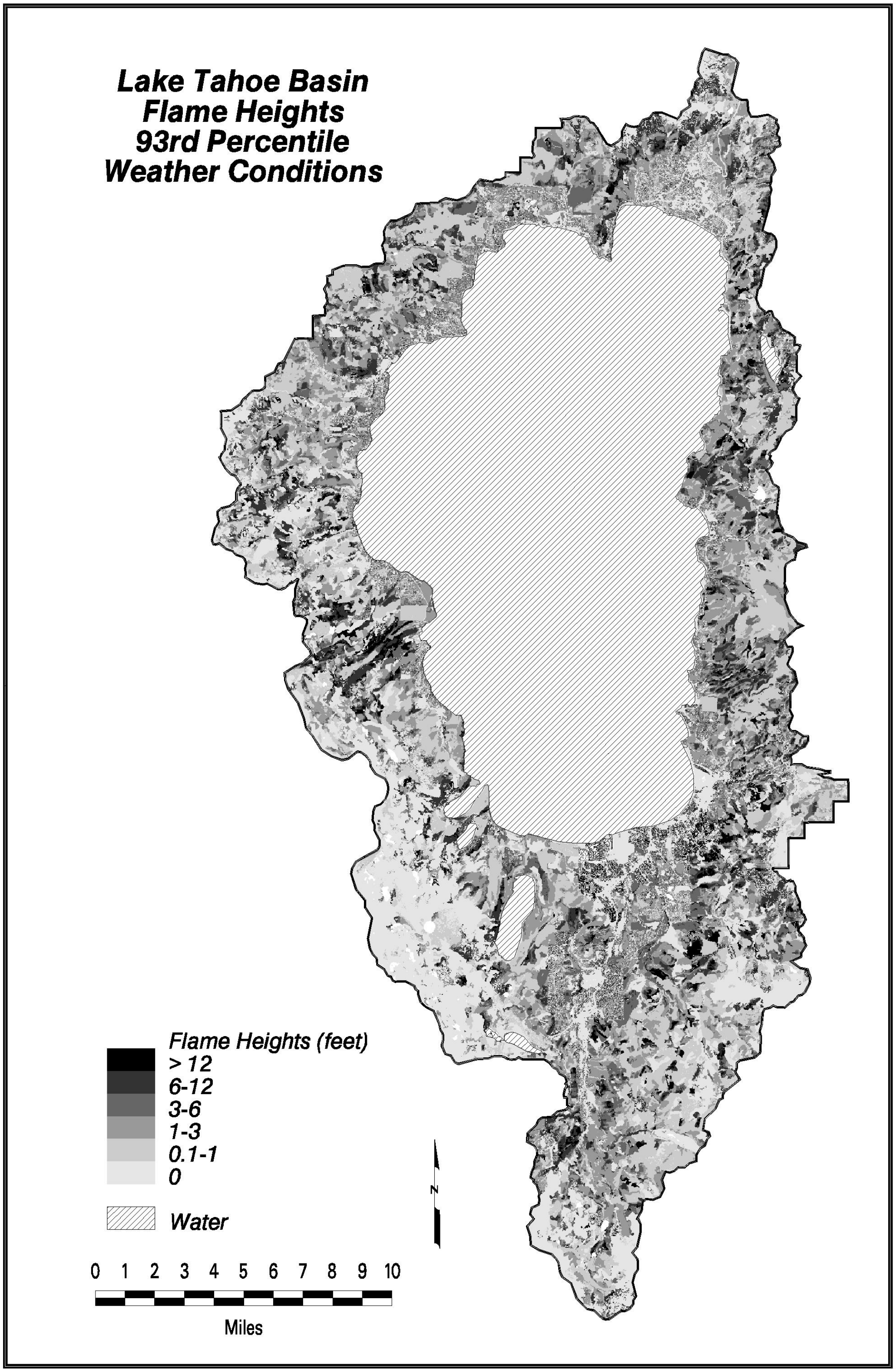


Figure 5-14c—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 93rd percentile weather set in the Lake Tahoe basin.

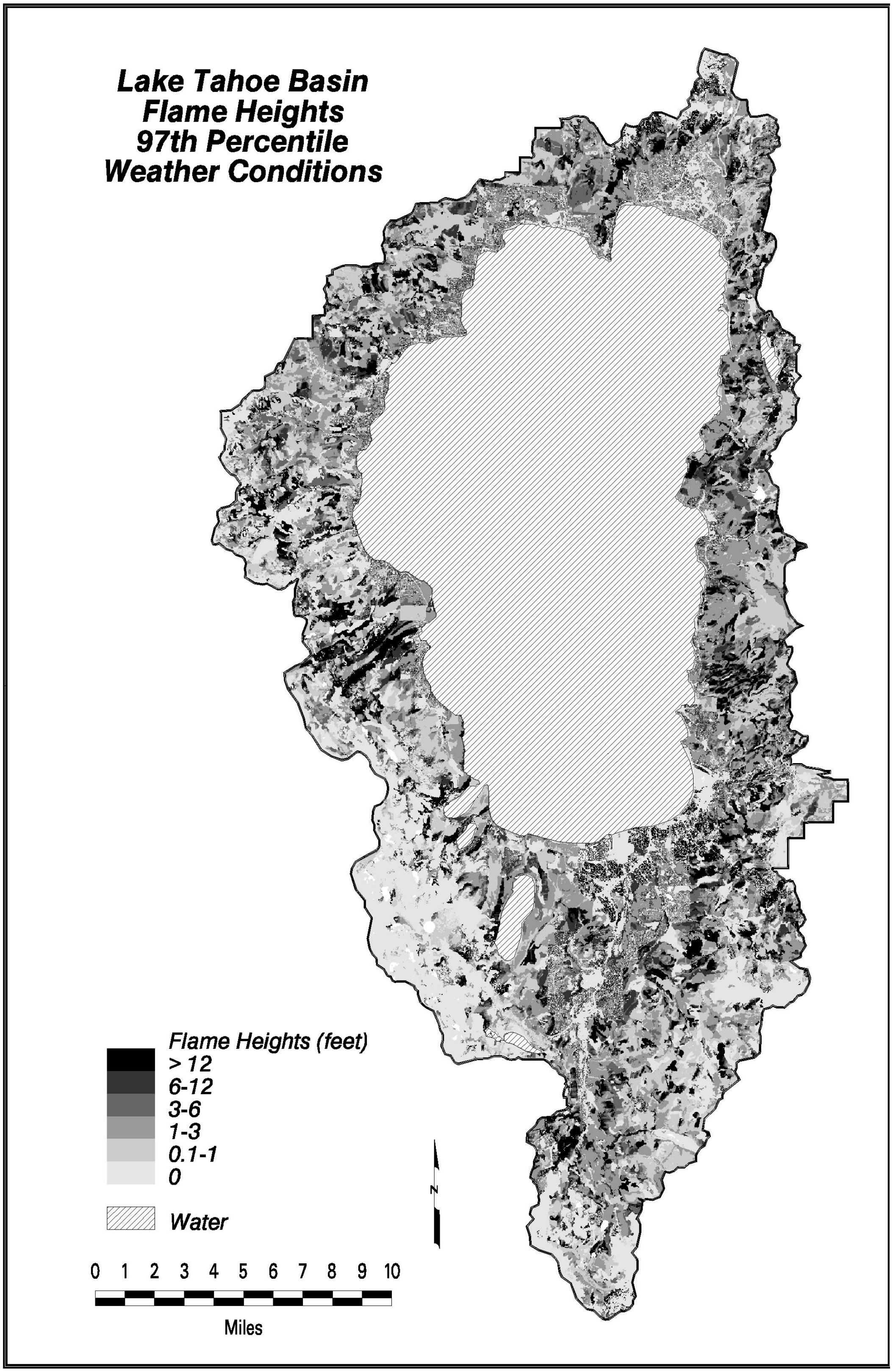


Figure 5-14d—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 97th percentile weather set in the Lake Tahoe basin.

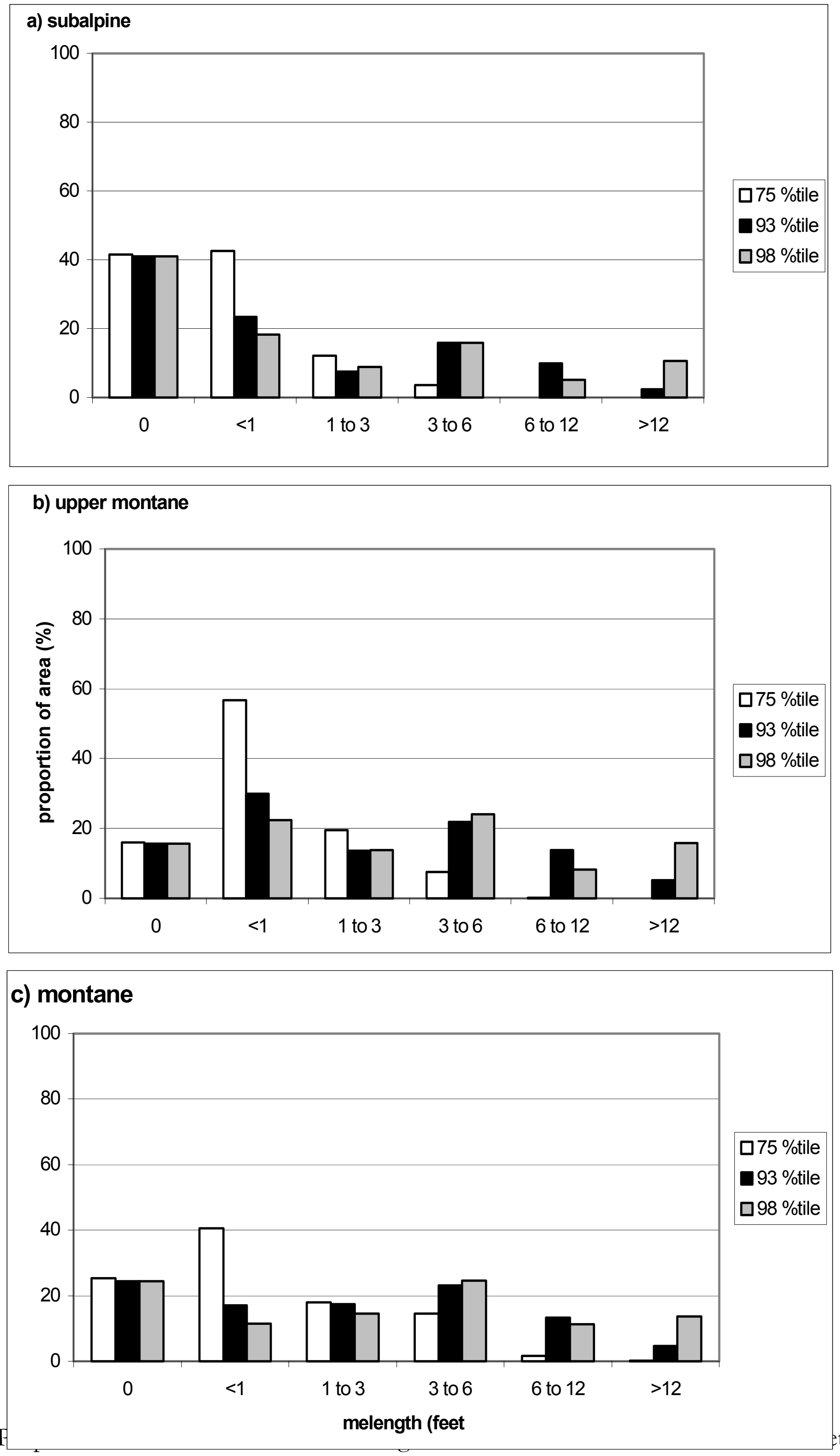


Figure 5-15—F… …ts: 75th percentile (moderate); 93rd percentile (high); and 98th percentile (extreme).

material stored next to houses are also important. Roof composition is critical to potential fire effects in urban areas; wood roofs provide a readily available combustible material, whereas metal, cement, or slate roofs are not combustible. Litter accumulations on any roof provide locations where embers can ignite. Flammable materials, such as firewood, stored in the yard and especially next to the house also provide fuel for fire. Exposed decks also provide a potential fire hazard. Even fiberglass boats, when they have flammable material stored in them, can increase the fuel load and likelihood of structure fires. Determining the continuity of fuel between lots across an entire subdivision and the flammability of structures in that subdivision is most critical to predicting the likely effects of fire on urban areas in the basin.

How will susceptibility to fire change in the future when snags fall to the ground?

This question is difficult to answer in detail because of the complexity in modeling the effects of snags and logs on fire behavior, effects, and suppression. Fire behavior models use only material smaller than three inches in diameter because these are the fuels that most influence intensity and rate of spread. Logs can influence fire effects and suppression, but available models are limited in their ability to portray the effects. For these reasons we provide a general qualitative discussion.

Snags provide ready receptors for embers in the air to land on and ignite (spotting). Also, pockets or concentrations of snags affect fire line tactics during suppression. They pose a danger of falling on fire fighters during combustion. Logs on the ground can slow fire line construction (reduced production rates) during suppression because it takes additional time to saw through and then dig a fire line. The effect on fire line production depends on the distribution of the logs. If logs are uniformly spread at high levels, then it will reduce production rates everywhere. If logs are patchy, then production rates may not be affected.

Logs can result in more severe fire effects, depending on how they are distributed within a patch of vegetation. Large logs next to individual trees result in higher intensities of fire and especially longer duration of heat. Both of these effects can increase the likelihood of mortality of adjacent trees.

The effect of recent and future mortality on fire in the basin depends on where in the basin the mortality occurs. At higher elevations and the red fir zone, effects can be less dramatic than at lower elevations in the mixed-conifer and pine zones. At higher elevations, shorter dry seasons reduce the window when logs are dry and contributes to the fire spread and its effects. The higher intensities of fire and the heat associated with them during a fire are important in producing a complex spatial pattern of varying fire patterns and effects that influence horizontal and vertical vegetation complexity. What is difficult to ascertain are the historic levels of snags and logs compared to current levels.

Where are the key areas to restore or manage to reduce the likelihood of unplanned, large, or severe fires?

Two different approaches were used to assess the key areas to restore or reduce the likelihood of unplanned fire. First, the spatial patterns of the fire susceptibility index were examined. Secondly, an analysis of values at risk was conducted by watershed.

The combined information from the fire occurrence layer and fire behavior outputs from FLAMMAP, reflected in the relative fire susceptibility index, show that the most critical areas to reduce fire hazard and risk are low elevation areas (Figure 5-16 and Table 5-20), especially in proximity to urban/wildland interfaces (Figure 5-17). Mixed conifer and pine forests are the most important. There are two approaches that would be effective in reducing fire risk for the entire Tahoe basin by management in this zone. First is increased fire prevention patrols and education to reduce human-caused ignitions. Humans have caused all but one fire since 1973. Second, reduction of fuels in the urban areas and urban/wildland interface would reduce fire risk for the entire basin. Most of the fires are ignited in these areas, most of the heaviest fuels

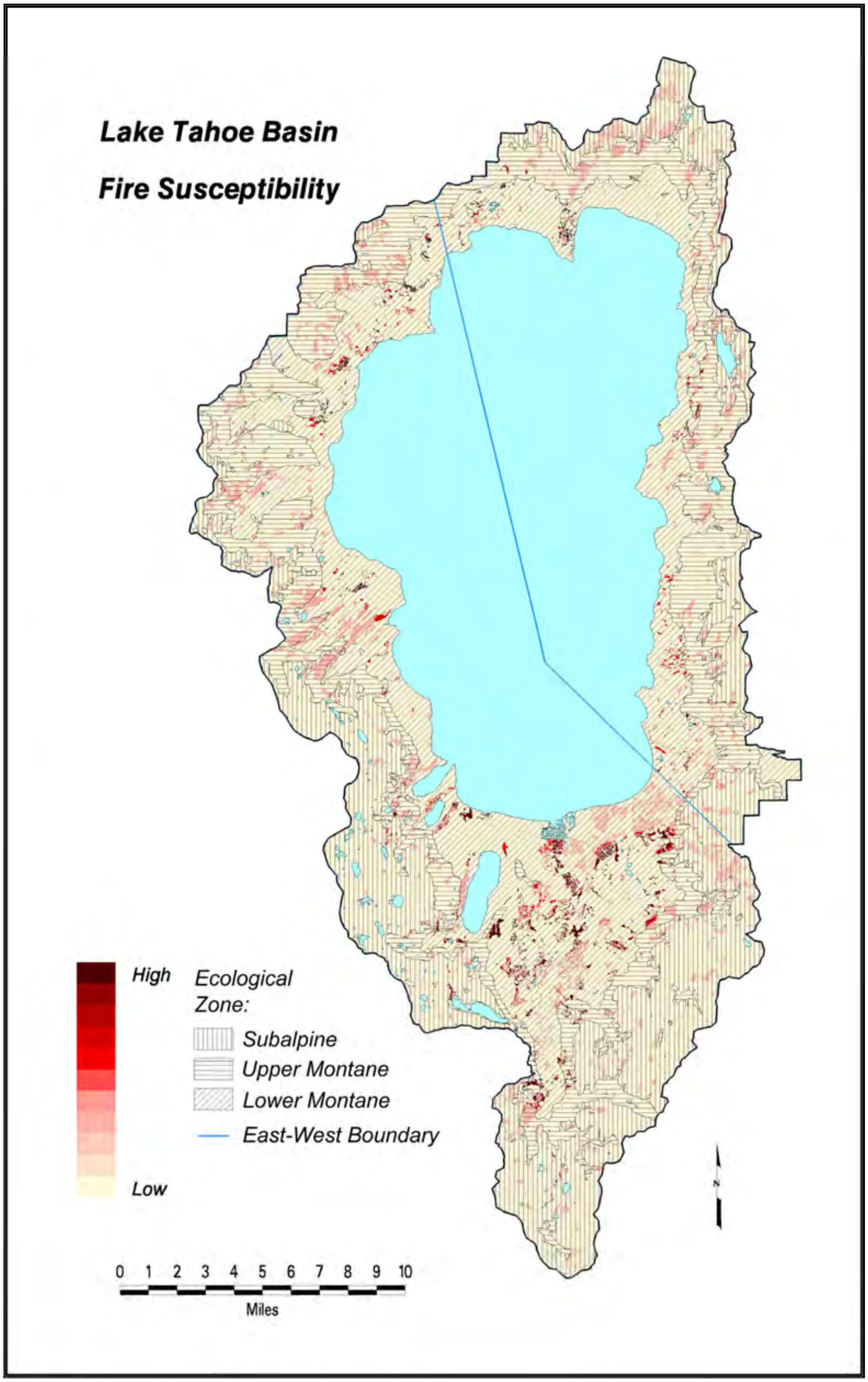
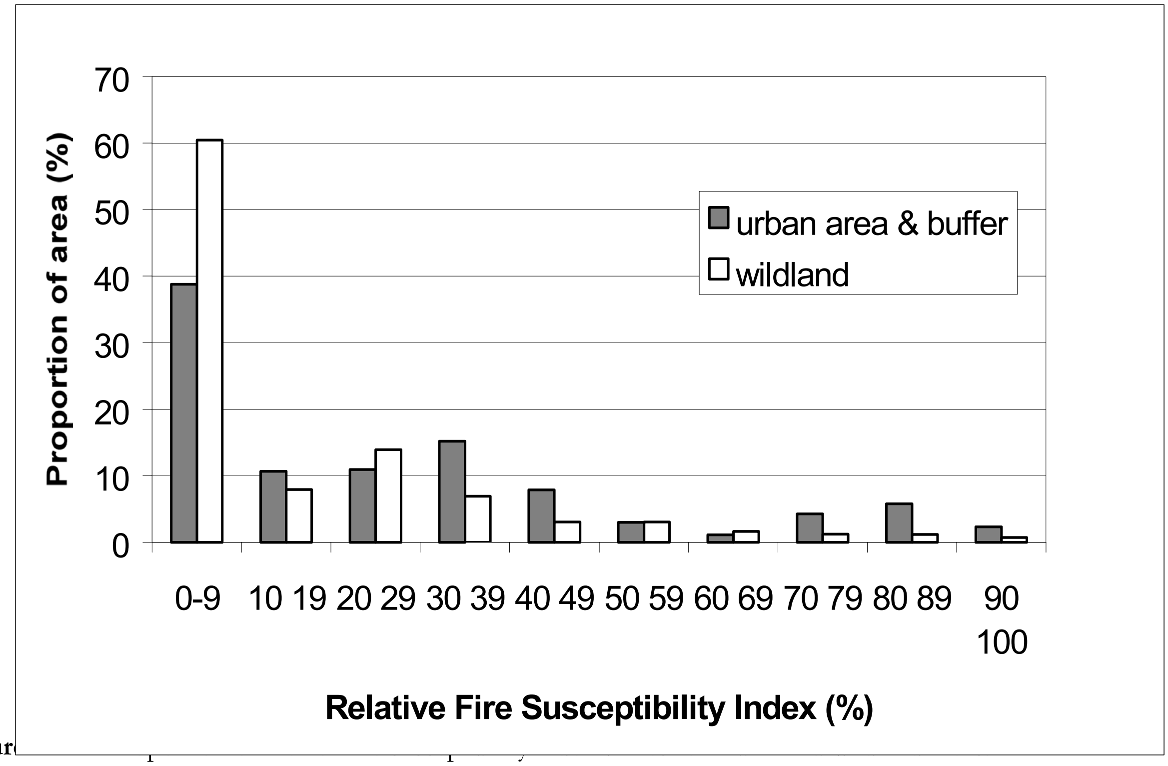


Figure 5-16—Spatial patterns of relative fire susceptibility index by major ecological and elevation zones (montane, upper montane and subalpine).



Figur

Table 5-20—Relative fire susceptibility index by major elevation zones and east and west portions of the basin. Only nonwater area is included in area calculations. The fire susceptibility index is based on the ratio among expected acres to be burned within a fire occurrence zone and burnable acres and fire spread potential (from FLAMMAP). Because the acres expected to be burned are not precise, the index is relative. Precise estimates of acres burned would be required to produce an actual probability of an acre burning.

Relative Fire Susceptibility Index	West zone (% area)			East zone (% area)		
	Montane	**Upper Montane**	**Subalpine**	**Montane**	**Upper Montane**	**Subalpine**
0-24%	60	71	81	61	73	71
25-49%	23	20	14	28	21	25
50-74%	7	5	3	9	5	3
75-100%	11	4	2	2	1	1

occur there, and the longest fire season is in this zone. Contributing to the fuel hazard are the flammable building materials (i.e., shingle roofs) frequently used in the basin.

The primary emphasis should be on surface fuels, which create intensity and affect rate of fire spread. Lastly, there may be some need to reduce tree crowns, but reducing crown density is not effective in changing fire behavior if surface fuels are not treated first and effectively. Independent crown fires, where tree crowns carry fire independently of surface fuel, are rare in the Sierra Nevada. Opening the canopy allows more drying sunlight to reach surface fuels and increases wind speeds at low heights (Countryman 1955; Weatherspoon 1996). Reducing crown density may be more important for restoring historic forest densities than decreasing fire hazard and the likelihood of severe fire in the basin. In the immediate interface with urban areas, crown closures of 40 to 50 percent will keep sites sheltered from the wind and will reduce crown fire hazard if surface fuels are treated thoroughly. Reducing crown closures in other areas in the urban interface zone, and especially in such sensitive areas as riparian zones, should be weighed against ecosystem functions of maintaining the crown cover.

Values at risk were analyzed at the watershed scale because ecosystem values at risk, such as lake clarity, are impacted at these broader scales. Lake clarity is most likely to be affected by larger fires occurring in a particular watershed, with erosion and sediment and nutrients funneled through stream channels and roads. Such a watershed focus also will protect old-growth stands.

The area-weighted average of the fire susceptibility index rating (Figure 5-18) was used to determine the relative ratings of the likelihood of an unplanned large or severe fire for each watershed. The three values at risk assessed were soil erosion (primary potential influence on reduced lake clarity), human structures and developments, and old growth. For the human developments, the proportion of the area in each watershed in land with structures or developments was computed based on the TRPA land use layer. The area-weighted average of the erosion hazard rating from the soil survey layer was used to determine the relative risk of fire to reduce lake clarity. Finally, the proportion of area with old growth was computed from the updated existing vegetation maps completed for this assessment (patches with at least two trees per acre were used to calculate the old-growth area).

The greatest coincidence of watersheds with a high proportion of erodible soils and the likelihood of fire occurs on the east shore (Figure 5-19). Steep granitic soils and flammable fuels occur here. The south and north shores also contain some watersheds with high ratings. Urban and urban interface areas on the south and north shores have the greatest fire occurrence, whereas the west shore and the Incline area have relatively low ratings (Figure 5-20). However, fire occurrence data from the Incline area may be underestimated due to lack of fire ignition records in the USFS PCHA database used. The greatest concentrations of old growth occur on the west and south portions of the basin. Although old growth is more scattered on the northwest portion of the basin, fire occurrence is high, therefore the relative risk rating is moderate to high. There are few low priority areas in the basin due to low likelihood of fire or low value. Watersheds with little or no urban development, low soil erosion hazard (due to rocky soils), and low fire risk and hazard (high elevations) are the only areas not moderate or high on a combined rating. The overall low likelihood of a large, high severity fire provides an opportunity to reduce fire hazard and risk at a rate that will minimize affect on lake clarity.

The means for reducing fire hazard and risk are as important to consider as the key areas to restore. In the immediate urban interface areas, emphasis on mechanical treatment is probably the most appropriate. Smoke generated from fires is more likely to create health and nuisance problems for humans in this zone. Secondly, an extensive network of roads provides access for mechanical treatment. In upland areas, with erodible soils and

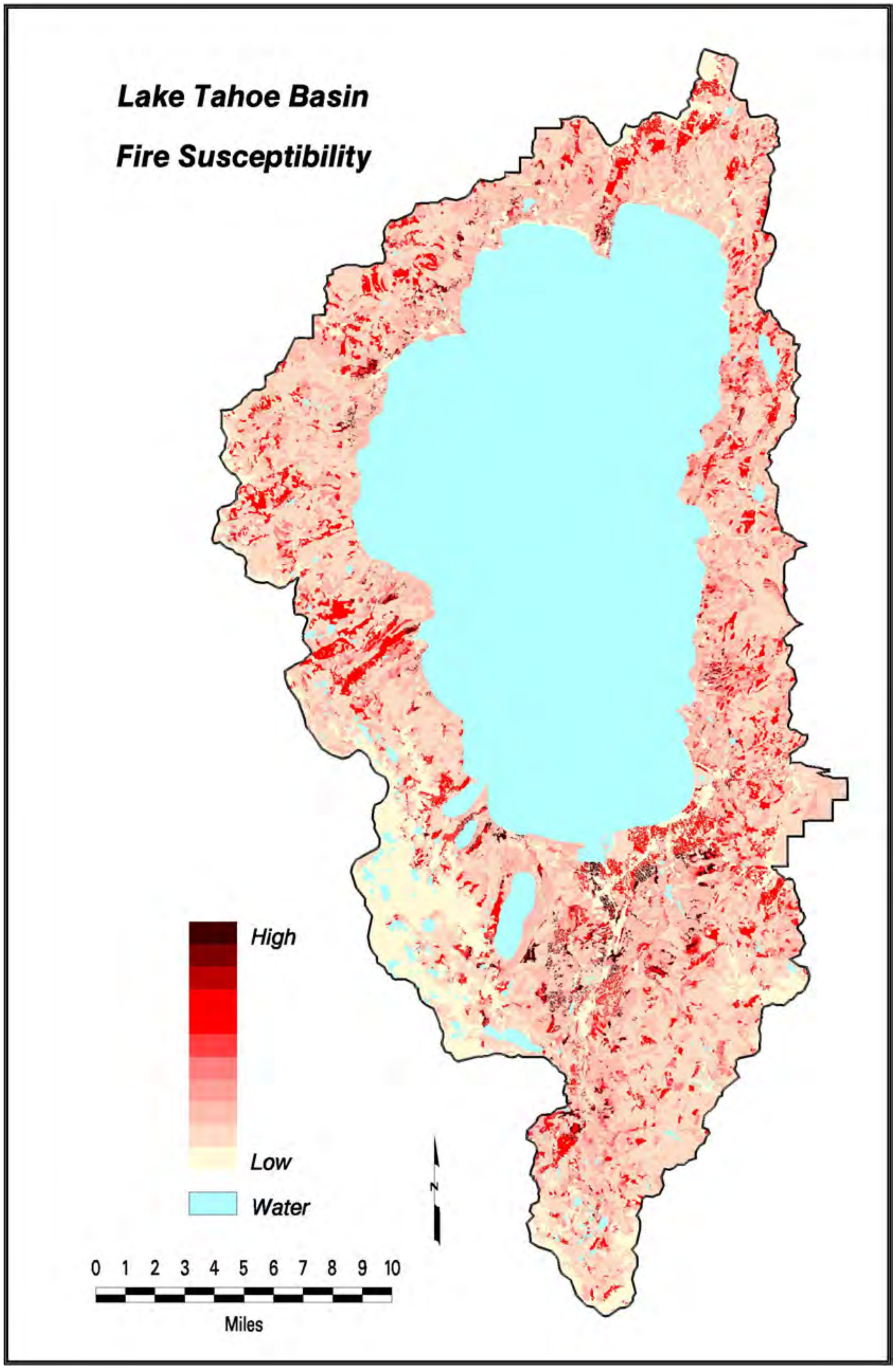


Figure 5-18—Mean fire susceptibility index values by watersheds.

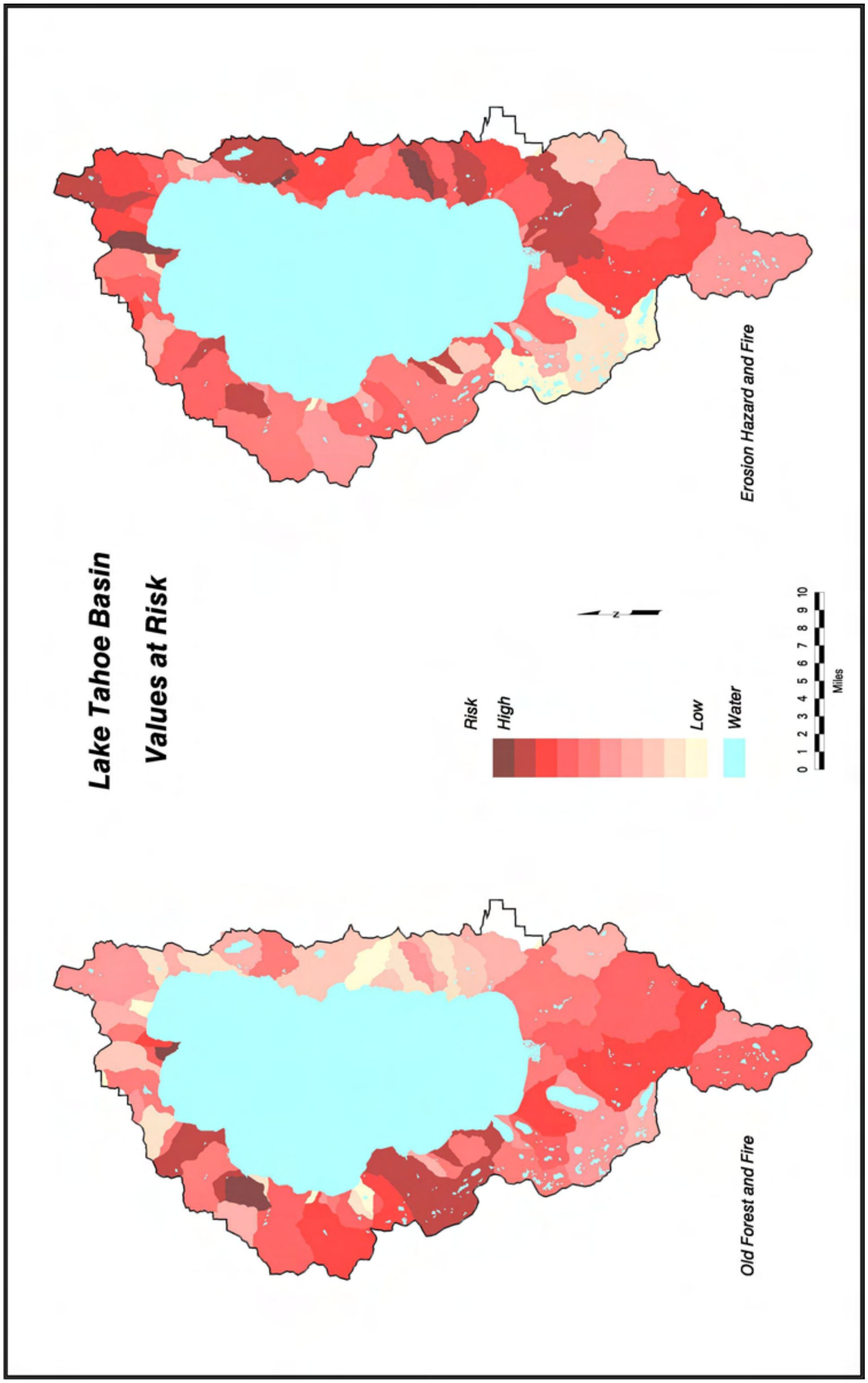


Figure 5-19—Combined watershed rating of fire susceptibility index (relative risk rating) and values at risk. Soil erosion hazard represents the value of lake clarity. Old-growth values are based on the proportion of the area in patches with greater than two trees (>30-inch diameter) per acre.

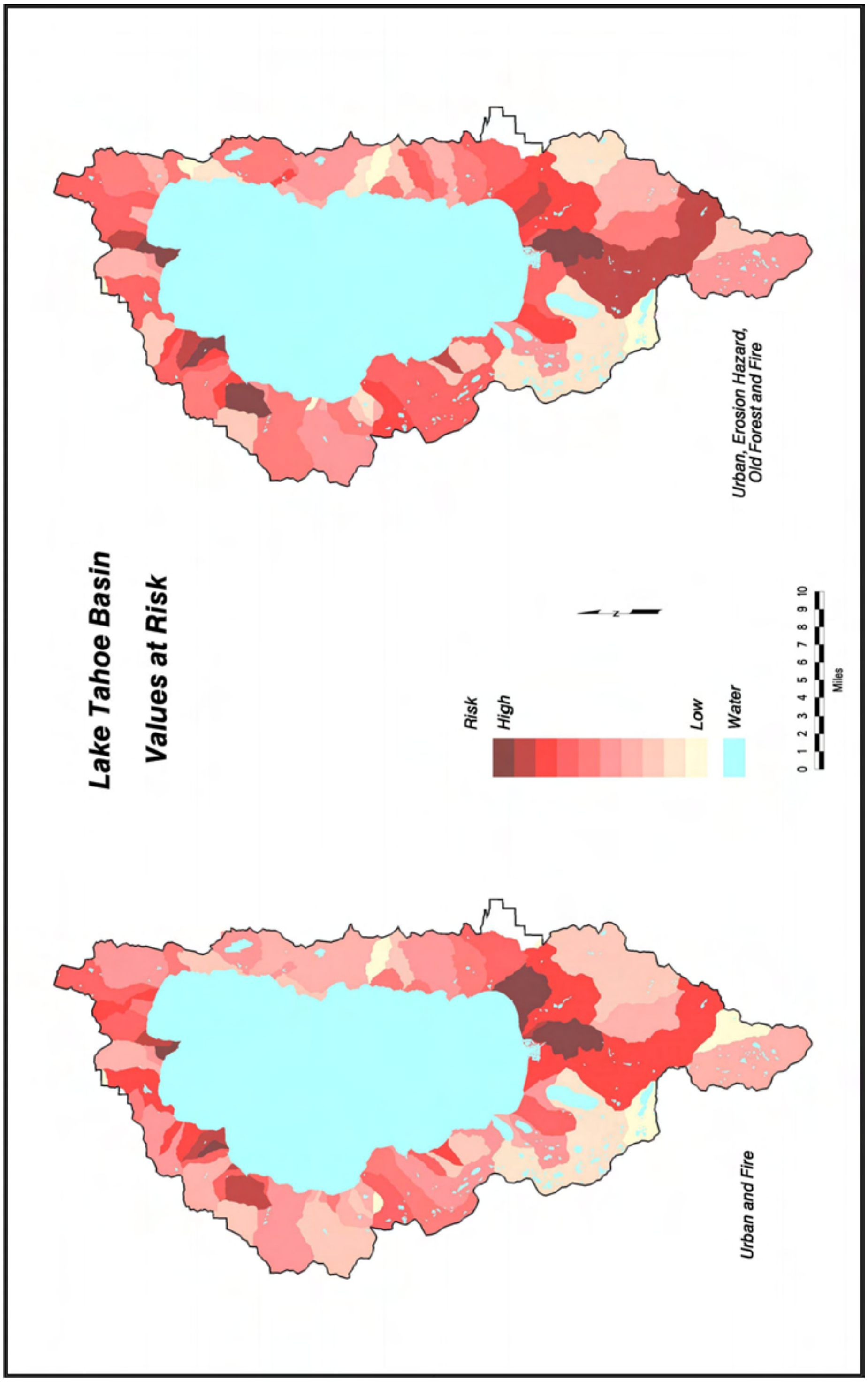


Figure 5-20—Combined watershed rating of fire susceptibility index (relative risk rating) and values at risk. Urban values are based on the proportion of the area in developed lots with structures from the TRPA land use map. The combined values at risk are the sum of urban values, lake clarity values at risk, and old-growth values, with the relative fire susceptibility rating by watershed.

concentrations of old growth, prescribed fire should be the major treatment. Mitigation for minimizing soil erosion from fuel reduction on erodible soils with mechanical treatment can be effective. Prescribed fire reduces surface fuels with minimal effects on soil erosion but may affect streamwater nutrient concentrations (see Chapter 4, Water Quality, for more detail). In old growth, prescribed fire is the best tool for reducing fuel hazard. We know little about the effects of mechanical treatment on the ecological function of old growth. Fire has played a role in shaping old-growth stands over time, and these forests have evolved with fire; therefore, prescribed fire in old growth not only can reduce fuel hazard but also can restore a key ecosystem process. With the limited ability to reintroduce fire in the basin due to air quality standards and concerns over the effects on lake clarity, it is important to use prescribed fire where it is most critical to ecosystem function.

Issue 3: The Need to Determine the Extent to which Prescribed Burning Reduces Fire Risk, Affects Wildlife Habitat, and Mimics the Process of Historic Fire

With contributions from Sue Husari and Steve Beckwitt

Prescribed burning is one of the tools that is important in reducing fire hazard and the likelihood of large or severe fire. In many situations, it is the most effective means of reducing surface fuels, the primary component of fire hazard. Prescribed burning is also critical in restoring fire as an important ecosystem process. Fire plays many important roles in shaping vegetation structure, composition, and landscape mosaics. Nevertheless, there are potential associated impacts on other resources with prescribed fire, including air quality (see Chapter 3) and lake clarity (see Chapter 4). Information on the historic role of fire, likely effects of prescribed fire, and effectiveness of the current prescribed burning program are summarized to address the trade-offs between reintroducing fire to reduce fire hazard and restoring fire as an integral ecosystem component with possible deleterious effects.

Three basic questions regarding the effects of prescribed fire are addressed under this issue and are as follows:

- What were the historic fire regimes in the Lake Tahoe basin?
- What is the state of knowledge of fire in the ecosystem in the Lake Tahoe basin?
- What is the effectiveness of current prescribed burning and other treatments in reducing fire hazard and risk, and mimicking the process of historic fire?

What were the historic fire regimes in the Lake Tahoe basin?

It is not enough to know that fire occurred historically in the basin; we also must consider the different fire regimes in order to understand the role of fire in shaping vegetation and the role of vegetation in the spread of fire. The fire regime includes fire return period (years between fire), predictability, extent, magnitude (severity), and timing or seasonality (Agee 1993).

Ignitions and Fire Return Intervals

Two sources of fire ignitions occurred historically (prior to European settlement) in the Lake Tahoe basin. Lightning is prevalent during the summer, especially late summer, and has a high enough density to ignite fires. Humans are the other source of ignitions. While the exact extent and frequency of Native American burning is not known, it is evident that the Washoe tribe used fire in the basin, particularly in or near meadows (Lindström, Chapter 2, this volume; Elliott-Fisk et al. 1997).

Most often, information on historic fire regimes is restricted to what can be derived from fire scars on trees. Very few fire history studies have been completed in the Lake Tahoe basin (Skinner and Chang 1996). We supplement the fire history data of Taylor (1998) with fire history data from similar areas outside of the basin to develop descriptions of historic fire regimes (Table 5-21).

Fire history data were summarized by forest type, based on dominant tree species. Only fire history studies that had dendrochronological cross-dating and a known area were included. (Fire return

Table 5-21—Summary of historic fire return intervals from fire history studies in the Tahoe basin or in areas in the Sierra Nevada or southern Cascades with similar vegetation and climate.

Location	Forest Type	Average Annual Precipitation (cm)	Mean Fire Return Interval (years)	Range of Fire Return Intervals (years)	Area Sampled (ha)	Reference
Caribou Wilderness, Lassen National Forest	White fir-red fir	91	53		several ha	Solem 1995
Lake Tahoe basin, eastshore	Red fir	56	16	9-36	several ha	Taylor 1998
Swain Mountain, Lassen National Forest	Red fir-white fir	110	42	5-65	.48	Taylor and Halpern 1991
Swain Mountain, Lassen National Forest	Red fir-white fir	110	40	17-65	1	Taylor and Halpern 1991
Swain Mountain, Lassen National Forest	Red fir-white fir	110	13*		3	Taylor 1993
Swain Mountain, Lassen National Forest	Red fir	110	26*		3	Taylor 1993
Mammoth to June Lake Region, Inyo National Forest	Red fir-lodgepole pine	68	28	11-41		Millar and Woolfenden (1999)
Lake Tahoe basin, eastshore	Red fir-lodgepole pine	74	13	8-23	several ha	Taylor 1998
Lassen National Park & Caribou Wilderness, Lassen National Forest	Lodgepole pine-red fir	109	35		several ha	Solem 1995
Lake Tahoe basin, eastshore	Jeffrey pine-white fir	76	12	5-28	several ha	Taylor 1998
Lake Tahoe basin, eastshore	Jeffrey pine-red fir	79	22	9-47	several ha	Taylor 1998
Caribou Wilderness, Lassen National Forest	Jeffrey pine-white fir	97	23		several ha	Solem 1995
Caribou Wilderness, Lassen National Forest	Jeffrey pine-white fir	97	32		several ha	Solem 1995
Prospect Peak, Lassen National Park	Jeffrey pine-white fir	89	29		several ha	Solem 1995

* Only intervals prior to 1850 were included.

intervals are sensitive to the area sampled [Agee 1993], therefore, to make relative comparisons, the spatial scale of sampling has to be taken into account.) The fire return intervals summarized here (Table 5-21) are point or plot composites, which means they are the sum of fire intervals for several to many trees in an area of several hectares or less. This scale is useful for comparing fire patterns and effects on different vegetation. The data summarized represent a period that generally encompasses several hundred years prior to European settlement.

Fires were most frequent in the vegetation types found on drier sites, such as lower elevation Jeffrey pine and Jeffrey pine-white fir forests (mean fire return intervals of 12 to 32 years) (Taylor 1998). Higher elevation red fir forests on the east shore of the Tahoe basin, where precipitation is considerably lower than in the red fir forests on the west shore, also had short intervals between fires (13 to 16 years) (Taylor 1998). Data from the Lassen National Forest and Lassen National Park (Solem 1995; Taylor 1993; Taylor and Halpern 1991) were used to represent red fir and mixed red fir and white fir forests on the west shore, which receives greater precipitation than the east shore. Average fire return intervals ranged from 26 to 53 years. One site (Taylor 1993) had a mean fire return interval of only 13 years. There is some uncertainty of the similarity in weather and therefore fire regimes between the Lassen and Lake Tahoe basin areas, but these data provide a first approximation. Parts of the west shore are wetter than these areas in the Lassen area. A study of red fir and lodgepole pine forests on the Inyo National Forest showed slightly lower fire return intervals (28 years) (Millar and Woolfenden, 1999). However, there were periods of 100 years or more when no fires were recorded, including the most recent period, presumably due to lack of ignitions.

Keifer found that evidence of fire in the subalpine zone varied with the bark characteristics of the species affected. Thin-barked lodgepole pine, which is common in subalpine forests in the Lake Tahoe basin, showed evidence of fire, whereas the more thick-barked foxtail pine did not. Lightning ignitions are common in subalpine forests, but because of the discontinuous pattern of vegetation and fuels, fires are small and often are limited to a single tree or patch of trees. Based on analysis of lightning-ignited fires in Yosemite National Park, van Wagtendonk (1998) estimated that the fire return interval in white bark pine forests would be over 26,000 years.

Variation in intervals between fires at any one site is more critical than average intervals to understanding the effects of fire over time on vegetation. For example, one 70-year interval between fires on a site is sufficient to allow white fir or red fir to establish and grow to a size where they are fire resistant (Agee 1993; Taylor 1993). A short interval between fires tends to favor pines because of their thicker bark and more protected buds. Fire return intervals are generally more variable on moister sites or in higher elevation red fir or subalpine zones. Moister sites, such as riparian or north-facing slopes, are less likely to have fuels sufficiently dry to burn as frequently as fuels on drier or south/west-facing slopes. Variation in snowpack and the length of the snow-free period can greatly alter the likelihood of fire in the higher elevation red fir and subalpine zones. Furthermore, red fir also has small needles that compact under the heavier snowpack in that zone, making surface fuels more resistant to combustion.

Fire return intervals interpreted from fire scars are generally considered conservative because data is limited to those fires that leave trees scarred (Skinner and Chang 1996). When fuels are more resistant to fire or are less continuous, a lack of fire scars may be due to a patchy burn pattern (some trees previously scarred are missed) or very low intensity burning (insufficient heat to scar trees). The range of intervals for all of the studies examined was relatively great (Table 5-21) compared to lower elevation mixed-conifer forests on the western slopes of the Sierra Nevada (Fites-Kaufman 1997). In particular, areas with higher precipitation in the red fir forests tended to have the greatest variability. This is consistent with observations of current fire patterns in Yosemite National Park (van Wagtendonk 1998), where fire patterns in red fir are highly variable in space and time. Information on historic vegetation composition from dendrochronological reconstruction (Taylor 1998) and General Land Office Survey Data provide additional insight into variability in fire return intervals.

Taylor's reconstruction (1998) revealed that five out of six stands reconstructed in the pine-white fir zone were codominated by Jeffrey pine and white fir. The remaining one had only one cohort of white fir. Because young white firs are not especially resistant to fire and Jeffrey pines are resistant, this indicates either that fires were discontinuous or that there was sufficient variability in intervals between fires to occasionally allow white firs to establish and survive. The General Land Office survey data further corroborates this pattern, with white fir comprising a substantial proportion of the trees measured in the late 1800s.

We developed two statistical models of historic fire return intervals based on regressions of mean fire return interval and average annual precipitation (Figure 5-21, Table 5-22). Current precipitation was used as an indicator of historic precipitation. Both models were statistically significant, and the shapes of the modeled curves are similar. They provide two similar but slightly different estimates of fire return patterns and burned acres. They should be considered working hypotheses of historic patterns (Figure 5-22) because much of the data is from areas outside of the basin, and there has been no validation of the models.

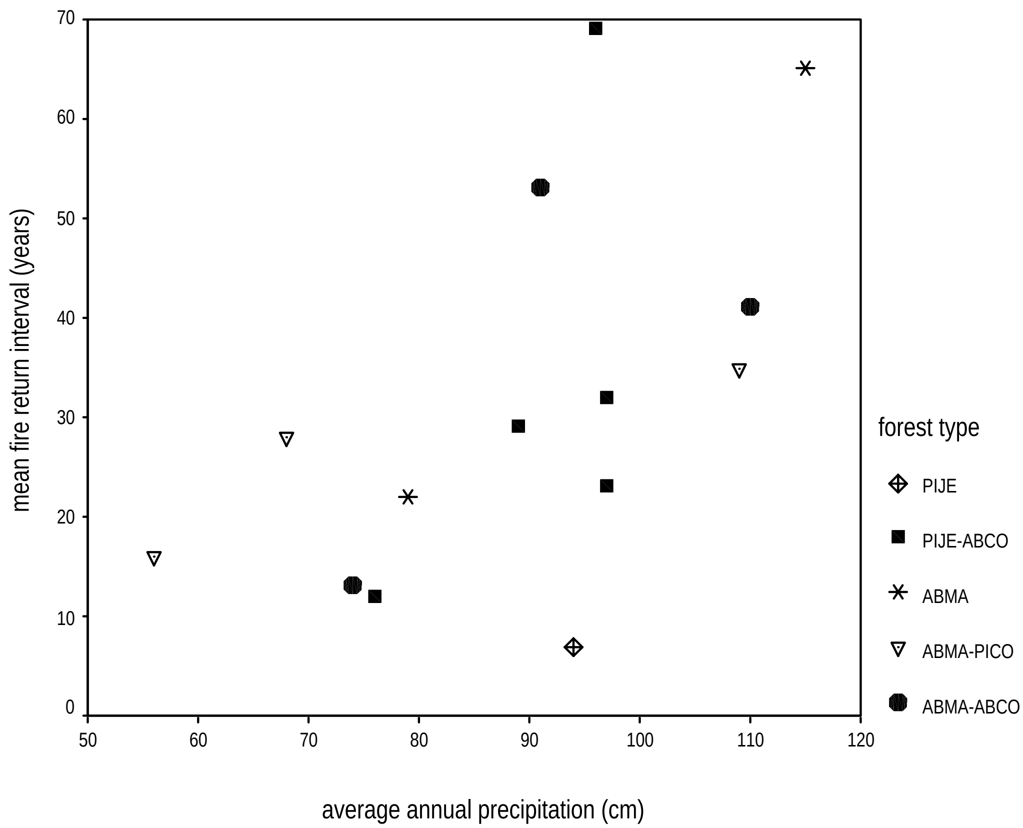


Figure 5-21—Mean fire return intervals (years) plotted against average annual precipitation (cm) by major forest type for fire history studies in or applicable to the Lake Tahoe basin. Forest types are abbreviated as follows: PIJE—Jeffrey pine, PIJE-ABCO—Jeffrey pine-white fir, ABMA—red fir, ABMA-PICO—red fir—lodgepole pine, ABMA-ABCO—red fir-white fir.

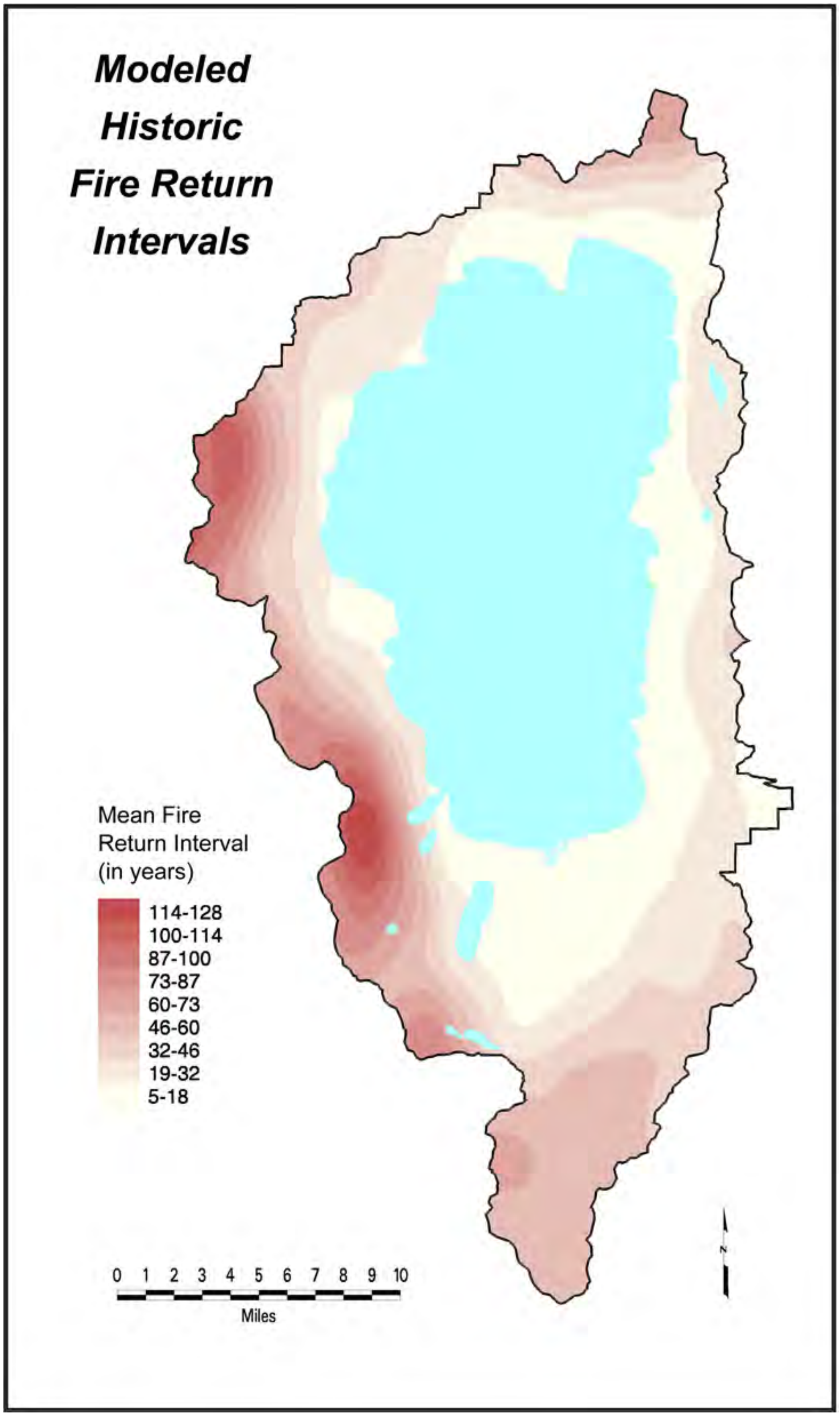


Figure 5-22—Modeled spatial patterns of historic fire return intervals based on nonlinear regressions of fire return intervals as a function of average annual precipitation.

The models enabled us to estimate the historic average of acres burned annually. The estimates were summarized for major vegetation zones and east versus west portions of the basin (Table 5-23). The differences in the models provide one measure of the variability in acres that may have burned—between 2,000 and 8,000 acres on average each year. Nearly half or more of the acres burned were at the lower elevations in the montane zone. Consequently, the montane zone had the greatest proportion of area burned annually, averaging 1.3 to 6 percent of the total area on average. Similar acres of the upper montane and subalpine zones burned, but the relative proportion of the area burned was slightly higher in the upper montane (0.9-3.3 percent) than in the subalpine zone (0.8-2.3 percent).

Fire Severity

High severity refers to high mortality of overstory trees, while low severity refers to little or low mortality of overstory trees. It is not possible to measure historic fire severity directly. Inferences generally are drawn based on patterns of fire return intervals and sometimes age-structure or species composition.

In the montane forests of the Lake Tahoe basin, fires were relatively frequent, therefore it is likely that most of them were low in severity. However, on moister sites, where fir was likely more dominant, fire severity may have been more of a mixture of intensities, leading to highly localized mortality. Little work has been done on patterns of fire in white fir. Taylor and Halpern (1991) studied

Table 5-22—Results of regressions of historic fire return interval as a function of average annual precipitation (ppt).

Model & Variables	Coefficient	adjusted R^2	F statistic significance
Cubic model		.33	.06
Ppt	-0.126		
ppt^2	0.005		
Constant	6.063		
Compound model		.46	.01
Ppt	1.02		
Constant	3.84		

Table 5-23—Estimates of acres burned annually (average) in the Lake Tahoe basin in the several hundred years prior to European settlement. Data are based on regressions of mean fire return intervals, from point composites, as a function of average annual precipitation (current). Low acre estimates are from the composite regression model, and high acre estimates are from the cubic regression model.

	Estimated Area Burned (acres)		
Vegetation Zone	West	East	Total
Montane	689-2964	326-1592	1015-4556
upper montane	291-838	261-1045	552-1883
Subalpine	389-1011	153-525	542-1536
Total	1369-4813	740-3162	2109-7975

mixed white fir and red fir stands on the Lassen National Forest and suggested that highly variable fire severity occurred. Russell et al. (1999) studied post-fire succession for several more recent fires (the early and mid 1900s) and found that these fires in the basin were high severity. However, it is not clear whether these high severity fires were influenced at least in part by human activities. Lindström (see Chapter 2) summarizes early accounts that reveal high severity fires ignited by sheepherders across broad areas or ignited inadvertently by settlers in logging slash. It is uncertain whether the oldest fire that Russell et al. describe in 1890 was a lighnting caused fire in natural vegetation or if it was ignited by European settlers and their activities.

In upper montane forests, fire intensity and severity were likely more variable than in the montane zone. Fires on sites with rocky or very shallow soils with scattered vegetation, such as Jeffrey pine, would result in little mortality due to lack of fuels. On more productive red fir sites, fire severity likely varied considerably. Recent wildland fires in red fir in Yosemite National Park exhibit diverse levels of mortality even within the same fire event (van Wagtendonk 1998). Mortality ranges from less than 20 percent to greater than 80 percent. Patches of high mortality are generally limited to less than 100 acres. The Yosemite patterns are consistent with the work of Taylor and Halpern (1991), Taylor (1993), and Solem (1995). In red fir and lodgepole pine forests on the Inyo National Forest, Millar and Woolfenden (1999) inferred that fire frequency and fire severity varied considerably over time, from no fire for a period over 100 years to high severity, widespread fire (possibly tied to volcanic activity), to a moderate period of frequent low severity fire.

Limited research has been conducted on fire history in subalpine forests in the Sierra Nevada on which to surmise historic fire severity (Skinner and Chang 1996). Observations of current fire patterns indicate that fires tend to burn and kill individual trees or small clumps of trees, although there is one stand of mountain hemlock in the Desolation Wilderness to the west of the Lake Tahoe basin, where all but two trees apparently burned in a fire in the early 1900s.

Seasonality and Extent

Data on seasonality of historic fire is extremely limited in the Sierra Nevada. In one of the few studies that included seasonality, Taylor (1998) reported that over 90 percent of the fires occurred in the dormant season (presumably late summer and fall) on the east shore of the Lake Tahoe basin; the remaining 10 percent occurred in the growing season. This is consistent with the typical lightning patterns observed currently in the basin, with most of it striking in the late summer.

The spatial extent of historic fire is time-consuming to reconstruct, and as a result very few studies have been conducted that include spatial extent. Taylor (1998) examined synchrony of fire events across a portion of the east shore, representing several thousand acres. A fire in 1794 burned through the entire study area. Other widespread fires, where more than 50 percent of the study sites burned, had a median fire return interval of 18.5 years, indicating a relatively high frequency of fires that covered large areas on the east shore.

The only other applicable study that has examined fire extent is that by Solem (1995) in upper montane forests of the Caribou Wilderness in Lassen National Forest. He examined a 4,800-acre area and estimated that seven different fires occurred prior to 1850 within this area, ranging in size from 55 acres to 1,600 acres. Three of these fires were between 200 and 300 acres, three were between 30 and 60 acres, and one was 1,600 acres. This pattern of predominantly small to medium sized fires is similar to current patterns of fires allowed to burn in the red fir forests of Yosemite National Park (van Wagtendonk 1998).

The topography of the basin and wind patterns discussed in the fire risk section of this chapter indicate that fires historically were usually not greater than several hundred or several thousand acres.

Riparian Areas, Meadows, and Wetlands

There is no information on fire regimes in riparian areas, meadows, or wetlands in the basin, except for information on burning practices of the

Washoe tribe in some of these areas (see Chapter 2). Fire history studies in riparian areas are particularly rare in the entire western US Fire history studies in westside mixed-conifer forests on the Eldorado National Forest (Fites-Kaufman 1997) and in the Klamath Mountains on the Shasta-Trinity National Forest (Skinner and Chang 1996) indicate fire presence in riparian areas in montane regions of California. In mixed-conifer forests of the Eldorado, Fites-Kaufman (1997) found that mean fire return intervals in riparian areas varied by the size and landscape position of riparian areas. Fire return intervals for a riparian zone associated with a small, intermittent stream in a dry portion of the landscape (upper slope) was similar to adjacent upland areas. In contrast, fire return intervals for a riparian zone associated with a large perennial stream at the bottom of a slope were considerably longer than other similar upland areas. Historic fire regimes in riparian areas, meadows, and wetlands in the basin likely varied with stream size and landscape position as well. Numerous fire-scarred trees have been observed around Meek's meadow in the basin, indicating either Native American and or lightning-caused fires played a role in some meadows in the basin.

What is the state of knowledge of fire in the ecosystem in the Lake Tahoe basin?

Our knowledge of the effects of prescribed fire in the basin is limited. Some monitoring of prescribed fire is conducted, most extensively by California Department of Parks Parks and Recreation, but the design does not address some key questions, such as the effects of burning on lake clarity or air quality. Secondly, the spatial pattern of fire effects is critical in understanding effects on fire risk, vegetation, and wildlife habitat. Current monitoring protocols are based on randomly placed plots. This scheme was not designed to detect and characterize the spatial patterns of effects. Further, most burn units are smaller and less intensely burned than in the time before European contact.

Increasing our knowledge of the effects of prescribed fire on nutrient transport is probably best achieved through research, because it will require methods not yet developed (see chapters on air and water quality). Effects of fire on vegetation, fire hazard, and some aspects of wildlife habitat may be addressed adequately with monitoring; however, comparisons of effects of fire with other vegetation treatments, such as thinning, would require a more formal experimental design, such as the proposed National Fire/Fire Surrogates Study (Weatherspoon and Skinner 1999).

What is the effectiveness of current prescribed burning and other treatments in reducing fire hazard and risk, and mimicking the process of historic fire?

To evaluate the effectiveness of prescribed burning and other treatments in reducing fuel hazard and mimicking the process of historic fire, an analysis of the scale and spatial pattern of treatment and the actual effects of treatments must be undertaken. Currently, fewer than 1,000 acres are underburned annually in the Tahoe basin. This is in contrast to estimates of historic burning of up to 8,000 acres. (The actual amount of historic burning may be higher because of the lack of detailed fire history data throughout the basin and the conservative means of interpreting fire history data.) The implication is that current burn treatments only superficially mimic the historic process of fire at the landscape scale. Current burn units are smaller and less intensely burn areas before European contact.

Some of the burning that occurs in the Tahoe basin is pile burning rather than underburning. Pile burning is the act of burning piles of thinned trees, pruned branches, cut vegetation, or gathered surface fuels. Sometimes the fire spreads between piles, but the primary purpose is to burn the pile. Underburning refers to the application of prescribed fire across an entire area, although not every location within is necessarily burned. The effectiveness of pile burning in reducing fire hazard and mimicking the process of historic fire is variable, depending on how it is applied. When piles are composed of thinned material from the understory and larger surface fuels on the ground, fire hazard can be reduced, but this does not always reduce smaller surface fuels (Stephens 1998). When piles are composed only of thinned material from the understory, then burning usually has little effect on surface fuels, except under the piles or when the fire creeps a little. The residence time (or duration of heat in one place) during pile burning replicates to some degree that of historic fire or underburns, where there were accumulations of large wood. However, the spatial extent and quantity of piles is likely much greater than accumulations of large wood historically.

The effectiveness of such burning in reducing fire hazard or likelihood of large, severe, unplanned fire is variable. Recent theoretical modeling by Finney (in preparation) suggests that the proportion of the area treated and the spatial arrangement of the treatments are critical to reducing the rate of spread, fire intensity, and sometimes fire size. In areas where treatments are strategically placed in a given location, such as in Sugar Pine Point State Park or Incline, it is likely that there is a trend toward decreasing fire hazard and reduced likelihood of large or severe unplanned fires. But to draw firm conclusions, more detailed analysis of all mapped locations of treatments and the effects of those treatments on reducing fuels is necessary. Real-time monitoring of activities and their effects would provide this information.

Other treatments to reduce fire hazard and to mimic the process of historic fire involve removing vegetation through thinning or chipping. Little information exists in the basin or elsewhere in the western states on the ecological impacts of mechanical treatments or their effectiveness in reducing fire hazard compared to burning. Researchers have begun a large multidisciplinary, multistate research project (Fire Surrogate Study, Joint Fire Science Program) to address this lack of information (Weatherspoon and Skinner 1999). Another research effort on the Teakettle Experimental Forest in the southern Sierra Nevada also is addressing these questions (North 1998).

The effects of fire on ecosystem composition, structure, processes, and functions are not always well understood (Chang 1996). However, while some effects of fire can be mimicked at least partially by mechanical treatment, there are other effects we know of that cannot. For example, heat or smoke generated by fire that scarifies seeds of some species to germinate is not mimicked by mechanical treatment. There are other more subtle effects of fire in creating spatial heterogeneity in forest structure (patchiness) (Bonnickson and Stone 1991; Taylor and Halpern 1991; Franklin and Fites-Kaufman 1996; Fites-Kaufman 1997) where there is uncertainty of our ability to mimic with mechanical treatment.

While little research exists on the direct effects of different treatments (for example, thinning or burning) on fuel loading and configuration and thus on fire hazard, there are several obvious differences. First, only burning actively reduces duff, litter, and litter layers. Mechanical treatments may redistribute these ground and surface fuels, making them less continuous, but they are not removed. Both fire and mechanical treatments, especially biomass treatments, can reduce ladder fuels in the understory. Fires burn materials that are low to the ground and of small diameter. Biomass operations remove shrubs and small trees to varying degrees, depending on the objective, but with current technology biomass operations are limited to less steep areas.

Issue 4: The Need to Develop a Conceptual Model of Forest Vegetation and Function as a Basis for Identifying Attributes of Integrity

With contributions from David Rizzo and Yiqi Liu

A conceptual model of the basin ecosystem is important because it shows which things to monitor to know the direction and magnitude of changes caused by management actions. Adaptive management requires information about change as early as possible so that management procedures can be altered if necessary. So far, ecologists have had a remarkable lack of success in deciding what to monitor; that is, in deciding what would be the most sensitive, reliable, early indicators of change in such slow-moving ecosystems as forests and deep lakes.

We addressed two questions about a conceptual model of forest health: What are the key ecosystem processes and stressors and what are the potential attributes of integrity that are useful for monitoring.

What are the key ecosystem processes and stressors?

We recognize the following five key ecosystem processes for all vegetation types in the basin. These processes are just the most important or key processes among a much longer list of all processes.

- Nutrient cycling, particularly of carbon, nitrogen, and phosphorus;
- Energy cycling, as expressed by each trophic level's caloric content;
- Water cycling, including transpiration and canopy interception of precipitation;
- Occurrence of disturbance (frequency, intensity, distribution) by such factors as fire, wind, pathogens, bark beetles, and leaf-eating insects; and
- Successional change, as expressed by vegetation structure, canopy closure, population age structure, species composition, and litter chemistry.

The most important stressors (i.e., affectors) (Manley et al. in press) of the key processes above vary with the vegetation type. For forests in the basin, we identified the primary affectors as those listed below, in declining order of importance:

- Changes in the fire regime;
- Active management (thinning, disease control or introduction, prescribed fire);
- Type conversion (ski developments, urbanization);
- Recreation;
- Climate change and episodic extreme fluctuations (drought);
- Atmospheric pollutants;
- Introduction and spread of exotic plants; and
- Livestock grazing.

For wetlands, the sequence of importance in the list of affectors are grazing, recreation, type conversion, climate change, pollutants in surface or ground water flows, and management of adjacent forested lands, such as change in fire regime.

What are the potential attributes of integrity that are useful for monitoring?

Affectors typically modify processes in complex ways, but our objective was to search for relatively simple items to measure that might serve as surrogates for the total effect of the affector. The simple items that are measured and monitored are called "elements" in the terminology of Manley (1997). Table 5-24 lists some elements that could be monitered as surrogates for various processes. Each element also was categorized as being a strong, moderate, or weak surrogate.

As shown in the table, those elements we think most promising for monitoring are litter production, depth, and decomposition rates, nitrogen mineralization rate, tree density or mortality by species and size/age class (in particular young and very old age classes), canopy cover or leaf area index, and the carbon:nitrogen ratio and pH of litter and soil. These elements are relatively easy to quantify by standard techniques, they require minimal training of observers, they are inexpensive to quantify and, should give the earliest indications of ecosystem change.

The key importance of these elements is clear from a conceptual forest health model (Figure 5-23). From the model, one can see that litter decomposition rates impact the lake water chemistry; when fire consumes plant biomass it generates atmospheric pollutants that can inhibit photosynthesis and productivity and can affect water chemistry; and vegetation structure and species composition provides the matrix within which wildlife move and function (that is, vegetation conditions could be a surrogate for wildlife).

Such models sometimes illustrate unexpected relationships. For example, management can increase disease incidence as well as reduce it. Thinning an overly dense forest usually wounds some trees left standing and creates freshly cut stumps. Both wounds and stumps are avenues for pathogens to enter, and, once they are in the root system of the cut or injured trees, they can be carried to healthy trees through natural underground root grafts. A forest with a high density of disease-susceptible tree species, such as white fir (*Abies*

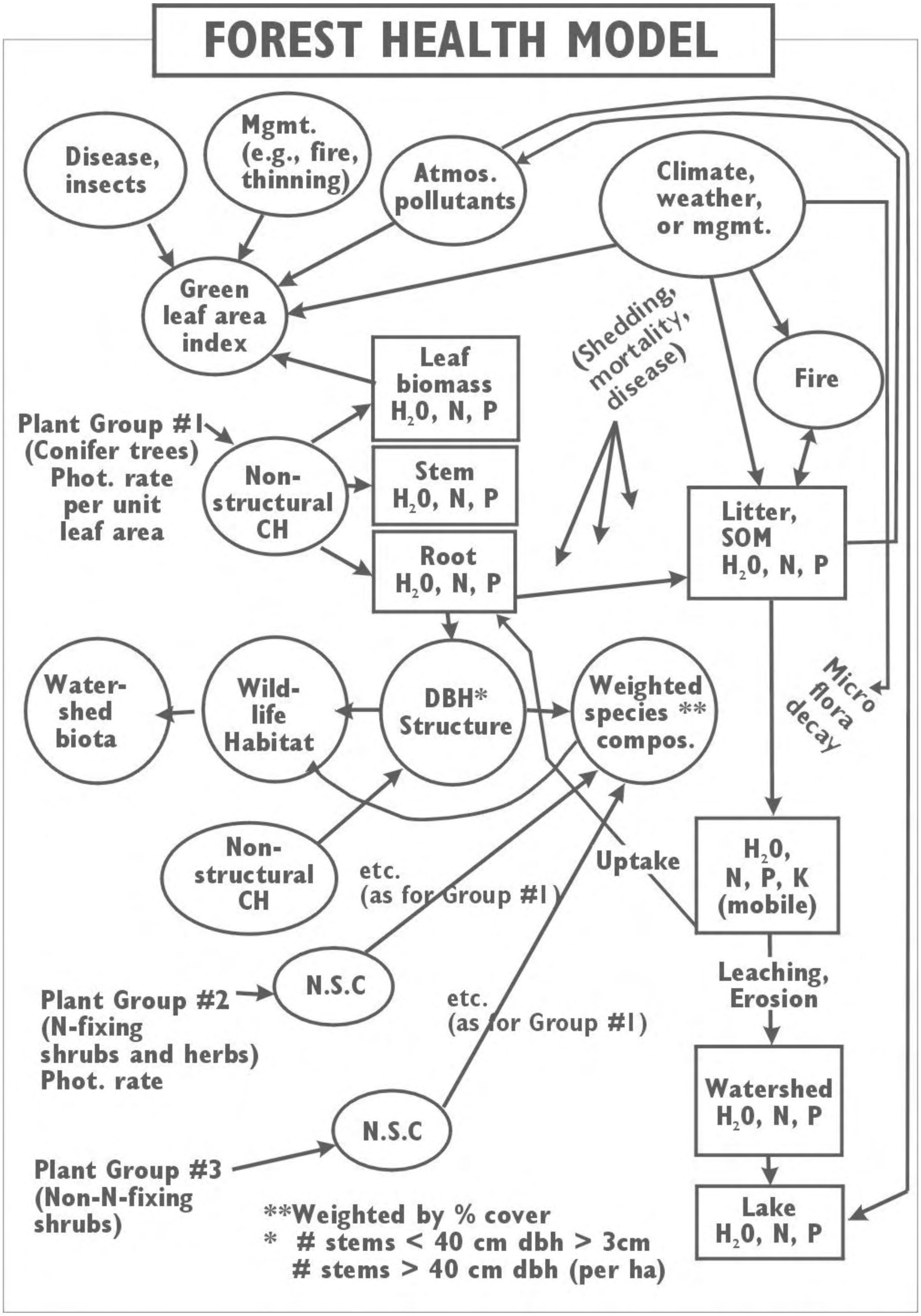


Figure 5-23—Conceptual forest health model.

Table 5-24—Elements that might serve as measurable surrogates for important ecosystem processes. The strength of connection between each element and each process is categorized as "strong," "moderate," or "weak."

Process	Strongly Linked Elements	Moderately Linked	Weakly Linked
Carbon cycling	litter producing, standing biomass	litter decomposition biomass accumulation (change in dbh)	
Nutrient cycling		nitrogen mineralization rate, C:N ratio	P availability, ratio of N uptake:loss by leaching
Disturbance by pests, insects, or pathogens	Incidence (% of trees with symptoms)	tree density and mortality by species and size class	densities of bark beetle or needle engraver beetles
Successional change in spp composition	Abundance or presence of tree, shrub, herb spp; diversity in microbial flora	mortality by species and size class, species richness, species diversity	
Successional change in vegetation structure	Growth form spectrum, tree diameter or age class distribution, seedling survival, shrub decadence	canopy cover, leaf area index, ratio of bacteria:fungi in isoil, tree mortality by size or age class	cone and seed production

concolor), can transmit root diseases faster than can a forest with a lower density of white fir.

The model further suggests that monitoring only three growth forms of plants—three functional groups—can be more effective than monitoring all the hundreds of individual species that occur in these forests. The three functional groups are as follows:

- Conifer trees, which dominate the biomass and create the microclimate for associated shrubs and herbs, therefore their choice as an important growth form to monitor is obvious;
- Nitrogen-fixing shrubs and herbs that modify the nitrogen cycle, enrich the soil, and speed recovery/succession from disturbance, including species in the genera alder (*Alnus*), loco weed (*Astragalus*), *Ceanothus*, mountain mahogany (*Cercocarpus*), *Lotus*, lupine (*Lupinus*), and bitterbrush (*Purshia*); and
- All other shrub taxa, important because they contribute a significant amount of cover (almost 20 percent) and they compete for soil moisture with conifer seedlings, saplings, and overstory trees. Most Sierran shrubs are capable of stump-sprounting after fire; hence, they survive both surface and catastrophic crown fires. In addition, the seeds of nonsprouting ceanothus shrubs are triggered to germinate after a fire by the heat having cracked their seed coats. Shrub dominance after a crown fire can be so extensive as to delay the regeneration and recovery of conifers.

All other growth forms, such as nonnitrogen-fixing herbs, vines, and broadleaf trees, contribute less than one percent of all plant cover; so even though they have high species richness, their impact on forested ecosystems is negligible. We caution, however, that total species richness and the change in abundance of any dominant individual species may be important and that these traits should not be lost by a complete focus on growth forms. Furthermore, functional groups other than the few identified above might turn out to be excellent surrogates for predicting ecological health or total biotic diversity—if we only knew more about them.

Issue 5: The Condition of Aquatic Ecosystems in the Basin

With contributions from Craig Oehrli, Jeffrey Reiner, Jennifer S. Hodge, J. Shane Romsos

Aquatic ecosystems in the Sierra Nevada have been severely degraded in the past two centuries (Moyle 1996), as evidenced by declines in native amphibians (Jennings 1996), fish (Moyle et al. 1996), aquatic invertebrates (Erman 1996), and interruptions in water availability (Kattleman 1996). Many of these changes in aquatic ecosystems have resulted from the introduction of exotic species, grazing, channel alteration, water diversions, and changes in water quality (Moyle 1996). Aquatic ecosystems provide vital habitat for a variety of plant and animal species, indispensable water sources, and important recreational opportunities for people. Although much of the focus on aquatic ecosystems in the Lake Tahoe basin has been on Lake Tahoe itself, an assessment of the status of all of the basin's aquatic ecosystems will assist their preservation and sustainable use.

The following questions were addressed in relation to the condition of aquatic ecosystems:

- What aquatic ecosystems are there currently in the basin?
- How have aquatic ecosystems changed from historic times to the present?
- Which aquatic ecosystems are potentially imperiled or vulnerable to future imperilment in the basin, and what is the state of knowledge about these ecosystems?
- What data gaps were revealed in the process of assessing aquatic ecosystems?
- What monitoring, conservation, and research activities are most appropriate for the focal aquatic ecosystems identified?

What aquatic ecosystems currently occur in the basin?

We used a modified version of Moyle's (1996) aquatic habitat classification scheme to identify and describe the types of aquatic environments occurring in the Lake Tahoe basin. Moyle (1996) identified 66 aquatic types in the Sierra Nevada, which fell into two broad categories: lotic (flowing water) and lentic (standing water) types. His classification divided the Sierra Nevada into two geographic areas: the Sacramento-San Joaquin Province (western slope of the Sierra Nevada; 28 types), and the Great Basin Province (eastern slope of the Sierra Nevada; 38 types). The Lake Tahoe basin is on the eastern slope of the Sierra Nevada, and Moyle (1996) considered Lake Tahoe part of the Great Basin Province. Therefore, we used the Great Basin Province classification to identify aquatic types in the basin, adding the categories of marshes and wet meadows. These two additional aquatic environments contribute significantly to the diversity of aquatic and terrestrial biota in the Lake Tahoe basin.

Many of the aquatic types recognized by Moyle (1996) are defined based on physical conditions and associated biota. Because aquatic ecosystems in the basin have not yet been fully classified, we used our local knowledge of the aquatic ecosystems in the Lake Tahoe basin to identify the types occurring in the basin. Our local knowledge of lotic ecosystems was significantly enhanced by reference to classification data obtained for 36 streams in the basin (USDA, unpublished data) using methods developed by Hawkins et al. (1993), Montgomery and Buffington (1993), and Rosgen (1995).

We identified 17 aquatic ecosystems in the Lake Tahoe basin: nine types of lotic aquatic ecosystems and eight types of lentic aquatic ecosystems (Table 5-25). Lotic aquatic types range from alpine snowmelt streams to small forest or meadow associated streams to large mainstem rivers. Lentic aquatic types range from fens and bogs to small ponds and lakes to Lake Tahoe. The Lake Tahoe basin hosts representatives of almost 45 percent (17 of 38) of all the Great Basin aquatic types. Although we did not have data on the diversity of types in other similarly sized areas in the Sierra Nevada, it appears that the Lake Tahoe basin contains a relatively high diversity of aquatic types for its area and thus contributes significantly to the diversity of Great Basin aquatic types in the Sierra Nevada.

Table 5-25—Aquatic ecosystems of the Lake Tahoe basin, with descriptions adapted from Moyle's (1996) classification for the Great Basin Province (GBP; "C" numbers) and their approximate equivalents in the Sacramento-San Joaquin Province (SSJP; "A" numbers). Examples in the Lake Tahoe basin are included.

Type Name	GBP number, SSJP number	Description	Examples in the basin
Lotic ecosystems			
Spring	C2213 A2413	Springs have constant temperature and flow, fine substrates and clear water and can support unusual/endemic invertebrates. Several unite to form a meadow stream.	Fountain Place in the Cold Creek drainage
Alpine snowmelt stream	C2110 A2110	Small, exposed, high gradient streams mainly above the timberline that exist only when snow is melting.	Fourth Creek Jabu Creek
Alpine stream	C2212 A2411	Most streams above 3,000 m elevation contained no fish until various salmonids were introduced in the late 19th century. Originally dominated by aquatic insects and amphibian larvae.	Round Lake Tributary Upper Truckee River
Conifer forest snowmelt stream	C2120 A2120	Small intermittent streams in conifer forest areas that also exist primarily when snow is melting but whose flows are enhanced by seepage from bogs and meadows. Occasionally important as spawning areas for trout (*Oncorhynchus* spp.).	North Fork Ward Creek
Meadow stream	C2215 A2414	First or second order streams through alpine meadows, low gradient with sinuous or braided channel. Where not heavily grazed, abundant frogs. May have introduced trout populations.	Burton Creek
Trout headwater stream	C2310 A2421	Small alpine streams with meadow systems; originally containing Lahontan cutthroat (*Oncorhynchus clarki henshawi*) or Paiute cutthoat (*O. c. seleneris*) but now usually containing nonnative trout.	Upper Blackwood Creek
Forest stream	C2214 A2412	Second or third order streams in fir, pine, or deciduous forest areas that are too small or too high in gradient to support fish.	Upper Saxon Creek
Stream with trout	C2331 A2422	Coldwater streams containing the typical Lahontan fish community (5-6 species, including Lahontan cutthroat trout).	Lower Meeks Creek
Mainstem rivers and their larger tributaries	C2350 A2441	Large streams that contain complete Lahontan fish fauna, including mountain whitefish (*Prosopium williamsoni*) and large adults of cutthroat trout and Tahoe sucker (*Catostomus tahoensis*). Cutthroat trout are now replaced by nonnative species.	Lower sections of the Upper Truckee River

Table 5-25—*(continued)*

Type Name	GBP number, SSJP number	Description	Examples in the basin
Lentic ecosystems			
Fen	C1241 A1290	Minerotrophic, spongy, spring fed peaty areas located on hillsides and dominated by nonsphagnum mosses and sedges.	Unknown
Sphagnum bog	C1242 A1280	True bogs containing marshy vegetation, including carnivorous plants and ranid frogs.	Grass Lake
Wet meadow	-	Seasonally flooded wetlands where standing water is usually present during the late fall, winter, and early spring and where the water table often drops below the surface during the summer and early fall. Grasses, rushes, and sedges are dominant plants (Caduto 1990).	Burton/Antone Meadows
Marsh	-	Wetlands where standing water, generally less than 2 m, exists year-round, except in the shallower areas during late summer or unusually dry years. Marshes may support the growth of emergent plants, such as cattails, bulrushes, reeds, and sedges, as well as many floating and submergent plants (Caduto 1990).	Pope Marsh
Mountain pond	C1120 A1152	Shallow (<1.5 m deep) ponds or small (<1 ha) lakes in alpine areas that periodically dry up, freeze solid, or become deoxygenated in winter; often associated with meadows or cirques.	Glacial tarns in the Desolation Wilderness
Alpine lake/pond without native fish	C1210 A1210	Small, usually isolated, oligotrophic lakes in high mountain areas usually formed by glaciers or in cones of volcanoes.	Triangle Lake
Alpine lake/pond with native fish	C1311 -	Oligotrophic, permanent lakes with connections to streams with fish.	Cascade Lake Fallen Leaf Lake
Lake Tahoe	C1312 -	A large, deep, extraordinarily clear lake containing complex fish fauna and unusual deep water invertebrates.	Lake Tahoe

How have aquatic ecosystems changed from historic times to the present?

Historical data on changes in environmental conditions are incomplete, but some contemporary accounts contain descriptions that allowed us to infer general trends in ecosystem conditions. Chapter 2 provides a detailed account of environmental and cultural changes in the Lake Tahoe basin over the past 150 years. Here we summarize those changes most relevant to the status of aquatic ecosystems. The majority of the discussion regarding the introduction of exotic species is in Issue 7 and discussion of introductions of fish to Lake Tahoe is in Chapter 4. We describe changes in the condition of aquatic ecosystems and their associated species over the four major periods established in Chapter 2: Prehistoric Era (pre-1860), Comstock Era (1860 to 1900), Post-Comstock Era (1900 to 1960), and Urbanization Era (1960 to present).

Prehistoric Era

From historic accounts, it appears the Washoe people, the only human inhabitants of the basin during this period, had minor effects on environmental conditions in the basin. Elliott-Fisk et al. (1997) suggest that the Washoe used advanced horticultural practices (such as burning, weeding, pruning, copicing, and selective plant harvesting) that could have affected the distribution and characteristics of meadows. It is generally accepted that aquatic ecosystems functioned naturally, with relatively little manipulation by humans (Nevers 1976; Strong 1984).

Comstock Era

Wetlands, meadows, and forest floors throughout the basin were severely affected by grazing animals during this era (McKelvey and Johnston 1992). The Washoe stated that livestock grazing in the basin damaged many plants important to them (Elliott-Fisk et al. 1997). Not only did sheep denude the landscape of grasses, shrubs, and riparian vegetation, but sheepherders burned extensive areas, especially targeting large downed logs, to promote regeneration of forage and to facilitate movement of sheep through the forest. Sudworth (1900) described the basin at the end of this era: "There are practically no grasses or other herbaceous plants. The forest floor is clean. . . . [I]t is evident that formerly there was an abundance of perennial forage grasses throughout the forest in this territory. . . . [I]t would seem that this bare condition of the surface in the open range has been produced only through years of excessive grazing by millions of sheep—a constant overstocking of the range."

During the Comstock Era, many land use practices contributed to the degradation of water quality in both lakes and streams and to the creation of unnatural bodies of water. At least two-thirds of the basin's forests were clear-cut (see Chapter 2); clear-cutting and uncontrolled grazing probably caused the discharge of heavy loads of sediment into regional water bodies (Elliott-Fisk et al. 1997; Heyvaert 1998). In addition, Strong (1984) noted that it was common to dump sawmill waste, such as sawdust, directly into streams and Lake Tahoe. Heyvaert (1998) estimated that sediment deposition rates into Lake Tahoe increased between seven- and 12-fold during this era compared to predisturbance deposition rates. Streams and lakes throughout the basin, such as Marlette and Spooner lakes, were dammed and diverted to maintain a supply of water to logging flumes (Strong 1984; Landauer 1995). This practice created artificial water bodies and changed water levels in existing water bodies such that lowland vegetation and riparian communities were presumably converted to aquatic systems. Some historians speculate that the diversion of streams and the deposition of large quantities of sediment and silt in streams and lakes were partially responsible for the decline of native trout (Scott 1957; Gerstung 1988; Elliott-Fisk et al. 1997).

The depth and clarity of Lake Tahoe's waters were first measured in 1873, and the best uses of Lake Tahoe began to be discussed during this era. John LeConte estimated that Lake Tahoe was between 900 and 1,645 feet deep and measured its clarity using a dinner plate at 108 feet (Landauer 1995). In the 1870s, the first dam on Lake Tahoe was built at the Truckee River outlet, and its use was debated by local residents (Landauer 1995). The dam raised the lake's water level by 2 meters (6 feet) (Elliott-Fisk et al. 1997). Raised lake levels may have altered the dynamics of marshes surrounding the lake and new shoreline inundation probably changed the distribution of riparian-associated plants.

Post-Comstock Era

Specific descriptions of the condition of wetlands from 1900 to 1960 are not available, but contemporary accounts (James 1915, and others in Strong 1984; Landauer 1995) provide some indication of their condition during this era. Grazing was still common in meadows and probably occurred to some extent on wetlands or along their edges (Barnett 1999; Pepi 1999). Rowland's Marsh (currently known as Pope and Barton marshes and the Tahoe Keys in South Lake Tahoe) originally occupied approximately 1,300 acres at the mouth of the Upper Truckee River and extended 4.3 km (2.6 miles) along the shoreline of Lake Tahoe (Landauer 1995). Photographs of Rowland's Marsh taken in 1930 show an extensive and virtually unfragmented meadow/wetland system (Orr and Moffitt 1971). Many bird species associated with wetlands and meadows were recorded in Orr and Moffitt (1971) during the first half of the twentieth century, suggesting that these areas provided valuable bird habitat in the basin.

During the latter part of this era, the basin's streams again began to experience excessive nutrient loading, this time from excess effluent rather than from erosion and run-off caused by logging (Strong 1984). Throughout the 1940s and 1950s, development put more pressure on the basin's limited sewage disposal system. Sewage effluent was sprayed directly onto the land in many watersheds and subsequently was released into the basin's streams and lakes (Strong 1984).

During this era, controversy arose regarding the fate of the waters of Lake Tahoe itself. Appropriation of "excess" waters from Tahoe for hydroelectric power and reclamation projects in Nevada (necessitating a varying lake level) seemed incompatible with the desire of resorts and navigation interests to maintain a constant high lake level for the tourist industry (Landauer 1995). Landauer (1995) recounts the events surrounding the appropriate use of Lake Tahoe's water, as summarized here. In 1913 the original dam on the lake's outlet at Tahoe City (built in the 1870s) was replaced with a more modern version by a power syndicate supported by the US Department of the Interior. A crisis occurred in 1924 when the lake level dropped so low that no water could leave the lake to supply Nevada farmers with water via the Truckee River. Negotiations led to the construction of Boca Reservoir and the development of alternative supply strategies (specified in the Truckee River agreement of 1934). In 1930 and 1931, at least 20,000 acre-feet of water were drawn from the lake to supplement Nevada's water supply during a drought. In 1955, Congress established a California/Nevada Interstate Compact Commission to determine the most appropriate use of local water. The conflict was not resolved for many years.

Urbanization Era

Wetlands and meadows experienced rapid change from 1960 to the present. Since the mid 1900s, approximately 75 percent of marshes and 50 percent of meadows have been degraded, and around 25 percent of the basin's marshlands were developed between 1969 and 1979 (Western Federal Regional Council 1979, cited in Elliott-Fisk et al. 1997). The Tahoe Keys development, for example, filled, fragmented, and highly altered 750 acres of the once intact Rowland's Marsh (Landauer 1995). The marsh remains the largest extant marsh in the Lake Tahoe basin, but its reduced size limits habitat for species uniquely associated with marshes in the basin, and there are concerns that the hydrologic function of the remaining marsh has been compromised by the Tahoe Keys development (Strong 1999).

Concern for the basin's water quality has steadily increased since the 1960s, as research continues to reveal the impacts of urban pollution, particularly sewage and runoff, on the basin's watersheds and on Lake Tahoe itself (Goldman 1989). Most sources of pollution have long-lasting effects; in the 1970s, Heavenly Creek still carried 60 times the nutrient load of Ward Creek five years after sewage effluent was no longer released around Heavenly Creek (Strong 1984). To address these problems, the TRPA announced a set of environmental thresholds in 1982 that were designed to control nutrient loading and other damage to Lake Tahoe's natural resources (TRPA 1982).

In the 1980s and 1990s, numerous erosion control and stream restoration projects were undertaken. In 1988 the USDA Forest Service began restoring 11 square miles of the watershed at Blackwood Canyon on the west shore and an area at Cold Creek (Landauer 1995). Since the early 1980s, the Burton-Santini program has attempted to purchase and restore environmentally sensitive lands, especially wetlands and sites of significant erosion (Elliott-Fisk et al. 1997). In addition, at least 65 acres of disturbed wetlands had been restored by the Forest Service by 1996, and many other agencies were actively involved in similar efforts (Elliott-Fisk et al. 1997).

Several lakes and reservoirs in the basin were altered in the Urbanization Era; for instance, several dams were built at lake outlets. Spooner Lake, the second largest lake on the east shore, was drained and refilled in the winter of 1996 in an effort to enhance its suitability for trout and improve the sport fishery. Water from lakes and reservoirs is available for fire suppression efforts and construction projects on National Forest System lands (Organic Act 1897), and is frequently used for such purposes in the Lake Tahoe basin (Derrig 1999), having unknown effects on biological integrity. However, other lentic systems are in the process of being restored, such as the large wet meadow near the mouth of Snow Creek (Insera 1999).

Synthesis of Historical Changes in Aquatic Ecosystems

The aquatic ecosystems of the Lake Tahoe basin have undergone a significant transformation since the arrival of Euroamerican settlers in the 1850s. As with other areas within the Sierra Nevada, the basin was viewed as an area rich in natural resources that were available for extraction. From 1860 until around 1900, uncontrolled sheep grazing virtually eliminated all grass and herbaceous cover throughout the basin, and rivers and creeks were diverted and degraded by logging, grazing, and development. Stocking Lake Tahoe and naturally fishless lakes with exotic fish began in the Comstock Era and continues today. As the mining and timber industries simultaneously declined toward the turn of the century, tourism developed into the base of the region's economy. Increasing settlement in the basin led to reduction in the area of marshes and an increase in the manipulation of aquatic ecosystems (e.g., through draining and damming). Stream channels were altered in various ways over time, with the greatest manipulations occurring during the Comstock and Urbanization eras. During the Urbanization Era, some aquatic ecosystems have been restored.

Implications for Biological Integrity

Alterations to aquatic ecosystems have almost certainly reduced biological integrity in the basin. Probable impacts to aquatic biota include competition from and predation by introduced species, disruption of movement patterns due to stream channel alterations, and habitat loss from increased sedimentation resulting from riparian grazing. Below, we address some specific examples of these phenomena and their likely consequences for biological integrity.

Probably the single greatest impact to biological integrity in the Lake Tahoe basin in recent years was the conversion of much of Rowland's Marsh to the Tahoe Keys. Marshes are among the most diverse and productive ecosystems in California (Kramer 1988) and in the basin, and their destruction represents a staggering blow to biodiversity. Very likely, all of the basin's waterfowl species used the marsh to some degree in the past (see Orr and Moffitt 1971), and all portions of the marsh provided habitat for countless other vertebrates, invertebrates, and plants. The loss and fragmentation of the basin's largest marsh, though not known to have directly caused the extirpation of any species, certainly engendered declines in biodiversity.

Other, more subtle, changes in biological integrity undoubtedly have resulted from the alteration of other lentic ecosystems in the basin. Pond draining has reduced local biological integrity by obliterating aquatic habitat, especially on the east and north sides of the basin, which historically contained relatively few lentic ecosystems. Introductions of exotic trout, bullfrogs (*Rana catesbeiana*), crayfish (*Pacifastacus leniusculus*), and opossum shrimp (*Mysis relicta*) have very likely negatively affected many native fish, amphibian, and invertebrate species through competition and predation. Declines in biological integrity in lotic ecosystems in the basin have been primarily caused by the construction of dams and diversions and the manipulation of riparian vegetation. Dams and diversions have doubtless had impacts on stream fish and invertebrates by preventing daily and seasonal movements and by facilitating increased human recreation (Moyle et al. 1996; Erman 1996). Sheep and cattle grazing in riparian areas has caused sedimentation, reduced vegetative cover, and accelerated the erosion of stream banks (Moyle et al. 1996). Sedimentation caused by grazing and timber harvest has probably adversely affected invertebrates (and likely other animals and plants) by reducing available habitat, inhibiting respiration, and obstructing feeding (Erman 1996).

Several human activities may cause further declines in biological integrity in aquatic ecosystems in the basin. Exotic species continue to negatively affect aquatic communities composed of native species (Jennings 1996; Moyle 1996; Moyle et al. 1996), particularly in lentic systems. Small dams represent a chronic, though perhaps minor, disturbance, sometimes altering flows and movements of biota (Moyle et al. 1996). Grazing may continue to degrade meadow systems and cause more damage to streams in the basin. Finally, several activities in and around lentic systems, such as heavy recreational use and removal of water for fire suppression or road construction, may become problems unless restricted.

Which aquatic ecosystems are potentially imperiled or vulnerable to future imperilment in the basin, and what is the state of knowledge about these ecosystems?

In general, conservation efforts have a dual focus: protect communities and ecosystems of concern and interest and protect species of greatest concern and interest (Noss and Cooperrider 1994). Terrestrial ecosystems of concern have been discussed earlier in this document; we identified 'focal' aquatic ecosystems for the Lake Tahoe basin to address aquatic ecosystems of concern. Ecosystems of concern are generally ones that are rare, that have been degraded by human activity, or that are poorly protected. Our focal aquatic ecosystems represent ecosystems we determined to be potentially imperiled or vulnerable to future imperilment according to their rarity, degree of disturbance, and level of existing protection. Aquatic ecosystems with particularly high ecological value are addressed in Issue 6.

Methods Used to Assess Aquatic Ecosystems

We used Moyle's (1996) aquatic habitat rating approach to determine the status of aquatic ecosystems in the Lake Tahoe basin. Moyle (1996) rated the status of each aquatic type for the entire Sierra Nevada by three criteria: rarity, degree of disturbance, and level of existing protection (Table 5-26). The overall status, based on the sum of the ratings for each criterion, was interpreted as one of four conditions: secure, special concern, threatened, or imperiled (Table 5-27).

The assessment of lotic types was based on empirical data on stream habitat and watershed characteristics within the basin. Data on channel characteristics were gathered by the U.S. Forest Service (unpublished data) from 1989 through 1997 using methods developed by Hawkins et al. (1993), Montgomery and Buffington (1993), and Rosgen (1995). Data on the characteristics of the 36 streams classified in the basin were useful for assessing of the condition of watersheds throughout the basin. The assessment of lentic types was based on digital USGS 1:24,000 topographic feature maps, which displayed the distribution of lentic units, considerations of geology for identification of potential sites for some types, and qualitative local knowledge.

The status of aquatic types was evaluated by orientation (north, south, east, and west) within the basin, as well as across the entire basin (Figure 5-24; Appendix B). The linear and circular landscape of the basin (a thin belt of land between Lake Tahoe and the crests), the diversity of climatic conditions, and the variation in levels of past and present disturbance within the basin has created a different set of conservation concerns and priorities for each orientation. A level of confidence in the ratings was assigned to reflect the state of knowledge regarding the three criteria for each aquatic type (Appendix B).

We ranked lentic and lotic types in order of decreasing concern based on the average of the status values (the sum of values across the three criteria) across all orientations (Table 5-28). The three lotic types of highest concern were mainstem rivers, meadow streams, and forest streams. The three lentic types of highest concern were marshes, fens, and alpine lake/pond with native fish. Across all aquatic types, only mainstem rivers received the rating of highest concern, "imperiled." This rating highlights the rarity and vulnerability of the Upper Truckee River. No other lotic types received the top two concern ratings. A large proportion of types (29 percent) were rated as threatened, the second highest level of concern, and all of these types were lentic types. Nearly 50 percent of the types were rated as of

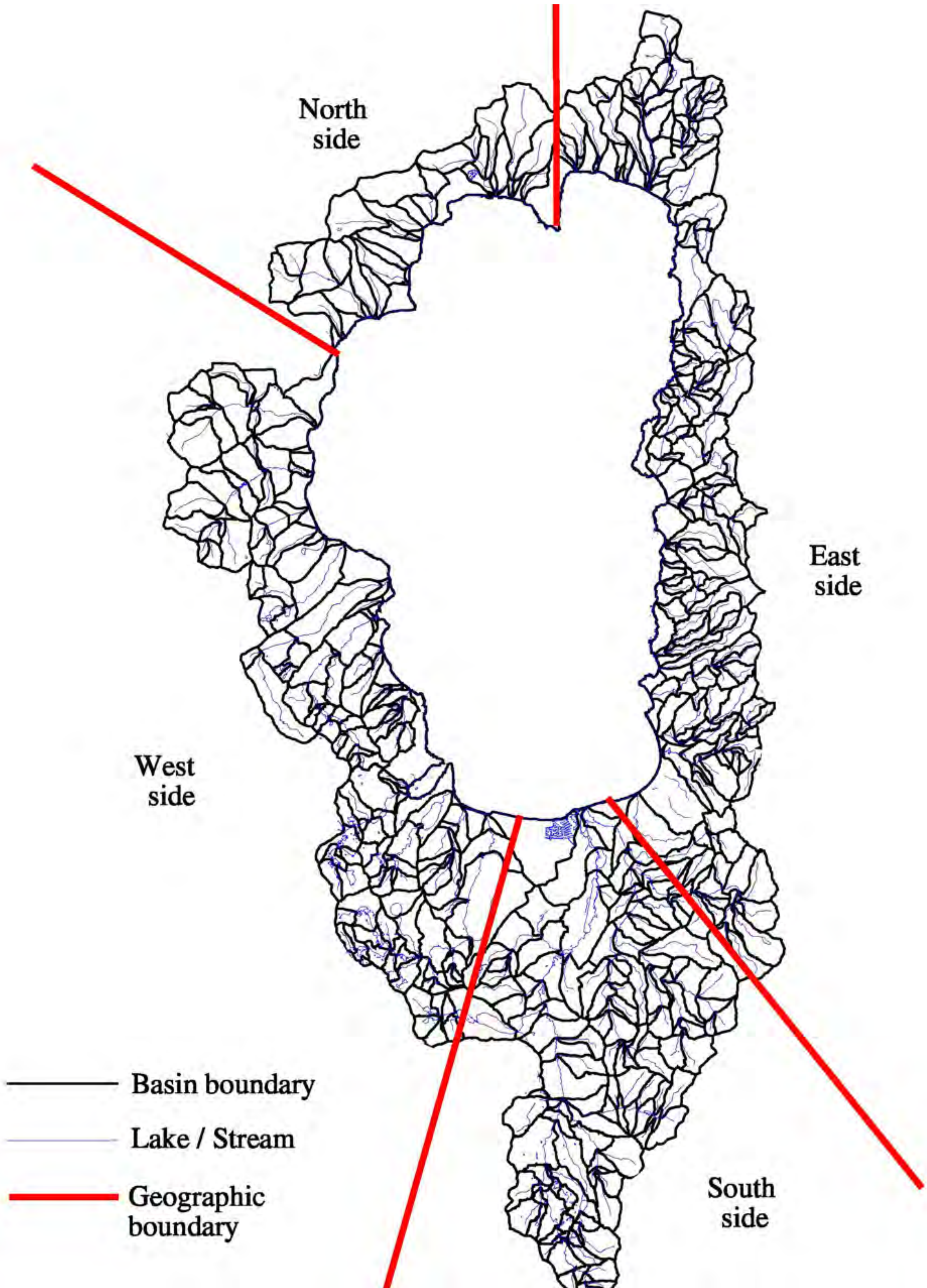


Figure 5-24—Division of the Lake Tahoe basin into four orientations for assessment of the status of aquatic ecosystems.

Table 5-26—Aquatic habitat rating criteria (adapted from Moyle 1996).

Rating	Value	Description
Rarity:		
Absent	0	Does not exist in a particular basin orientation (N,E,S,W)
Unique	1	Only one or two examples exist
Rare	2	Probably only 2-5 examples exist, or a formerly common habitat type in which most examples have been irreversibly altered
Unusual	3	Scattered or infrequent examples exist
Common	4	Examples easy to find
Widespread	5	A major existing habitat type
Disturbance:		
Very high	0	All known examples highly disturbed, not recoverable
High	1	All known examples highly disturbed/altered but some are recoverable to a defined desirable state
Moderate to high	2	All known examples moderately to highly disturbed or altered but most are recoverable
Moderate	3	Most examples disturbed but some relatively undisturbed examples exist, or all known examples moderately to lightly disturbed (recoverable with minimal effort)
Moderate to low	4	Fairly even mixture of disturbed and relatively undisturbed areas or all known examples lightly disturbed
Low	5	Most examples in good condition (relatively undisturbed)
Existing protection:		
No protection	1	No known examples in protected areas (e.g., National Park, wilderness area, research natural area)
Limited protection	2	No known examples in protected areas; mostly on public land; may be just one or two protected examples
Partial protection	3	3-5 protected examples exist but most unprotected or a rare habitat type with partial protection
Moderately secure	4	Several protected examples, many with de facto protection because of such factors as location or a rare habitat type with de facto protection
Secure	5	Many examples in protected areas or with de facto protection or a rare habitat type in protected area

Table 5-27—Status rating system for aquatic ecosystem types (adapted from Moyle 1996).

Status	Sum of ratings	Description
Imperiled	1 to 3	Extirpated, likely to be extirpated, or at risk of significant loss of integrity if protective action is not taken
Threatened	4 to 7	Rapidly declining in abundance and quality
Special concern	8 to 11	Declining in abundance and quality, but many examples still exist or a habitat type with only one or two examples in existence
Secure	12 to 15	Widespread, with many examples in good condition

Table 5-28—Relative ranking of concern from high to low for lotic and lentic aquatic types in the Lake Tahoe basin.

Aquatic type	Average status score across all orientations	Basin-wide status
Lotic types:		
Mainstem river	2.25	Imperiled
Meadow stream	7.50	Special concern
Forest stream	8.50	Special concern
Spring	9.25	Special concern
Stream with trout	10.00	Special concern
Alpine stream	10.48	Special concern
Alpine snowmelt stream	11.25	Secure
Trout headwater stream	11.50	Secure
Conifer forest snowmelt stream	12.00	Secure
Lentic types:		
Marsh	5.00	Threatened
Fen	5.80	Threatened
Alpine lake/pond with fish	6.25	Threatened
Sphagnum bog	6.90	Threatened
Lake Tahoe	7.00	Threatened
Alpine lake/pond without fish	8.40	Special concern
Mountain pond	9.25	Special concern
Wet meadow	10.00	Special concern

Table 5-29—Average values for rarity, disturbance, and protection across all aquatic ecosystem types in the Lake Tahoe basin.

Evaluation criterion	Lentic types (n = 8)	Lotic types (n = 9)	All types
Rarity	1.75	3.06	2.53
Disturbance	2.38	2.81	2.64
Protection	3.13	3.32	3.24
Sum	7.25	9.19	8.42

special concern, the third highest level of concern, and most of these types were lotic. Finally, three aquatic types (18 percent) were rated as secure, the lowest level of concern, and all of these were lotic types.

The relative contributions of the three criteria--rarity, disturbance, and level of protection--to overall levels of concern were assessed (Table 5-29). Rarity was the greatest contributor to levels of concern for lentic types, then disturbance, and finally the level of protection. The three evaluation criteria contributed nearly equally to the overall status of lotic types in the basin. The level of concern for lotic types was nearly 30 percent greater than for lentic types, based on the sum of average values for all three criteria. Across all aquatic types, the same pattern emerged as for lentic types: rarity was the greatest contributor, followed by disturbance and protection.

We assessed the degree to which aquatic types were of concern by orientation in the basin. Aquatic ecosystems on the east side of the basin were of greatest concern, followed by the north, south, and west sides (Figure 5-25). Aquatic ecosystems were rarest on the north and east sides, and most disturbed and most poorly protected on the east side. Aquatic ecosystems on the west side of the basin were most common, least disturbed, and best protected. Although the south side of the basin includes the largest disturbed area (South Lake Tahoe), it also contains a large, relatively undisturbed region of the Upper Truckee watershed. Aquatic ecosystems were moderately disturbed overall on the south side. Across all basin orientations, aquatic ecosystems on the east side were of greatest concern (total score of 6.7), followed by north side ecosystems (7.6), south side ecosystems (8.5), and west side ecosystems (10.4).

The results of our analysis were consistent with historical patterns of land use in the basin, with the north and east sides being most affected and the west side being the least affected by human land use. The north and east sides of the basin were most affected by heavy logging during the Comstock Era and a variety of other human uses because of their proximity to more populated areas in the Carson Valley. In contrast, the west side of the basin had the most secure and least threatened ecosystems because of limited access to upper watershed areas, steep terrain, and the protection granted by the establishment of Desolation Wilderness in 1969. The south side of the basin has been subjected to a level of disturbance intermediate between that of the west and east sides because areas near the lake have been heavily affected by development, but most of the watershed area remains relatively undisturbed.

Finally, we examined the level of concern for aquatic types in the basin relative to the Sierra Nevada as a whole. Aquatic ecosystems appear, on average, to be at greater risk in the Lake Tahoe basin compared to the Sierra Nevada as a whole (Figure 5-26). A greater proportion of the basin's aquatic types was considered "imperiled" or "threatened" than was determined by Moyle (1996) for the same aquatic types across the Great Basin Province or the Sacramento-San Joaquin Province. The apparent greater imperilment of aquatic types in the Lake Tahoe basin compared to the provinces as a whole could be attributed to a couple of factors. First,

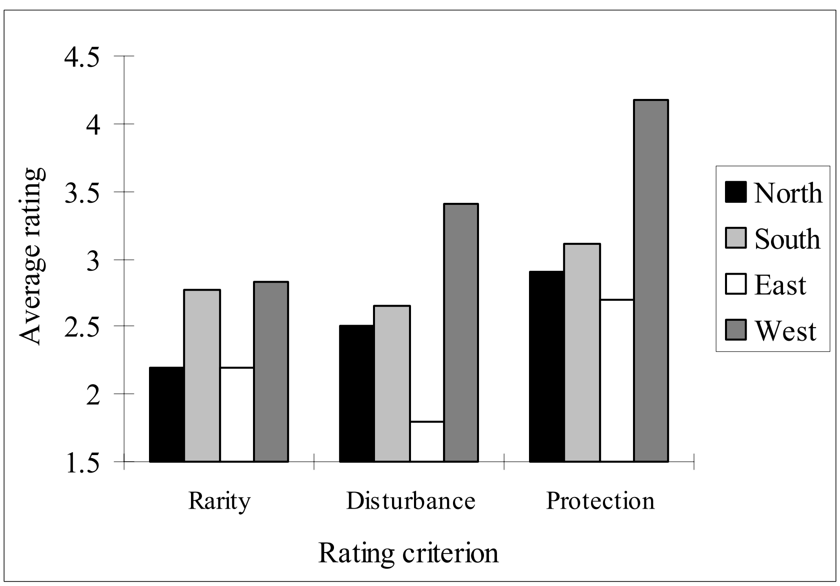


Figure 5-25—Average ratings for rarity, disturbance, and protection of aquatic ecosystem types in the Lake Tahoe basin's four orientations.

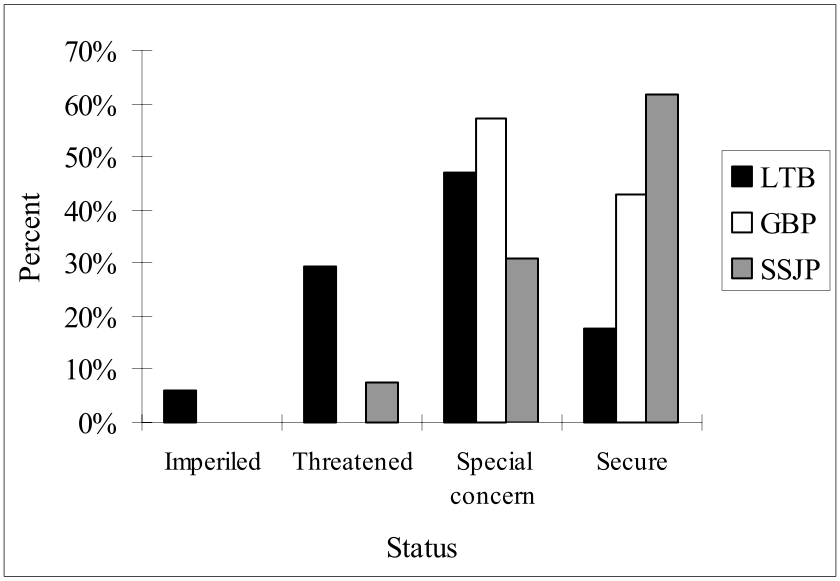


Figure 5-26—Status of aquatic habitat types in the Lake Tahoe basin (LTB), Great Basin Province (GBP) (Moyle 1996), and Sacramento-San Joaquin Province (SSJP) (Moyle 1996).

perhaps aquatic types in the basin are truly at greater risk of degradation or loss of biological integrity than they are in other locations in the Sierra Nevada. Second, smaller scale applications of this approach might yield a more sensitive assessment of aquatic ecosystem status. And third, perhaps we rated the status of types in the basin more conservatively than did Moyle (1996), erring on the side of higher concern. We suggest that the difference results from a combination of greater sensitivity of the approach at smaller scales and a truly greater risk to aquatic types in the basin. At a small geographic scale such as the basin, there are naturally fewer representatives of each aquatic ecosystem type. In addition, the relatively high diversity of types in the basin is expected to be accompanied by increased overall rarity (Brown 1995). Disturbance was the next highest contributor, after rarity, to the high rating of concern associated with aquatic types in the basin, particularly lentic types. The basin is one of the most highly visited locations in the Sierra Nevada, in addition to having a large resident population relative to the rest of the Sierra Nevada. The high human density and high value of aquatic environments as water sources and recreational environments have resulted in significant direct and indirect pressure on aquatic environments in the basin. These pressures are reflected in the disturbance ratings. We are relatively confident that aquatic ecosystems, particularly lentic types, are more imperiled in the basin than in the Sierra Nevada as a whole as a result of their rarity and their level of disturbance.

Focal Aquatic Ecosystems

We identified "focal" aquatic ecosystems to assist in focusing conservation, monitoring, and research efforts on the aquatic ecosystems of greatest concern. To identify focal aquatic ecosystems, we used the status ratings for each aquatic ecosystem type in each orientation (Appendix B). We did not identify specific aquatic ecosystems of cultural importance, as we did for species and populations (Issue 7, below) because we considered all aquatic ecosystems in the basin important to humans for subsistence and recreation. We used a hierarchical cluster analysis (SPSS 1993) on the 17 ecosystem types to identify focal aquatic ecosystems. The cluster analysis was based on ordinal ratings for rarity, disturbance, and level of protection for each type in each of the four orientations (Figure 5-27). For types not occurring in a particular orientation, we assigned a rarity value of "0" and disturbance and protection values equal to the average value for the orientations in which the type did occur. We performed the cluster analysis

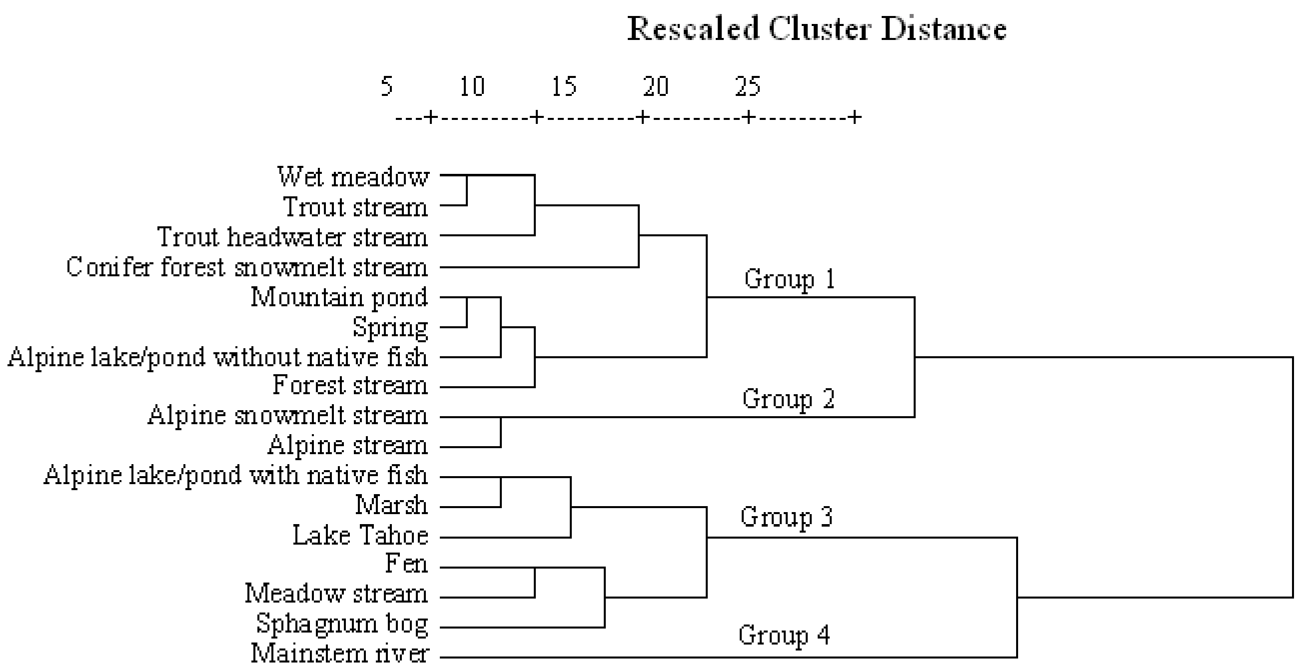


Figure 5-27—Dendrogram resulting from a hierarchical cluster analysis of 17 aquatic ecosystem types in the Lake Tahoe basin. Clustering was based on 12 variables—rarity, disturbance, and level of protection (Moyle 1996)—in each of four orientations in the basin: north, south, east, and west.

using between-groups linkage and the squared Euclidean distance measure (SPSS 1993).

We recognized four groups in the dendrogram resulting from the cluster analysis (Figure 5-27). Group 4 was determined to be of highest concern and consisted of one type (mainstem rivers). Members of Group 4 were present in a single orientation and were uncommon and highly disturbed (Table 5-30). Group 3 was determined to be of the second highest concern and consisted of six types, including meadow streams and most lentic types. Members of Group 3 were uncommon and disturbed in all orientations and were moderately well protected (Table 5-30). Group 1 was determined to be of the third highest concern and consisted of eight types, including wet meadows, mountain ponds, alpine lakes without native fish, and several lotic types. Members of Group 1 were relatively common, moderately disturbed, and moderately well-protected in all orientations (Table 5-30). Group 2 was determined to be of the lowest concern and consisted of two types: alpine snowmelt streams and alpine streams. Members of Group 2 were absent in the north and disturbed in the east, while being generally common, undisturbed, and well protected everywhere else (Table 5-30).

We identified the seven aquatic types in the two groups of highest concern (groups 3 and 4) as focal ecosystems (Table 5-31). In addition, we examined the level of concern by basin orientation for the remaining types, and included five additional types as focal in particular orientations (Table 5-31). Specifically, springs, forest streams, mountain ponds, and alpine lakes without native fish were uncommon and highly disturbed on the north and east sides of the basin, even though they were in the third lowest concern group over all orientations (Appendix B). Alpine streams were rare and highly disturbed on the east side, even though they were in the lowest concern group over all orientations (Appendix B).

Summary

Many aquatic ecosystems were determined to be of concern in the Lake Tahoe basin. In general, lentic types were of greater concern in the basin than lotic types. For lentic types and across all types, rarity was the greatest contributor to the level of concern, followed by disturbance and protection. For lotic types, the three criteria contributed similarly to the level of concern. Aquatic types were rarest on the north and east sides of the basin, with types on the east side being the most disturbed and poorly protected. Aquatic types on the west side of the basin were most common, least disturbed, and best protected. Further, aquatic ecosystems appear to be of greater concern in the Lake Tahoe basin than throughout the entire Sierra Nevada. This pattern is most likely due to the concentration of historic and present day patterns of human use and occupation of the Lake Tahoe basin relative to the rest of the Sierra Nevada. The integrity of aquatic ecosystems, as well as their abundance and distribution, have been shown to be extensively affected by human disturbance; many are in need of protection and restoration.

Accounts of focal aquatic ecosystems were intended to provide a synopsis of the state of knowledge for each ecosystem as a mechanism to assist in furthering appropriate activities in conservation, monitoring, and research. We developed two such accounts, for sphagnum bogs and fens and for the Upper Truckee River. If these accounts prove useful, we suggest that accounts be developed for the remaining focal aquatic ecosystems identified in this issue. We addressed a consistent set of topics in each account (Table 5-32). The accounts are in Appendix C.

What data gaps were revealed in the process of assessing aquatic ecosystems?

In assessing aquatic ecosystems in the basin, we discovered significant data gaps that hindered our evaluation. By identifying these data gaps, we hope to encourage inventory, monitoring, and research efforts that will provide these valuable data.

The lack of definitive information regarding the aquatic ecosystem types occurring in the basin was an obstacle to our assessment. Lotic and lentic types in the basin have not been extensively cataloged, and in several cases we relied on local knowledge of the basin to determine where certain

Table 5-30—Average rarity, disturbance, and protection for four groups resulting from a cluster analysis on 17 aquatic ecosystem types in the Lake Tahoe basin.

Cluster group	n	Average rarity	Average disturbance	Average protection	Average total rank	Level of concern
1	8	3.8	2.8	3.3	3.3	3rd highest
2	2	2.9	3.7	4.3	3.6	Lowest
3	6	1.0	2.2	3.2	2.1	2nd highest
4	1	0.3	1.0	1.0	0.2	Highest

Table 5-31—Focal aquatic ecosystems in the Lake Tahoe basin.

Focal aquatic ecosystem type	Cluster group	Level of concern	Priority orientation(s)
Mainstem river	4	highest	all
Alpine lake/pond with native fish	3	2nd highest	all
Lake Tahoe	3	2nd highest	-
Fen	3	2nd highest	all
Meadow stream	3	2nd highest	all
Sphagnum bog	3	2nd highest	all
Marsh	3	2nd highest	all
Spring	1	3rd highest	north, east
Forest stream	1	3rd highest	north, east
Mountain pond	1	3rd highest	north, east
Alpine lake/pond without native fish	1	3rd highest	north, east
Alpine stream	2	lowest	east

Table 5-32—General outline for aquatic ecosystem and Ecologically Significant Area descriptive accounts.

- General
  - Distribution in California, Nevada, and the basin
  - Source of data for the basin
  - Method of inventory
- Ecology
  - Key physical and biological characteristics (components, structures, processes)
  - Contribution to biological diversity in the basin
  - Geology, hydrology, soils
  - Successional stages
  - Response to natural disturbance
  - Research needs
- Effects of human activities (historic/current/anticipated)
  - Impacts of activities
  - Current management
  - Management objectives
  - Response to management scenarios
- Conservation
  - Current conservation
  - Conservation objectives
  - Potential conservation measures and priorities

aquatic ecosystem types occurred. For example, fens have not been documented and may not occur in the basin. For other types, such as marshes and wet meadows, it is likely that we have not fully inventoried their occurrence within the basin (USDA 1990). Incomplete inventories resulted in an incomplete accounting of types, and some sites valuable to overall ecological diversity may have been overlooked.

Similarly, our identification of focal aquatic ecosystems would have been improved by better information on the rarity and degree of disturbance of existing aquatic types. The lack of a thorough inventory of types introduced some uncertainty into our assessments of status, particularly in regard to rarity and disturbance. Our disturbance ratings, like Moyle's (1996), were based on local knowledge of the types and locations of disturbance and their relative impact on aquatic systems. Different disturbance agents cause different responses from and impacts to biological diversity. An assessment of disturbance factors acting on aquatic types requires better information about the status of disturbances, such as exotic species, recreation, grazing, timber harvest, and roads, and their interactions with populations of native species. This vital information, ideally based on field assessments, would greatly improve our ability to identify focal aquatic ecosystems and ultimately to develop more specific monitoring and conservation strategies.

What conservation, monitoring, and research activities are most appropriate for the focal aquatic ecosystems identified?

Appropriate monitoring, conservation, and research activities will vary among focal aquatic ecosystems based on the feasible alternatives for conservation, the level of interest shown by managers and the public, and the nature of the aquatic ecosystem. Here, we address general considerations and some specific opportunities for conservation, monitoring, and research regarding focal aquatic ecosystems and discuss basic inventory data needed to design these activities.

Prerequisite Inventory Data

The first step in monitoring and conserving the 12 focal aquatic types is to have an accurate inventory of their number and locations within the basin. With the exception of two aquatic ecosystem types (mainstem river and Lake Tahoe), information about the number and location of types is incomplete and imprecise. Distinguishing among types is an essential step in defining populations that then can be monitored and conserved meaningfully as a group. In addition, a basic inventory describing the number and location of types and some description of their level and type of disturbance is needed to facilitate and prioritize restoration planning.

Inventories can be accomplished in an efficient and cost-effective manner. Existing locations could be used to develop predictive models of environmental features with a high probability of association with these types. Surveys then could be conducted to confirm or reject the prediction of aquatic ecosystem occurrence. This approach would represent a relatively quantitative method of inventorying these types in the basin. As for the more common types, the inventory would consist of classifying the entire population of aquatic units into particular types. An adequately thorough inventory of all aquatic types within the basin probably would not require more than three individuals working for six months, using maps, aerial photo interpretation, and field verification.

Conservation

Conservation measures are an essential component of any strategy to maintain or improve biological integrity. The development of an Aquatic Conservation Strategy (ACS) for conserving aquatic systems throughout larger landscapes has been shown to be an effective mechanism for focusing efforts on priority actions (e.g., FEMAT 1993). Aquatic conservation strategies are essentially aquatic management plans. An ACS was developed for the Northwest Forest Plan (FEMAT 1993), and the USFS is currently developing one for the National

Forests in the Sierra Nevada. The development of an ACS for the basin would serve to bring various interests in the basin together to determine how best to maintain and restore biological integrity and to achieve ecological sustainability for aquatic ecosystems. This assessment has identified aquatic ecosystems that are most at risk or that have been degraded and need to be addressed directly in such a strategy. An ACS for the basin could contain detailed information, including commitments as to the nature, timing, location, and desired outcomes of management and conservation actions. Below we identify some of the key emphasis areas of consideration for inclusion in an ACS for the basin. We do not address conservation considerations for Lake Tahoe here, as they are covered in Chapter 4.

We identified three general types of conservation actions: awareness and education, measures to protect biological integrity, and restoration strategies. Awareness and education can be achieved in a variety of ways, including (but not limited to) concerns highlighted in such publications as this assessment, workshops, campfire talks, web sites, newspaper and radio media, school programs, research symposia, and public involvement in monitoring and conservation efforts. Measures to protect biological integrity include the implementation of actions intended to safeguard aquatic ecosystems or to mitigate impacts to them. Restoration options include measures to improve the quality or quantity of an aquatic ecosystem, including improving physical and biological conditions, restoring natural processes (e.g., fire and flooding), reducing human disturbances, and increasing the number of aquatic units (where feasible). Restoration activities would be warranted only when degradation of an aquatic unit is noted. Conservation of biological integrity will be most successful if all three types of conservation actions are employed.

Awareness and Education—Awareness and education efforts on behalf of aquatic ecosystems would likely be a very effective conservation activity. People value aquatic ecosystems for their aesthetic and recreational appeal. Key messages of an awareness and education effort could be the high ecological and cultural value of aquatic ecosystems, as well as the fragility and vulnerability of these systems, in the basin. An effective and mutually beneficial approach to awareness and education could be the involvement of the public in inventory, monitoring, conservation, and restoration efforts.

Measures to Protect and Restore Biological Integrity—The following types of measures would contribute toward maintaining, protecting, and restoring the biological integrity of focal aquatic ecosystems in the basin. Overall, needs for conservation are greatest for lentic types; however, needs for conservation are also significant for lotic types. The following is a short list of effective measures for consideration in inclusion in an ACS developed by management agencies; many other measures may be appropriate and could be considered for an ACS.

Lentic Types

1. Identifying specific concerns for focal lentic ecosystems by orientation, as well as specifying acceptable and unacceptable activities and management actions by lentic type and orientation. Restoration potential and recommendations for all focal lentic types could be analyzed as part of the ACS.
2. Limiting biological and physical manipulations of lentic types on the north and east sides to conservation and restoration-oriented activities.
3. Protecting and restoring the rarest of the focal lentic types, including sphagnum bogs, fens, marshes, and springs, in all orientations.
4. Minimizing disturbance in all focal lentic types. In general, the most common and powerful agents of disturbance in lentic types in the basin are exotic species, grazing, habitat loss, water diversions, and recreation pressure. A variety of less detrimental manipulations also may pose risks, such as siphoning and dams.
5. Categorizing and describing management activities that have positive, neutral, and negative effects for each focal type.
6. Prioritizing restoration efforts to address the most disturbed units that have the greatest potential to recover. The most disturbed lentic types (disturbance ranking $\leq$ 2) were marshes, fens, and alpine lakes with native fish.

7. Evaluating focal lentic types for the value and potential of eradicating nonnative species. For example, small populations of bullfrogs presently occur in a number of lakes that could serve as points of departure for the further spread of populations within the basin (Manley and Schlesinger, in preparation).
8. Removing nonnative species from focal lentic types where feasible. This includes removing nonnative trout from some units. Fish stocking is an action that has created much debate throughout the Sierra Nevada and elsewhere. Stocking nonnative trout has detrimental effects on many biota, including entire assemblages of aquatic biota (Jennings 1996; Moyle et al. 1996). However, it is an action that has strong public support because of the recreation benefits it confers. Some units of each focal lentic type in each orientation could be made exempt from fish stocking, thereby redirecting them toward other cultural values. The number and location of lentic units that are not stocked could be determined based on considerations of current uses, ability to eradicate existing nonnative trout, current level of biological integrity, and value to focal species of ecological concern. In those units selected for eradication of nonnative fish, other nonnative species also could be removed. Perhaps education could generate interest in a stocking program for native fish species. Specific recommendations on the restoration of populations of native species are addressed in Issue 7.
9. Protecting and restoring marshes within the basin—this is perhaps one of the most influential conservation efforts that could be undertaken on behalf of lentic biological integrity. Creation of the Tahoe Keys not only reduced the area of Rowland's marsh but also created a number of ecological problems in the remaining aquatic environments in and around the Keys. Mitigation measures are limited but could involve eradicating or controlling populations of such exotic species as bullfrogs, fish, and Eurasian watermilfoil (*Myriophyllum spicatum*). Improving or restoring hydrologic function in the remaining portions of Rowland's marsh (and also the Meeks wetland on the west shore) is a topic of much discussion and research by local agencies and universities and we do not address it here, other than to emphasize the importance of such restoration efforts to biological integrity in the basin.

Lotic Types

1. Limiting biological and physical manipulations of all lotic types on the north and east sides to conservation and restoration oriented activities.
2. Protecting the rarest of the focal lentic types, including the mainstem river, meadow streams, and alpine streams, by limiting biological and physical manipulations in all basin orientations to conservation and restoration oriented activities. A specific management plan for the Upper Truckee River (the mainstem river) would be a significant contribution to the ACS.
3. Directing restoration efforts at the most disturbed units that have the potential to recover. The most disturbed lotic types (disturbance ranking $\leq$ 3) were mainstem river, meadow streams, and streams with trout. These types are good candidates for priority restoration; restoration potential and recommendations for all focal lotic types could be analyzed as part of the ACS. In general, the primary sources of degradation in lotic types are dams, diversions, channelization, unmaintained dirt roads, and grazing. Dams and diversions serve to change the magnitude and frequency of flow and the hydrologic function of streams, while the remaining disturbances primarily increase sedimentation and can change channel geomorphology. Significant efforts by the USDA Forest Service already are underway to reduce the number of dirt roads in the

basin, with the intent of decreasing sedimentation loads within streams. Grazing impacts on focal lotic types need to be defined more fully, and mitigation or protective measures need to be identified.
4. Developing conservation measures for wet meadows. Although wet meadows are not a focal type, the integrity of these lentic types significantly influences the integrity of the lotic units with which they are associated. Wet meadows are subject to a number of disturbance factors, including grazing, mountain biking, and off-road vehicle use.
5. Evaluating and prioritizing the value of and potential for eradicating nonnative species from all focal lotic types.

Monitoring

Monitoring designed to describe the status of and changes in the integrity of aquatic ecosystems would provide a wealth of information about their current conditions, how their conditions are changing over time, and basic relationships between their conditions and the changing environment in which they occur. Developing a monitoring scheme entails identifying attributes to describe conditions and designing and implementing data collection and analysis. Monitoring attributes can consist of direct measures of condition as well as indirect measures that serve as indicators of integrity. Indicators can provide a strong signal about conditions with relatively few attributes. The notion of indicators has a long history in the ecological literature (see Griffith and Hunsaker 1994), but successes in using indicators are few. It appears worthwhile to attempt to identify indicators and to monitor their conditions on a trial basis, but it is premature to rely entirely on indicators before their value as a signal is confirmed (USDA Committee of Scientists 1999).

The development of a monitoring strategy would require a more careful evaluation of the potential attributes (both direct and indirect measures), an examination of the questions the attributes would address, and an evaluation of design options. Here, we make some general recommendations as to attributes that would directly measure aquatic ecosystem conditions. First, the monitoring program would need to determine whether all units of a given aquatic type need to be monitored (i.e., a census) or whether a sample can be monitored to represent the condition of all units. More imperiled aquatic types might warrant a census, whereas a sample might suffice for less imperiled aquatic types.

A strong approach to monitoring consists of a balance of physical, biological, and disturbance attributes for each unit selected for monitoring. First we address potential attributes for lentic types. We do not intend that these attributes to apply to Lake Tahoe (refer to Chapter 4 for monitoring considerations regarding Lake Tahoe). Physical attributes consist of abiotic conditions, such as surface area, volume, water chemistry, substrate, and cover. Biological attributes could include occlusion by aquatic vegetation, the relative abundance of various types of aquatic vegetation (e.g., submergent, emergent, and floating), and the presence of water-dependent vertebrate species, select indicator macroinvertebrates, and nonnative species. The high productivity of some lentic types, such as marshes, may justify a more thorough account of biological attributes, such as the relative abundance of taxa, to assess the extent of their contributions to biological diversity over time. Disturbance attributes could include intensity of grazing, presence of dams and diversions, the occurrence of draining, stocking, and pollution events, attributes of fishing and other recreational pressures, timber harvest, fire (prescribed, natural, and accidental), pollutants, and wholesale transformations of conditions.

Appropriate attributes to monitor for lotic types differ somewhat from those identified for lentic types. Physical attributes for lotic types could include changes in channel morphology, sediment transport, and deposition dynamics, water chemistry, temperature, and flow volume. Biological attributes would resemble those of lentic types, including the presence of aquatic vegetation of various types, water-dependent vertebrate species, and select indicator macroinvertebrates. Disturbance attributes for lotic types could include the occurrence of channel alterations and pollution events and attributes of fishing and other recreational pressures.

In addition to monitoring directed toward tracking trends in the biological integrity of focal aquatic types, it would be prudent to track the fate of nonfocal aquatic types, perhaps at a lower level of investment. We identified aquatic types of greatest concern, but few of the remaining types are secure, and their status could decline. Monitoring nonfocal types could be restricted to basic physical attributes, a few biological attributes, and some simple measures of disturbance. Sample sizes and frequency of visits to nonfocal types could be limited to reduce the level of investment in monitoring. A more detailed evaluation of appropriate attributes for all types would need to be conducted to make final selections for monitoring.

Finally, monitoring the success of protective and restoration measures would be highly beneficial. In the context of monitoring, this entails tracking the conditions of individual sites. A complementary research component could entail sampling a number of sites representative of all treatments of a given type and evaluating the treatment's overall effectiveness.

Research Opportunities

The development of an ACS by management agencies will require the involvement of researchers and managers, and it will help to identify priority research opportunities. In general, research should be targeted toward the most crippling of information gaps. In addition, research questions related to the influence of various management actions, such as prescribed fire and timber management, particularly where they appear to have opposing effects on two or more desired outcomes, are a high priority investment in terms of investigating cause-effect relationships.

A few specific research opportunities surfaced in the course of assessing aquatic ecosystem conditions in the basin. The research opportunities identified here represent some activities that could contribute substantially to the conservation of aquatic ecosystems in the basin. They are not intended to represent a comprehensive list of research needs and opportunities.

1. We need to determine the influence of various types of disturbance (e.g., grazing, roads, and prescribed fire) on the biological integrity of lentic and lotic ecosystem types.
2. We need to understand the potential threat of nonnative trout to the successful reintroduction of mountain yellow-legged frogs and native fish to lotic and lentic units in the basin.
3. We need to develop reference conditions for biological diversity in lentic and lotic types.
4. We need to develop and test indicators for monitoring the biological integrity of aquatic ecosystem types.
5. We need to evaluate the effectiveness of various management and conservation measures.
6. Modeling potential "habitat" for rare aquatic types such as bogs, fens, and springs would be beneficial.
7. We need to assess the relative effectiveness of various control measures for Eurasian watermilfoil.
8. Modeling potential habitat for each amphibian species would be beneficial.

Issue 6: The Need to Understand the Identity and Condition of Ecologically Significant Areas in the Basin

With contributions from J. Shane Romsos

Conservation efforts often consist of a dual approach: (1) protect communities and ecosystems of greatest concern and interest and (2) protect species of greatest concern and interest (Noss and Cooperrider 1994). A few criteria have been frequently recommended in the evaluation of priorities for the conservation of communities and ecosystems (Margules and Usher 1981; Kirkpatrick 1983; Soule and Simberloff 1986; Margules et al. 1988; Noss and Cooperrider 1994). These commonly applied criteria, listed here, represent a mix of high ecological value and vulnerability to loss.

- Rarity—communities and ecosystems that naturally occur infrequently or that are uncommon in a given geographic area;

- Area—sites where a community or ecosystem occupies an unusually large area, such as Lake Tahoe;
- Naturalness—sites where a community or ecosystem type has experienced minimal human disturbance, thus having a full complement of native species, intact natural disturbance regimes, and no or few exotic species;
- Representativeness—a suite of sites that together represent a full assortment of community types characteristic of a geographic area or areas that represent the diversity that exists at a number of levels of organization, such as genes, individuals, species, habitats, ecosystems, and landscapes;
- Biological diversity—sites that are extraordinarily high in biological diversity based on native species richness, endemism, and community diversity; and
- Threat of impacts from human activity—communities in imminent danger because of degradation of biological integrity or wholesale loss of area from harvest, development, or recreation.

We identified some Ecologically Significant Areas (ESAs) in the Lake Tahoe basin based on three of the criteria listed above: minimal human disturbance (naturalness), rarity, and biological diversity. The remaining criteria would have required time and resources beyond the scope of this assessment, but would be valuable to apply to the identification of ESAs in the basin. Our purpose in identifying ESAs was to highlight "hotspots" of diversity, rarity, or uniqueness at the organizational level of communities and ecosystems. In some cases, the species associated with ESAs may also be rare or unique, but they were not the impetus for ESA designation. The location and habitat associations of potentially imperiled, vulnerable, or culturally important species are discussed in Issue 7, where the organizational level of species and populations is addressed. Here, we address the uniqueness of community and ecosystem types, both in terms of their physical conditions and biological assemblages.

This issue addresses the following questions:

What are some of the most ecologically unique and biologically intact environments and areas in the basin, and what is the state of knowledge about these areas?

What data gaps were revealed in the process of assessing ecologically significant areas?

What monitoring, conservation, and research activities are most appropriate for the ecologically significant areas identified?

What are some of the most ecologically unique and biologically intact environments and areas in the basin, and what is the state of knowledge about these areas?

We used three specific criteria to identify ESAs in the Tahoe basin: minimal human disturbance, rarity, and biological diversity. We used a variety of methods to identify ESAs, including simple mapping of known ecosystems and complex predictive modeling exercises. Many of the ESAs coincided with Millar et al. (1996) Significant Natural Areas (SNAs) identified within the basin for the Sierra Nevada Ecosystem Project. Discrepancies occurred if the SNAs had been based on nonecological criteria or single-species considerations.

We identified nine types of ESAs (Table 5-33). They represent a range of community and ecosystem types and conditions. The ESAs we identified are not an exhaustive accounting of rare, diverse, and intact communities but are a starting point for conservation. Additional considerations, analyses, and data would lead to identifying a more thorough accounting of ESAs in the basin. The nine types we identified are described in more detail below. The maps we provide on the location and extent of ESAs are approximations based on available information, and their use should be informed by the data limitations described later in this issue.

We used a variety of techniques to identify the location and extent of our nine ESAs within the basin; however, we relied most heavily on remotely sensed data and continuous data coverages ("layers")

Table 5-33—Ecologically Significant Areas (ESAs) in the Lake Tahoe basin and criteria for their identification.

ESA	Minimal human disturbance	Rarity	Biological diversity
Old forests	X		
Bogs and fens		X	
Marshes		X	X
Deep-water plant beds		X	
Cushion plant		X	
Aspen		X	X
Lentic riparian			X
Lotic riparian			X
Community diversity			X

derived from data available on GIS. Continuous data coverages and GIS analysis tools are now commonly used to identify areas for conservation (e.g., Noss and Cooperrider 1994, Davis and Stoms 1996, Davis et al. 1996). GIS allows an investigator to layer different thematic maps, such as vegetation, soil, riparian corridors, and existing reserves of a region of interest to identify high priority areas for conservation.

Minimally Disturbed Ecosystems

The Lake Tahoe basin has a long history of human occupancy (see Chapter 2); as such, very few ecosystems in the basin can be considered undisturbed by humans. We identified a single ecosystem type, the old forest ecosystem, that has been minimally disturbed. Other examples of minimally disturbed ecosystems may occur in the basin and could be explored as a next step in basin management.

Old Forests—As discussed in Issue 1 of this chapter, old forests with minimal current and historical human disturbance provide an important reference for potential old forest characteristics in the basin. Old forests, also known as old-growth or late-successional forests, are forests with a high degree of structural complexity and a high density of large trees, snags, and downed logs (Franklin and Fites-Kaufman 1996). They make an important contribution to biological integrity because their structural complexity and natural disturbance regimes support relatively unique assemblages of biota and natural processes. Old forest acreage has varied greatly over time in the Lake Tahoe basin, due to timber harvest and fire suppression. The 38 old forest stands identified by Barbour and others (see Issue 1, this chapter) and selected here as ESAs range from five to 50 hectares and are located throughout the basin (Figure 5-28).

Rare Communities and Ecosystems

We examined all aquatic ecosystem types, all CalVeg vegetation types (USDA 1991), and SNAs (Millar et al. 1996) to identify rare communities and ecosystems. From Issue 5, we identified four aquatic ecosystem types that were rare in the basin (basin rarity rating of $\leq$ 1.5 on a scale of one to five), as well as throughout the Sierra Nevada (Moyle 1996): sphagnum bogs, fens, marshes, and Lake Tahoe. Associated with Lake Tahoe is an equally rare community type, deep-water plant beds, which we identified as an additional ESA. All of the CalVeg vegetation types had greater than 100 occurrences in the basin, and so none of them was considered rare. Finally, one terrestrial community type identified as an SNA, the cushion plant community, had only one occurrence in the basin and was considered rare (TRPA 1982). Each of the six community and ecosystem types is described briefly below, with the exception of Lake Tahoe which is discussed in detail in Chapter 4.

Sphagnum Bogs and Fens—Bogs and fens are standing water systems occurring on poorly drained soils that contain a buildup of peat. Bogs and fens are comprised primarily of mosses, but also contain sedges, grasses, lichens, shrubs, and some flowering plants (Caduto 1990). They are inherently rare ecosystems and usually consist of unique plant communities and plant and animal species, including many plant species not occurring in other habitats. We recognized three sphagnum bogs in the basin: Grass Lake (at Luther Pass), Hell Hole, and Osgood Swamp (Figure 5-28). Millar et al. (1996) also recognized Grass Lake and Osgood Swamp as SNAs. Additional small pockets of *Sphagnum* moss apparently occur in the basin (Allessio 1999), but only larger mapped bogs were considered ESAs. We were unsure if fens occurred in the basin; however, Sawyer and Keeler-Wolf (1995) note that bogs and fens are often quite difficult to distinguish from one another.

Marshes—Freshwater marshes represent one of the most productive ecosystems in the basin and in California in general (Kramer 1988). They provide habitat for a multitude of plant and animal species, with some species depending on marshes for their entire life cycles (Kramer 1988). Marshes are rare in the Lake Tahoe basin, occurring at the mouths of creeks on the south shore. Based on the marsh/swamp/muskeg symbols shown on USGS 1:24,000 scale topographic maps and local knowledge of the basin, we identified five marshes in the basin: Baldwin, Barton, Pope, Taylor Creek north, and Taylor Creek south (Figure 5-28).

Deep-water Plant Beds—Frantz and Cordone (1967) noted that deep-water plant beds in Lake Tahoe, which consisted of Bryophyta, Characeae, and algae, are a unique type of ecological community found in few other lakes. The plant beds provide spawning grounds for lake trout (*Salvelinus namaycush*) (Beauchamp et al. 1992) and habitat for invertebrates, including several species endemic to Lake Tahoe (Frantz and Cordone 1966). We identified all known deep-water plant bed communities as ESAs (Figure 5-28), which consisted of two approximate locations (Allen 1999). Comprehensive surveys for deep-water plant beds have not been conducted; therefore, we included a model of potential locations of deep-water plant beds (Hall, in preparation). The model used depth and substrate information from Frantz and Cordone (1967) and Loeb and Hackley (1988), as well as Lake Tahoe bathymetry data (Gardner et al. 1998), to predict the occurrence of deep-water plant beds in the lake. The slight discrepancy between the known locations and potential locations is likely due to the approximate nature of the location of known sites. Preliminary surveys to confirm the presence of modeled deep-water plant beds are planned (Johnson 1999).

Cushion Plant Communities—Cushion plant communities are rare, high-elevation communities consisting of small plants, such as phlox, ragwort, and *Draba* species, specially adapted to high-elevation, tundra-like conditions (TRPA 1982). We considered cushion plant communities ESAs because of their rarity in the basin and elsewhere. Only one cushion plant community has been identified in the basin (TRPA 1982) (Figure 5-28). Millar et al. (1996) also identified this community as an SNA in the basin ("Freel Peak").

Biologically Diverse Ecosystems

We identified areas of high species diversity considering a variety of taxa and using a variety of methods of analysis. After qualitatively evaluating the full range of community types (i.e., aquatic ecosystems and terrestrial vegetation communities), we identified three community types with unusually high species richness: marshes, aspen groves, and riparian areas. Marshes are discussed earlier under rare communities, as they are also rare in the basin.

Aspen—Aspen groves are forest stands dominated by quaking aspen (*Populus tremuloides*), generally occurring in association with streams, meadows, and other wet areas. Aspen groves were selected as ESAs because they have an exceptionally diverse array of associated species (DeByle and Zasada 1980; Verner 1988) and they are uncommon in the Lake Tahoe basin (covering less than 0.5 percent of the basin's land area). We used the 1991 CalVeg vegetation layer (USDA 1991) for the basin to identify the location of aspen groves. We considered as ESAs all aspen stands ≥ 1 ha, yielding 117 stands ranging in size from 1 to 23 ha (2.5 to 57.0 ac) (Figure 5-28). We selected stands ≥ 1 ha only because of the questionable accuracy (dated and low resolution) of the vegetation layer for representing the number and location of smaller

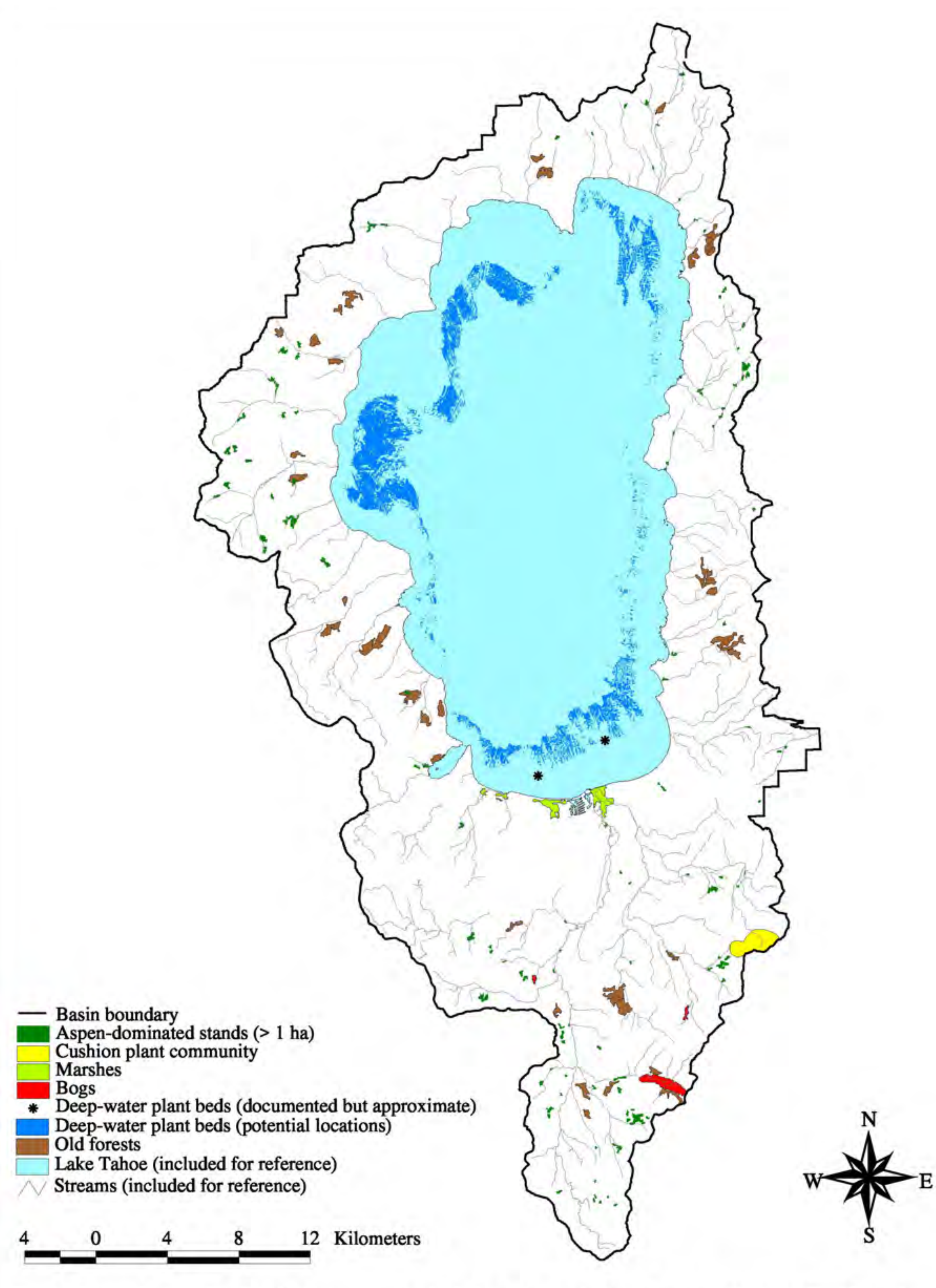


Figure 5-28—Rare and minimally disturbed ecosystems in the Lake Tahoe basin identified as Ecologically Significant Areas.

stands and because the options for managing smaller stands are limited.

Riparian Areas—Riparian areas consist of vegetation commonly associated with lentic (standing) or lotic (running) water, such as willows, alders, aspen, and meadows. They are extremely productive and diverse ecosystems (Kondolf et al. 1996) and provide habitat for a wide range of plant and animal species in the Sierra Nevada, many of which depend on riparian habitats (Graber 1996). In the Lake Tahoe basin, efforts to map riparian areas have been in progress for a number of years (USGS 1994; Butt 1999), and biodiversity studies (e.g., Manley and Schlesinger, in preparation) have helped illuminate the substantial contribution of riparian areas to biological diversity.

Riparian areas occur throughout the Tahoe basin, lining the many miles of streams and surrounding the hundreds of lakes and wet meadows, and occupying approximately 5.5 percent (7325 hectares; 18,605 acres) of the basin. Although basic protective measures for riparian areas are implemented on public lands throughout the basin (e.g., USDA 1988), we know relatively little about the location of especially diverse areas and how to avoid degradation of their values. We modeled the potential biological diversity of lentic and lotic riparian areas throughout the basin to improve our understanding of which areas might be the greatest contributors to biological diversity in the basin.

We used the species richness of a variety of taxonomic groups as our measure of biological diversity, and used regression models to predict species richness based on selected explanatory variables. Empirical data on species richness at a sample of lentic and lotic units, combined with a number of explanatory variables, were used to develop regression models that predicted the richness of each taxonomic group for all lentic or lotic riparian areas in the basin. This modeling exercise served to display patterns of biological diversity in the basin, identify potential "hotspots" of biological diversity that might merit special attention or consideration in management, and highlight parameters that appear to have the greatest influence on species richness for each taxonomic group. Models developed for each measure of biological diversity for lentic and lotic riparian areas are described in more detail below.

Lentic Riparian Areas with High Bird Diversity—Two measures of bird diversity were used to represent the relative potential diversity of lentic riparian areas in the basin: aquatic/riparian bird species richness and total bird species richness. Aquatic/riparian birds are defined as bird species that depend on or are most frequently associated with aquatic, riparian, or meadow habitats. Bird richness data were obtained from Manley and Schlesinger (in preparation), who conducted point counts along the perimeters of 88 lentic units (lakes and wet meadows) in the basin from 1997 to 1998. Bird species that were detected during point counts were classified as aquatic/riparian or upland according to their life history and behavioral characteristics (Ziener et al. 1990a; Ehrlich et al. 1988).

Lentic riparian areas were defined as areas within a fixed distance from lentic aquatic types. Lentic aquatic types consisted of all permanent standing bodies of water, including wet meadows, lakes, ponds, and tarns. The populations of lakes and some wet meadows in the basin were defined by digital versions of USGS 1:24,000 scale topographic maps. Based on local knowledge, wet meadows (as indicated by the marsh/swamp/muskeg indicators) are known to be underrepresented on USGS topographic maps. The wet meadow population estimate was supplemented by including "moist meadows" and "wet meadows" designations from a digital version of a hand-drawn map of riparian areas (the "riparian vegetation layer") derived from professional interpretation of 1:30,000 infrared aerial photographs from 1987 (USGS 1994). A total of 349 lakes and 1,771 wet meadows were identified. Lakes as small as 0.005 hectares and wet meadows as small as 0.004 hectares were present in the population, suggesting that our population of lentic units was a fairly complete accounting of all lentic units in the basin.

Twelve explanatory variables derived from digital map data available on GIS were used as independent variables in a multiple regression analysis to create predictive models for biodiversity in lentic riparian areas. The 12 explanatory variables included elevation, mean annual precipitation, unit area, percent canopy cover, percent slope, and proportion of land occupied by each of seven vegetation types (shrubs, meadow, wooded riparian, decidious/coniferous riparian, aspen, mixed conifer, and subalpine conifer).

Values for each of the 12 explanatory variables were variously derived to describe lentic units. Elevation and unit area were derived from USGS 1:24,000 topographic maps, and values for each variable were assigned to each lentic sample unit. Elevation was described at the lake or meadow surface. The remaining ten independent variables were described within a 200-meter radius area ("analysis area") around each lentic unit. A 200-meter radius was chosen as an appropriate scale within which to describe environmental variables because it is slightly larger than the distance at which almost all birds are detected from point counts (Ralph et al. 1993). Nearly every bird detected was using habitat within 200 meters of lentic units.

The seven vegetation types were derived by a three step process. First, we combined some of the 12 vegetation types (we excluded water, barren, and urban) identified in the CalVeg vegetation layer (USDA 1991) to represent vegetation at the series level (e.g., Sawyer and Keeler-Wolf 1995), resulting in the identification of 5 types: mixed conifer, quaking aspen, subalpine conifer, shrub, and meadow (Table 5-34). Second, we combined some of the 5 vegetation types identified in the riparian vegetation layer described above (USGS 1994) to represent vegetation at the series level, resulting in the identification of 3 riparian types: wooded riparian, decidious/coniferous riparian, and meadow (Table 5-34). Third, we overlaid the map of the 3 riparian vegetation types on top of the map of the 5 CalVeg vegetation types to derive a combined map, with areas of overlap being assigned the vegetation type from the riparian vegetation layer. The resulting map displayed seven vegetation types because the "meadow" vegetation type occurred on both vegetation maps. The value for each vegetation type for each lentic unit was the proportion of the analysis area occupied by each vegetation type.

Table 5-34—Plant community types used in riparian biodiversity models and the analysis of plant community diversity in the Lake Tahoe basin and their CalVeg (USDA 1991) and riparian vegetation (USGS 1994) GIS layer origins.

Riparian biodiversity models	Original vegetation type[a]	Community diversity model
Shrub	Basin sagebrush (C)	Basin sagebrush
	Huckleberry oak (C)	Huckleberry oak
	Mixed alpine scrub (C)	Mixed alpine scrub
	Montane chaparral (C)	Montane chaparral
Mixed conifer	Jeffrey pine (C)	Jeffrey pine
	Mixed conifer – fir (C)	Mixed conifer
	Mixed conifer – pine (C)	
Quaking aspen	Quaking aspen (C)	Quaking aspen
Subalpine conifer	Red fir (C)	Red fir
	Subalpine conifer (C)	Subalpine conifer
	Water (C)	Water
Meadow	Wet meadow (C)	Meadow
	Moist meadow (R)	
	Wet meadow (R)	
Wooded riparian	Coniferous riparian (R)	Wooded riparian
	Deciduous riparian (R)	
Deciduous/coniferous riparian	Decid/con riparian (R)	Deciduous/coniferous riparian

[a] C = vegetation type from CalVeg vegetation layer (USDA 1991); R = vegetation type from riparian vegetation layer (USGS 1994).

The derivation of values was similar for the four remaining explanatory variables. We obtained mean annual precipitation from PRISM data (Daly et al. 1994; Daly et al. 1997; Daly and Johnson 1999). A slope polygon map was derived by interpreting topographic isoclines. We obtained canopy cover values from the CalVeg data layer. The digital data for all three of these variables represented their values as membership in value classes. Percent slope was reported in 10 classes: 0-5, 6-15, 16-25, 26-35, 36-45, 46-55, 56-65, 66-75, 76-85, and 86 and greater. Percent canopy cover was reported in 9 classes: no canopy cover, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80-89. Precipitation was reported in one-inch increments. To calculate an average value for these variables for each lentic analysis unit, we performed the following steps: 1) calculated the proportion of the total buffer occupied by each class (for example, 10-19 percent slope); 2) multiplied that proportion by the average value of the class (in this example, 14.5) to obtain the contribution to the final value associated with each class; and 3) summed those values across classes to arrive at the final value for each lentic unit buffer.

We performed all possible subsets regression analyses (NCSS 1995; Stevens 1996) on the sample of 88 lentic units, using aquatic/riparian bird richness and total bird species richness as dependent variables and the 12 explanatory environmental variables as independent variables. Independent variables were transformed when needed to make their distributions approximate a normal distribution more closely (Appendix D). For each dependent variable, we selected the regression model with the lowest root mean square error (MSE) (Zar 1984). The regression models then were used as predictive models to assess the potential aquatic/riparian bird richness and total bird species richness of all lentic units in the basin.

We predicted species richness for each lentic analysis unit by applying the predictive regression model to the environmental values assigned to each lentic analysis unit. Values for explanatory variables were described in the same manner for all lentic analysis units as for lentic sample units, with one exception. Wet meadows in close proximity to each other (≤ 400 m) were combined and the cluster treated as one lentic analysis unit. In these cases, the 200-meter analysis area around the clustered lentic units overlapped and formed a single 200-meter wide analysis area around the perimeter of the cluster, and values for the explanatory variables were described for newly delineated analysis area. In treating meadow clusters as single analysis units, we are analyzing them as meadow complexes. The 1,771 wet meadows originally identified in the basin formed 213 wet meadow analysis units, composed of 35 individual wet meadows and 178 meadow clusters.

Once a species richness value was predicted for each lentic analysis unit, three additional steps were taken to derive the final value to represent the relative richness of lentic analysis units. First, we calculated a 90 percent confidence interval for each estimate by subtracting an error estimate of 1.282 (the z-score for a 90 percent level of confidence) times the square root of the model's MSE (see Hogg and Tanis 1983). The value indicating the lower bound of the 90 percent confidence interval was assigned to the lentic analysis unit as the richness estimate, so that 90 percent of the time the true species richness of the unit was likely to be at or above the assigned value. Second, the richness estimate assigned to each lentic analysis unit was standardized so that the richness estimate varied from 0 to 1. When the model predicted negative values of species richness, values for all lentic sample units were rescaled such that the lowest number was zero before they were standardized. Finally, we assigned each lentic analysis unit to one of five richness classes based on the standardized values: high (0.8 to 1.0), moderate-high (0.6 to 0.8), moderate (0.4 to 0.6), low-moderate (0.2 to 0.4), and low (0.0 to 0.2).

Patterns of Aquatic/Riparian Bird Species Richness in Lentic Riparian Areas—Details on the model used to predict aquatic/riparian bird species richness are in Appendix D. In short, nine variables were selected for the regression model (elevation, precipitation, slope, unit area, canopy cover, and four vegetation types), with an adjusted R^2 of 0.70. Richness values were unevenly distributed among the five richness classes, with the majority of lentic analysis units occurring in the moderate (12.3 percent), low-moderate (22.4 percent), and low (14.8

percent) richness classes, and only 14 units (2.5 percent) occurring in the high richness class (Table 5-35, Figures 5-29a and b). Lentic analysis units with high potential aquatic/riparian bird species richness were generally found at lower elevations with an abundance of nearby meadows and minimal nearby forest. These potential hotspots of aquatic/riparian bird diversity were chiefly large areas in basins with gently sloping topography. Areas of low potential richness were high elevation areas in basins with steep topography and either abundant forest cover or a lack of any vegetative cover.

The 12 lakes and two wet meadows in the high richness class were considered potential hotspots of aquatic/riparian bird species richness (Figures 5-29a and b), and their locations are described below:

- The pond west of Tallac Lagoon;
- Four ponds at the Lake Tahoe Golf Course;
- The pond at Tahoe Paradise Golf Course;
- The "Fishpond" south of South Tahoe High School near Highway 50;
- Four lakes and ponds at Edgewood Golf Course;
- The pond at the southeast end of Rabe Meadow near the intersection of highways 50 and 207; and
- Meadows along the Upper Truckee River just south of the northernmost crossing of Highway 50 and near the confluence with Angora Creek.

Table 5-35—Numbers of lakes and wet meadows in five classes of predicted aquatic/riparian bird species richness in the Lake Tahoe basin.

Richness Class	Lakes	Wet Meadows	Total	Percent
Low	42	52	94	16.7
Low-moderate	215	92	307	54.6
Moderate	66	43	109	19.4
Moderate-high	14	24	38	6.8
High	12	2	14	2.5

Patterns of Total Bird Species Richness in Lentic Riparian Areas—Details on the model used to predict total bird species richness are in Appendix D. In short, six variables were selected for the regression model (elevation, slope, unit area, and three vegetation types), with an adjusted R^2 of 0.48. Richness values were unevenly distributed among the five richness classes, with the majority of lentic analysis units occurring in the moderate (18.5 percent) and moderate-high richness (16 percent) classes, and only 57 units (10.1 percent) occurring in the high richness class (Table 5-36, Figures 5-30a and b). Lentic units with high predicted total bird species richness were generally low elevation areas with an abundance of nearby meadow, riparian vegetation, and mixed conifer forest. These lakes and wet meadows were generally large and occurred in basins with gently sloping topography. Areas with low potential richness were high elevation areas in basins with steep topography and a lack of meadow, riparian, or mixed conifer forest cover.

The 21 lakes and 36 wet meadow units in the high richness class were considered potential hotspots of total bird species richness (figures 5-30a and b). All 14 of the lakes and wet meadows identified as hotspots of aquatic/riparian bird species richness were also identified as hotspots of total bird species richness, with the exception of the pond on Tahoe Paradise Golf Course. The additional 44 lakes and wet meadows identified as potential hotspots of total bird species richness are listed below:

- A pond along Blackwood Creek near an OHV staging area;

Table 5-36—Numbers of lakes and wet meadows in five classes of predicted total bird species richness in the Lake Tahoe basin.

Richness Class	Lakes	Wet Meadows	Total	Percent
Low	24	7	31	5.5
Low-moderate	111	51	162	28.8
Moderate	126	68	194	34.5
Moderate-high	67	51	118	21.0
High	21	36	57	10.1

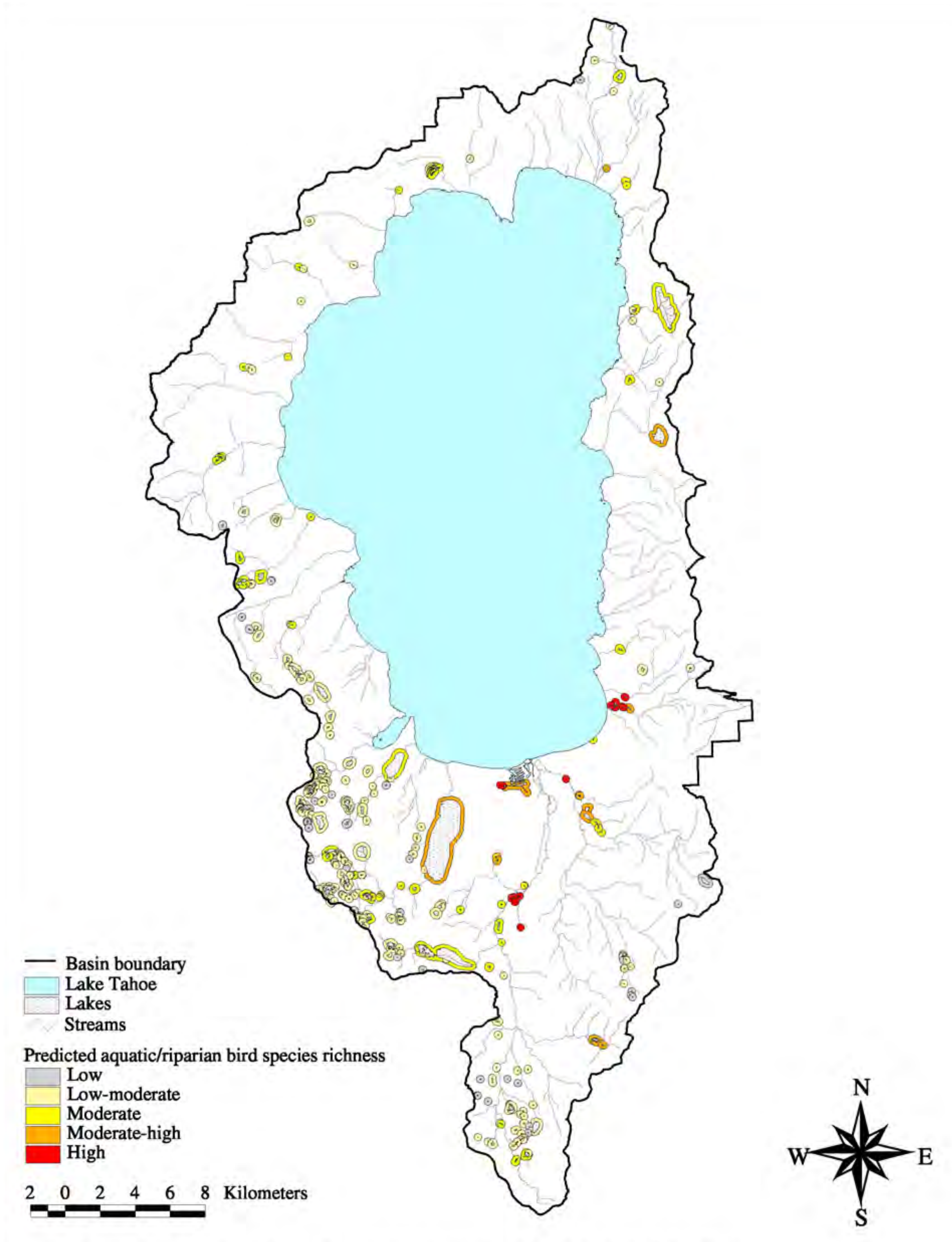


Figure 5-29a—Predicted species richness of aquatic/riparian birds at lakes in the Lake Tahoe basin.

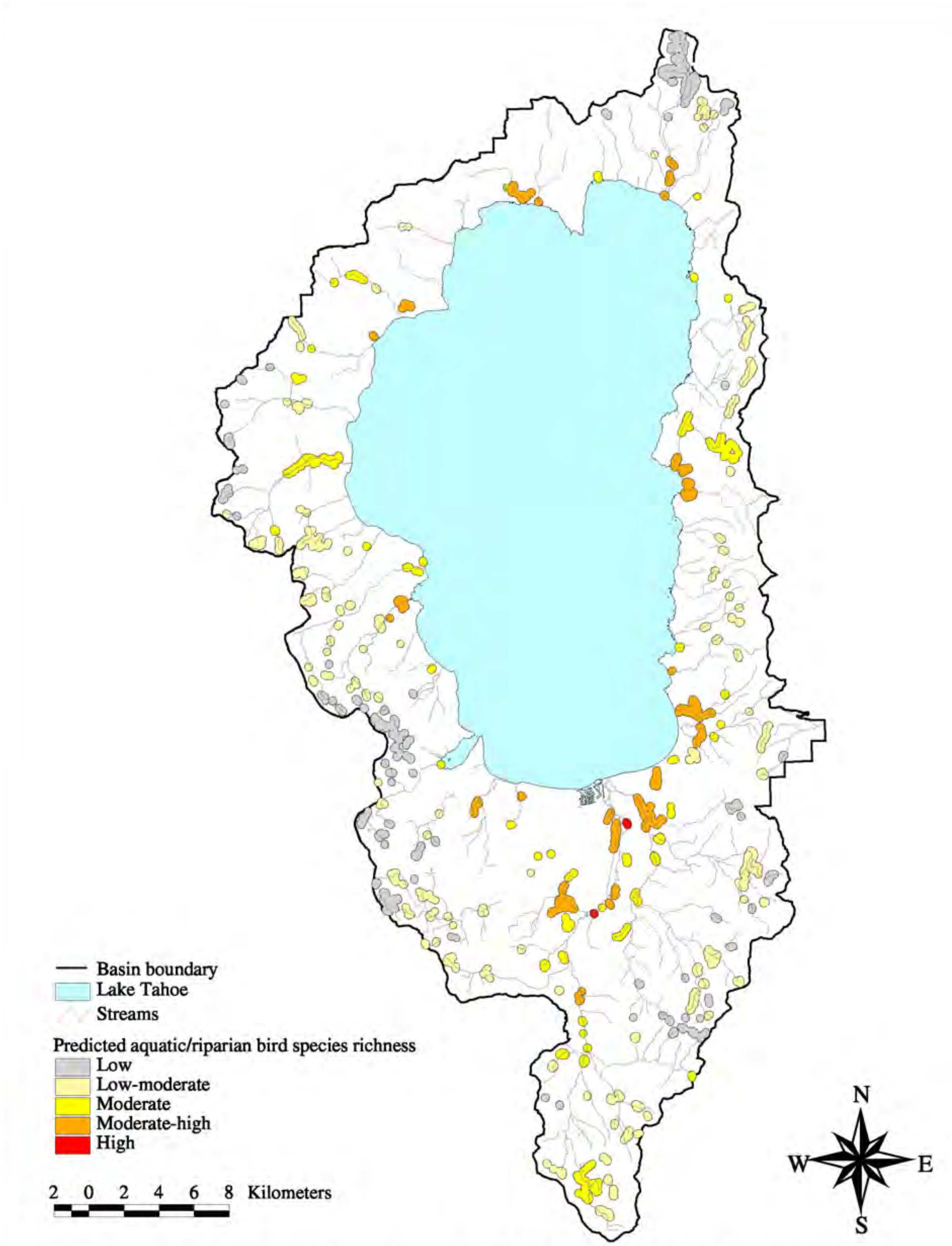


Figure 5-29b—Predicted species richness of aquatic/riparian birds at wet meadows in the Lake Tahoe basin.

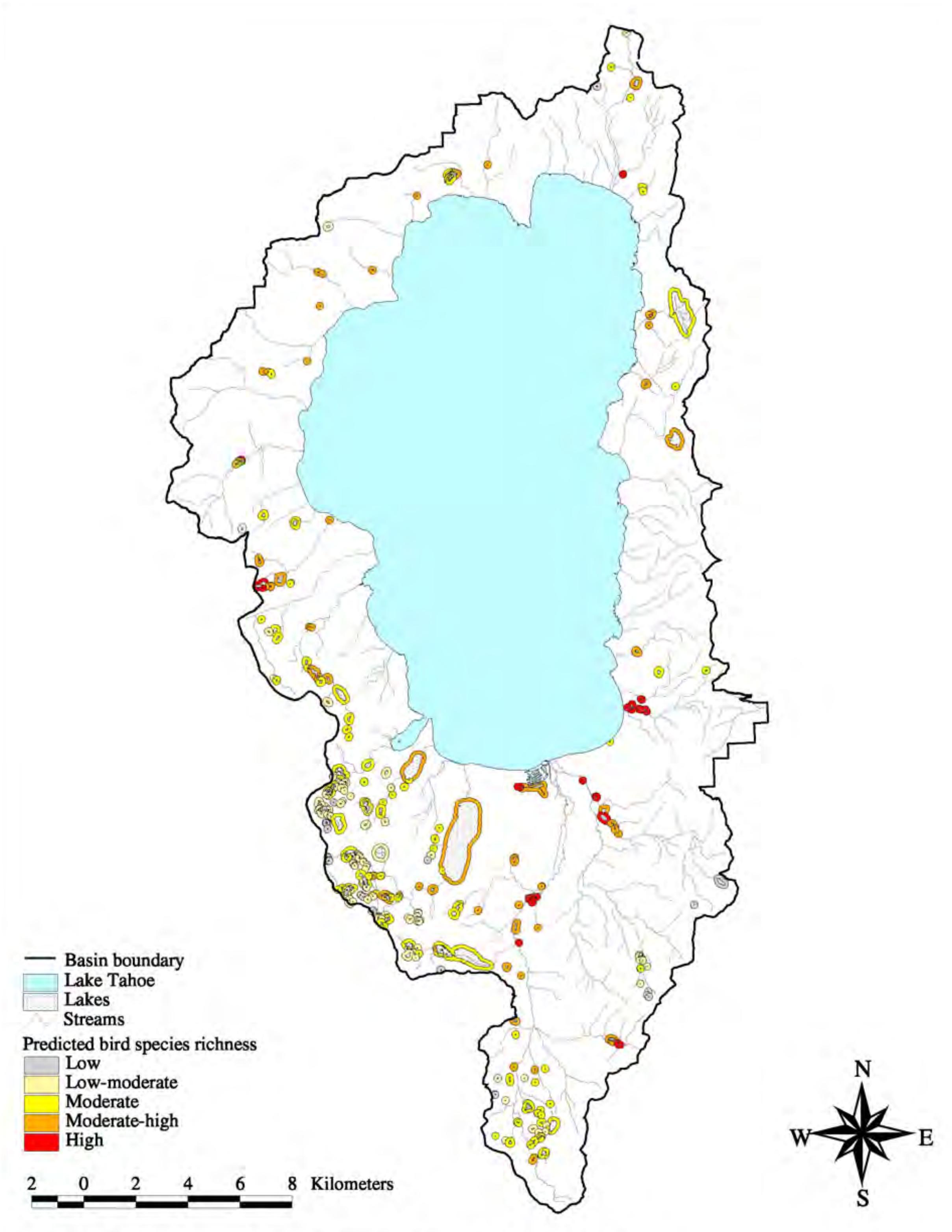


Figure 5-30a—Predicted species richness of all birds at lakes in the Lake Tahoe basin.

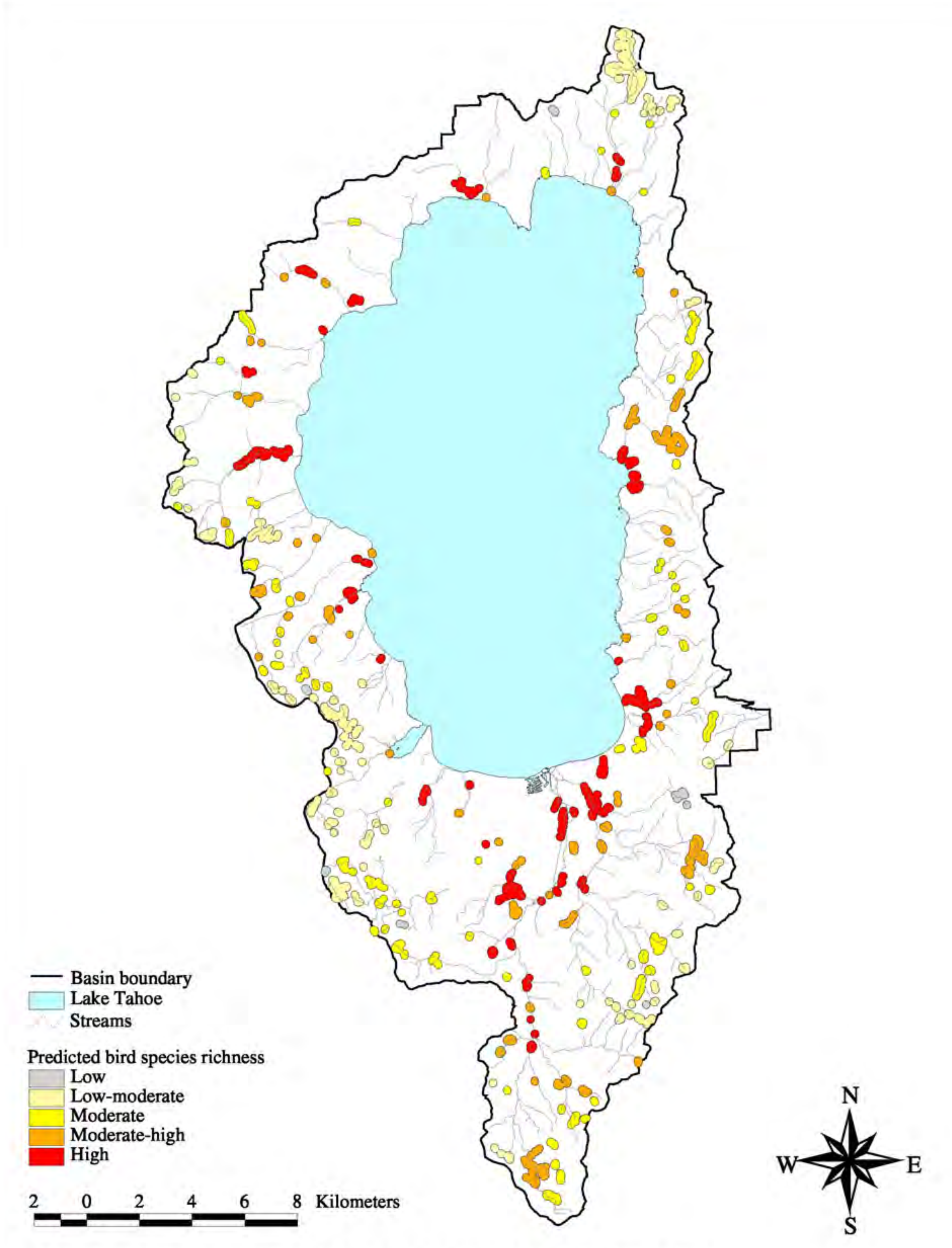


Figure 5-30b—Predicted species richness of all birds at wet meadows in the Lake Tahoe basin.

- Lily Lake in the McKinney Creek drainage and the pond immediately south;
- The pond southwest of the intersection of Highway 50 and Highway 89 in Meyers;
- Lake Christopher;
- The two ponds in the South Tahoe Public Utility District's sewage treatment plant east of the Sierra Tract;
- An additional pond at Edgewood Golf Course;
- Grass Lake at Luther Pass;
- The pond along Incline Creek at Incline Golf Course;
- Meadows along Snow Creek;
- Meadows along Burton Creek near Lake Forest;
- Antone Meadows in Burton State Park;
- A meadow at Tahoe City Golf Course;
- Page Meadows;
- Meadows along Blackwood Creek from near the mouth to past the OHV staging area;
- Meadows near the mouth of General Creek;
- Meeks Meadow;
- A meadow near the mouth of the creek north of D.L. Bliss State Park;
- Meadows along Tallac Creek southwest of Highway 89;
- A meadow along Taylor Creek near Highway 89;
- A meadow south of the junction of Fallen Leaf Lake Road and Tahoe Mountain Road;
- Thirteen meadows and meadow complexes along the Upper Truckee River and its tributaries;
- Meadows along Trout Creek upstream of where Highway 50 crosses it and at its confluence with Saxon Creek;
- Meadows at Bijou Golf Course;
- Meadows at Edgewood Golf Course;
- Rabe Meadow;
- A meadow at the mouth of McFaul Creek;
- Meadows at the mouths of Glenbrook and Slaughterhouse Creeks; and
- Meadows along Third and Incline Creeks near Incline Golf Course.

Lotic Riparian Areas with High Biodiversity—Four measures of biological diversity were used to represent the relative potential diversity of lotic riparian areas in the basin: aquatic/riparian bird species richness, total bird species richness, mammal species richness, and vascular plant species richness. Aquatic/riparian birds were defined using the same criteria and sources as for the lentic diversity analysis. Data were obtained from Manley and Schlesinger (in preparation), who collected data at 80, 300-meter long lotic units (stream reaches) in the basin from 1995 to 1996.

Lotic riparian areas were defined as areas within a fixed distance from 300-meter lengths of permanent streams ("lotic analysis units"). The population of permanent streams was defined by digital versions of USGS 1:24,000 scale topographic maps, with permanent streams indicated on original maps by solid blue lines. The population of all lotic analysis units in the basin was defined by dividing perennial streams into 300-meter lengths, starting randomly in the first 300 meters above the stream mouth (for main stream channels) or confluence with the main stream (for tributaries).

The riparian area delineated around each 300-meter length of stream varied among the measures of biological diversity. Lotic analysis units for aquatic/riparian and total bird richness consisted of a 300-meter radius area around each stream length. Bird data were collected as far as 200 meters from the stream; the 300-meter radius area encompassed all point count stations plus the estimated maximum 100 meter detection distance for most bird species. Lotic analysis units for mammal richness consisted of a 100-meter radius area around each stream length. Mammal data were collected up to 35 meters from the stream; the 100 meter radius area encompassed all detection locations plus a distance equivalent to the radius of the median home range size (56 meters, based on Ziener et al. 1990b) of all the mammals detected. Lotic analysis units for plant richness consisted of a 30-meter radius area around each stream length. Plant data were collected within 30 meters of the stream; the 30 meter radius area matched the survey area for plants.

The number of lotic analysis units varied slightly among each of the analyses for three reasons. First, the population of 300-meter stream lengths was generated *de novo* for the analysis of each taxonomic group (birds, mammals, and plants) to accommodate the different analysis areas for each group. The random start point created minor variation in the number of units identified. Second, lotic analysis units with ≥ 5 percent of their area falling outside the basin boundary were excluded from the analysis. The larger the analysis unit, the greater the number of units that intersected the basin boundary. Third, data were missing for a small geographic area for one set of variables used in the analysis of plant richness, excluding approximately 35 lotic analysis units in one drainage (Dagget Creek, located in the southwest corner of the basin) from the population. The resulting populations of lotic analysis units were 1,998 units in the analyses of aquatic/riparian bird and total bird richness, 2,018 units in the analysis of mammal richness, and 1,997 units in the analysis of plant richness.

Thirty-one explanatory variables derived from digital map data available on GIS were used as independent variables in multiple regression analyses to create predictive models for biodiversity in lotic riparian areas. Eleven explanatory variables were included in the analysis of bird and mammal richness, including elevation, mean annual precipitation, percent canopy cover, percent slope, proportion of land occupied by 7 vegetation types (wooded riparian, aspen, decidious/coniferous riparian, meadow, mixed conifer, shrubs, and subalpine conifer). For the analysis of plant richness, we also included the proportion of land occupied by each of 20 soil series (Cagwin, Celio, Elmira, Fugawee, Gravelly alluvial land, Graylock, Inville, Jabu, Jorge-Tahoma, Loamy alluvial land, Marsh, Meeks, Meiss, Rockland, Stony colluvial land, Tahoma, Tallac, Toem-Rock, Umpa, and Waca-Rock). All of the explanatory variables were described within the bounds of the lotic analysis unit (as defined above for each species group). Soil series were derived from Rogers (1974), and elevation was converted from a categorical variable (mapped as 30 meter increments) to a continuous variable using the same method applied to slope, precipitation, and canopy cover for the lentic riparian analysis. All other variables were derived from the same data sources as for the lentic models.

We performed multiple regression analyses on the sample of 80 lotic sample units, using the richness measures as dependent variables and the 11 to 31 explanatory variables as independent variables. Independent variables were transformed when needed to make their distributions approximate a normal distribution more closely (Appendix D). We performed all possible subsets regression analysis (NCSS 1995; Stevens 1996) to generate the bird and mammal models, and selected the regression model with the lowest root MSE (Zar 1984). For the vascular plant model, we used backward stepwise regression (SPSS 1993) with an alpha level of 0.10 in lieu of the all possible subsets regression as there were too many variables to use the all possible subsets method.

We predicted species richness for each lotic analysis unit by applying the predictive regression model to the values assigned to each lotic analysis unit for each explanatory variable. Values for explanatory variables were described in the same manner for all lotic analysis units as for lotic sample units. The same procedure as was used for lentic riparian modeling was used to derive the final value to represent the relative richness of lotic analysis units, including assigning the lower bound of the 90 percent confidence interval for richness to the analysis unit, standardizing the values, and then assigning each lotic analysis unit to one of five richness classes (low to high) based on their standardized values.

Patterns of Aquatic/Riparian Bird Species Richness in Lotic Riparian Areas—Details of the model used to predict aquatic/riparian bird species richness are in Appendix D. In short, six variables were selected for the regression model (elevation, precipitation, wooded riparian, meadow, shrubs, and subalpine conifer), with a resulting adjusted R^2 of 0.52. Predicted species richness for most lotic analysis units fell into the low-moderate (48.2 percent) and moderate (30.9 percent) richness classes, with only 3.7 percent (n = 73) of the units in the high richness class (Table 5-37). In general, predicted species richness of aquatic/riparian birds increased with decreasing elevation and increasing proportion of meadow and wooded riparian vegetation, and most lotic analysis units with high richness were at or near the mouths of streams (Figure 5-31).

Table 5-37—Number and percent of lotic units in each class of predicted aquatic/riparian bird species richness in the Lake Tahoe basin.

Bird Species Richness Class	Number of Lotic Units	Percent of Total
Low	144	7.2
Low-moderate	962	48.1
Moderate	617	30.9
Moderate-high	202	10.1
High	73	3.7

The 73 lotic analysis units in the high richness class were considered potential hotspots of aquatic/riparian bird species richness (Figure 5-31). These 73 lotic units were spatially clumped, representing nine general locations described below:

- Meeks Creek: at Meeks meadow;
- Tallac Creek: mouth at Baldwin Beach south to Highway 89;
- Taylor Creek: mouth at Taylor Creek Marsh south just past Highway 89;
- Upper Truckee River: from the mouth south to the north end of the Lake Tahoe airport, at the south end of the Lake Tahoe Airport, and at its confluence with Angora Creek at Lake Tahoe Golf Course;
- Angora Creek: in Washoe Meadows State Park;
- Trout Creek: near its mouth;
- Edgewood Creek: east of the large pond at Edgewood Golf Course;
- Burke Creek: at its mouth; and
- Glenbrook Creek: the mouth east to Highway 50.

Patterns of Total Bird Species Richness in Lotic Riparian Areas—Details of the model used to predict total bird species richness are in Appendix D. In short, 5 variables were selected for the regression model (precipitation, wooded riparian, meadow, mixed conifer, and canopy cover), with a resulting adjusted R^2 of 0.26. Predicted species richness for most lotic analysis units fell into the low-moderate (26.5 percent), moderate (47.5 percent), and moderate-high richness classes (15.2 percent), with 4.5 percent (n = 90) of the units in the high richness class (Table 5-38). In general, predicted bird species richness decreased with increasing precipitation (which is positively correlated with elevation) and most lotic analysis units with high richness were at or near the mouths of streams (Figure 5-32).

The 90 lotic analysis units in the high richness class were considered potential hotspots of total bird species richness (Figure 5-32). Most of the hotspots of aquatic/riparian bird species richness (identified above) were also hotspots of total bird species richness, with the exception of Meeks Creek and Burke Creek. Two areas were uniquely identified as hotspots for total bird species richness:

- Trout Creek: from its confluence with Cold Creek to its mouth; and
- Third and Incline Creeks: at Incline Golf Course.

Patterns of Mammal Species Richness in Lotic Riparian Areas—Details of the model used to predict mammal species richness are in Appendix D. In short, seven variables were selected for the regression model (elevation,

Table 5-38—Number and percent of lotic units in each class of predicted total bird species richness in the Lake Tahoe basin.

Bird species richness class	Number of lotic units	Percent of total
Low	82	4.1
Low-moderate	572	28.6
Moderate	950	47.5
Moderate-high	304	15.2
High	90	4.5

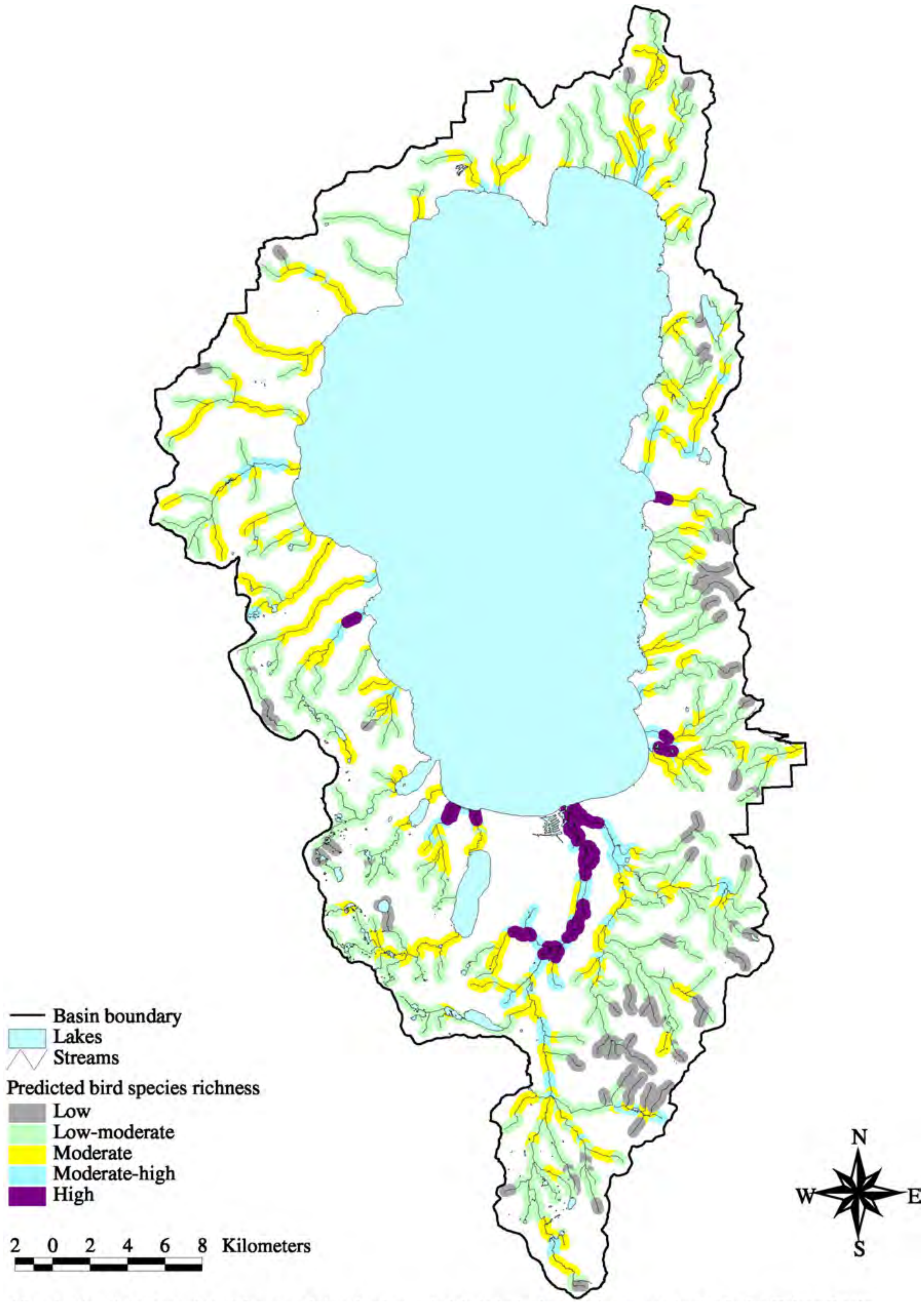


Figure 5-31—Predicted species richness of riparian/aquatic birds in lotic riparian areas in the Lake Tahoe basin.

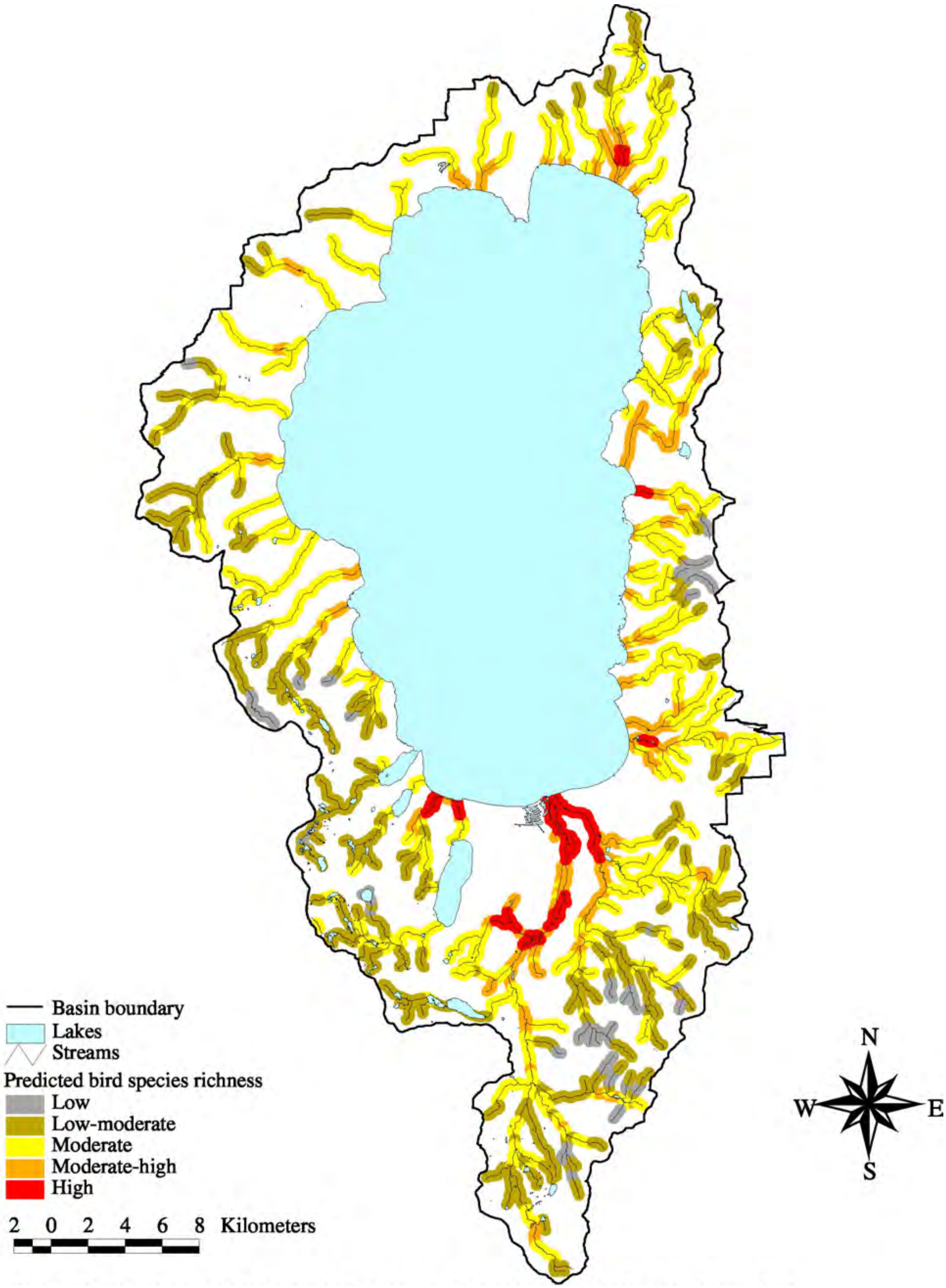


Figure 5-32—Predicted species richness of all birds in lotic riparian areas in the Lake Tahoe basin.

percent slope, wooded riparian, decidious/coniferous riparian, shrubs, mixed conifer, and meadow), with a resulting low adjusted R^2 of 0.15. Predicted species richness for most lotic analysis units occurred in the moderate (43.3 percent) and moderate-high (44.8 percent) richness classes, with 7.6 percent (n = 153) of the units in the high richness class (Table 5-39). Predicted species richness of mammals generally increased with elevation and was greater on east side of the basin (flanks of the Carson Range) than on west side of the basin (flanks of the Sierra Crest) (Figure 5-33).

The 153 lotic analysis units in the high richness class were considered potential hotspots of mammal species richness (Figure 5-33). These 153 lotic units were spatially clumped, representing 12 general locations described below:

- Griff Creek: approximately 1.7 kilometers (one mile) from the headwaters;
- General Creek: southwest of Lost and Duck lakes;
- Cascade Creek: near the headwaters and Kalmia Lake;
- Upper Truckee River: and its tributaries various locations near Benwood Meadow, Grass Lake, Dardanelles Lake, Meiss Lake, and south of Meiss Lake;
- Trout Creek: at Hell Hole and near Fountain Place;
- Cold Creek: upper portions, including High Meadows;
- Heavenly Valley Creek: southwest of Heavenly Valley;
- Edgewood Creek: near Daggett Pass;
- McFaul, Lincoln, Logan House, North Logan House, and Glenbrook Creeks: upper reaches;
- The creek north of Zephyr Creek: upper reaches;
- North Canyon Creek: reaches near Marlette Lake south approximately 3 kilometers (1.8 miles); and
- Incline and Third Creeks: upper reaches.

Patterns of Vascular Plant Species Richness in Lotic Riparian Areas—Details on the model used to predict vascular plant species richness are in Appendix D. In short, ten variables were selected for the regression model, including mean annual precipitation, five vegetation types, and four soil types, with a resulting adjusted R^2 of 0.44. Vascular plant species richness for most lotic analysis units occurred in the moderate (32.9 percent) and moderate-high (52.1 percent) richness classes, with 6.3 percent (n = 125) of the units in the high richness class (Table 5-40). Predicted vascular plant species richness reached its highest values at high levels of precipitation, and was greatest on the west and south sides of the basin (Figure 5-34).

The 125 lotic analysis units in the high richness class were considered potential hotspots of plant species richness (Figure 5-34). These 125 lotic units were spatially clumped, representing 12 general locations described below:

- Watson Creek: northwestern portion;
- Ward Creek: almost the entire length west of the middle of Section 23, including all tributaries west of that point;

Table 5-39—Number and percent of lotic units in each class of predicted mammal species richness in the Lake Tahoe basin.

Mammal species richness class	Number of lotic units	Percent of total
Low	10	0.5
Low-moderate	75	3.7
Moderate	876	43.4
Moderate-high	904	44.8
High	153	7.6

Table 5-40—Number and percent of lotic units in each class of predicted vascular plant species richness in the Lake Tahoe basin.

Plant species richness class	Number of lotic units	Percent of total
Low	23	1.2
Low-moderate	150	7.5
Moderate	658	32.9
Moderate-high	1,041	52.1
High	125	6.3

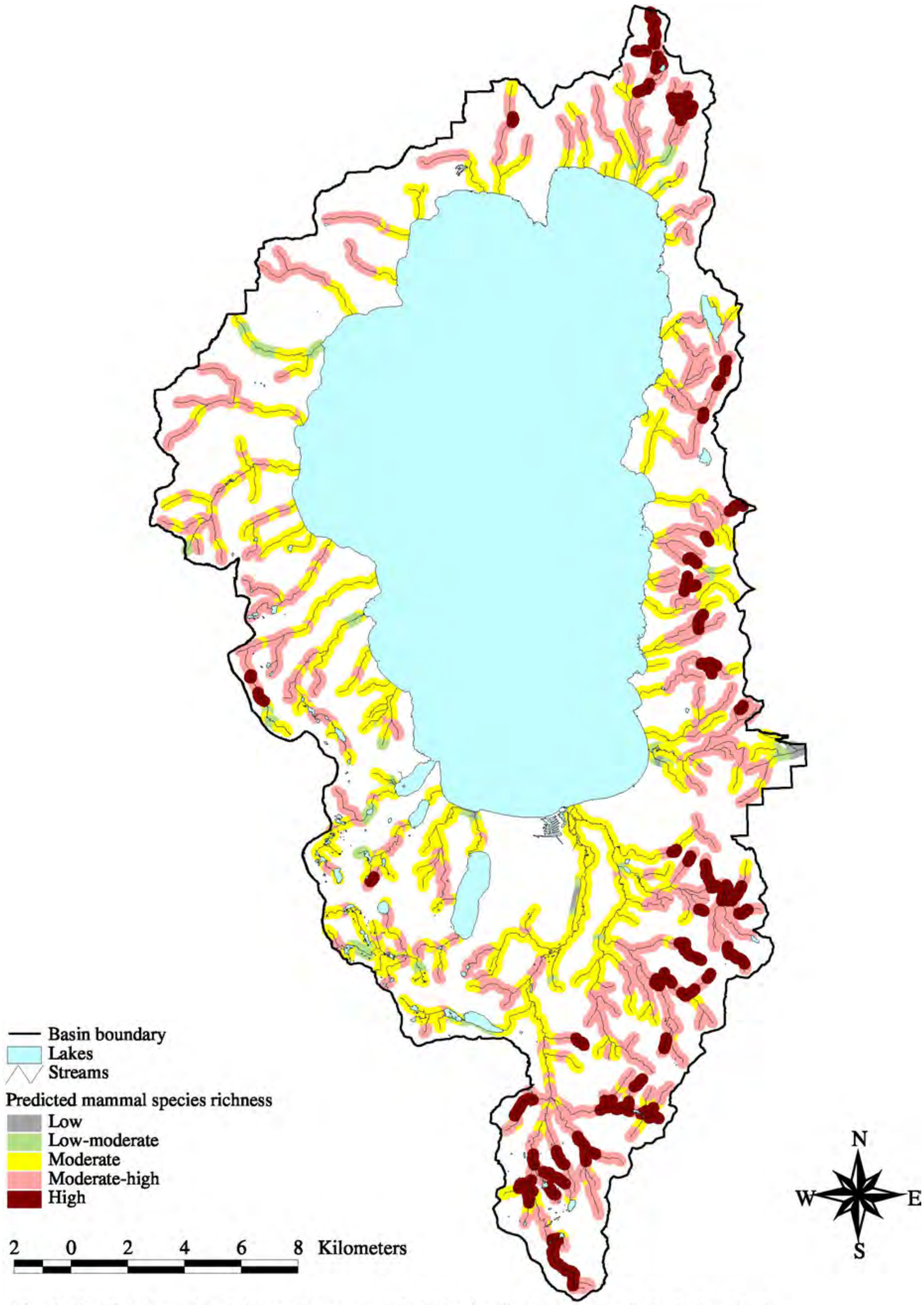


Figure 5-33—Predicted species richness of mammals in lotic riparian areas in the Lake Tahoe basin.

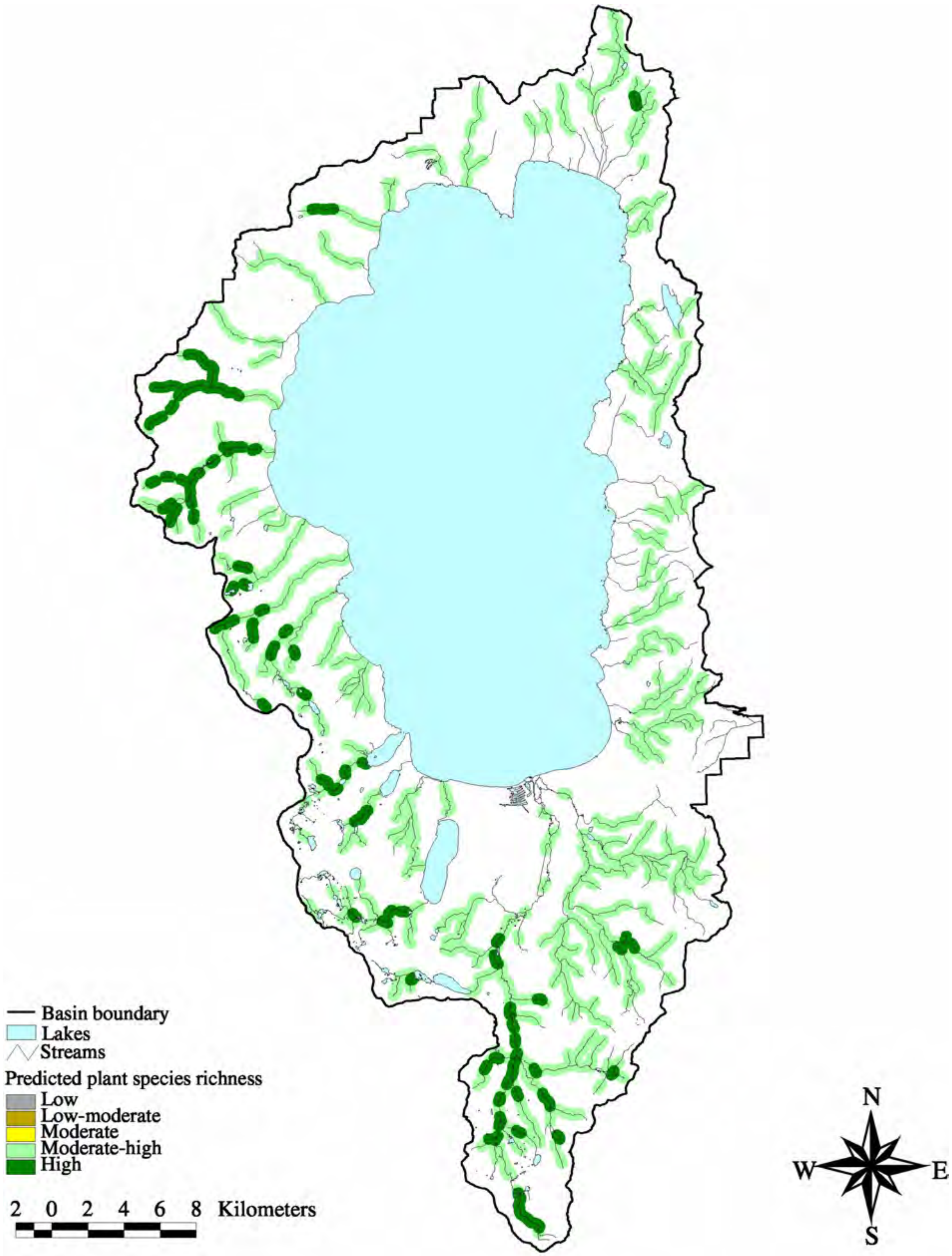


Figure 5-34—Predicted species richness of vascular plants in lotic riparain areas in the Lake Tahoe basin.

- Blackwood Creek: portions along the entire length, including tributaries;
- McKinney Creek: stretches between and around McKinney and Lily Lakes and a portion just south of Buck Lake;
- General Creek: at the junction of the tributary to Lost and Duck Lakes, along the tributary to Lost and Duck Lakes, at the point where the creek bends southeast, and at the headwaters in Desolation Wilderness;
- Meeks Creek: portions above Meeks Meadow inside and outside of Desolation Wilderness, and near Shadow Lake;
- Eagle Creek: just above Emerald Bay, and around Eagle Lake;
- Cascade Creek: at and below the confluence of creeks draining Azure and Snow Lakes;
- Glen Alpine Creek: above Lily Lake and immediately west of Grass Lake;
- Upper Truckee River: and tributaries in Washoe Meadows State Park, west of Upper Echo Lake, at Benwood and Upper Benwood Meadows, near Grass Lake, at Big Meadow, near and south of Meiss Lake, and at many other points along the main channel and tributaries; and
- Trout Creek near Fountain Place; and
- Incline Creek northern portion.

Synthesis and Analysis of Riparian Biodiversity Models—The modeling exercises described above identified many potential hotspots of diversity in riparian areas in the basin. In general, bird, mammal, and vascular plant hotspots were geographically distinct (Figure 5-35). Grass Lake at Luther Pass, and lotic and lentic riparian areas along the Upper Truckee River and its tributaries (particularly from near Celio Ranch to north of Dardanelles Lake) however, stand out as having the potential for high species richness of all three species groups. Other areas that are potential hotspots for multiple species groups include portions of Ward Creek (birds and plants), Blackwood Creek (birds and plants), McKinney Creek (birds and plants), the Upper Truckee River at Highway 50 in Meyers (birds and plants) and from Meiss Lake south (mammals and plants), Trout Creek (mammals and plants), and northern Incline Creek (mammals and plants). The limited overlap among the hotspots for each species group indicates that distinct environmental parameters have different influences on the species richness of each group. For instance, mammal species richness tended to increase with elevation, while bird species richness decreased with elevation, so very few locations were identified as hotspots for both birds and mammals. Only a few areas in the basin, described above, present the appropriate conditions for high richness in more than one group of species.

The varying degrees of success we had in modeling species diversity in riparian areas reflect the explanatory power of the map-based variables. We were able to explain more than 70 percent of the variation in aquatic/riparian bird species richness in lentic riparian areas and more than 50 percent in lotic riparian areas, indicating that our map-based variables were good predictors of aquatic/riparian bird species richness. The unexplained variation is most likely associated with fine-scale environmental characteristics that might influence species richness, such as prey base, water depth, and vegetation structure. The lentic and lotic models for total bird species richness were not as strong (more than 50 percent of the variation explained for lentic riparian areas but only 26 percent for lotic riparian areas) suggesting that some important habitat elements for upland birds were not well represented in our models. Also, the models for lentic riparian areas were based on data from single visits to each site (although in many cases, multiple point counts were conducted), which may not have detected some species associated with the lentic unit. Ideally, one would use data from several visits to each site to characterize the bird fauna more thoroughly. We were able to explain almost 45 percent of the variation in vascular plant species richness. The unexplained variation may lie in such factors as soil moisture and nutrient content, neither of which was available in GIS. The regression model for mammal species richness explained only 15 percent of the variation. Fine-grained habitat elements, such as snags, downed woody debris, and ground cover, were not available on GIS and are likely to influence mammal species richness.

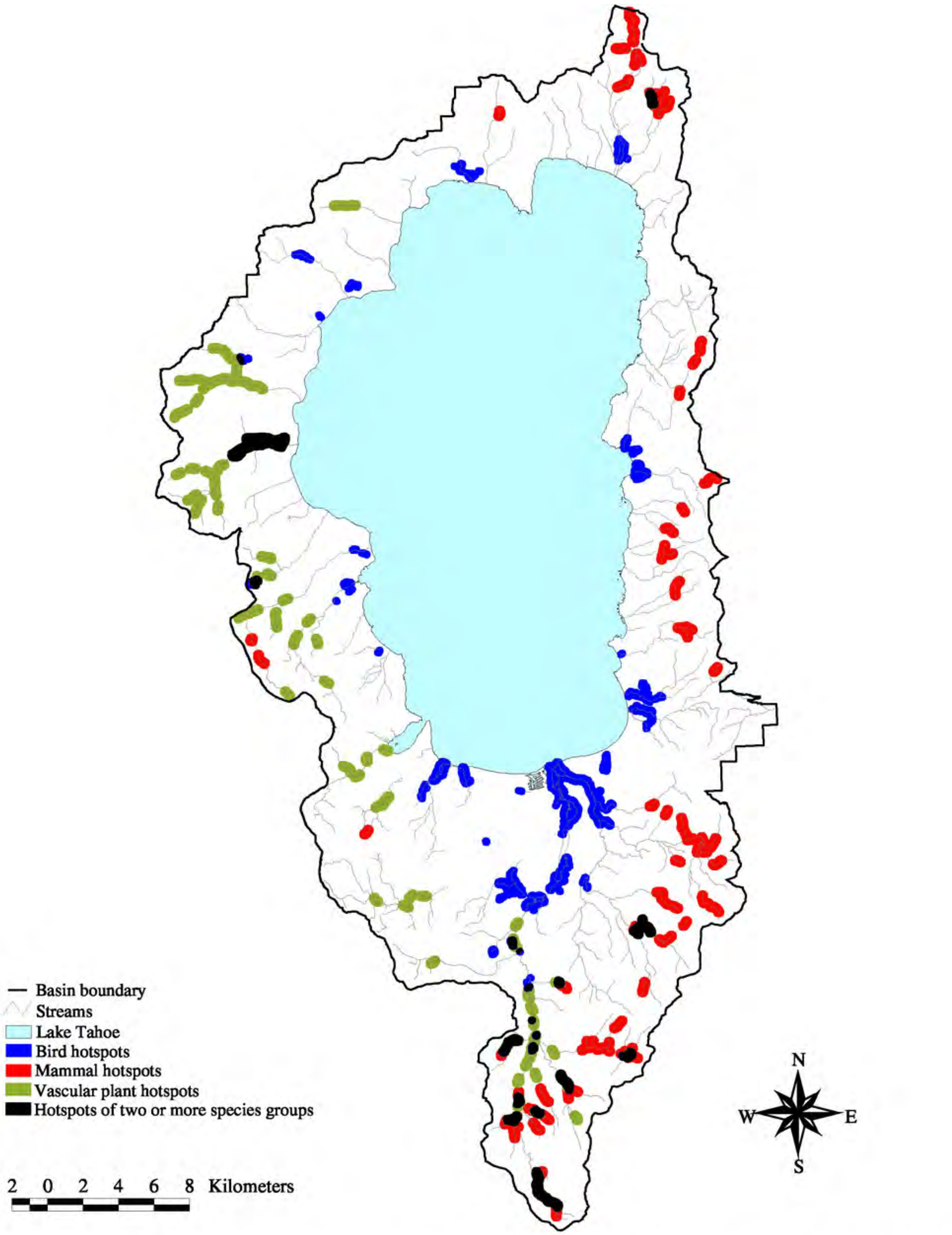


Figure 5-35—Predicted hotspots of bird, mammal, and vascular plant species richness in lentic and lotic riparian areas in the Lake Tahoe basin.

Model predictions may be less accurate than suggested by the 90 percent confidence intervals because human disturbance was not included as an explanatory variable in any of these analyses. For example, many areas predicted to have high bird species richness were in highly disturbed sites such as golf courses; this pattern was probably because of the classification of golf courses as meadows in the vegetation map layer. Bird species richness is positively correlated with meadows, but it is likely that golf courses would support a lower diversity of species because of homogeneity of vegetation structure and composition, use of herbicides, and human visitation. However, golf courses might provide quality habitat for some birds; lentic sites on golf courses were among the most species-rich sites surveyed by Manley and Schlesinger (in preparation). Other human disturbance factors such as recreation, grazing, and timber harvest also were not considered in the modeling exercises.

A few follow-up efforts are suggested by the successful results of these modeling exercises for lotic and lentic riparian areas. The lake and wet meadow maps for the basin may have included some lentic units no longer in existence and omitted some units not currently mapped. Field validation of sites with potential high richness is vital to confirm the existence of lentic units and to test our predictions of species richness. In addition, other species groups, such as amphibians, invertebrates, and fungi, could be modeled in a similar manner based on data from Manley and Schlesinger (in preparation). Finally, models for upland environments could be generated if data become available.

Community Diversity—Communities represent an intermediate level of biological organization between species and landscapes and constitute an important component of biological diversity (Noss 1990). Leopold (1933) observed that areas with a diverse assemblage of plant communities generally supported a rich and diverse assemblage of wildlife species, particularly species that require more than one habitat type. Certainly the same patterns hold for plant species richness, as these communities are defined by shifts in plant species composition. We conducted an analysis to identify areas with high vegetation community diversity as described by the richness of community types and then included them as ESAs.

We identified 13 vegetation community types for use in the community diversity analysis (Table 5-34). The 13 vegetation types were derived by a three step process similar to that used to derive the seven vegetation types in the analysis of biologically diverse riparian areas. First, we adopted the original 12 vegetation types as identified in the CalVeg vegetation layer, with 2 exceptions. We combined mixed conifer - fir with mixed conifer - pine to create mixed conifer because we were not confident that the vegetation layer accurately discerned these two types, and we included water (as identified in CalVeg) as part of the map layer based on the assumption that an aquatic environment would have an effect at least as great as another vegetation type in an area. Second, we treated the riparian vegetation layer in the same manner as it was for the riparian diversity analysis, resulting in 3 riparian types. Third, as with the riparian diversity analyses, we overlaid the map of the 3 riparian vegetation types on top of the map of the 11 CalVeg types to derive a combined map, with areas of overlap being assigned the vegetation type from the riparian vegetation layer. The resulting map displayed 13 vegetation types because the "meadow" vegetation type occurred in both vegetation maps.

The analysis was conducted using a nearest neighbor analysis through ARC/GRID GIS functions. We first converted the vegetation vector layer into a grid layer and specified a 30 square-meter cell size using ARC/INFO GRID (ESRI 1994). To visualize the process, imagine a fishnet draped over a thematic map (e.g., a vegetation map). Where the thematic map intersects with the netting of the fishnet (cells), the integer value from the thematic map is transferred to the cell. In this case, the net was composed of 30 x 30 meter grid cells. The nearest neighborhood analysis systematically searched for community types within a specified search area around each focal cell. The output of the analysis was a map that displayed the number of community types in the vicinity of each cell.

We performed the nearest neighborhood analysis to determine the number of different community types within 120 meters of each cell, an area of approximately two hectares (5 acres). We chose a two hectare area as the area of influence for the 30 meter cell because it is a large enough area to influence the suitability of the 30 m cell for most animal species, and small enough to be within the dispersal distance of most plant species.

The total number of communities associated with any one cell ranged from one to eight (Figure 5-36). A decreasing proportion of the basin was occupied by cells with higher numbers of communities (Table 5-41). We created five classes of community richness to display the range of community richness among cells: 1, 2, 3, 4, and $\geq$ 5 communities associated with a given cell. Approximately 1,450 hectares (3,580 acres) of the basin occurred in the highest richness class ($\geq$ 5 communities). Areas of high community diversity primarily occurred on the southwest side of the basin, with some additional areas on the north side of the basin (Figure 5-36).

We identified seven hotspots of community diversity, defined as areas $\geq$ 1 hectare that were associated with $\geq$ 7 community types (Figure 5-36). Community diversity hotpots as identified here occupied approximately 18 hectares and their locations are described below:

- Near the mouth of Burton Creek;
- The mouth of Meeks Creek;
- Approximately 1.5 kilometers (0.9 miles) up Cascade Creek from Cascade Lake near the Desolation Wilderness boundary;
- Just north of Upper Echo Lake;
- Just east of Lower Echo Lake; and
- Two areas near the headwaters of the Upper Truckee River.

Table 5-41—Proportion of the basin occupied by areas (as defined by 30 m^2 grid cells) associated with 1 to 8 community types.

Number of neighboring communities	Area occupied (percent of the basin)
1	54.4
2	24.9
3	15.0
4	4.7
5	0.9
6	0.14
7	0.02
8	0.002

We conducted a multiple linear regression analysis to determine the environmental factors driving the diversity of plant community types. Five abiotic variables were used as explanatory variables: elevation, precipitation, slope, distance to stream, and distance to lake. Values for each variable were assigned to each 30-meter grid cell. Elevation, precipitation, and slope were generated in the same manner as for the riparian biodiversity models (above). Distance to stream and distance to lake were obtained from digital USGS 1:24,000 topographic maps.

We used backward stepwise regression (SPSS 1993) with an alpha of 0.10 to derive the regression model. Details of the model are in Appendix D. In short, the model consisted of all five variables ($F_{5,129933}$ = 9938.36, $P < 0.0001$, adj. R^2 = 0.28). Areas with the highest community diversity were those at high elevations, with high annual precipitation, high percent slope, and short distances to streams and lakes. The association of high community diversity with short distance to streams and lakes reflects the strong influence of riparian vegetation on community diversity. Inclusion of soil type and human disturbance (e.g., road density) in the model would likely explain a greater proportion of the variation in community diversity.

We expect hotspots of community diversity to correlate roughly with species richness, given that a diversity of communities is expected to support a wide variety of species (Leopold 1933). We cannot directly compare the community diversity map to the maps of potential species richness in riparian areas because community diversity was calculated for the entire basin while the models of biodiversity were generated for riparian areas only. Nonetheless, it appears that community diversity increases near water (i.e., near riparian areas) and tends to have similar environmental relationships to those for mammal and vascular plant species richness (increasing with increasing elevation and precipitation, respectively). Additional modeling of species richness with data from upland areas would be necessary to compare the two exercises fully.

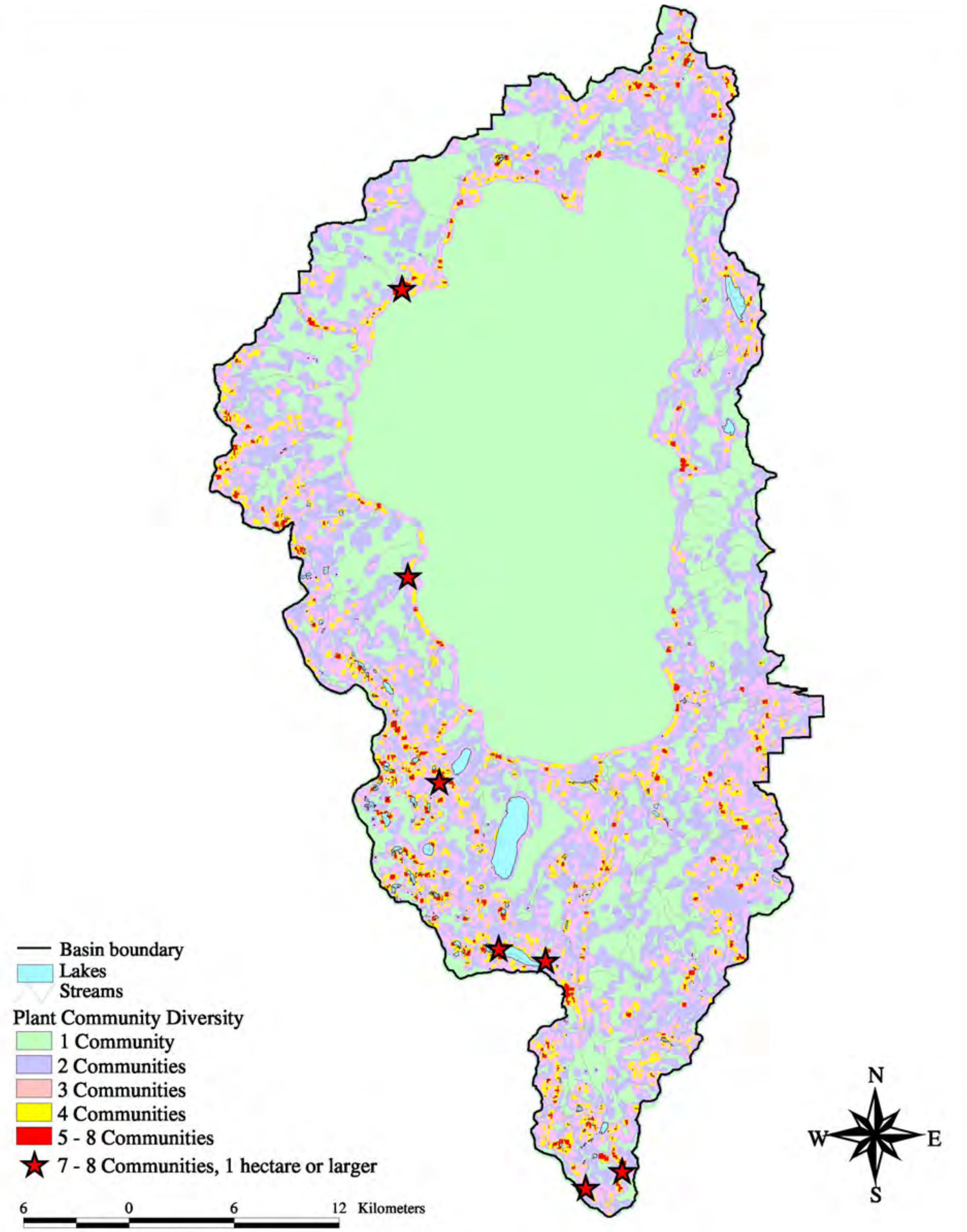


Figure 5-36—Levels of community diversity in the Lake Tahoe basin.

State of Knowledge about ESAs

ESA accounts are intended to provide a synopsis of the state of knowledge about ESAs, which can assist in furthering appropriate activities in monitoring, conservation, and research. We developed such accounts for three ESAs: aspen groves, deep-water plant beds, and *Sphagnum* bogs and fens. If these accounts prove useful, we suggest ESA accounts be developed for the six remaining ESAs identified in this issue, and for any future ESAs that may be identified. We addressed a similar set of topics in each account (Table 5-32). The accounts are in Appendix D.

What data gaps were revealed in the process of assessing ecologically significant areas?

The greatest limitation we encountered in the identification of ESAs in the Tahoe basin was a lack of basic inventory data. First, species richness data representative of the entire basin were not available. Such data would have complemented the riparian diversity assessments by identifying upland sites with potentially high species diversity. Also, we wanted to identify areas with a high diversity of focal species based on various criteria (e.g., rare, exotic) (see Issue 7), but inventory data for these species were not adequate to conduct the analysis.

We had to depend heavily on remotely sensed data for our modeling exercises and the mapping of most ESAs. The accuracy of these remotely sensed data is variable and potentially low. For example, the identification of many ESAs (aspen, high diversity riparian areas, and high community diversity areas) depended on CalVeg (USDA 1991) and riparian vegetation (USGS 1994) GIS layers. Schwind (1998) assessed the accuracy of conifer type classification and canopy cover estimates in the CalVeg vegetation layer for the Lake Tahoe basin and found high variability in the accuracy of vegetation classifications among conifer types. He found that conifer type classifications ranged from 67 to 100 percent accuracy, and canopy cover classifications ranged from 21 to 92 percent accuracy among conifer types. However, his assessment was based on a small sample size, and no confidence intervals were provided for the accuracy estimates. Alternatively, the riparian vegetation layer (USGS 1994) was determined to have relatively high and consistent accuracy, being approximately 80 per cent accurate (USDA 1990). No accuracy assessments have been conducted for shrub and meadow types.

Inaccuracies may also exist in terms of the specific locations and boundaries of some ESAs, such as old forests, deep-water plant beds, marshes, bogs and fens, and the cushion plant community. These inaccuracies could likely be improved in the course of monitoring the status of and changes in these ESAs (see below) and would not warrant a separate field effort.

A number of data gaps regarding specific ecological relationships within the basin hindered our assessment of the value and vulnerability of some ESAs. Basin-specific information on the relationships between biological diversity and the size of aspen groves would have been helpful in determining minimum patch sizes for ecologically significant stands and direction of future conservation efforts. Also, information on the effects of anthropogenic disturbance on ESAs is generally sparse, yet such disturbance poses the greatest threat to the continued integrity of many ESAs. Conservation measures would be greatly informed by empirical data on the influence of various types of anthropogenic disturbance on the biological integrity of ESAs.

What monitoring, conservation, and research activities are most appropriate for the ecologically significant areas identified?

Appropriate monitoring, conservation, and research activities will vary among ESAs based on the feasible alternatives for conservation, the relative level of interest, and the nature of the ESA. Some ESAs are readily defined and identified (e.g., aspen groves), whereas others are derived through models and will require additional work to verify their number, location, and contribution to biological diversity (e.g., riparian areas of high biological diversity). Investments in assessing and maintaining biological integrity can be in the form of conservation, monitoring, or research. Here, we address general considerations and some specific opportunities for conservation, monitoring, and research regarding ESAs, as well as a discussion of inventory data needed to design conservation, monitoring, and research activities. Conservation, monitoring, and research needs for some ESAs were addressed in previous issues, specifically old forests (Issue 1) and bogs, fens, and marshes (Issue 5); therefore, we address them in less detail here.

Prerequisite Inventory Data

The first step in conserving and monitoring selected ESAs is to take an accurate inventory of their number and locations in the basin. Knowledge is more complete regarding the distribution of some types of ESAs than others. We are relatively confident of the locations of all old forests in the basin because of the work of Barbour and others (see Issue 1, this chapter). Also, aspen communities over 1 hectare are accurately inventoried and reliably mapped. The single identified cushion plant community is well known; however, other cushion plant communities may exist in the basin in such areas as the Mount Rose Wilderness (Allessio 1999). A modeling and validation effort could be conducted to assist in identifying potential locations of cushion plant communities in the basin. Surveys need to be conducted for deep-water plant beds in Lake Tahoe to document their number, location, and species composition.

Conservation

The integrity of the basin's ESAs would best be served if conservation measures were developed, adopted, and implemented for all ESAs in the basin. We identified three general types of conservation actions: (1) awareness and education, (2) measures to protect biological integrity, and (3) restoration options. Awareness and education can be achieved in a variety of ways, including (but not limited to) concerns highlighted in such publications as this assessment, workshops, campfire talks, Internet web sites, newspaper and radio media, school programs, research symposia, and public involvement in monitoring and conservation efforts. Measures to protect biological integrity include implementing actions intended to safeguard ESAs or to mitigate impacts to them. Restoration options include measures to improve the quality or quantity of an ESA, including improving physical and biological conditions, restoring natural processes (e.g., fire, flooding), reducing human disturbances, and increasing the number or area of the ESA (where feasible). Restoration activities would be warranted only if degradation of ESAs were noted. Conserving biological integrity of ESAs will be most successful if all three types of conservation actions are employed. Below, we discuss some options and opportunities for conserving ESAs.

Awareness and Education—Awareness and education efforts in regard to ESAs could convey the high ecological and cultural value of ESAs in the basin; in addition, they could highlight their potential fragility and vulnerability. The public could become involved in inventory, monitoring, and conservation efforts, which could be a powerful mechanism for education and awareness.

Measures to Protect Biological Integrity—Some examples of measures that would contribute toward the maintenance and protection of biological integrity of ESAs in the basin are provided below. They represent a short list of effective measures; many other measures may be appropriate and could be identified in the course of developing a conservation strategy for ESAs in the basin. A conservation strategy for biological integrity and diversity in the basin would facilitate full consideration of appropriate protection and enhancement options and priorities. Here we simply provide some first thoughts.

Bogs and Fens—Simple conservation measures to protect the integrity of bogs and fens include the following: (1) limit trampling from grazing and human visitation, (2) avoid alteration of drainage patterns, (3) avoid subsurface water removal (e.g., wells) in the vicinity of bogs, and (4) avoid any activities that may affect pH (e.g., road salting, addition of nutrients through fertilizers) (Shevock 1999).

Aspen Groves—Curtailing grazing in aspen groves could maintain the natural diversity of herbaceous cover and natural succession pathways (Greenway 1990). In addition, recreation has a high likelihood of disturbing the use of aspen by wildlife. Restricting recreation to well-established hiking trails would minimize this disturbance. Restricting motorized recreation in aspen groves would be the greatest contribution to reducing disturbance from recreation, particularly from spring to fall. Larger aspen groves (> 5 ha) would be the highest priority for these conservation measures.

Cushion Plant Community—Avoiding any direct interaction (management or recreation) with the cushion plant community is probably the most effective protective measure for this ESA and would help ensure its continued biological integrity. Because the Freel Peak area is used by hikers but no designated trails exist, establishment of designated trails would ensure that dispersed recreation has minimal impacts to cushion plants.

Deep-water Plant Beds—Maintenance of lake clarity is probably the best way to protect the biological integrity of deep-water plant beds. Reducing disturbance to deep-water plants, once their locations are better identified and their vulnerabilities are defined, also will help maintain the integrity of the plant beds.

Old Forests—Old forest ESAs and their natural processes can be readily maintained by curtailing timber management activities and by using prescribed fire to maintain forest structure and vegetation composition. Grazing in old forest ESAs should be reviewed to ensure that no detrimental effects are being incurred.

Riparian Biodiversity Hotspots—Protecting and maintaining biological diversity in riparian diversity hotspots identified as ESAs is best accomplished by allowing such natural processes as flooding and fire to occur and by limiting impacts from livestock and people, including soil compaction, trampling, alteration of woody vegetation, declines in water quality, sedimentation, introduction of exotic species, and the alteration of behavioral patterns resulting from human presence. Published literature (e.g., Kondolf et al. 1996) can be consulted to determine how best to manage riparian areas and their associated aquatic ecosystems to maintain their biological and physical integrity.

Community Diversity—Protecting and maintaining biological diversity in community diversity hotspots, as identified by ESAs, is best accomplished by allowing such natural processes as fire and succession to occur and by limiting impacts from grazing, timber harvest, soil compaction, and the introduction of exotic species. Community diversity also can be maintained and protected by providing incentives for new and existing human developments to maintain native vegetation and a diversity of vegetation types.

Restoration Options

Bogs and Fens—No restoration options for bogs and fens are evident at this time. Bogs and fens are delicate systems that would be difficult to restore.

Aspen Groves—Low- to moderate-intensity burning in and around aspen areas that mimics natural fire regimes would perpetuate aspen communities by improving soil conditions (Cryer and Murray 1992) and eliminating encroaching conifer saplings.

Cushion Plant Community—No restoration opportunities are apparent at the current time, but this could change if new populations are discovered.

Deep-water Plant Beds—Improving the clarity of Lake Tahoe will improve environmental conditions for deep-water plant beds.

Old Forests—Restoring the role of natural fire in old forests is likely to be a strong contributor to restoring integrity and is likely to be a challenging endeavor. Restoring the role of natural fire through the use of prescribed fire is a relatively high priority in the basin, as indicated in Issues 1, 2, and 3 in this chapter.

Riparian Biodiversity—The potential to improve the biological diversity of riparian areas would apply only to areas that have been degraded. The process of assessing degradation involves determining the existing versus potential diversity and falls largely in the realm of research (see below). However, once degraded areas have been identified, appropriate restoration activities could be identified for individual degraded areas. Restoration activities could include planting woody vegetation, enhancing snag and log populations, restoring natural channel routes, altering channel morphologies, eradicating exotic species, reintroducing native species, and enhancing habitat for native species.

Community Diversity—The potential to improve the diversity of communities is probably limited and would apply only to areas that have been degraded. The primary source of degradation is development and it is unlikely that developed areas can be improved in terms of community diversity. A few cases may exist where community diversity has been degraded in an undeveloped area as a result of heavy recreation use or the conversion from one community type to another (e.g., marsh to meadow). If areas with the potential for restoration were identified and prioritized, a restoration plan could be developed for them. In most cases, the restoration of focal communities (aquatic and terrestrial) will serve to enhance community diversity as well.

Monitoring

Monitoring designed to describe the status of and change in the integrity of ESAs would provide a wealth of information about their current conditions, how their conditions are changing over time, and basic relationships between their condition and the changing environment in which they occur. Developing a monitoring scheme entails identifying attributes to describe conditions, and designing and implementing data collection and analysis. Monitoring attributes can consist of direct measures of condition as well as indirect measures that serve as indicators of integrity. Indicators can provide a strong signal of conditions through the use of relatively few attributes (e.g., Barber 1994). It would be worthwhile to attempt to identify indicators and to monitor their conditions on a trial basis, but it is premature to rely entirely on indicators before the strength of their signal has been validated.

The development of a strong monitoring strategy will require a careful evaluation of potential attributes (both direct and indirect measures), articulation of the questions to be answered, and consideration of effective design options. Here, we make some general recommendations as to attributes that would provide direct measures of ESA conditions.

A strong approach to monitoring the condition of ESAs consists of a balance of physical, biological, and disturbance attributes for each unit selected for monitoring (Table 5-42). Physical attributes consist of abiotic conditions, such as soil, water, and channel conditions. Biological attributes can consist of the frequency or relative abundance of selected plant, vertebrate, invertebrate, and fungal taxa, the vertical and horizontal structure of the vegetation, and snag and downed woody debris characteristics. Disturbance attributes could include intensity of recreation, grazing, timber harvest, fire (prescribed, natural, and accidental), pollutants, and physical disturbances caused by human activities.

Table 5-42—Potential attributes for monitoring status and change of Ecologically Significant Areas (ESAs). Attributes associated with each ESA are indicated.

	Ecologically Significant Areas				
Monitoring attributes	**Bogs, fens, marshes**	**Deep-water plant beds**	**Old forests, aspen, cushion plant**	**Riparian diversity**	**Community diversity**
Physical:					
Substrate	X	X			
Water temperature	X	X		X	
Water depth	X	X		X	
Water clarity		X			
Flooding regime	X			X	
Soil strength				X	
Water chemistry	X	X		X	
Biological:					
Species composition	X	X	X	X	X
Species abundance	X	X	X	X	X
Vegetation structure	X	X	X	X	X
Disturbance:					
Grazing	X		X	X	X
Timber harvest			X	X	X
Prescribed burning	X		X	X	X
Pollutants	X	X	X	X	X
Recreationists	X	X	X	X	X

Issue 7: The Need to Understand the Condition of Species and Populations in the Basin

With contributions from Erik R. Holst, Sheryl L. Ferguson, J. Shane Romsos, and Jennifer S. Hodge

As management and settlement of the basin proceed over the coming years, species and populations are at risk of increasing stress from direct interactions with people and declines in the quality and quantity of their habitats. We assessed the species and population component of biological integrity in the basin by identifying species and populations that might be at greatest risk of future decline or extirpation and that are of particular cultural importance. Many factors can herald the decline of species and populations, including historic population declines, inherent life history characteristics that make species vulnerable to physical disturbances or rapid habitat changes, and excessive or chronic harvesting. We used a number of criteria to identify species of concern or interest within the basin across all species of macrobiota, including vertebrates, invertebrates, vascular and nonvascular plants, and fungi (including lichens). The unique characteristics of individual species of concern require consideration in identifying the appropriate action to take on their behalf. Conservation, management, research, and monitoring are all actions that are necessary to maintain and restore native and desired nonnative species and populations as part of our effort to conserve biological integrity and achieve ecological sustainability in the Lake Tahoe basin.

Our assessment of species and populations in the Lake Tahoe basin addresses the following questions:

- What species currently occur in the basin?
- How has species composition changed from historic times to the present?
- Which species should be of special focus within the basin based on ecological and cultural criteria?
- What is the status of our knowledge about select focal species of greatest interest to local agencies and organizations?
- What data gaps were revealed in the process of assessing species and populations?
- What monitoring, conservation, and research activities are most appropriate for the focal species identified?

What species currently occur in the basin?

We compiled lists of species occurring in the Tahoe basin by taxonomic group: vascular plants, nonvascular plants, vertebrates, invertebrates, and fungi. An accurate determination of current biotic composition in the basin was challenged by incomplete information for some taxonomic groups, and multiple, sometimes obscure sources of data with varying levels of reliability for data on all groups. Information on vertebrates and vascular plants was relatively comprehensive, and we believe the species lists we compiled are fairly accurate and complete. Information on nonvascular plants, invertebrates, and fungi was sparse, and therefore the species lists we compiled are a starting point for further work.

We include both native and nonnative (exotic) species in the species tallies presented here. Detrimental impacts from exotic species can include nest parasitism, resource competition, overgrazing, habitat conversion or degradation, disease transmission, and increased predator pressure (Atkinson 1989). In later sections of this issue, we treat exotic species separately from native species to discuss considerations unique to native and nonnative species.

The sources consulted for basin species occurrences varied in their reliability. We assigned reliability ratings to the documentation of species occurrence in the basin based on the source(s) of the information. The highest reliability rating (high) was given to a species if its occurrence was confirmed by a scientific study, inventory, or museum collection. Ratings reflecting lower confidence in the data (moderate and low) were assigned to species whose occurrence in the basin were documented in nonscientific sources or personal communications or whose occurrence was suggested for a general region (e.g., the Sierra Nevada) without any records in the basin. These ratings are noted in association with each species (appendices E through I) and were useful in identifying gaps in our knowledge of the basin's species composition as well as interpreting historical trends.

Vascular Plants

Vascular plants are plants with veins and include all flowering plants; they comprise the most well-known division of plants, the Anthophyta (Wilson and Loomis 1967; Hickman 1993). Given the large area, complex topography, and lack of extensive plant surveys in the basin, developing a definitive list of plant species was difficult. We compiled a list of vascular plant species known to occur and potentially occurring in the Lake Tahoe basin (Appendix E).

We consulted a variety of sources for identifying plants occurring in the Lake Tahoe basin. Occurrences documented by a specimen (i.e., museum, university, or agency collection) or through a scientific source (e.g., scientific studies) were considered confirmed. Three data sources were available for confirmed sightings: Smith (1973, 1983), Manley and Schlesinger (in preparation), and USFS ecology plot data (USDA 1995a). Smith (1973, 1983) confirmed the occurrence of 923 taxa in the Lake Tahoe basin. Field surveys from Manley and Schlesinger (in preparation) in the basin identified 490 taxa. Finally, the USFS (USDA 1995a) noted 232 plant species. Between these three sources, a total of 1,077 taxa were confirmed to occur in the basin.

Species identified as potentially occurring in the basin but without documented sightings (e.g., some species from the CalFlora database) were considered unconfirmed. Three sources were consulted for species potentially occurring in the basin but lacking confirmed sightings: CalFlora database (Dennis 1995), Rarefind database (CDFG 1999), and the Forest Service manual (USDA 1995b). We queried the CalFlora database (Dennis 1995) for plants that occur in the Tahoe region (Sierra, Nevada, Placer and El Dorado counties east of the Sierra Nevada crest) above 1,880 meters (6,200 feet), which added 361 taxa (species, subspecies, and varieties) to the list. We were not able to query efficiently for the small portion of Alpine County that occurs in the Lake Tahoe basin (approximately 15.5 square kilometers [six square miles]), nor were similar databases available for the Nevada side of the basin. Two species were added from the Forest Service Manual (USDA 1995b). Hickman (1993) and Munz (1968) were consulted to aid in identifying ranges, elevational limits, and current nomenclature.

A few species were removed from the list of potentially occurring species based on consultation with local botanists. We removed three taxa that USDA Forest Service botanists (Taylor 1999; Urie 1999) determined were unlikely to occur in the basin: Dog Valley mousetail (*Ivesia aperta* var. *canina*), mountain lady's slipper (*Cypripedium montanum*), and Sierra Valley mousetail (*Ivesia aperta* var. *aperta*). Truckee barberry (*Berberis aquifolium* var. *repens*) was removed from the list because of data that suggest it is not a distinct variety (Taylor 1999; Urie 1999).

The final list of plants for the Lake Tahoe basin consisted of 1,308 species. Of these, 957 species were identified to the species level only, while 351 species were further identified to subspecies or varieties. The list contains 481 subspecies and varieties, for a total of 1,438 unique taxa. The final plant list is based on the nomenclature and taxonomy of Hickman (1993).

Nonvascular Plants

Our treatment of nonvascular plants included plants commonly referred to as bryophytes. Other taxonomic groups are sometimes included (e.g., lichens), but only bryophytes are formally considered nonvascular plants (USGS 1997; Goodman 1996). Bryophytes are classified into three divisions: Bryophyta (mosses), Hepatophyta (liverworts), and Anthocerophyta (hornworts). They are multicellular, eukaryotic organisms that possess chlorophyll (Richardson 1999).

Data on the nonvascular plants of the Lake Tahoe basin were sparse and incomplete. However, some data have been collected, and confirmations of recent species occurrences do exist (e.g., Manley, unpublished data; UCB 1999a), as well as documentation of species occurring in the Sierra

Nevada (Shevock 1996). We identified 110 species and 5 additional genera, for a total of 115 unique taxa, recorded or potentially occurring in the basin (Appendix F). Our list of nonvascular plants recorded or potentially occurring in the basin is undoubtedly lacking many taxa but is intended to serve as a working hypothesis about the nonvascular plant flora of the Lake Tahoe basin (Appendix F).

Vertebrates

Vertebrates include mammals, birds, reptiles, amphibians, and fish. Throughout this document, we make the distinction between "terrestrial" vertebrates and fish for sake of simplicity, recognizing, however, that many terrestrial species, such as amphibians, also use aquatic habitats. To our knowledge, no complete list of vertebrates in the Lake Tahoe basin has been previously compiled. Numerous lists of one or more vertebrate groups (clades) exists, but none have addressed all vertebrates. Published research and local knowledge about the basin's vertebrates varies widely by taxonomic group; the basin's birds have been studied scientifically and watched by amateurs more than the other vertebrate groups, but fish have attracted almost as much attention because of widespread interest in sport fisheries. Reptiles and amphibians (herpetofauna), on the other hand, are generally more cryptic, are of less interest to the general public, and are the focus of fewer scientific studies. Therefore, the basin's birds are best known, followed by fish, then mammals, and finally herpetofauna.

We consulted the following primary data sources: Orr (1949), Miller (1951), Moyle (1976), Cordone et al. (1971), Orr and Moffitt (1971), TRPA and USDA (1971a, b), Beauchamp et al. (1994), Hall (1995), Tatum (1998a, 1998b), Pierson (1998), the Lake Tahoe basin bird species pamphlet (Eastern Sierra Interpretive Association ca. 1993), and recent sightings generated by scientific studies (e.g., Keane and Morrison 1994; Manley and Schlesinger, in preparation) and agency field personnel (USDA, unpublished data). A complete listing of all sources consulted for each taxonomic group accompanies the species list in Appendix G.

Many additional sources could have been consulted to determine other vertebrate species potentially occurring in the basin. However, the references we consulted represent the primary sources of information on vertebrate species occurrences in the basin. A few additional sightings undoubtedly could be garnered by querying more tangential data sources, but it is improbable that they would substantively change the vertebrate species list or conclusions regarding general trends in species composition over time. In addition, we could have gone beyond confirmed species sightings and used range maps and habitat associations to predict vertebrate species occurrence, which would have yielded many additional species. We felt that such an extrapolation would only obscure patterns of change that might be apparent from examining species records. Therefore, our species list represents only documented vertebrates.

Based on the data sources consulted, we estimate that the basin has 312 vertebrates as residents or regular, if not frequent, visitors ("current" species; Appendix G). This total represents 217 bird, 59 mammal, five amphibian, eight reptile, and 23 fish species. An additional 57 species have been recorded in the basin and are considered accidental visitors or extirpated from the basin. Considerations for extirpated species are addressed in later portions of this issue even though extirpated species are not considered to be current.

Invertebrates

Invertebrates for purposes here, include insects, crustaceans, and spiders. Although data on the invertebrate fauna of the Lake Tahoe basin are sparse and incomplete, some data have been collected and confirmations of recent species occurrences do exist. We consulted the following data sources: Frantz and Cordone (1966, 1996), SFSU (1999a), NAMC (1999), Storer and Usinger (1963), and Manley and Schlesinger (in preparation). Other sources (e.g., Powell and Hogue 1979, Milne and Milne 1988, Borror and White 1970, Furniss and Carolin 1977, Baker 1994, UCR 1999, Hanson and Walker 1999, FUNET 1999, USDA 1999a) were consulted to provide additional or supportive information. A total of 810 unique taxa have been recorded in the basin or potentially occur there, including 379 families, with many of their genera and species identified (Appendix H). These families and the other taxa listed in Appendix H include taxa that are documented or potentially occur in the Lake Tahoe basin. Taxa described as potentially occurring are those that have been recorded in the Sierra Nevada but not in the basin. This list of taxa is intended to serve as a working hypothesis about the invertebrate fauna of the Lake Tahoe basin (Appendix H).

Fungi and Lichens

Members of the kingdom Fungi are multicellular eukaryotic organisms (UCB 1999b). These plant-like organisms generally lack chlorophyll and so obtain their food through saprophytic or parasitic absorption of nutrients from other organic matter (Arora 1986). Fungi typically take the form of thread-like filaments called hyphae (that collectively form the mycelium) and reproduce by means of microscopic spores. The spores are produced in a reproductive structure or fruiting body, which is commonly known as a mushroom. Lichens are classified as members of the kingdom Fungi but consist of a unique symbiotic relationship between algae (tiny photosynthetic plants) and fungi. They have three alternative growth forms: crustose (forming thin crusts on rocks and other substrates), foliose (leaf-like structures attached to plants and rocks), and fruticose (stiff hair-like structure attached to and often hanging from plants) (Hale and Cole 1988). Life cycles of fungi and lichens can be extremely complex and vary considerably among taxa.

Data on the fungi and lichens of the Lake Tahoe basin are sparse and incomplete. However, some data collection has been conducted (Ryan 1990; Manley, unpublished data), and confirmations of recent occurrences do exist. In addition, various works (e.g., Desjardin 1997, SFSU 1999b) have identified species, genera, families, and orders known to occur in the Sierra Nevada. We have noted 612 unique taxa of fungi and lichens as documented or potentially occurring in the Lake Tahoe basin (Appendix I), consisting of 573 species from 300 genera plus 39 additional genera. Known varieties are indicated on the table. This list of recorded and potentially occurring taxa is intended to serve as a working hypothesis about the potential fungi and lichens of the Lake Tahoe basin.

How has species composition changed from historic times to the present?

Historical data were limited for most biota; however, data sources for vertebrates were available to evaluate coarse changes over time. Orr (1949) and Orr and Moffitt (1971) compiled species records for the basin and Grinnell et al. (1937) and Hall (1995) included some basin sightings, all of which were valuable in describing the historical occurrences of birds and mammals. We considered only current species, excluding those considered especially uncommon, because addressing species that do not have an established population in the basin would have obscured major patterns of change. Details on how we derived this subset are described later in this issue. We describe the status of information and changes in vertebrate species composition over the four major time periods established in Chapter 2: Prehistoric Era (pre-1860), Comstock Era (1860 to 1900), Post-Comstock Era (1900 to 1960), and Urbanization Era (1960 to present). Discussion of introductions of fish to Lake Tahoe appear in Chapter 4. For the more recent eras, the availability of more detailed data facilitated separate treatment of native and nonnative (referred to as exotic [Allaby 1994]) species.

Prehistoric Era

No formal inventories of terrestrial and aquatic species were conducted during this period, so a lack of data is noted for most vertebrates for this era (Appendix J). Nevers (1976) noted that Washoe history mentions the presence of mountain sheep (*Ovis canadensis californiana*) in the basin. In addition, a few references to fish species do exist for this era. Historic accounts often mention the abundance of Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*), mountain whitefish (*Prosopium williamsoni*), and "abalone" (species unknown) during this era (Nevers 1976) (Appendix J). More recent research suggests that tui chub (*Gila bicolor*), Lahontan redside (*Richardsonius egrefius*), speckled dace (*Rhinichthys osculus*), Tahoe sucker (*Catostomus tahoensis*), and Piute sculpin (*Cottus beldingi*) were also common in Lake Tahoe prior to the arrival of European settlers in the basin (see Elliott-Fisk et al.

1997) (Appendix J). Although few records exist for the Prehistoric Era, it is likely that native plants and animals documented in the Comstock Era were also present during the Prehistoric Era.

Comstock Era

Information on species composition during the Comstock Era is available but incomplete. In terms of terrestrial species, we were able to find documentation of 66 bird species during this era, but records of mammals, reptiles, and amphibians were not available for this time period (Appendix J). The composition of native species of mammals, reptiles, and amphibians in this era was probably very similar to the composition of native species during the Post-Comstock Era because conditions varied more within than between these eras. Variation in population sizes is likely to be the greatest source of change within and between these eras in response to the major shifts in environmental conditions. However, no data exist on population sizes.

Changes in fish species composition were evident in the Comstock Era, with the introduction of nonnative species constituting the greatest known change (Appendix J). The eastern brook trout (*Salvelinus fontinalis*) was probably the first non-native fish species to be introduced into the streams and lakes of the Lake Tahoe basin (Miller 1951; Elliott-Fisk et al. 1997). Circa 1880, brook trout were first planted in Marlette Lake (Scott 1957), and from 1891 to 1893 large numbers were introduced into Lake Tahoe itself (CDFG 1957). In 1895, the Fish Commission (later to become the California Department of Fish and Game) planted 65,000 Great Lakes mackinaw (*Salvelinus namaycush*) fingerlings from a fish hatchery near Mount Shasta into lakes above Meeks Bay (Scott 1957). By the 1920's, mackinaw trout were established in Lake Tahoe, having migrated down Meeks Creek from lakes in the upper Meeks Creek drainage (Scott 1957).

Post-Comstock Era

Native Species—Fifty-seven species of mammals and 135 species of birds were recorded in the basin during the Post-Comstock Era by various observers and biologists (Appendix J). The increased number of bird species recorded in the Post-Comstock Era compared to the Comstock Era is probably reflective of increased field effort and greater abundance of historical accounts rather than true increases in native species richness in the basin. For example, naturalists such as George Wharton James (James 1915) wrote accounts about the basin, describing the character of the forests and noting the occurrence of certain "charismatic" species in a series of his anecdotes and observations. He noted that bald eagles (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*) were often seen, but apparently nested outside the basin, mountain lions (*Felis concolor*) and black bears (*Ursus americanus*) sometimes preyed upon flocks of sheep, and rangers in the forest reserve reported infrequent but significant outbreaks of porcupine (*Erethizon dorsatum*) damage to trees (James 1915).

The dynamics of aquatic communities changed significantly during this era, and declines in populations of native fish species became apparent. James (1915) noted that in smaller lakes in the basin, native trout were becoming rare, but in Tahoe itself they did not seem to have been "driven out" by introduced species. However, populations of the native Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*) declined steadily even after the California legislature banned commercial fishing in regional lakes and streams in 1917 (Gerstung 1988).

Exotic Species—Successful introductions and invasions of exotic aquatic species were numerous during the Post-Comstock Era. In a major effort to enhance Lake Tahoe's fishery, over 14 million nonnative fish were planted in the lake from 1944 to approximately 1960 (Strong 1984). Kokanee salmon (*Oncorhynchus nerka kennerlyi*) were first introduced in 1944 and were released in greater numbers after 1950 (Cordone et al. 1971). Adult Lahontan cutthroat of the Heenan Lake strain were introduced annually in Taylor Creek and the Upper Truckee River from 1956 through 1964 (Strong 1984).

Data on the distribution and abundance of exotic terrestrial vertebrates are limited to the European starling (*Sturnus vulgaris*). It was first recorded in the basin in 1959 (Orr and Moffitt

1971). During this era, starlings were undergoing a range expansion on a continental scale, typically occupying environments subject to human disturbance (Ehrlich et al. 1988). The arrival of starlings in the basin is most likely the result of a combination of their general range expansion and an increasing proportion of the basin occupied by human dominated environments (see Chapter 2 for descriptions of historic environmental changes).

Urbanization Era

Native Species—Many native species declined or were apparently extirpated during this era. One hundred forty-five bird species, 54 mammals, five amphibians, and eight reptiles were recorded in the basin during the Urbanization Era (Appendix J). Wolverines (*Gulo gulo*) and northern leopard frogs (*Rana pipiens*) appear to have been extirpated, and grizzly bears (*Ursus arctos*) and mountain sheep no longer occur in the basin. Twenty-three species of fish were recorded in the Urbanization Era (Appendix J); the Lahontan cutthroat trout was temporarily extirpated from the basin but was subsequently reestablished during this era (Reiner 1999). Populations of mountain whitefish and Tahoe suckers are suspected to be at extremely low numbers (Elliott-Fisk et al. 1997). The Tahoe yellowcress (*Rorippa subumbellata*), a plant endemic to the basin, was so threatened by shrinking habitat, unnatural manipulation of lake levels, and recreational disturbance of the shoreline (TRPA 1996).

Exotic Species—For the Urbanization Era, documentation of exotic species was much more detailed than in earlier periods. At least seven exotic terrestrial vertebrate species were first recorded in the basin during the Urbanization Era, including the bullfrog (*Rana catesbeiana*), rock dove (*Columba livia*), wild turkey (*Meleagris gallopavo*), and beaver (*Castor canadensis*) (Appendix J). Four additional species possibly could be considered exotic species, as they are native to the US but occur in the basin outside their typical geographic and elevational ranges: brown-headed cowbird (*Molothrus ater*), common raven (*Corvus corax*), western gray squirrel (*Sciurus griseus*) (Jameson and Peeters 1988), and California quail (*Callipepla californica*) (Ahlborn 1990a) (Appendix J).

The growth of sport fishing as a recreational activity and associated further development of marinas and boat launching facilities precipitated the introduction of many exotic aquatic species. Six species of exotic fish, including three species of trout, were introduced into Lake Tahoe (Appendix J). Three strains of "wild" rainbow trout (Kamloops, Pyramid Lake, and Williams Lake) (*Oncorhynchus mykiss*) and domestic trout were released between 1960 and 1963. The success of exotic fish species may have been aided by the introduction and proliferation of exotic aquatic plants, such as Eurasian watermilfoil (*Myriophyllum spicatum*), by increasing water temperatures associated with inland marinas (Kilgore et al. 1989), and the intentional introduction of exotic food sources (Frantz and Cordone 1996). Between 1963 and 1965, approximately 333,000 mysid shrimp (*Mysis relicta*), also referred to as opossum shrimp, were introduced at various locations around Lake Tahoe in an effort to improve the food supply for the mackinaw trout (Frantz and Cordone 1996). These shrimp are suspected to have caused declines in native invertebrates (Goldman et al. 1979).

Synthesis and Analysis of Historical Changes

Impacts of past land uses on biological diversity are unknown and difficult to quantify because site-specific information is scarce, especially for periods prior to 1900. One can only speculate, based on historical descriptions of the landscape, on the extent to which humans have influenced changes in species composition. Elliott-Fisk et al. (1997) and McKelvey and Johnston (1992) provide a thorough review of available information on historical land uses in the basin, while several sources (e.g., Orr 1949; Orr and Moffitt 1971; Hall 1995) contain accounts of vertebrate species that were also helpful in attempts to describe the occurrence of birds and mammals in the basin. Only within the past 25 years have comprehensive surveys and monitoring efforts begun to document and thus increase our understanding of species composition in the basin (Manley and Schlesinger, in preparation; Keane and Morrison 1994; USDA unpublished data).

The apparent decline in abundance and distribution of many native species in aquatic communities has been attributed to reduction of species' historic ranges, destruction of spawning habitat, and introduction of exotic species (Strong 1984; Gerstung 1988). Many aquatic ecosystems in the basin did not contain fish historically and it is possible that introductions of nonnative trout have reduced or eliminated populations of aquatic amphibians as is suspected to have occurred throughout the Sierra Nevada (Moyle 1996). In addition, disturbances that have degraded aquatic habitats in the past, such as development and recreation, may have been more pronounced within the basin because of the greater concentration of human activity compared to the rest of the Sierra Nevada (see Issue 5, this chapter).

We evaluated shifts in species presence across the eras to identify potential or known additions to or extirpations from the vertebrate fauna of the basin (Table 5-43). The apparent additions or extirpations (based on trends in presence and absence across the eras) were evaluated further by considering information on the species' residential status (i.e., regular resident versus vagrant), population trend (i.e., declining or stable), and the reliability of the data (i.e., limited historical data available, present data represented by one or many sightings). All determinations of gains or losses are made in the context of the data consulted and are simply intended to serve as points of further clarification.

Changes in the Bird Fauna—The current species composition of birds in the basin is relatively well documented. Thus, the possibility of extirpation was evaluated for any species not recorded as present in the Urbanization Era. Four bird species were considered potentially extirpated from the basin because they were present in previous eras but were not recorded in the Urbanization Era: peregrine falcon (*Falco peregrinus*), savannah sparrow (*Passerculus sandwichensis*), Lewis's woodpecker (*Melanerpes lewis*), and canyon wren (*Catherpes mexicanus*) (Table 5-43). The peregrine falcon is noted as having occurred within the basin during the Post-Comstock Era by Reed (1981), but her sources were not documented. No peregrine falcons have been sighted in the basin in the Urbanization Era, with the exception of those individuals involved in an unsuccessful effort to reestablish the species in the late 1980s and early 1990s (TRPA 1996; USFS, unpublished data). The savannah sparrow was noted in Orr and Moffitt (1971) as a common summer visitor, Lewis's woodpecker was noted in Orr and Moffitt (1971) as an irregular summer visitor, and the canyon wren was noted by Orr and Moffitt (1971) as rare or irregular. All four of these species were considered only potentially extirpated because it is unknown if they ever established populations in the basin. Finally, 30 species of birds described by Eastern Sierra Interpretive Association (ca. 1993) as "accidental" or "rare" were documented in the Comstock and Post-Comstock eras but not in the Urbanization Era (Table 5-43); these species were not considered extirpations because they may never have established populations in the basin.

Twenty-seven species of birds were recorded only in the Urbanization Era, including six known additions and three potential additions (Table 5-43). Five of the six known additions were exotic species: wild turkey, European starling, California quail (*Callipepla californica*), rock dove (*Columba livia*), and house sparrow (*Passer domesticus*). The brown-headed cowbird is the sixth known addition. It is a brood parasite that has expanded its range from east of the Mississippi to the west coast this century in response to changing land use patterns (Ehrlich et al. 1988).

Three species that may have populated the basin in the Urbanization Era are common raven, spotted owl (*Strix occidentalis*), and downy woodpecker (*Picoides pubescens*). All three of these species have been recorded only in the Urbanization Era and are relatively easy to detect. In addition, changes in ecological conditions (i.e., regeneration of forests, high density of trees, large numbers of snags [see Issue 1]) over the past 150 years suggest that habitat conditions for these species have improved based on their basic habitat associations (Zeiner et al. 1990a). The specific circumstances related to each species are discussed below.

Table 5-43—Potential or verified extirpations ("lost") and additions ("gained") to the vertebrate fauna of the Lake Tahoe basin. Potential changes are indicated by a "maybe" in the "lost" or "gained" column. The era in which species' presence has been verified is indicated by an X (n.d. = no data available for the era).

Common Name	Scientific Name	Exotic	Prehistoric Era (pre-1860)	Comstock Era (1860-1900)	Post-Comstock Era (1901-1960)	Urbanization Era (1961-present)	Lost[a]	Gained
Birds[b]:								
California Quail	*Callipepla californica*	X	n.d.		X	X		Yes
Canyon Wren	*Catherpes mexicanus*		n.d.	X	X		Maybe	
Rock Dove	*Columba livia*	X	n.d.			X		Yes
Common Raven	*Corvus corax*		n.d.			X		Maybe
Peregrine Falcon	*Falco peregrinus*		n.d.		X		Maybe	
Lewis's Woodpecker	*Melanerpes lewis*		n.d.	X	X		Maybe	
Wild Turkey	*Meleagris gallopavo*	X	n.d.			X		Yes
Brown-headed Cowbird	*Molothrus ater*		n.d.			X		Yes
House Sparrow	*Passer domesticus*	X	n.d.		X	X		Yes
Savannah Sparrow	*Passerculus sandwichensis*		n.d.		X		Maybe	
Downy Woodpecker	*Picoides pubescens*		n.d.			X		Maybe
Spotted Owl	*Strix occidentalis*		n.d.			X		Maybe
European Starling	*Sturnus vulgaris*	X	n.d.		X	X		Yes
Mammals[c]:								
Beaver	*Castor canadensis*	X	n.d.	n.d.		X		Yes
Wolverine	*Gulo gulo*		n.d.	n.d.	X		Maybe	
White-tailed hare	*Lepus townsendii*		n.d.	n.d.	X		Maybe	
Mountain sheep	*Ovis canadensis californiana*		X				Maybe	
Canyon mouse	*Peromyscus crinitus*		n.d.	n.d.	X		Maybe	
Heather vole	*Phenacomys intermedius*		n.d.	n.d.	X		Maybe	
Western gray squirrel	*Sciurus griseus*		n.d.	n.d.		X		Yes
Grizzly bear	*Ursus arctos*		n.d.	n.d.	X		Yes	
Sierra Nevada red fox	*Vulpes vulpes necator*		n.d.	n.d.	X		Yes	
Amphibians[d]:								
Bullfrog[e]	*Rana catesbeiana*	X	n.d.	n.d.	?	X		Yes
Northern leopard frog	*Rana pipiens*	?	n.d.	n.d.	X		Maybe	

Table 5-43—*(continued)*

Common Name	Scientific Name	Exotic	Prehistoric Era (pre-1860)	Comstock Era (1860-1900)	Post-Comstock Era (1901-1960)	Urbanization Era (1961-present)	Lost[a]	Gained
Fish[e]:								
Goldfish	*Carassius auratus*	X				X		Yes
Lake whitefish	*Coregonus clupeaformis*	X		X	X			Yes
Carp	*Cyprinus carpio*	X				X		Yes
Mosquito fish	*Gambusia affinis*	X				X		Yes
Brown bullhead	*Ictalurus nebulosis*	X				X		Yes
Bluegill	*Lepomis macrochirus*	X				X		Yes
Largemouth bass	*Micropterus salmoides*	X				X		Yes
Smallmouth bass	*Mircopterus dolomieui*	X				X		Yes
Golden shiner	*Notemigonus crysoleucas*	X				X		Yes
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*		X	X	X		Yes[f]	
Rainbow trout	*Oncorhynchus mykiss*	X			X	X		Yes
Kokanee salmon	*Oncorhynchus nerka kennerlyi*	X			X	X		Yes
Chinook salmon	*Oncorhynchus tshawytscha*	X		X	X			Yes
White crappie	*Pomoxis annularis*	X				X		Yes
Black crappie	*Pomoxis nigromaculatus*	X				X		Yes
Golden trout	*Salmo aquabonita*	X		X	X	X		Yes
Atlantic salmon	*Salmo salar*	X		X	X			Yes
German brown trout	*Salmo trutta*	X			X	X		Yes
Brook trout	*Salvelinus fontinalis*	X		X	X	X		Yes
Mackinaw (lake) trout	*Salvelinus namaycush*	X		X	X	X		Yes
Arctic grayling	*Thymallus arcticus*	X		X	X			Yes

[a] Losses and gains were determined by reviewing the pattern of presence by era, resident status, exotic status, and population trends.
[b] Data sources for birds included Orr and Moffitt (1971), Keane and Morrison (1994), Manley and Schlesinger (in preparation), and USFS (unpublished data). Because there was virtually no documentation of bird occurrence prior to the arrival of Euroamerican settlers, no attempt was made to guess at bird species occurrence during the Prehistoric Era. However, in situations where a bird was not recorded between 1901 and 1959 but was recorded before and after this period, we assumed that that species occurred between 1901 and 1959.
[c] Data sources for mammals included Grinnell et al. (1937), Orr (1949), Keane and Morrison (1994), Manley and Schlesinger (in preparation), and USFS (unpublished data). We did not find written documentation of mammal occurrence prior to 1901.
[d] Data sources for amphibians and reptiles included Museum of Vertebrate Zoology, University of California, Berkeley, Keane and Morrison (1994), and Manley and Schlesinger (in preparation).
[e] Data sources for fish included Miller (1951), Moyle (1976), Beauchamp et al. (1994), Tahoe Regional Planning Agency (1971a), Cordone et al. (1971), Manley and Schlesinger (in preparation.), and S. Lehr (1999.).
[f] The Lahontan cutthroat trout was extirpated from the basin and subsequently reintroduced.

The spotted owl was only recorded in the Urbanization Era. It has a large home range, requiring approximately 3,420 acres of suitable habitat per pair (Zabel et al. 1992). If the basin consisted entirely of suitable habitat, it could at best support 57 pairs of owls. It is plausible that the spotted owl was present in the basin prior to the Comstock Era. However, during the Comstock Era, much of the basin was logged, with the exception of portions of the west side of the basin. In light of the lack of documented occurrence, we assumed that no owls resided in the basin during this era. In the Post-Comstock and Urbanization eras, forested areas regenerated, and today many large trees occur in the basin once again (see Chapter 2). Surveys have identified an increasing number of breeding pairs of birds in the basin, with recent estimates at six pairs (USDA Forest Service, Lake Tahoe Basin Management Unit, unpublished data). These data suggest that the spotted owl may have reestablished a population in the basin that was lost during the Comstock Era.

The common raven was also only recorded in the Urbanization Era. It is a large conspicuous bird that is common in both wilderness and areas with an urban/wildland interface (Ehrlich et al. 1988). It is unlikely that such a conspicuous bird would go unnoticed if present in previous eras. In our evaluation, the common raven was considered an addition to the basin's avifauna and we attributed its current presence to the increase in human-dominated environments in the basin (see Chapter 2).

The downy woodpecker is the smallest-bodied woodpecker found in the basin and is a common inhabitant of forests on the west side of the Sierra Crest. Woodpeckers are conspicuous because of their frequent vocalizations and drumming (Terrill 1983). The downy woodpecker tends to forage on smaller diameter woody material than the larger-bodied woodpeckers also occurring in the basin (e.g., hairy woodpecker (*Picoides villosus*) and pileated woodpecker (*Dryocopus pileatus*) (Zeiner et al. 1990a). As forests regenerated during the Post-Comstock and Urbanization eras and fire suppression became a standard practice, large stands of densely forested areas, including many younger trees whose growth was suppressed, became prevalent (see Chapter 2). Present day forest stand structure and conditions in the basin correspond with suitable habitat for the Downy Woodpecker (Ziener et al. 1990a), perhaps facilitating the species' establishment. In our evaluation, the Downy Woodpecker was considered a likely addition to the basin's avifauna.

Many species recorded only in recent eras were not considered additions to the bird fauna. The green heron (*Butorides striatus*) was recorded by Keane and Morrison (1994) only (Appendix J); it is not considered an addition because it is most likely a vagrant in the basin. An additional 17 species described by Eastern Sierra Interpretive Association (no date) as "accidental" or "rare" that were recorded only in the Urbanization Era (Appendix J) were not considered additions because they may not have established populations in the basin. An additional 79 species recorded in the Post-Comstock and Urbanization eras but not earlier (Appendix J) were not considered additions because of the paucity of data from earlier eras.

Changes in the Mammal Fauna—Historical data on mammals were limited to the two most recent eras. As such, it was difficult to determine any trends in occurrence for individual species. However, a few changes were discernible, including one known extirpation, six potential extirpations, and two potential additions. These species are discussed in more detail below.

The evidence and conclusions varied among the seven species absent from the Urbanization Era: grizzly bear, Sierra Nevada red fox (*Vulpes vulpes necator*), wolverine (*Gulo gulo*), white-tailed hare (*Lepus townsendii*) heather vole (*Phenacomys intermedius*), canyon mouse (*Peromyscus crinitus*), and mountain sheep. The grizzly bear extirpation is certain because this species is known to have been extirpated from the entire Sierra Nevada (Graber 1996). The Sierra Nevada red fox also may have been extirpated from the entire Sierra Nevada, based on the lack of current records and the failure to confirm individuals despite considerable survey effort (Zielinski 1999). The wolverine was documented in the basin by Grinnell et al. (1937) with a single record but subsequent inventories and studies have not detected it; it is treated as a likely extirpation because it has not been detected in over 60 years and it is known to have declined in the Sierra Nevada (USDA 1999b). The white-tailed hare was noted by Orr (1949) as "relatively rare" in the basin and has not been documented since. The species is known to have declined in the Sierra Nevada as well (USDA 1999b). Sufficient surveys have not been conducted to conclude that the species has been extirpated from the basin, so it is considered only a potential extirpation. The heather vole was noted by Orr (1949) as extremely rare in the basin, and it has not been detected in the Urbanization Era despite inventory efforts designed to detect small mammals (e.g., Keane and Morrison 1994; Manley and Schlesinger in preparation). The canyon mouse was detected in the basin during the Post-Comstock Era (Museum of Vertebrate Zoology, University of California, Berkeley); however, it has not been detected during the Urbanization Era. Both the heather vole and canyon mouse are considered only potential extirpations because they may never have established populations in the basin. The mountain sheep was documented as occurring in the basin by the Washoe Tribe (Nevers 1976), and to the north of the basin in the Truckee River basin in the mid-1850s (Hall 1995). It has not been documented in the current era and is considered a potential extirpation because the quality of data documenting its historical occurrence is poor. Finally, the black-tailed hare (*Lepus californicus*) has not been detected in the Urbanization Era (Appendix J) but was not considered an extirpation because Orr (1949) considered the species to be a vagrant in the basin.

Two species of mammals were identified as potential or known additions to the mammal fauna in the Urbanization Era: western gray squirrel and beaver. The western gray squirrel is a conspicuous animal that commonly occupies open habitats (Burt and Grossenheider 1980) and was not detected before the Urbanization Era. It tends to fare well in urban/wildland interfaces, but the basin is above its typical elevational limit (Jameson and Peeters 1988). It is highly likely that the western gray squirrel is a new addition to the mammal fauna in the basin, facilitated at least in part by the increase in settlement around Lake Tahoe. The beaver is generally considered exotic to the Sierra Nevada, recently introduced for the purpose of fur trapping (Graber 1996). Consideration of the beaver as a recent addition to the basin is supported by Orr (1949), who did not list the beaver as occurring in the basin.

Four other species with records in the Urbanization Era only were not considered additions. The Brazilian free-tailed bat (*Tadarida brasiliensis*) and California myotis (*Myotis californicus*) were not considered additions because extensive surveys for bats were not conducted until the Urbanization Era. The least chipmunk (*Tamias minimus*) and desert woodrat (*Neotoma lepida*) were detected only by Manley and Schlesinger (in preparation), but both species were uncommon in their surveys (20 and two detections, respectively). Furthermore, both species were detected only on the east side of the basin, where historical records are sparse. It is likely that both species were present in earlier eras but were not detected because of their apparent rarity; therefore, they are not considered additions to the mammal fauna of the basin.

Changes in the Herpetofauna—Historical data on amphibians and reptiles were limited to the two most recent eras. One potential extirpation and one addition to the herpetofauna are suggested based on the data (Table 5-43). The northern leopard frog may have been extirpated from the basin. Historical occurrence of northern leopard frogs is documented by several records on the south shore (Appendix J), and the species formerly occurred in numerous locations throughout the northern Sierra (Jennings and Hayes 1994). Although the species has experienced population declines in the Sierra Nevada, it is debatable if the northern leopard frog ever had established a population in the basin, and if it did, it may have been introduced by humans (Jennings and Hayes 1994). The only addition to the amphibian fauna in the basin is the bullfrog. The bullfrog is exotic west of the Rocky Mountains (Stebbins 1985) and has been expanding its range rapidly over the past 100 years or so (Moyle 1973). The bullfrog typically occurs only below 1,220 meters (4,000 feet) in the Sierra Nevada (Morey 1988), but it has been able to establish populations at the lowest elevations in the basin (1,880 meters;

6,200 feet) in lakes and the mouths of streams that empty into Lake Tahoe (Manley and Schlesinger, in preparation). Two additional species, the southern alligator lizard (*Elgaria multicarinata*) and the common garter snake (*Thamnophis sirtalis*), which were recorded only in the Urbanization Era (Appendix J), were not considered additions because very few surveys for reptiles were conducted in earlier eras.

Changes in the Fish Fauna—Historical data on fish species in the basin are relatively comprehensive, with historical accounts dating back to the Prehistoric Era. One extirpation and 16 additions have occurred in the fish fauna of the basin according to the historical record of the past 150 years (Table 5-43). The Lahontan cutthroat trout is the only fish species known to have been extirpated from the basin. Of the 20 species of exotic fish that were introduced into lakes and streams in the basin, 16 currently maintain populations within the basin. Most of these fish species have been introduced to support sport fishing (Scott 1957).

Driving Forces of Observed Changes

The potential and known vertebrate species extirpations and additions within the basin appear to be have been caused by multiple factors. Factors that may be responsible for vertebrate extirpations include larger-scale declines, fire suppression, and topographic isolation. Larger-scale (i.e., regional or continental) population declines are likely responsible for the loss of red fox, grizzly bear, wolverine, white-tailed hare, and northern leopard frog. The exclusion of fire has changed forest structure and composition in the basin, as well as the composition and productivity of shrublands, meadows, and forested vegetation types with shrub or grass understories (e.g., lodgepole pine) (see Issues 2 and 3, this chapter). The exclusion of fire may be responsible for potential losses of the savannah sparrow, Lewis's woodpecker, canyon wren, heather vole, and canyon mouse. The high elevation topographic features creating the basin serve as a selective barrier to the movement of some biota, thus lowering immigration and emigration rates for some species compared to rates in unrestricted landscapes (Udvardy 1969; Brown 1995). For some species, a slowed immigration of new individuals, combined with the limited amount of suitable habitat for many species (resulting from the relatively small area of the basin and the linear distribution of terrestrial environments), may result in smaller population sizes and decreased rates of reestablishment if populations become extirpated (Udvardy 1969; Brown 1995).

The notion that the topographic features creating the lake basin serve as a barrier for some species is further suggested by the lack of species that would be expected to occur in similar but less isolated environments. For example, species with limited mobility, such as the western pond turtle (*Clemmys marmorata*), western skink (*Eumeces skiltonianus*), western rattlesnake (*Crotalus viridis*), and California newt (*Taricha torosa*), could find suitable habitat at low elevations in the basin (Zeiner et al. 1988) but apparently have never occurred in the basin. Their absence is likely the result of the inability to disperse across the high elevation terrain that surrounds the basin.

Many factors may have caused the addition of certain species of vertebrates: direct introductions, fire suppression, an increased level of settlement, increased abundance of large trees, and topographic isolation. Direct introductions are responsible for the addition of bullfrogs and all exotic fish. Fire suppression, while potentially responsible for some vertebrate extirpations, also may be responsible for the potential establishment of downy woodpecker populations. The increased level of settlement in the basin has shifted a greater proportion of the basin's ecological communities, particularly those in proximity to Lake Tahoe, to human-dominated landscapes (see Chapter 2). These changes have increased the suitability of environments around the lake for some native species, specifically brown-headed cowbird and common raven, as well as a number of exotic species, specifically European starling, house sparrow, and rock dove. The regrowth of forests during the Post-Comstock and Urbanization eras resulted in the recurrence of large trees (Strong 1984), which may have facilitated the apparent reestablishment of a spotted owl population. Finally, smaller population sizes and the absence of some species (possibly excluded by the topographic barriers surrounding the basin) may concomitantly reduce levels of competition such that new species arriving in the basin have a greater probability of successfully establishing a population. Lower species richness and abundance can reduce competition below typical levels, enabling species to establish populations where they would otherwise be outcompeted (Elton 1958). This phenomenon has been witnessed on oceanic islands, such as Hawaii, as well as landscape islands (Atkinson 1989). In the basin, the western gray squirrel, California quail, bullfrog, European starling, and house sparrow have all established populations at elevations higher than those at which they typically occur throughout their range. Although most of these species are also generalists, it is possible that they would not have successfully established populations at this elevation in a less isolated, more competitor-rich environment.

The physical and biological factors identified as potential causes of extirpations and additions of vertebrate species undoubtedly have similar implications for the presence, distribution, and abundance of other biota in the basin. We suspect that some species of native and exotic plants, invertebrates, and fungi have been extirpated or added to the fauna as the result of the factors discussed above. In addition, decreases in the quantity and quality of aquatic ecosystems such as marshes and lakes have certainly changed the distribution and abundance of many aquatic species of plants, animals, and fungi. For example, lack of fire has apparently increased the abundance of some conifer species, such as white fir (*Abies concolor*), and decreased the abundance of other species, such as sugar pine *(Pinus lambertiana*) (see Issue 1). Another example is an apparent increase in the abundance of species that can flourish in landscapes altered by humans, such as the coyote (*Canis latrans*), Steller's jay (*Cyanocitta stelleri*), and California ground squirrel (*Spermophilus beecheyi*).

Implications for Biological Integrity

The implications for biological integrity of these documented and suspected changes in species composition can be inferred but are difficult to ascertain. One thing is certain in regard to species and populations: the Lake Tahoe basin has declined in biological diversity and, concomitantly, in biological integrity. Many of the extirpated species were members of high trophic levels (i.e., grizzly bear and Sierra Nevada red fox), had relatively specific habitat requirements (e.g., Lahontan cutthroat trout), or were associated with habitats that are becoming increasingly rare in the basin (e.g., Lewis's woodpecker). All of these traits contribute significantly to biological integrity. For instance, the loss of higher trophic level species can have dramatic consequences for populations of species lower on the food chain (Carpenter et al. 1985; Power et al. 1996). Species gained represent generalists or exotic species and as the proportion of generalist species increases, beta diversity (the degree to which species composition changes along environmental gradients; Whittaker 1972) decreases because of the reduction in diversity of life history traits and habitat requirements represented among species. In addition, as generalists and exotic species become more common, the basin's contribution to biological diversity across the Sierra Nevada declines.

Which species should be of special focus within in the basin based on ecological and cultural criteria?

Criteria for Identifying Focal Species

Biologists involved with regional assessments and monitoring programs have often focused on a subset of species to address the critical elements of biodiversity, recognizing that such assessments and programs cannot address the viability of all species in a management area. These subsets of species were termed "special species" in the Southern Appalachian Assessment (Southern Appalachian Man and the Biosphere 1996), "emphasis species" in the Southern California Mountains and Foothills Assessment (USDA, in preparation), and "focal species" by the USDA Committee of Scientists (1999). Among the "special" and "emphasis" species in the two regional assessments mentioned above were the following: federal and state threatened, endangered, and special concern species, other species with viability concerns (due for example to population declines or very specific habitat requirements), game species, and species of high management or public interest.

"Focal species," as defined by the USDA Committee of Scientists (1999), included a broader suite of species including those intended to represent the integrity of ecosystems as well as species of concern. The USDA Committee of Scientists (1999) recognized that information about the ecological function of species is often sparse and that designations of species as focal serve only as working hypotheses until more data are collected through research and monitoring. Here, we identify focal species using criteria more similar to those of the two large-scale assessments mentioned above and do not intend for our focal species to serve as indicators of ecosystem conditions. Additional analyses would be necessary to identify indicator species and the associated validation monitoring required.

Often, species prioritization exercises (e.g., Millsap et al. 1990; Manley and Davidson 1993; Given and Norton 1993) have combined criteria for potential imperilment and potential vulnerability into a single analysis, occasionally including management (or "action") variables as well. A species that has declined (i.e., is potentially imperiled) and that also possesses a characteristic that might lead to further decline (i.e., is potentially vulnerable) is usually of greater concern than a species that has declined only. This reasoning has led some investigators to combine the two factors in their analyses. However, our goal was not to prioritize species, but rather to generate an inclusive list of species of concern and interest that could be assessed to determine appropriate conservation, restoration, and management measures for each species. In light of this goal, we believed it was important to identify all imperiled and potentially vulnerable species, and to maintain the distinction between these two criteria in our analysis.

We selected focal species using two main sets of criteria: ecological and cultural. Ecological criteria included some or all of the following, depending on the taxonomic group: extirpated and potentially extirpated species, potentially imperiled species, potentially vulnerable species, rare species, endemic species, and exotic, domestic, and native ecological pest species. Cultural criteria included some or all of the following, depending on the taxonomic group: harvested species, watchable species, human conflict species, and management agency emphasis species. These criteria are described in more detail below.

Ecological Criteria

Extirpated—Extirpated species represent a loss of biological diversity. Because this assessment addresses the potential for restoring biological diversity in the basin, we wanted to recognize that extirpated species can be restored to the basin's fauna. Therefore, all species determined to be extirpated or potentially extirpated were considered focal species. We were able to analyze extirpated species for vertebrates only (Table 5-44), because data on historical trends in species occurrence were available for that group only (see previous question).

Potentially Imperiled—We defined imperiled species as those with recognized population declines and/or range contractions. We identified potentially imperiled species using one or both of the following two criteria: listing by the federal and state governments as threatened, endangered, or special concern and having very small populations, recognized population declines and/or range contractions in the Sierra Nevada. We analyzed population and range characteristics to identify potentially imperiled species in addition to "listed" species because the political process of listing often lags behind the availability of scientific data (the most relevant data here being knowledge of species' declines). Population characteristics are useful for identifying imperiled species because species with small populations are more vulnerable to extinction from phenomena such as reduction of genetic diversity (through inbreeding or genetic drift) and environmental and demographic stochasticity (random events) than species with large populations (Rabinowitz 1981; Diamond et al. 1987; Kattan 1992; Karron 1997; Cody 1986). Range contractions often accompany population declines and species with small ranges are especially vulnerable to extirpation (Millsap et al. 1990). Clearly, this approach will not work for all species in all situations; there are examples of species with large populations going extinct and species with small populations persisting. Our method therefore represents an estimate of which species are most

Table 5-44—Criteria used to identify focal species in each of six taxonomic groups in the Lake Tahoe basin.

	Ecological Criteria							Cultural Criteria			
		Potentially Imperiled		Potentially Vulnerable							
Taxonomic group	**Extirpated**	**T, E, SC**	**Pop/ Range**	**Life History**	**Rare**	**Endemic**	**Exotic**	**Harvested**	**Watchable**	**Human Conflict**	**Agency Emphasis**
Vascular plants		X	X		X	X	X	X		X	X
Nonvascular plants		X			X	X					X
Terrestrial vertebrates	X	X	X	X		X	X	X	X	X	X
Fish	X	X	X			X	X	X	X		X
Invertebrates		X	X			X	X	X	X		X
Fungi		X			X	X		X			X

imperiled based on one set of criteria. We included listed species in all taxonomic groups as focal and analyzed population and range characteristics for vascular plants, terrestrial vertebrates, fish, and invertebrates only; population and range information was not available for nonvascular plants or fungi (Table 5-44).

Potentially Vulnerable—We define vulnerable species as those susceptible to declines in population size or range, that is, those species most likely to become imperiled. We assessed potentially vulnerable species using one or more of three criteria, depending on the taxonomic group: possession of life history characteristics associated with vulnerability, association with old forests, and rarity.

Several life history characteristics have been connected to increased vulnerability to extirpation or extinction: high degree of habitat specificity (Rabinowitz 1981; Kattan 1992; MacNally and Bennett 1997), large home range (Terborgh 1974), poor dispersal ability, or mobility (Burbridge and McKenzie 1989; MacNally and Bennett 1997), tendency to migrate (Terborgh 1974; Reed 1995), high degree of population concentration (Terborgh 1974; Millsap et al. 1990), and low rate of population increase (Millsap et al. 1990). We analyzed the potential vulnerability of species based on three habitat-related life history characteristics: habitat specificity, home range size, and mobility. Each of these parameters represents a facet of species' life histories related to the species' ability to cope with habitat disturbance; species with a large home range, low mobility, or high habitat specificity are more likely to be affected by reductions in the quantity or quality of habitat than species with small home ranges, high mobility, or low habitat specificity (Terborgh 1974; Burbridge and McKenzie 1989; MacNally and Bennett 1997; Rabinowitz 1981; Kattan 1992). Other characteristics also might be good predictors of vulnerability, such as susceptibility to cowbird parasitism (Reed 1995) or human activities, but these were not addressed here because of the difficulty of applying these criteria across vertebrate groups and the lack of available data. We conducted an analysis of life history characteristics for vertebrate species only, as data were not available for other taxonomic groups (Table 5-44).

Old forests in the Sierra Nevada and elsewhere have generated a great degree of public interest because of their high cultural value and importance to many species (USDA 1998a). Old forests, also known as late-successional, late-seral, or old-growth forests, are forests with a high degree of structural complexity and a high density of large trees, snags, and logs (Franklin and Fites-Kaufman 1996; Issue 1, this chapter). They are now much less abundant in the basin than they were in pre-settlement times, primarily due to timber harvest and fire suppression activities (Issue 1, this chapter). Identifying species dependent on old forests will aid in managing these ecosystems in the basin and determining whether their biological integrity is being maintained. Only vertebrates have been identified as dependent on old forests (Table 5-44).

Rarity is commonly used as an indication of vulnerability to extirpation or extinction (e.g., Williams and Given 1981, Perring and Farrell 1983, Gaston 1994). The term rarity has a variety of meanings in common usage (Harper 1981), but rare species are generally regarded as those having low abundance, small ranges, or small population sizes. They differ from species imperiled because of population characteristics as a matter of degree. Reveal (1981) states, "rarity is merely the current status of an extant organism which, by any combination of biological or physical factors, is restricted either in number or area to a level that is demonstrably less than the majority of other organisms of comparable taxonomic entities." Schoener (1987) uses rarity to mean occurrence in relatively few censuses and/or at relatively low abundances. The California Native Plant Society (CNPS) assigns rarity ratings to plants based on each species' distribution and frequency of occurrence (Skinner and Pavlick 1994; Dennis 1995). Rarity by itself does not indicate a species risk of extinction, but is undoubtedly highly related to a species risk of extirpation or extinction (Gaston 1994). In this sense it provides a reasonable criterion for identifying species most in need of conservation. We used the CNPS rarity rating system to identify rare plants in our assessment; rarity data were not available for other taxonomic groups (Table 5-44).

Endemism—Endemic species are those found only in a particular region and nowhere else (Meffe and Carroll 1994) and are most relevant to conservation planning in regard to species with very limited ranges (Terborgh and Winter 1983; Gentry 1986). Endemism is a consideration in the conservation and assessment of biological diversity because endemics often contribute significantly to the species richness of a given area (Gentry 1992) and because their typically limited population sizes and ranges make them vulnerable to extirpation and extinction (Cody 1986; Nott and Pimm 1997). We included endemic species in all taxonomic groups as focal (Table 5-44).

Exotics, Domestics, and Native Ecological Pests—Exotic species are "species that occur in a given place, area, or region as the result of direct or indirect, deliberate or accidental introduction of the species by humans and for which introduction has permitted the species to cross a natural barrier to dispersal" (Noss and Cooperrider 1994). The successful invasion of an exotic species and its subsequent effects on a native ecosystem are difficult to predict and depend on complex interactions among many characteristics of the species and the ecosystem in question (Meffe and Carroll 1994). In most cases documented so far, exotic species have had a negative effect on native biological diversity, displacing local species through such processes as predation, resource competition, and habitat degradation (Atkinson 1989). However, this is not always the case (Lugo 1994). Exotics differ in their potential to invade an area, and communities differ in their susceptibility to invasion, resulting in varying degrees of threat posed by exotic species (Meffe and Carroll 1994). We included exotic vascular plants, terrestrial vertebrates, fish, and invertebrates as focal; data were not available for nonvascular plants or fungi (Table 5-44).

Domesticated species, which are typically nonnative species tamed for human use, often have ecological consequences similar to those of exotic species. However, for the most part, domesticated species have not established populations in the wild. We have included domesticated species as a special subset of exotic species. This category applied to terrestrial vertebrates only.

Native ecological pests are species native to an area that can become unusually abundant as a result of human activities and disturbance. Species that thrive in environments altered by humans may have further exacerbated the negative effects of disturbance on native species. At typical abundance levels, these species are a natural part of the ecosystem, but at unusually high abundances they can pose threats to ecosystem integrity. Potential ecological pests are often predators and generalist species that benefit from anthropogenic changes in the environment and, because of their natural history characteristics, can take an inordinate toll on the survival and reproductive success of a wide variety of other species. Only vertebrates were considered native ecological pests.

Cultural Criteria—Some species are of special interest primarily because of their importance to humans rather than their contribution to biological diversity. For example, species that are hunted or observed for pleasure, like deer, contribute toward people's experiences of nature and appreciation of biodiversity. Other species, such as squirrels or bears, may occasionally detract from the quality of life for humans by damaging property or by posing potential threats to pets or children. Local management and regulatory agencies also have recognized the importance of some species to humans and have listed species of special interest for ecological and cultural reasons. One or more of the following criteria were considered in the identification of culturally important species: harvested species, watchable species, human conflict species, and management agency emphasis species.

The four cultural criteria varied widely in the cultural values they represented. Harvested species include all species consumed for any purpose, including food, medicine, products, religious purposes, or sport. Watchable species (Clark 1992) are those species whose beauty, behavior, size, or color are generally appealing to the general public. Human conflict species are those that represent a potential liability to humans or a potential barrier to some desired condition. Conflicts can range from interference with or damage to property (such as houses, yards, or personal possessions) to potential or actual bodily harm to individuals. Management agency emphasis species are species identified as deserving special emphasis by the local land management and regulatory agencies: the USFS and the TRPA. Other local agencies, such as California State Parks, and Nevada State Parks, do not have special emphasis species outside of state listed species, which we address as an ecological criterion. Agency emphasis is considered as a cultural criterion because of the highly variable reasons USFS and TRPA choose to emphasize species in management. TRPA's list of special interest species consist of species that are "typically uncommon and/or have a high degree of aesthetic appeal to visitors and locals" (TRPA 1982, p. 32). The latter portion is clearly a cultural criterion. USFS's list of sensitive species consists of species "for which population viability is a concern," (USDA 1995c, p. 12). The criteria used to identify species of concern include global, national, and state criteria, but these tend to vary over time. The USFS criteria for sensitive species are generally ecological criteria, but in order to give equal consideration across agencies, we consider agency emphasis a cultural criterion. We included all agency emphasis species as focal (Table 5-44).

Summary of Criteria Used to Identify Focal Species—We identified focal species of concern and interest using a variety of ecological and cultural criteria (Figure 5-37). The criteria we used depended on the taxonomic group being considered (Table 5-44) because the major taxonomic groups considered (vascular plants, nonvascular plants, terrestrial vertebrates, fish, invertebrates, and fungi) differed widely in terms of available data. We were able to address terrestrial vertebrates using the widest variety of criteria, while we addressed fish and vascular plants at moderate levels of detail. The least information was available for nonvascular plants, fungi, and invertebrates; we identified focal species for these taxa using only a few criteria.

Focal Vascular Plants

Ecological Criteria—Ecological criteria for vascular plants included potential imperilment, potential vulnerability, endemism, and exotic status.

Potentially Imperiled Vascular Plants—Species were determined to be potentially imperiled based on their listing as endangered, threatened, or of special concern by federal and state governments and based on population trends. One species in the Lake Tahoe basin, Tahoe yellowcress (*Rorripa subumbellata)*, is state-listed as endangered (Table 5-45). Seven plant species identified as species of concern by the USFWS, including Tahoe yellowcress, also occur in the basin (Table 5-45). No quantitative data were available for population trends across all plant species in the basin. We considered a single species, whitebark pine (*Pinus albicaulis*), as focal because of qualitative observations of population declines (Urie 1999).

Potentially Vulnerable Vascular Plants—Species we considered potentially vulnerable were those that are rare in California. The CNPS has identified rare plants in California and rated them based on their distribution and frequency of occurrence (Skinner and Pavlick 1994; Dennis 1995). CNPS divided rarity into three categories: rare but stable, rare - limited occurrence, and rare - highly restricted. "Rare but stable" was defined as " . . . rare, but found in sufficient numbers and distributed widely enough that the potential for extinction is low at this time." A total of 21 plants with this designation currently occur in the basin, but they were not included as focal species because they were considered the least vulnerable at this time. "Rare - limited occurrence" was defined as " . . . distributed in a limited number of occurrences, occasionally more if each occurrence is small." A total of 8 plants with this designation currently occur in the basin, and they were considered focal species (Table 5-46). "Rare – highly restricted" was defined as " . . . distributed in one to several highly restricted occurrences, or present in such small numbers that it is seldom reported." A total of 16 plants with this designation currently occur in the basin, and they were considered focal species (Table 5-46).

Endemic Vascular Plants—Four hundred and five vascular plant taxa are endemic to the Sierra Nevada (Shevock 1996), 70 of which occur in the

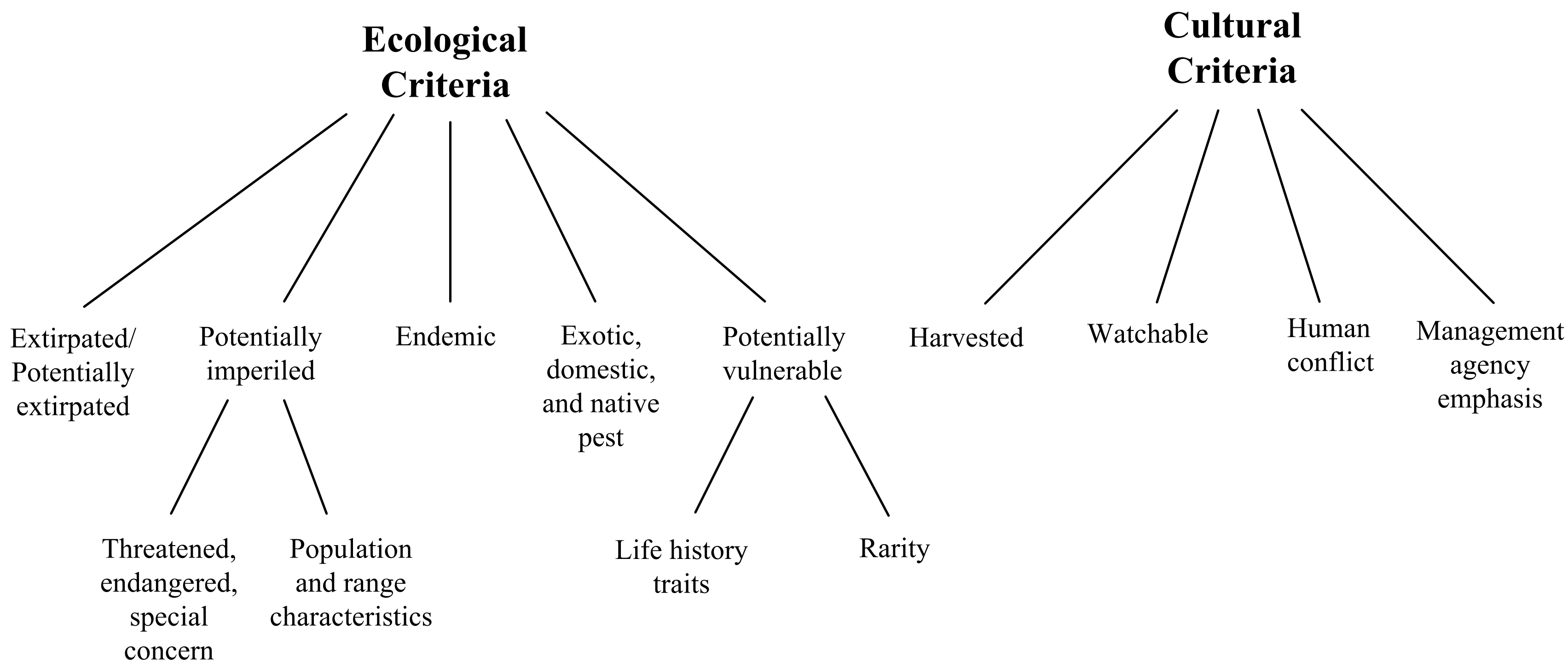


Figure 5-37—Criteria used to identify focal species for the Lake Tahoe basin.

Table 5-45—Vascular plant species occurring in the Lake Tahoe basin identified as threatened, endangered or of special concern by the US Fish and Wildlife Service or the Natural Resources Agency for the State of California.

Common Name	Scientific Name	Federal Listing Status	State Listing Status
Federal and State Threatened and Endangered:			
Tahoe yellowcress	*Rorippa subumbellata*	Species of Concern	CA and NV Endangered
Federal Species of Concern:			
Galena rock cress	*Arabis rigidissima* var. *demota*	Species of Concern	
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	Species of Concern	
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*	Species of Concern	
Oregon fireweed	*Epilobium oreganum*	Species of Concern	
Plumas mousetail	*Ivesia sericoleuca*	Species of Concern	
Webber's ivesia	*Ivesia webberi*	Species of Concern	
Long-petaled lewisia	*Lewisia longipetala*	Species of Concern	

Table 5-46—Rare vascular plant species of the Lake Tahoe basin, as designated by the California Native Plant Society (Skinner and Pavlick 1994) and determined to occur in the basin. Species included here are those with designations of "rare - limited occurrence" and "rare - highly restricted."

Common Name	Scientific Name
Rare - limited occurrence:	
Twin arnica	*Arnica sororia*
Mud sedge	*Carex limosa*
Starved fleabane	*Erigeron miser*
Close-throated beardtongue	*Penstemon personatus*
Ribbonleaf pondweed	*Potamogeton epihydrus* ssp. *nuttallii*
Water bulrush	*Scirpus subterminalis*
Marsh skullcap	*Scutellaria galericulata*
Woolly violet	*Viola tomentosa*
Rare - highly restricted:	
Mountain bentgrass	*Agrostis humilis*
Galena Creek rockcress	*Arabis rigidissima* var. *demota*
Green spleenwort	*Asplenium trichomanes-ramosum*
Trianglelobe moonwort	*Botrychium ascendens*
Lake Tahoe draba	*Draba asterophora* var. *asterophora*
Cup Lake draba	*Draba asterophora* var. *macrocarpa*
Subalpine fireweed	*Epilobium howellii*
Marsh horsetail	*Equisetum palustre*
Buckwheat	*Eriogonum ovalifolium* var. *vineum*
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*
Webber's ivesia	*Ivesia webberi*
Long-petaled lewisia	*Lewisia longipetala*
Tahoe yellowcress	*Rorippa subumbellata*
American scheuchzeria	*Scheuchzeria palustris* ssp. *americana*
Smooth goldenrod	*Solidago gigantea*
Grey-leaved violet	*Viola pinetorum* ssp. *grisea*

Lake Tahoe basin (Appendix E). Of these 70 species, five are endemic to the Truckee River Basin (the Calwater river basin in which the Lake Tahoe basin resides) (Shevock 1996) and occur in the Lake Tahoe basin (Table 5-47). These five plant species were designated as focal because they may be vulnerable to extinction because of their restricted range. Of these five species, only the Tahoe yellowcress is endemic to the Lake Tahoe basin.

We chose to identify only a subset of Sierra Nevada endemics as focal species—specifically, those recognized as rare—because of the large number of Sierra Nevada endemics. Based on the CNPS designation of rarity (Skinner and Pavlick 1994), we identified 13 additional Sierra Nevada endemics that are rare (Table 5-47).

Exotic Vascular Plants—Eighty-four plant species have been introduced to the basin in recent history and are considered exotic (Hickman 1993, Appendix E). Many exotic plants exist without drastically affecting native species, while others have severe effects on the natural environment because they are highly invasive, have fast growing populations, and are therefore able to out-compete and reduce populations of local native species (Hickman 1993). Exotic plants with severe negative environmental effects are commonly termed "noxious weeds" by the USDA (1995b). The USDA (1995b) defines noxious weeds as "generally possess[ing] one or more of the following characteristics: aggressive and difficult to manage, poisonous, toxic, parasitic, a carrier or host of disease and being nonnative or new to or not common to the Unites States or parts thereof."

We identified only those exotic plants recognized by USDA as noxious weeds as focal because of the large number of exotic plant

Table 5-47—Focal endemic vascular plant species, including species endemic to the Truckee River basin and rare Sierra Nevada endemics.

Common Name	Scientific Name	Truckee River Basin Endemic	Rare Sierra Nevada Endemic
Galena Creek rockcress	*Arabis rigidissima* var. *demota*	X	
Austin's milkvetch	*Astragalus austiniae*	X	
Balloon pod milkvetch	*Astragalus whitneyi* var. *lenophyllus*	X	
Davy's sedge	*Carex davyi*		X
Sierra clarkia	*Clarkia virgata*		X
Lake Tahoe draba	*Draba asterophora* var. *asterophora*		X
Cup Lake draba	*Draba asterophora* var. *macrocarpa*		X
Subalpine fireweed	*Epilobium howellii*		X
Starved fleabane	*Erigeron miser*		X
Sierra fleabane	*Erigeron petrophilus* var. *sierrensis*		X
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*		X
Plumas mousetail	*Ivesia sericoleuca*		X
Long-petaled lewisia	*Lewisia longipetala*		X
Close-throated beardtongue	*Penstemon personatus*		X
Bacigalupi's perideridia	*Perideridia bacigalupii*		X
Tahoe yellowcress	*Rorippa subumbellata*	X	X
Lake Tahoe serpentweed	*Tonestus eximius*	X	X
Woolly violet	*Viola tomentosa*		X

species in the Lake Tahoe basin. We identified 12 species as focal exotic species (Table 5-48). The two species not recognized as noxious weeds, but included as focal exotic species, were Eurasian watermilfoil and tall whitetop (*Lepidium latifolium*). Eurasian watermilfoil is recognized by the Lahontan State Water Quality Control Board as having potential long-term detrimental environmental impacts in Lake Tahoe (Ferguson 1999). Eurasian watermilfoil can choke waterways, deplete dissolved oxygen in the water, and reduce invertebrate species populations (USGS 1999). Tall whitetop appears to be a recently introduced species and is considered potentially noxious (Benoit 1997). TRPA recently noted occurrences of tall whitetop at Incline Village and along the south shore of Lake Tahoe (Benoit 1997).

Specific data on the timing of the introductions of these exotic species are lacking, but most of the introductions probably occurred in the Urbanization Era (1960 to present). All the focal exotic species are herbaceous, and the most likely transmission vectors to the basin are personal vehicles, watercraft, or heavy-duty construction equipment and/or material transport associated with residential and road building projects (Taylor 1999).

Cultural Criteria—Cultural criteria included harvest status, human conflict, and management agency emphasis. Further efforts could identify "watchable" plants, such as wildflowers and large trees, but we were unable to conduct such an analysis for this assessment. Species identified as focal in each of the three categories are described below.

Harvested Vascular Plants—People are highly dependent on plants for survival, and the range of uses of plants by people in general and within the basin is vast. As such, it was difficult to develop a definitive list of plants used for various purposes. The list of plants presented here represents only a subset of commonly harvested species.

Plants harvested for medicinal uses were identified by consulting numerous sources (Chatfield 1997; Anderson 1993; Beckstrom-Sternberg et al. 1995a, 1995b; Blackburn and Anderson 1993; Hill 1972; LaLande 1993). Based on these sources, we identified 393 plant species as having medicinal properties (Appendix E). Given this large number, we chose to highlight those medicinal plants whose populations are considered rare by CNPS (Skinner and Pavlick 1994) as an indication of their vulnerability or potential imperilment. This analysis produced four plant species (Table 5-49).

Eight vascular plant species are commercially harvested in the basin and all of them are conifers: white fir (*Abies concolor*), red fir (*A. magnifica* var. *magnifica*), incense cedar (*Calocedrus decurrens*), lodgepole pine (*Pinus contora* var. *murrayana*), Jeffrey pine (*P. jeffreyi*), sugar pine (*P. lambertiana*), western white pine (*P. monticola*), and ponderosa pine (*P. ponderosa*) (Parsons 1999). All of these were considered focal species.

Table 5-48—Focal exotic vascular plant species of the Lake Tahoe basin.

Common Name	Scientific Name
Cheatgrass	*Bromus tectorum*
Plumeless thistle	*Carduus acanthoides*
Musk thistle	*Carduus nutans*
Diffuse knapweed	*Centaurea diffusa*
Spotted knapweed	*Centaurea maculosa*
Bullthistle	*Cirsium vulgare*
Scotch Broom	*Cytisus scoparius*
Klamathweed	*Hypericum perforatum*
Tall whitetop	*Lepidium latifolium*
Dalmatian toadflax	*Linaria genistifolia* ssp. *dalmatica*
Eurasian watermilfoil	*Myriophyllum spicatum*
Scotch thistle	*Onopordum acanthium* ssp. *acanthium*

Table 5-49—Rare medicinal plants identified as focal vascular plants in the Lake Tahoe basin.

Common Name	Scientific Name	Rarity category: Stable	Limited	Highly Restricted
Brown-margined buckwheat	*Eriogonum ovalifolium* var. *eximium*	X		
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*			X
Marsh skullcap	*Scutellaria galericulata*		X	
Smooth goldenrod	*Solidago gigantea*			X

The Washoe tribe has used wild plants in the basin for centuries. Many of these culturally important plants have been documented based on the Washoe tribe and the investigative work of many individuals (Rucks 1999). The names of 52 plants have been translated to current taxonomy; 41 of these species occur or potentially occur in the Lake Tahoe basin (Appendix E). Many of these plant species are common in the basin and do not merit focal species status. We chose to recognize these traditionally used plants as focal if they were also rare species according to CNPS (Skinner and Pavlick 1994). We identified one species, long-petaled lewisia (*Lewisia longipetala*) as focal because it is "rare - highly restricted" and because the Washoe use plants of the genus *Lewisia*.

Human Conflict Vascular Plants—The Eurasian watermilfoil, an exotic plant (see exotic species section above), is identified here as a human conflict species. This invasive plant occludes waterways and poses a significant problem for several marinas around the lake. It is recognized by the Lahontan State Water Quality Control Board as having potential long-term detrimental economic impacts in Lake Tahoe (Ferguson 1999).

Management Agency Emphasis Vascular Plants—Five plants are currently identified by TRPA and 16 by the USFS as sensitive species in the Lake Tahoe basin (Table 5-50). Four species were identified by both agencies, for a total of 17 focal species based on management agency emphasis.

Summary—Fifty-seven focal vascular plants were identified (Appendix K), 25 as focal based solely on ecological criteria, 11 as focal based solely on cultural criteria, and 21 as focal based on both ecological and cultural criteria.

Focal Nonvascular Plants

The incomplete and broad geographic nature of the data available on nonvascular plants made it difficult to conduct a thorough and meaningful analysis of focal species for the Lake Tahoe basin. We considered a limited set of ecological and cultural criteria in the identification of focal nonvascular plants (Table 5-44).

We considered three ecological criteria in identifying focal nonvascular plants: potential imperilment, potential vulnerability, and endemism (Table 5-44). No species of nonvascular plants currently listed as threatened or endangered by the federal or state government are known or suspected to occur in the Lake Tahoe basin. Potential vulnerability was assessed based on rarity. Shevock (1996) identified 17 rare species of nonvascular plants in the Sierra Nevada. Of the 17 rare mosses, *Mielichoferia tehamensis* could not occur in the basin because it is endemic to Lassen National Park. The remaining 16 species potentially do occur in the basin, and were considered focal species (Table 5-51). Two species of mosses are known to be endemic to the Sierra Nevada: *Grimmia hamulosa* and *Orthotrichum spjutii*. They have not been confirmed but could occur in the Lake Tahoe basin. They were both considered focal species (Table 5-51).

We considered one criterion in identifying cultural focal nonvascular plants: agency emphasis species. None of the local agencies currently designate any nonvascular plants as emphasis species.

Sixteen nonvascular plant species were identified as focal in the Lake Tahoe basin. All species were focal based solely on ecological criteria.

Table 5-50—Vascular plant species identified as sensitive by the TRPA or the USFS (TRPA 1982; USDA 1998).

Common Name	Scientific Name	TRPA	USFS
Galena Creek rockcress	*Arabis rigidissima* var. *demota*		X
Anderson's aster	*Aster alpigenus* var. *andersonii*		X
Trianglelobe moonwort	*Botrychium ascendens*		X
Mariposa sedge	*Carex mariposana*	X	
Lake Tahoe draba	*Draba asterophora* var. *asterophora*	X	X
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	X	X
Subalpine fireweed	*Epilobium howellii*		X
Oregon fireweed	*Epilobium oreganum*		X
Starved fleabane	*Erigeron miser*		X
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*		X
Plumas mousetail	*Ivesia sericoleuca*		X
Webber's ivesia	*Ivesia webberi*		X
Long-petaled lewisia	*Lewisia longipetala*	X	X
Close-throated beardtongue	*Penstemon personatus*		X
Tahoe yellowcress	*Rorippa subumbellata*	X	X
American scheuchzeria	*Scheuchzeria palustris americana*		X
Grey-leaved violet	*Viola pinetorum grisea*		X

Table 5-51—Focal nonvascular plant species in the Lake Tahoe basin. All species are mosses and are focal based on ecological criteria.

Scientific Name	Rare	SN Endemic
Andreaea nivalis	X	
Bruchia bolanderi	X	
Campylium stellatum	X	
Distichium inclinatum	X	
Grimma mixleyi	X	
Grimmia hamulosa	X	X
Hydrogrimmia mollis	X	
Lescuraea pallida	X	
Mnium arizonicum	X	
Myurella julacea	X	
Orthotrichum euryphyllum	X	
Orthotrichum spjutii	X	X
Polytrichum sexangulare	X	
Racomitrium hispanicum	X	
Tayloria serrata	X	
Tortula californica	X	

Focal Terrestrial Vertebrate Species

In identifying focal vertebrate species, we first created a list of *candidate* focal species consisting of those species with some evidence to suggest they have an established a population in the Tahoe basin (Millsap et al. 1990; Gaston 1994), plus species that are confirmed or potentially extirpated from the basin. All confirmed and potentially extirpated species were identified earlier in this Issue. Current populations of vertebrates were assessed to confirm the potential for established populations. For mammals, reptiles, and amphibians, any current records (Urbanization Era) of occurrence in the basin were considered sufficient evidence of potential populations in the basin. However, birds are far more mobile than other terrestrial vertebrates, and the record of an occurrence in the Tahoe basin does not necessary suggest the occurrence of a population. A variety of specific criteria (Appendix L) were used to identify bird species likely to be only occasional visitors, which were eliminated as candidate focal species. Thus, the list of candidate focal species included all extirpated species and excluded 68 bird species. In total, we considered 229 terrestrial vertebrate species as candidates for focal species designation: 149 birds, 66 mammals, six amphibians, and eight reptiles (Appendix G). A range of ecological and cultural criteria were applied to candidate focal species (Table 5-44) to derive the final list of focal species. Each of the criteria and its application are described in detail below.

Ecological Criteria—We considered five ecological criteria to identify focal terrestrial vertebrates: known or potential extirpation, potential imperilment, potential vulnerability, endemism, and exotic, domesticated, or ecological pest status.

Extirpated and Potentially Extirpated Terrestrial Vertebrates—The analysis of historical changes in the basin's species composition resulted in the identification of 12 extirpated and potentially extirpated terrestrial vertebrate species: four birds, seven mammals, and one amphibian (Question 2, Table 5-43).

Potentially Imperiled Terrestrial Vertebrates—Species in the Lake Tahoe basin with potentially imperiled populations were identified based on their status at local and range-wide scales, including the Sierra Nevada physiographic region, the states of California or Nevada, and the entire United States. No specific data were available for population trends in the basin. Species whose populations are potentially imperiled at larger geographic scales (e.g., the Sierra Nevada) are likely to be imperiled in the Lake Tahoe basin. In addition, the Lake Tahoe basin plays an important role in supporting viable populations at larger geographic scales. Because of the lack of data on population trends specifically for the basin, we were unable to address species that may have declined in the basin but not elsewhere.

Species were determined to be potentially imperiled in the Sierra Nevada if they were listed as endangered, threatened, or of special concern by federal and state governments, or if they were recognized as having declining populations, contracted ranges, and/or small population size.

Listed Species—Eight species were classified as threatened or endangered and 22 species were classified as Species of Special Concern by the federal government or by the states of California or Nevada (Table 5-52).

Potentially Imperiled Because of Population or Range Characteristics—Three variables were used to assess species potentially imperiled because of population characteristics: Sierra Nevada population size, population trend in the Sierra Nevada, and range change in the Sierra Nevada (Keane and Zielinski, in preparation). Data were obtained from the Sierra All Species Information (SASI) database (USDA 1999b) and were based on expert opinion acquired through questionnaires sent to taxa experts familiar with the Sierra Nevada (Appendix L). Each variable consisted of five or six categories, which were combined into three categories for this analysis: low, moderate, and high imperilment (Appendix L). All 229 candidate terrestrial vertebrate species were included in the analysis and their scores for each of the three variables appear in Appendix M.

Species were considered focal if they were highly imperiled for one or more of the three variables or if they were moderately imperiled for all three variables (n = 43). Species that were

Table 5-52—Listed terrestrial vertebrates of the Lake Tahoe basin.

Common Name	Scientific Name	Federal Listing Status	State Listing Status[a]
Federal and State Threatened and Endangered:			
Birds:			
Willow Flycatcher	*Empidonax traillii*		CA Endangered
Peregrine Falcon	*Falco peregrinus*		CA, NV Endangered
Bald Eagle	*Haliaeetus leucocephalus*	Threatened[b]	CA, NV Endangered
Bank Swallow	*Riparia riparia*		CA Threatened
Mammals:			
Wolverine	*Gulo gulo*	Special Concern	CA Threatened
Mountain sheep	*Ovis canadensis californiana*	Endangered	CA Threatened
Grizzly bear	*Ursus arctos*	Threatened	
Sierra Nevada red fox	*Vulpes vulpes necator*	Special Concern	CA Threatened
Federal and State Special Concern:			
Birds:			
Cooper's Hawk	*Accipiter cooperii*		Special Concern
Northern Goshawk	*Accipiter gentilis*	Special Concern	Special Concern
Sharp-shinned Hawk	*Accipiter striatus*		Special Concern
Golden Eagle	*Aquila chrysaetos*		Special Concern
Barrow's Goldeneye	*Bucephala islandica*		Special Concern
Northern Harrier	*Circus cyaneus*		Special Concern
Yellow Warbler	*Dendroica petechia*		Special Concern
Common Loon	*Gavia immer*		Special Concern
California Gull	*Larus californicus*		Special Concern
Osprey	*Pandion haliaetus*		Special Concern
American White Pelican	*Pelecanus erythrorhynchos*		Special Concern
Spotted Owl	*Strix occidentalis*	Special Concern	Special Concern
Mammals:			
Pallid bat	*Antrozous pallidus*		Special Concern
Mountain beaver	*Aplodontia rufa*	Special Concern	Special Concern
Sierra Nevada snowhoe hare	*Lepus americanus tahoensis*	Special Concern	Special Concern
White-tailed hare	*Lepus townsendii*		Special Concern
Fisher	*Martes pennanti*	Special Concern	Special Concern
Long-eared myotis	*Myotis evotis*	Special Concern	
Fringed myotis	*Myotis thysanodes*	Special Concern	
Yuma myotis	*Myotis yumanensis*	Special Concern	Special Concern
Lodgepole chipmunk	*Tamias speciosus*	Special Concern	
Amphibians:			
Mountain yellow-legged frog	*Rana muscosa*	Special Concern	Special Concern
Northern leopard frog	*Rana pipiens*		Special Concern

[a] State Special Concern status applies only to California.
[b] The Bald Eagle has been proposed for delisting as of July 2000.

considered moderately imperiled for all three population and range variables were those potentially susceptible to the cumulative effects of small population size, declining population, and range contraction. Nine species were considered highly imperiled because of population size (Sierra Nevada population presumed extirpated or estimated to consist of ≤ 100 individuals; Appendix L; Table 5-53). Twenty-six species were considered highly imperiled because of population decline (those with known declines in the Sierra Nevada since approximately 1900; Appendix L; Table 5-53). Thirteen species were considered highly imperiled because of range contractions (those with suspected range contractions of ≥ 50 percent since historic times; Appendix L; Table 5-53). Finally, nine additional species were identified as focal because they were considered moderately imperiled for all three population and range variables (estimated Sierra Nevada population size of 100 to 1,000 individuals, suspected population decline in the Sierra Nevada, and estimated range contraction of < 50 percent; Appendix L; Table 5-53).

Potentially Vulnerable Terrestrial Vertebrates—Terrestrial vertebrate species were determined to be potentially vulnerable to future imperilment if they possessed life history characteristics that might increase their vulnerability to disturbance or if they were dependent on old forests.

The vulnerability of species was assessed based on habitat specificity, mobility, and home range size. Data were obtained from the SASI database (USDA 1999b; Appendix L). Mobility reflects the ability of individuals of a species to move in response to daily and seasonal needs, reproductive needs, and/or habitat disturbance; it is considered a habitat-related variable because it represents the ability to access habitat. Mobility was characterized as low, moderate, or high. Home range size was characterized as large, moderate, or small, based on the average area occupied by a species. Habitat specificity was estimated by determining by the proportion of all California Wildlife Habitat Relationships (CWHR) (CDFG 1998a) vegetation type-structural/canopy cover classes (n = 563) suitable for each species. Habitat specificity information was not available for the grizzly bear, which was therefore eliminated from this analysis. Species were put into three groups based on the distribution of habitat specificity for species in the basin: high (< 30 percent of habitats suitable), moderate (30 to 60 percent of habitats suitable), and low (> 60 percent of habitats suitable). Each of the three variables' groups corresponded to high vulnerability, moderate vulnerability, and low vulnerability (Appendix L).

Analysis of vulnerability based on life history characteristics was conducted separately for species dependent upon aquatic habitats ("aquatic species") and all remaining species, characterized as terrestrial habitat associates ("upland species"). Information on dependence on aquatic habitat was obtained from Zeiner et al. (1988, 1990a, 1990b), as summarized in the SASI database (USDA 1999b; Appendix L). All species noted as "aquatic" or "semi-aquatic" (n = 51) were considered aquatic species because the two classifications both represented a reliance on aquatic habitats; we considered all other species upland species (n = 178).

All species that were habitat specialists or that were moderate habitat specialists and had low mobility and/or large home range were considered focal. We considered all aquatic species to be habitat specialists (based on their dependence), but included as focal only those species with either low mobility or large home range (27 species; Table 5-54). For upland species, we included as focal all species with high habitat specificity (39 species; Table 5-55a) because these species represented extreme habitat specialization. In addition, we included as focal those species with moderate habitat specificity and one of the following combinations of features: low mobility and large home range, low mobility and moderate home range, or moderate mobility and large home range (18 species; Table 5-55b).

Information on dependence on old-forest habitat was obtained from the SASI database (USDA 1999b), which adopted Graber's (1996) classification, with a few modifications (Appendix L). Sixteen species listed as dependent on old-forest habitat were included. We listed the species dependent on old forests in order of decreasing

Table 5-53—Focal terrestrial vertebrate species of the Lake Tahoe basin potentially imperiled due to small population size, known population declines, suspected range contraction, or cumulative effects of population and range characteristics in the Sierra Nevada. Data were obtained from the Sierran All Species Information database (USDA 1999b; Appendix L).

Common name	Scientific name	Small pop.[a]	Pop. decl.[b]	Range contrct.[c]	Cumul. effects[d]
Birds:					
American Robin	*Turdus migratorius*		1		
American White Pelican	*Pelecanus erythrorhynchos*		1		
Band-tailed Pigeon	*Columba fasciata*		1		
Barrow's Goldeneye	*Bucephala islandica*	1	1	1	
Belted Kingfisher	*Ceryle alcyon*		1		
Brown-headed Cowbird	*Molothrus ater*		1		
Chipping Sparrow	*Spizella passerina*		1		
Common Snipe	*Gallinago gallinago*				X
Forster's Tern	*Sterna forsteri*		1		
Greater Scaup	*Aythya marila*	2			
House Finch	*Carpodacus mexicanus*		1		
Lesser Goldfinch	*Carduelis psaltria*		1		
Lewis's Woodpecker	*Melanerpes lewis*				X
Northern Shoveler	*Anas clypeata*	2			
Olive-sided Flycatcher	*Contopus cooperi*		1		
Peregrine Falcon	*Falco peregrinus*	2			
Pied-billed Grebe	*Podilymbus podiceps*				X
Red-breasted Sapsucker	*Sphyrapicus ruber*		1		
Steller's Jay	*Cyanocitta stelleri*		1		
Swainson's Thrush	*Catharus ustulatus*		1	2	
Western Scrub Jay	*Aphelocoma coerulescens*		1		
Western Wood-pewee	*Contopus sordidulus*		1		
White-crowned Sparrow	*Zonotrichia leucophrys*		1	2	
Willow Flycatcher	*Empidonax traillii*			1	
Wood Duck	*Aix sponsa*	2			
Mammals:					
Badger	*Taxidea taxus*				X
Beaver	*Castor canadensis*			2	
Black bear	*Ursus americanus*				X
Fisher	*Martes pennanti*			3	
Fringed myotis	*Myotis thysanodes*				X
Grizzly bear	*Ursus arctos*	1	1	1	
Mink	*Mustela vison*				X
Mountain sheep	*Ovis canadensis californiana*		1	1	
Muskrat	*Ondatra zibethicus*			2	
Nuttall's Cottontail	*Sylvilagus nuttallii*				X
River otter	*Lutra canadensis*				X
Sierra Nevada red fox	*Vulpes vulpes necator*	1	1		
White-tailed hare	*Lepus townsendii*		1	2	
Wolverine	*Gulo gulo*	1	1	2	
Amphibians:					
Mountain yellow-legged frog	*Rana muscosa*		1	1	
Northern leopard frog	*Rana pipiens*	2		1	
Pacific treefrog	*Hyla regilla*		1		
Western toad	*Bufo boreas*		1		
Reptiles:					
Western terrestrial garter snake	*Thamnophis elegans*		1		

[a] 1 = potentially extirpated, 2 = estimated Sierra Nevada population of 1-100 individuals.
[b] 1 = species with known population declines.
[c] 1 = estimated Sierra Nevada range contraction of 90-100 percent, 2 = estimated range contraction of 50-89 percent, 3 = estimated range contraction of ≥ 50 percent..
[d] X = species not included in any of the above categories but considered moderately imperiled for each category.

Table 5-54—Potentially vulnerable terrestrial vertebrates of the Lake Tahoe basin. Species in this table are dependent on aquatic habitats and have low mobility or a large home range. Aquatic dependence was obtained from USDA (1999b). Also given are the CWHR habitat types[a] (Mayer and Laudenslayer 1988) occurring in the basin that are used by each species. "Mob" is a species' mobility—its ability to move in response to seasonal or reproductive needs (USDA 1999b; Appendix L); L = low, M = moderate. "Rng" is a species' home range (USDA 1999b; Appendix L); M = moderate, L = large. Also given are the CWHR habitat types (Mayer and Laudenslayer 1988) occurring in the basin that are used by each species.

Common name	Scientific name	Mob	Rng	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Birds:																					
Wood Duck	*Aix sponsa*	H	L			X	X		X			X			X		X	X	X	X	
Northern Pintail	*Anas acuta*	H	L															X	X	X	X
Mallard	*Anas platyrhynchos*	H	L														X	X	X	X	X
Great Blue Heron	*Ardea herodias*	H	L			X		X							X	X	X	X	X	X	X
Canvasback	*Aythya valisineria*	H	L															X	X	X	
Canada Goose	*Branta canadensis*	H	L															X	X	X	X
Common Goldeneye	*Bucephala clangula*	H	L																X	X	
Belted Kingfisher	*Ceryle alcyon*	H	L														X	X	X	X	X
Tundra Swan	*Cygnus columbianus*	H	L															X	X	X	X
California Gull	*Larus californicus*	H	L															X	X	X	X
Ring-billed Gull	*Larus delawarensis*	H	L															X	X	X	X
Hooded Merganser	*Lophodytes cucullatus*	H	L															X	X	X	
Common Merganser	*Mergus merganser*	H	L														X	X	X	X	X
Black-crowned Night Heron	*Nycticorax nycticorax*	H	L					X			X						X	X	X	X	X
Osprey	*Pandion haliaetus*	H	L			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
American White Pelican	*Pelecanus erythrorhynchos*	H	L																X	X	
Mammals:																					
River otter	*Lutra canadensis*	M	L														X	X	X	X	X
Mink	*Mustela vison*	M	L		X												X	X	X	X	
Muskrat	*Ondatra zibethicus*	L	M		X												X	X	X	X	X
Water shrew	*Sorex palustris*	L	S		X	X	X		X			X	X		X	X	X		X	X	X
Amphibians:																					
Long-toed salamander	*Ambystoma macrodactylum*	L	L				X		X			X			X	X	X	X	X		X
Western toad	*Bufo boreas*	L	L			X	X		X	X	X	X		X	X	X	X	X	X	X	X
Pacific treefrog	*Hyla regilla*	L	S	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bullfrog	*Rana catesbeiana*	L	S								X				X	X	X	X	X	X	X
Mountain yellow-legged frog	*Rana muscosa*	L	S		X		X		X			X	X		X	X	X	X	X	X	X
Northern leopard frog	*Rana pipiens*	L	S												X	X	X	X	X	X	X
Reptiles:																					
Western aquatic garter snake	*Thamnophis couchii*	L	S		X		X				X				X	X	X	X	X	X	X

[a] ADS = alpine dwarf scrub; ASP = aspen; EPN = Eastside pine; JPN = Jeffrey pine; JUN = juniper; LPN = lodgepole pine; LSG = low sage; MCH = Montane chapparral; RFR = red fir; SCN = subalpine conifer; SGB = sagebrush; SMC = Sierran mixed conifer; WFR = white fire; FEW = fresh emergent wetland; LAC = lacustrine; RIV = riverine; WTM = wet meadow; MRI = montane riparian.

Table 5-55a—Potentially vulnerable terrestrial vertebrates of the Lake Tahoe basin. Species in this table use terrestrial and riparian habitat types and are habitat specialists, using fewer than 30 percent of CWHR habitat type/seral stage combinations (CDFG 1998a). "Habspec" is the proportion of habitat type/seral stage combinations used (USDA 1999b; Appendix L). Also given are the CWHR habitat types[a] (Mayer and Laudenslayer 1988) in the basin used by each species (CDFG 1998a).

Common name	Scientific name	Habspec	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Birds:																				
Red-winged Blackbird	*Agelaius phoeniceus*	0.111														X	X			X
American Pipit	*Anthus rubescens*	0.115	X						X				X				X	X	X	X
Canyon Wren	*Catherpes mexicanus*	0.159								X						X				
Marsh Wren	*Cistothorus palustris*	0.063														X	X			X
Rock Dove	*Columba livia*	0.028																		
American Crow	*Corvus brachyrhynchos*	0.296												X	X	X		X	X	
Pileated Woodpecker	*Dryocopus pileatus*	0.195			X	X		X			X			X	X	X				
Hammond's Flycatcher	*Empidonax hammondii*	0.207		X	X	X					X			X	X	X				
Willow Flycatcher	*Empidonax traillii*	0.090														X				X
Horned Lark	*Eremophila alpestris*	0.119	X						X				X							X
Rosy Finch	*Leucosticte arctoa*	0.078	X						X			X	X							X
Red Crossbill	*Loxia curvirostra*	0.275			X	X		X			X	X		X	X	X				
Lincoln's Sparrow	*Melospiza lincolnii*	0.250		X	X	X		X			X			X	X	X	X			X
MacGillivray's Warbler	*Oporornis tolmiei*	0.223			X			X		X	X			X		X				X
House Sparrow	*Passer domesticus*	0.122																		
Savannah Sparrow	*Passerculus sandwichensis*	0.158					X		X	X			X							X
Black-billed Magpie	*Pica pica*	0.117					X						X			X				X
Black-backed Woodpecker	*Picoides arcticus*	0.065						X			X	X		X						
Pine Grosbeak	*Pinicola enucleator*	0.136						X			X	X				X				X
Green-tailed Towhee	*Pipilo chlorurus*	0.298		X	X	X	X	X	X		X		X	X	X	X				
Bank Swallow	*Riparia riparia*	0.287							X	X			X			X	X	X	X	X
Pygmy Nuthatch	*Sitta pygmaea*	0.259			X	X		X						X	X					
Williamson's Sapsucker	*Sphyrapicus thyroideus*	0.159		X	X	X		X			X			X	X	X				
Winter Wren	*Troglodytes troglodytes*	0.246			X	X					X			X	X	X				
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	0.053															X	X		X
Mammals:																				
Snowshoe hare	*Lepus americanus*	0.122		X		X		X			X	X		X	X	X				
White-tailed hare	*Lepus townsendii*	0.154	X		X	X	X	X	X		X	X	X							X
Fisher	*Martes pennanti*	0.223		X	X	X		X			X	X		X	X	X				
Pika	*Ochotona princeps*	0.298	X	X	X	X		X	X		X	X	X	X	X	X				X
Mountain sheep	*Ovis canadensis californiana*	0.060																		

Table 5-55a—*(continued)*

Common name	Scientific name	Habspec	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Dusky shrew	*Sorex monticolus*	0.252	X			X		X			X	X		X	X	X	X			X
Trowbridge's shrew	*Sorex trowbridgii*	0.291								X	X			X	X	X				
Belding's Ground Squirrel	*Spermophilus beldingi*	0.241	X	X	X	X		X	X	X	X	X	X	X	X	X				X
Nuttall's Cottontail	*Sylvilagus nuttallii*	0.088	X				X					X	X			X				
Least chipmunk	*Tamias minimus*	0.108	X			X	X		X				X							
Long-eared chipmunk	*Tamias quadrimaculatus*	0.111								X				X	X					
Lodgepole chipmunk	*Tamias speciosus*	0.124				X		X			X	X		X	X					
Douglas' Squirrel	*Tamiasciurus douglasii*	0.266		X	X	X		X			X	X		X	X	X				
Reptiles:																				
Sagebrush lizard	*Sceloporus graciosus*	0.284			X	X	X	X	X	X			X	X	X					

[a] ADS = alpine dwarf scrub; ASP = aspen; EPN = Eastside pine; JPN = Jeffrey pine; JUN = juniper; LPN = lodegepole pine; LSG = low sage; MCH = Montane chapparral; RFR = red fir; SCN = subalpine conifer; SGB = sagebrush; SMC = Sierran mixed conifer; WFR = white fire; FEW = fresh emergent wetland; LAC = lacustrine; RIV = riverine; WTM = wet meadow; MRI = montane riparian.

Table 5-55b—Potentially vulnerable terrestrial vertebrates of the Lake Tahoe basin. Species in this table use terrestrial and riparian habitats, are moderate habitat specialists, using 30 to 60 percent of CWHR habitat type/seral stage combinations (CDFG 1998a), and have either low mobility and large home range, low mobility and moderate home range, or moderate mobility and large home range. "Habspec" is the proportion of habitat type/seral stage combinations used (USDA 1999b; Appendix L). "Mob" is a species' mobility—its ability to move in response to seasonal or reproductive needs (USDA 1999b; Appendix L); L = low, M = moderate. "Rng" is a species' home range (USDA 1999b; Appendix L); M = moderate, L = large. Also given are the CWHR habitat types[a] (Mayer and Laudenslayer 1988) in the basin used by each species (CDFG 1998a).

Common name	Scientific name	Habspec	Mob	Rng	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Mammals:																						
Northern flying squirrel	*Glaucomys sabrinus*	0.341	L	M		X	X	X		X			X	X		X	X	X				
Wolverine	*Gulo gulo*	0.369	M	L	X	X		X		X			X	X		X	X	X				X
Yellow-bellied marmot	*Marmota flaviventris*	0.385	L	M	X	X	X	X		X	X		X	X	X	X	X	X				X
Marten	*Martes americana*	0.369	M	L		X	X	X		X			X	X		X	X	X				X
Long-tailed vole	*Microtus longicaudus*	0.515	L	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X
Desert woodrat	*Neotoma lepida*	0.477	L	M							X	X			X							
Brush mouse	*Peromyscus boylii*	0.586	L	M	X		X	X	X		X	X		X	X	X	X	X				
Canyon mouse	*Peromyscus crinitus*	0.337	L	M	X		X		X		X	X		X	X							
Pinyon mouse	*Peromyscus truei*	0.550	L	M	X		X		X		X	X			X	X	X	X				X
Heather vole	*Phenacomys intermedius*	0.328	L	M	X		X	X		X			X	X		X	X	X				X
Broad-footed mole	*Scapanus latimanus*	0.332	L	M		X	X	X		X			X			X	X	X				X
Western gray squirrel	*Sciurus griseus*	0.513	L	M		X	X	X				X				X	X	X				
Vagrant shrew	*Sorex vagrans*	0.468	L	M	X	X		X		X		X	X	X		X	X	X	X			X
Yellow-pine chipmunk	*Tamias amoenus*	0.595	L	M		X	X	X	X	X	X	X	X	X	X	X	X	X				
Badger	*Taxidea taxus*	0.474	M	L	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X
Mountain pocket gopher	*Thomomys monticola*	0.314	L	M	X		X	X		X	X	X	X	X	X	X	X					X
Sierra Nevada red fox	*Vulpes vulpes necator*	0.424	M	L	X	X	X	X		X		X	X	X		X	X	X				X
Western jumping mouse	*Zapus princeps*	0.380	L	M	X	X	X	X		X			X	X	X	X	X	X				X

[a] ADS = alpine dwarf scrub; ASP = aspen; EPN = Eastside pine; JPN = Jeffrey pine; JUN = juniper; LPN = lodgepole pine; LSG = low sage; MCH = Montane chapparral; RFR = red fir; SCN = subalpine conifer; SGB = sagebrush; SMC = Sierran mixed conifer; WFR = white fire; FEW = fresh emergent wetland; LAC = lacustrine; RIV = riverine; WTM = wet meadow; MRI = montane riparian.

habitat specificity (USDA 1999b) (Table 5-56).

Endemic Terrestrial Vertebrates—No vertebrates are endemic to the Lake Tahoe basin, but the long-eared chipmunk (*Tamias quadrimaculatus*) is endemic to the Sierra Nevada (Graber 1996) and was considered a focal species.

Exotic Species—Seven exotic, undomesticated, terrestrial vertebrate species are currently found in the basin (Table 5-57). Five species are known exotics to the Sierra Nevada (Graber 1996) and therefore the Lake Tahoe basin. It is questionable if beavers are native to the basin; Orr (1949) does not discuss them, implying that they were not present in the basin during his surveys. We treat beavers as exotic. We assume that the California quail has been introduced to the basin, as suggested by Orr and Moffitt (1971). The northern leopard frog has been treated as exotic to the basin by some authors and native by others (Jennings and Hayes 1994); here, we simply note it as a possible exotic. Despite Graber's (1996) identification of the muskrat (*Ondatra zibethicus*) as exotic to the Sierra Nevada, Grinnell (1933) identified the species as native to Lake Tahoe; it is considered native here.

Domesticated Species—We identified six domesticated terrestrial vertebrates that may have significant impacts on the natural environment (Table 5-58). Pets, such as dogs (*Canis familiaris*) and cats (*Felis domesticus*), have been shown to harass and prey on native wildlife species (Frankel and Soule 1981; Graber 1996; Patronek 1998; Anon. 1997; Atkinson 1989). Pack animals, such as horses (*Equus* sp.), mules (*Equus* sp.), and llamas (*Lama glama*), may disturb the soil and trample native vegetation (Ratliff 1985; Cole and Landres 1995), as well as disperse seeds of nonnative grasses and herbs through their feces. Finally, grazing and possible trampling by cattle (*Bos* sp.) can greatly alter native vegetation and destroy habitat for native animals (Ratliff 1985; Atkinson 1989).

Native Ecological Pests—A small number of vertebrate species have the potential to become native ecological pests in the basin should their populations increase unchecked: brown-headed cowbird (a nest parasite; Brittingham and Temple 1983), house wren (*Troglodytes aedon*) (an aggressive

Table 5-56—Old-forest dependent terrestrial vertebrates of the Lake Tahoe basin (Graber 1996, as modified by USDA 1999b), listed in order of decreasing habitat specificity (USDA 1999b) (Appendix L).

Common name	Scientific name	Habitat specificity
Pileated Woodpecker	*Dryocopus pileatus*	0.195
Fisher	*Martes pennanti*	0.223
Winter Wren	*Troglodytes troglodytes*	0.246
Pygmy Nuthatch	*Sitta pygmaea*	0.259
Red Crossbill	*Loxia curvirostra*	0.275
Spotted Owl	*Strix occidentalis*	0.307
Northern flying squirrel	*Glaucomys sabrinus*	0.341
Cassin's Finch	*Carpodacus cassinii*	0.344
White-headed Woodpecker	*Picoides albolarvatus*	0.365
Marten	*Martes americana*	0.369
Brown Creeper	*Certhia americana*	0.378
Red-breasted Nuthatch	*Sitta canadensis*	0.408
Purple Finch	*Carpodacus purpureus*	0.428
Hermit Warbler	*Dendroica occidentalis*	0.507
Evening Grosbeak	*Coccothraustes vespertinus*	0.618
Northern Goshawk	*Accipiter gentilis*	0.674

Table 5-57—Exotic terrestrial vertebrates of the Lake Tahoe basin.

Common name	Scientific name
Birds:	
California Quail	*Callipepla californica*
Rock Dove	*Columba livia*
Wild Turkey	*Meleagris gallopavo*
House Sparrow	*Passer domesticus*
European Starling	*Sturnus vulgaris*
Mammals:	
Beaver	*Castor canadensis*
Amphibians:	
Bullfrog	*Rana catesbeiana*

Table 5-58—Terrestrial vertebrate species of the Lake Tahoe basin that are domesticated and are considered to have significant impacts on the natural environment.

Common name	Scientific name
Cow	*Bos* sp.
Domestic dog	*Canis familiaris*
Horse	*Equus* sp.
Mule	*Equus* sp.
Domestic cat	*Felis domesticus*
Llama	*Lama glama*

competitor for nesting cavities; Ehrlich et al. 1988), Steller's jay (*Cyanocitta stelleri*) (a nest predator; Ehrlich et al. 1988), coyote (a generalist predator; Ahlborn 1990b), and common raven (a nest predator; Ehrlich et al. 1988). Of these, the brown-headed cowbird is the only species that we determined is likely to attain problematic densities in the near future.

The reproductive strategy of the brown-headed cowbird may negatively affect many passerine species in the Lake Tahoe basin. Brown-headed cowbirds are generalist parasites, meaning that they lay their eggs in the nests of other species and allow the host species to hatch and rear the cowbird's young (Brittingham and Temple 1983; Ehrlich et al. 1988). Cowbird eggs usually hatch one day prior to those of the host brood; they develop rapidly and are larger than host chicks. Cowbird chicks are thus able to consume a larger share of the food provided by the parents, at the expense of the host brood. Brown-headed cowbirds are native to North America but have expanded their original range (prior to 1800) from the plains and prairies west of the Mississippi River to include most of North America (Brittingham and Temple 1983; Ehrlich et al. 1988). Ehrlich et al. (1988) considered the range expansion and population increase of the brown-headed cowbird to be a major threat to the continued survival of several parasitized species, mainly songbirds. Records indicate that brown-headed cowbirds have only recently (since 1960) expanded their range into the Lake Tahoe basin. Recent surveys by Manley and Schlesinger (in preparation) detected the brown-headed cowbird at over 75 percent of 80 lotic riparian areas and 28 percent of 88 lentic riparian areas in the basin.

Cultural Criteria—We used four criteria to identify culturally important vertebrate species:

harvest status, watchable status, human conflict, and management agency emphasis.

Harvested Terrestrial Vertebrates—Although many of the basin's terrestrial vertebrates are designated game species in California (CDFG 1998b) and Nevada (NDOW 1998), only a handful are actually harvested in the basin. Hunting activities are greatly restricted in the basin because of the high density of people. We identified two mammals and two birds that are the most commonly hunted animals in the basin (Bezzone 1999) (Table 5-59).

Table 5-59—Terrestrial vertebrate species that are occasionally hunted in the Lake Tahoe basin.

Common Name	Scientific Name
Birds:	
Blue Grouse	*Dendragapus obscurus*
Mountain Quail	*Oreortyx pictus*
Mammals:	
Mule deer	*Odocoileus hemionus*
Black bear	*Ursus americanus*

Watchable Terrestrial Vertebrates—Generally speaking, the most popular watchable wildlife species are large-bodied mammals and birds. We identified five birds and five mammals that are commonly viewed by the public, three of which have been extirpated from the Tahoe basin (Table 5-60).

Human Conflict Terrestrial Vertebrates—We identified 10 terrestrial vertebrates as human conflict species (Table 5-61). The most frequent complaints to the El Dorado County Animal Control office involved coyotes, black bears, Canada geese (*Branta canadensis*), raccoons (*Procyon lotor*), and three species of squirrel (Cecchettini 1999). Raccoons and bears frequently turn over garbage cans, bears and coyotes are seen as potentially dangerous to children and pets, squirrels get into houses, and geese leave their waste on structures and lawns. We assumed that only the most common squirrels that inhabit urban environments have conflicts with humans. We identified three additional species, two gulls and the rock dove, that inhabit urban environments and leave waste on human structures. Finally, we considered beavers potential

Table 5-60—Terrestrial vertebrate species of the Lake Tahoe basin that are commonly viewed by the public for pleasure. The Peregrine Falcon, mountain sheep, and grizzly bear are considered extirpated from the basin.

Common Name	Scientific Name
Birds:	
Mallard	*Anas platyrhynchos*
Canada Goose	*Branta canadensis*
Peregrine Falcon	*Falco peregrinus*
Bald Eagle	*Haliaeetus leucocephalus*
Osprey	*Pandion haliaetus*
Mammals:	
Coyote	*Canis latrans*
Mule deer	*Odocoileus hemionus*
Mountain sheep	*Ovis canadensis californiana*
Black bear	*Ursus americanus*
Grizzly bear	*Ursus arctos*

nuisance animals because the dams they create reconfigure stream channels in a manner often undesirable to residents.

Management Agency Emphasis Terrestrial Vertebrates—We identified 15 terrestrial vertebrates as focal based on their listing by the TRPA or USFS as special interest or sensitive species (Table 5-62). TRPA's list of special interest species (TRPA 1982) contains seven terrestrial vertebrates. USFS's list of sensitive species contains ten terrestrial vertebrates that regularly occur in the basin (USDA 1998b). The Townsend's big-eared bat (*Corynorhinus townsendii*) and great gray owl (*Strix nebulosa*) have not been recorded in the Tahoe basin and were therefore not considered focal, despite their listing as sensitive for the Lake Tahoe Basin Management Unit.

Summary—One hundred forty-five terrestrial vertebrate species were identified as focal in the Lake Tahoe basin (Appendix N): 83 birds, 53 mammals, six amphibians, and three reptiles. One hundred fifteen species were focal based on ecological criteria only, six species were focal based on cultural criteria only, and 24 species were focal based on both ecological and cultural criteria.

Table 5-61—Terrestrial vertebrate species of the Lake Tahoe basin with some level of conflict with humans.

Common Name	Scientific Name	Conflict(s)
Birds:		
Canada Goose	*Branta canadensis*	Property damage from waste
Rock Dove	*Columba livia*	Property damage from waste
California Gull	*Larus californicus*	Property damage from waste
Ring-billed Gull	*Larus delawarensis*	Property damage from waste
Mammals:		
Coyote	*Canis latrans*	Perceived as a threat
Beaver	*Castor canadensis*	Channel alteration
Raccoon	*Procyon lotor*	Trash disturbance
Western gray squirrel	*Sciurus griseus*	Unwanted entry into homes
California ground squirrel	*Spermophilus beecheyi*	Unwanted entry into homes
Douglas squirrel	*Tamiasciurus douglasii*	Unwanted entry into homes
Black bear	*Ursus americanus*	Trash disturbance; perceived as a threat

Table 5-62—Terrestrial vertebrates identified as sensitive or of special interest by the two primary management and regulatory agencies in the Lake Tahoe basin (TRPA 1982; USDA 1998). No records of occurrence exist in the basin for the Great Gray Owl (*Strix nebulosa*) and Townsend's big-eared bat (*Corynorhinus townsendii*), which are listed as sensitive for the Lake Tahoe Basin Management Unit.

Common Name	Scientific Name	TRPA Special Interest	USDA Forest Service Sensitive
Birds:			
Northern Goshawk	*Accipiter gentilis*	X	X
Golden Eagle	*Aquila chrysaetos*	X	
Willow Flycatcher	*Empidonax traillii*		X
Peregrine Falcon	*Falco peregrinus*	X	
Bald Eagle	*Haliaeetus leucocephalus*	X	
Osprey	*Pandion haliaetus*	X	
Spotted Owl	*Strix occidentalis*		X
Mammals:			
Pallid bat	*Antrozous pallidus*		X
Wolverine	*Gulo gulo*		X
Marten	*Martes americana*		X
Fisher	*Martes pennanti*		X
Mule deer	*Odocoileus hemionus*	X	
Mountain sheep	*Ovis canadensis californiana*		X
Sierra Nevada red fox	*Vulpes vulpes necator*		X
Amphibians:			
Mountain yellow-legged frog	*Rana muscosa*		X
Northern leopard frog	*Rana pipiens*		X

Focal Fish Species

Ecological Criteria—We used three ecological criteria to identify ecologically important focal species: potential imperilment, endemism, and exotic status. The specific analyses are described below.

Potentially Imperiled Fish—Fish species were determined to be potentially imperiled in the Sierra Nevada based on their designation as endangered, threatened, or of special concern by federal and state governments and based on population trends. Two fish species in the Lake Tahoe basin are listed by federal or state agencies (Table 5-63). The Lahontan cutthroat trout is federally listed as threatened, and the Lahontan Lake tui chub (*Gila bicolor pectinifer*) is a California state species of special concern.

Data were not available at the time of this assessment to facilitate detailed consideration of population characteristics to identify imperiled species. However, qualitative observations indicate that populations of the mountain whitefish in the basin may have declined (Reiner 1999). Moyle et al. (1996) provide no evidence of this for the Sierra Nevada as a whole, but we include mountain whitefish as a focal species in the hope that additional effort will confirm or deny suspected declines in the basin.

Exotic Fish—Sixteen of the 20 fish species that were introduced to the basin have extant populations and are considered exotic species (Table 5-63). Exotic trout species are suspected to be responsible for the decline of native amphibian populations throughout the Sierra Nevada, including the Lake Tahoe basin (Hayes and Jennings 1986; Bradford 1989; Drost and Fellers 1996).

Cultural Criteria—We used three criteria to identify culturally important focal fish species: harvest status, watchable status, and management agency emphasis. Nine cultural focal species were identified (Table 5-63). Eight focal fish species are commonly harvested in the Lake Tahoe basin (Bezzone 1999), one of which, the Kokanee salmon, is also considered a watchable wildlife species because its fall spawning run is viewed by many and celebrated with an annual festival. One focal species, the Lahontan Lake tui chub, is a USDA Forest Service sensitive species (USDA 1998b).

Summary—Nineteen fish species were identified as focal (Appendix N). The four species not identified as focal were small-bodied native species. The sizable recreational fishery in the basin is founded almost entirely on large-bodied exotic fish species.

Focal Invertebrate Species

Given the scarcity of information on invertebrates in the basin, our criteria for the identification of focal species were restricted to a limited set of ecological and cultural factors (Table 5-44).

Ecological Criteria—We used three criteria to identify ecologically important focal invertebrates: potential imperilment, endemism, or exotic status. The specific analyses are described below.

Potentially Imperiled Invertebrates—Two criteria were considered in identifying potentially imperiled invertebrates: listed species and species whose populations have apparently declined. No species of invertebrates occurring in the basin are designated as threatened or endangered by the federal or state governments. Two federally recognized species of special concern, the Mono checkerspot (*Euphydryas editha monoensis*) and Carson Valley silverspot butterfly (*Speyeria nokomis carsonensis*), may occur in the Lake Tahoe basin and were considered focal. One additional focal species, the Lake Tahoe benthic stonefly (*Capnia lacustra*), also is a federal species of special concern and is one of the few biota endemic to the basin.

The Lake Tahoe benthic stonefly is associated with deep-water plant beds and was noted in Lake Tahoe in the early 1960s (Frantz and Cordone 1996). However, more recent surveys have failed to detect this species. Declines in the Lake Tahoe benthic stonefly may be due to the introduction of opossum shrimp between 1963 and 1965 by the California Department of Fish and Game (Frantz and Cordone 1996). The Lake Tahoe benthic stonefly was designated a focal species in recognition of its possible decline (Table 5-64).

Endemic Invertebrates—Frantz and Cordone (1996) noted 10 species of benthic macroinvertebrates endemic to Lake Tahoe; all were considered focal (Table 5-64).

Table 5-63—Focal fish species of the Lake Tahoe basin, with applicable reasons for inclusion as focal species designated with an "X" in the appropriate columns. "Listed" refers to federal or state threatened, endangered, or special concern species. "Exotic" applies to fish species not native to the basin. "Watchable" applies to species viewed by the public for pleasure.

Common Name	Scientific Name	Listed	Population Decline	Exotic	Harvested	Watchable	USFS Sensitive
Goldfish	*Carassius auratus*			X			
Carp	*Cyprinus carpio*			X			
Mosquito fish	*Gambusia affinis*			X			
Lahontan Lake tui chub	*Gila bicolor pectinifer*	X					X
Brown bullhead	*Ictalurus nebulosis*			X			
Bluegill	*Lepomis macrochirus*			X			
Smallmouth bass	*Micropterus dolomieui*			X	X		
Largemouth bass	*Micropterus salmoides*			X	X		
Golden shiner	*Notemigonus crysoleucas*			X			
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*	X					
Rainbow trout	*Oncorhynchus mykiss*			X	X		
Kokanee salmon	*Oncorhynchus nerka kennerlyi*			X	X	X	
White crappie	*Pomoxis annularis*			X			
Black crappie	*Pomoxis nigromaculatus*			X			
Mountain whitefish	*Prosopium williamsoni*		X				
Golden trout	*Oncorhynchus aquabonita*			X	X		
German brown trout	*Salmo trutta*			X	X		
Brook trout	*Salvelinus fontinalis*			X	X		
Mackinaw (lake) trout	*Salvelinus namaycush*			X	X		

Table 5-64—Focal invertebrate taxa for the Lake Tahoe basin.

		Ecological Criteria				Cultural Criteria	
Common Name	**Scientific Name**	**Listed**	**Population Changes**	**Endemic**	**Exotic**	**Watchable**	**Harvest**
Terrestrial:							
Mono checkerspot	*Euphadryas deitha monoensis*	X					
Moths and butterflies	*Lepidoptera*					X	
Carson Valley silverspot butterfly	*Speyeria nokomis*	X					
Aquatic:							
Aquatic macroinvertebrate	*Candona tahoensis*			X			
Aquatic macroinvertebrate	*Capnia lacustra*	X	X	X			
Aquatic macroinvertebrate	*Dendrocoelopsis hymanae*			X			
Opossum shrimp	*Mysis relicta*				X		
Crayfish	*Pacifastacus leniusculus*				X		X
Aquatic macroinvertebrate	*Phagocata tahoena*			X			
Aquatic macroinvertebrate	*Rhyacodrilus brevidentus*			X			
Aquatic macroinvertebrate	*Spirosperma beetoni*			X			
Aquatic macroinvertebrate	*Stygobromus lacicolus*			X			
Aquatic macroinvertebrate	*Stygobromus tahoensis*			X			
Aquatic macroinvertebrate	*Utacapnia tahoensis*			X			
Aquatic macroinvertebrate	*Varichaetadrilus minutus*			X			

Exotic Invertebrates—Two species of invertebrates are known to be introduced to the basin and were considered exotics. Opossum shrimp were introduced to the basin between 1963 and 1965 by the California Department of Fish and Game (Cordone 1999). Crayfish (*Pacifastacus leniusculus*) also were introduced into the basin (Erman 1996). Both of these species were considered focal invertebrates (Table 5-64).

Cultural Criteria—We used three cultural criteria to identify culturally important invertebrates: harvest status, watchable status, and management agency emphasis (Table 5-64). Few invertebrates (outside of marine ecosystems) are held in high regard by people as culturally valuable based on their beauty or grandeur. More typically the mention of spiders, flies, or millipedes will evoke responses of indifference or disgust. However, a few taxa are held in high regard by people. The crayfish is of local interest as a harvest species (see Chapter 4). We identified butterflies and moths (Lepidoptera) as watchable species. No invertebrates have been identified as emphasis species by TRPA or the USFS.

Summary—Fourteen species and one order of invertebrates were identified as focal (Table 5-64). Thirteen species were focal based on ecological criteria alone, one order was focal based on cultural criteria alone, and one species was focal because of both ecological and cultural criteria.

Focal Fungi

Ecological Criteria—We used three ecological criteria to identify ecologically important fungi: potential imperilment, potential vulnerability, and endemism.

No federally or state-listed species of fungi or lichens are known or suspected to occur in the Lake Tahoe basin. However, qualitative observations indicate that one genus of lichen, *Bryoria*, may have declined in frequency and abundance in the basin (Hanson 1999). *Bryoria* is a fruticose lichen and may be particularly susceptible to the negative effects of poor air quality in the basin. We included *Bryoria* as a focal taxon with the hope that additional effort will confirm or deny suspected declines in the basin.

Eight rare species of lichen have been identified in the Sierra Nevada (Shevock 1996). With the exception of *Hydrothyria venosa*, an aquatic lichen, all of these species may occur in the basin (Hale and Cole 1988), although their occurrence has not been confirmed. Thus, seven rare lichens were considered focal fungi species in the Lake Tahoe basin (Table 5-65).

No fungi or lichens are currently recognized as endemic to the Lake Tahoe basin or the Sierra Nevada.

Cultural Criteria—Two cultural criteria were considered to identify focal fungi: harvest status and agency emphasis. No formal record (e.g., special use permits) of mushroom harvesting exist for the Lake Tahoe basin. However, individuals are known to collect mushrooms for personal consumption in the Lake Tahoe basin area (Allessio 1999). Thirteen species and one genus of commonly harvested fungi are known to occur in the basin and are suspected to be harvested at some level (Foster 1993; Taylor 1999) (Table 5-65). They were all considered focal. No fungi are currently designated as agency emphasis species.

Summary—Twenty species and two genera were identified as focal fungi for the Lake Tahoe basin (Table 5-65). Seven species and one genus were considered focal based solely on ecological criteria, and the remaining 13 species and one genus were considered focal, based solely on cultural criteria.

Summary of all Focal Species

Our analysis showed that many taxa are of concern and interest in the Lake Tahoe basin. Two hundred seventy-four focal taxa were identified: 57 vascular plants, 16 nonvascular plants, 83 birds, 53 mammals, six amphibians, three reptiles, 19 fish, 15 invertebrates, and 22 fungi and lichens. The identification of focal species has enabled us to highlight species of greatest interest and concern in the basin. We suggest that these species should receive special consideration in monitoring, management, conservation, and research. They represent a diversity of concerns and interests, and each species may require unique consideration. We

Table 5-65—Focal fungi in the Lake Tahoe basin.

Common Name	Scientific Name	Population Decline	Rare	Harvested
Coccora	*Amanita calyptrata*			X
Honey mushroom	*Armillariella mellea*			X
King bolete	*Boletus edulis*			X
Lichen	*Bryoria spp.*	X		
Giant puffball	*Calvatia gigantea*			X
Sierra puffball	*Calvatia sculpta*			X
Chantrelle	*Cantharellus cibarius*			X
Shaggy mane	*Coprinus comatus*			X
Lichen	*Dermatocarpon moulinsii*		X	
Lichen	*Dimelaena oreina*		X	
Lichen	*Hypogymnia metaphysodes*		X	
Delicious milk cap	*Lactarius deliciosus*			X
Morels	*Morchella spp.*			X
Oyster mushroom	*Pleurotus ostreatus*			X
Chicken of the woods	*Polyporus sulphureus*			X
Yellow coral mushroom	*Ramaria rasilispora*			X
Lichen	*Rhizoplaca glaucophana*		X	
Shrimp russula	*Russula xerampelina*			X
Cauliflower mushroom	*Sparassis crispa*			X
Lichen	*Thisoplaca marginalis*		X	
Lichen	*Umblicaria torrefacta*		X	
Lichen	*Waynea stoechadiana*		X	

address appropriate and recommended actions regarding the conservation, management, and monitoring of focal species later in this issue.

What is the status of our knowledge about select focal species of greatest interest to local agencies and organizations ?

The amount of available information about the basin's focal species varies widely. Some species are well-studied and much published literature is available, while others have not been the focus of much research. Furthermore, some species have been monitored in the basin for years, while the status of others in the basin is unknown. Species accounts can highlight the existing information and data gaps about a species. Species accounts are compilations of the state of knowledge regarding a species, including its distribution, ecology, life history, and responses to human activities. They are intended to assist in planning and the development of conservation, monitoring, and research activities. Accounts have been compiled for other efforts that address some of the focal species (e.g., Zeiner et al. 1988, 1990a, 1990b; Hickman 1993), but they are directed at a scale much larger than the basin, thereby decreasing their usefulness to local managers. Few species accounts specific to the basin exist, so we developed accounts for a few species of greatest interest to managers to provide some examples of how information could be compiled in a useful format for every focal species and also provide managers with a compendium of readily available information on some focal species (Appendix O).

Envirograms (Andrewartha and Birch 1984) are useful for identifying a full range of primary environmental factors influencing species populations. Envirograms distinguish five categories of environmental factors: resources, which includes components (food, water, cover temperature) necessary to support individuals and populations; predators, which includes species that eat or parasitize the focal species; mates, which include resources, habitat configurations, and population sizes necessary to facilitate mate location and reproduction; malentities, which include competitors, disease, and detrimental affectors; and subsidies, which are beneficial affectors. Habitat in this context includes any of these primary environmental factors. Environmental factors are displayed in a hierarchical manner, with the factors that act directly on the species being located in "the centrum" and factors acting indirectly on the species through the centrum being located in succeeding tiers of "the web" (Table 5-66). Links between the factors and the species and among the factors are typically indicated by drawing lines between them in an envirogram figure.

Apart from their use in displaying important environmental factors, envirograms can provide a strong foundation for quantifying interactions between species and environmental factors based on published literature and field data. Such an exercise can allow managers to predict the responses of species to management actions more accurately. We provide a few envirograms as examples of the utility of this approach (Appendix O).

Select Focal Species

Ideally, species accounts and envirograms would be developed for every focal species, but we did not have the resources to accomplish this. Therefore, we selected a subset of the focal species on which to concentrate our efforts. We wanted these "select focal species" to represent a range of interests (including land managers, regulatory agencies, and interest groups in the basin), to represent several taxonomic groups, and to represent species likely to be affected by proposed management in the basin.

To identify the set of select focal species to take to the next step of development, we queried the following agencies and organizations, asking them to choose 20 vertebrate and 10 plant species of greatest interest: USFWS, California Department of Fish and Game, Nevada Division of Wildlife, California State Parks and Recreation, USDA Forest Service, California Tahoe Conservancy, California State Lands Commission, and the League to Save Lake Tahoe. Individuals from these agencies and organizations providing responses are listed in Appendix P.

Respondents chose a wide variety of both vertebrate and plant species, but some species were clearly of greater concern than others to most respondents (tables 5-67 and 5-69). The specific selection processes and select species are described below.

Select Focal Animals—We created a weighted ranking system to determine the top 10 vertebrate species of interest to agencies. We asked respondents to note whether their vertebrate selections were of highest priority (top 10 species) or of secondary priority (next 10 species). We counted the number of agencies that selected a given species as first and second priority. We doubled the count of agencies choosing the species as first priority (giving them twice the weight) and then summed the counts. We selected the 10 species with the highest summed count (Table 5-67) as the top 10 species of interest to agencies.

The additional 10 vertebrate and one invertebrate species were selected by team consensus to balance the array of taxonomic groups represented and to represent species likely to respond significantly to management in the basin (Table 5-68). We selected the long-toed salamander and western aquatic garter snake (*Thamnophis couchii*) because their association with aquatic habitats makes them vulnerable to changes in management of

Table 5-66—Elements of an envirogram (Andrewartha and Birch 1984) and their general configuration.

Web			**Centrum**	
3	**2**	**1**		
Resources, predators, mates, malentities, and subsidies directly affecting Web 2	Resources, predators, mates, malentities, and subsidies directly affecting Web 1	Resources, predators, mates, malentities, and subsidies directly affecting the centrum	Resources, predators, mates, malentities, and subsidies directly affecting the species	**Species**

Table 5-67—The top 10 selections by questionnaire respondents of focal vertebrate species of the Lake Tahoe basin. We used a weighted ranking system in which those species designated as "first priority" (A) by respondents received twice the weight of species designated as "second priority" (B). Responses represent the opinions of individual biologists at the agencies and organizations noted and do not necessarily reflect the opinions of others at those agencies and organizations. CDFG = California Department of Fish and Game; CSP&R = California State Parks and Recreation; CTC = California Tahoe Conservancy; League = League to Save Lake Tahoe; NDOW = Nevada Division of Wildlife; TRPA = Tahoe Regional Planning Agency; USFS = USDA Forest Service, Lake Tahoe Basin Management Unit; USFWS = US Fish and Wildlife Service.

Common Name	Scientific Name	CDFG	CSP&R	CTC	League	NDOW	TRPA	USFS	USFWS	1st Priority Count	2nd Priority Count	Wtd Total[a]
Marten	*Martes americana*	A	B	A	A	A	A	A	A	7	1	15
Northern Goshawk	*Accipter gentilis*	A	A	A	A	A	A	A	B	7	1	15
Bald Eagle	*Haliaeetus leucocephalus*	A	A	B	A	A	A	B	A	6	2	14
Willow Flycatcher	*Empidonax traillii*	A	A	-	B	A	A	A	A	6	1	13
Mountain yellow-legged frog	*Rana muscosa*	A	-	B	A	B	A	A	A	5	2	12
Osprey	*Pandion haliaetus*	A	-	B	B	A	A	B	B	3	4	10
Spotted Owl	*Strix occidentalis*	A	A	-	A	A	B	B	-	4	2	10
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*	A	B	-	A	-	B	B	A	3	3	9
Pileated Woodpecker	*Dryocopus pileatus*	-	A	-	-	A	A	A	-	4	0	8
Northern flying squirrel	*Glaucomys sabrinus*	A	B	-	-	A	A	-	-	3	1	7

[a] Weighted total = $\sum$(1st priority count * 2) + $\sum$(2nd priority count)

Table 5-68—Select focal animal species for the watershed assessment in the Lake Tahoe basin.

Common Name	Scientific Name	Comments
Birds:		
Northern Goshawk	*Accipter gentilis*	High agency interest
Yellow Warbler	*Dendroica petechia*	Riparian associate, common cowbird host
Pileated Woodpecker	*Dryocopus pileatus*	High agency interest
Willow Flycatcher	*Empidonax traillii*	High agency interest
Bald Eagle	*Haliaeetus leucocephalus*	High agency interest
Brown-headed Cowbird	*Molothrus ater*	Indicator of change and potential ecological pest
Osprey	*Pandion haliaetus*	High agency interest
Spotted Owl	*Strix occidentalis*	High agency interest
Mammals:		
Pallid bat	*Antrozous pallidus*	Forest-associated bat
Coyote	*Canis latrans*	Top carnivore
Northern flying squirrel	*Glaucomys sabrinus*	High agency interest
Marten	*Martes americana*	High agency interest
Douglas' squirrel	*Tamiasciurus douglasii*	Forest-associated squirrel, important prey item
Black bear	*Ursus americana*	Upper level, large-bodied predator
Amphibians:		
Long-toed salamander	*Ambystoma macrodactylum*	Status unknown, aquatic
Mountain yellow-legged frog	*Rana muscosa*	High agency interest
Reptiles:		
Western aquatic garter snake	*Thamnophis couchii*	Aquatic reptile
Fish:		
Smallmouth bass	*Micropterus dolomieui*	Exotic deep water predator
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*	High agency interest
Rainbow trout	*Oncorhynchus mykiss*	Exotic predator of native frogs and fishes
Invertebrates:		
Lake Tahoe benthic stonefly	*Capnia lacustra*	Endemic species; status unknown

aquatic habitat in the basin and because both species are poorly studied in the basin. We selected the rainbow trout and smallmouth bass (*Micropterus dolomieui*) because they are both nonnative predators of native aquatic animals and they represent different habitat associations. The black bear and coyote are both large-bodied upper-level predators that are highly visible to residents and visitors. The Douglas' squirrel (*Tamiasciurus douglasii*) is a forest-dwelling small mammal that is a prey item year-round for raptors and mammals and is also highly dependent on the cone crops of conifers (Sullivan and Sullivan 1982). The squirrel is thus likely to exhibit a response to forest management activities. The brown-headed cowbird is an indicator of ecological change, responding favorably to the clearing of land and representing a potential threat to many open-nesting songbirds (Ehrlich et al. 1988). The yellow warbler (*Dendroica petechia*) is a small-bodied riparian-associated bird known to be negatively affected by cowbirds (Ehrlich et al. 1988; Dunn and Garrett 1997). We chose the pallid bat (*Antrozous pallidus*) because of its association with forests and likelihood of being affected by prescribed burning (Rahn 1999). Finally, we selected a single invertebrate, the Lake Tahoe benthic stonefly, because it is one of the few species endemic to the Lake Tahoe basin and its population status is unknown.

Select Focal Vascular Plants—A simpler method was used to identify select focal plants compared to that for vertebrates. Agency experts were provided a list of focal plant species and were asked to identify the 10 focal species of greatest interest. Fourteen species were selected by two or more of the nine agency representatives queried (Table 5-69). We added one harvest species (sugar pine) to round out the list, for a total of 15 select focal plant species (Table 5-70). Sugar pine was added because it is a harvest species that is becoming increasingly rare because of the spread of a fatal blister-rust (Urie 1999).

Species Accounts for Select Focal Species

We developed species accounts for 10 plants, 20 vertebrates, and one invertebrate. We addressed a range of topics in each species account (Table 5-71): population status, ecology, habitat relationships, effects of human activities, and conservation. Ideally, species accounts would be accompanied by distribution maps and a database of sightings in the basin, but we were not able to compile this information for this assessment. We prepared envirograms for five select focal species: sugar pine, Northern Goshawk, northern flying squirrel, long-toed salamander, and Lake Tahoe benthic stonefly. The full set of species accounts and envirograms for select focal species is in Appendix R.

What data gaps were revealed in the process of assessing species and populations?

Our assessment of species and populations in the Lake Tahoe basin was limited by data gaps, poor data, and time. Only the data gaps are addressed here. In this assessment, we relied most heavily on information on the species composition of the basin; however, more comprehensive data on distribution, relative abundance, and life history characteristics of the basin's species would have strengthened the assessment. In general, data are lacking on the occurrence, distribution, population levels, habitat use (for animals), and response to disturbance of most species within the basin. For example, for terrestrial vertebrates, the group for which we had the best information, we were forced to use estimates of population size, population trend, and degree of range change for populations in the Sierra Nevada instead of information specific to populations in the Lake Tahoe basin. Additionally, basic life history information is not easily accessible for most nonvertebrate organisms or is not presently compiled in a usable format. These are common data gaps often faced by biologists when evaluating species for federal or state listing or evaluating potential responses of species to management actions; the basin is not unusual in this regard. Specific limitations imposed on the assessment by these data gaps are described below for each taxonomic group.

Vascular Plants—Despite some significant efforts invested in the inventory of vascular plants by many agencies and researchers in the Lake Tahoe basin, comprehensive plant inventories have not been conducted, leaving large gaps in our knowledge

Table 5-69—The 14 vascular plant species of greatest interest to local agencies in the Lake Tahoe basin. Responses were solicited by a questionnaire, represent the opinions of individual biologists at the agencies and organizations noted, and do not necessarily reflect the opinions of others at those agencies and organizations. CDFG = California Department of Fish and Game; CSLC = California State Lands Commission; CSP&R = California State Parks and Recreation; CTC = California Tahoe Conservancy; League = League to Save Lake Tahoe; TRPA = Tahoe Regional Planning Agency; USFS (El Dorado)= USDA Forest Service, El Dorado National Forest; USFS (LTBMU) = USDA Forest Service, Lake Tahoe Basin Management Unit; USFWS = US Fish and Wildlife Service.

Common name	Scientific name	CDFG	CSLC	CSP&R	CTC	League	TRPA	USFS (El Dorado)	USFS (LTBMU)	USFWS	Total
Lake Tahoe draba	*Draba asterophora* var. *asterophora*	X	X	X	X	X	X		X	X	8
Tahoe yellow cress	*Rorippa subumbellata*	X	X		X	X	X	X	X	X	8
Bullthistle	*Cirsium vulgare*	X		X		X		X			4
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	X				X	X		X		4
Tall whitetop	*Lepidium latifolium*			X	X		X	X			4
Austin's milkvetch	*Astragalus austiniae*		X		X					X	3
Epilobium	*Epilobium howellii*				X	X			X		3
Eurasian watermilfoil	*Myriophyllum spicatum*				X	X	X				3
Long-petaled lewisia	*Lewisia longipetala*	X					X		X		3
Mariposa sedge	*Carex mariposana*		X			X				X	3
Mountain bentgrass	*Agrostis variabilis*	X	X					X			3
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*			X			X		X		3
Galena Creek rockcress	*Arabis rigidissima*	X	X				X				3
Water bulrush	*Scirpus subterminalis*	X	X								2

Table 5-70—Select focal vascular plant species in the Lake Tahoe basin.

Common Name	Scientific Name	Comments
Mountain bentgrass	*Agrostis humilis*	High agency interest
Galena Creek rockcress	*Arabis rigidissima* var. *demota*	High agency interest
Austin's milkvetch	*Astragalus austiniae*	High agency interest
Mariposa sedge	*Carex mariposana*	High agency interest
Bullthistle	*Cirsium vulgare*	High agency interest
Lake Tahoe draba	*Draba asterophora* var. *asterophora*	High agency interest
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	High agency interest
Epilobium	*Epilobium howellii*	High agency interest
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*	High agency interest
Tall whitetop	*Lepidium latifolium*	High agency interest
Long-petaled lewisia	*Lewisia longipetala*	High agency interest
Eurasian watermilfoil	*Myriophyllum spicatum*	High agency interest
Sugar pine	*Pinus lambertiana*	Uncommon, harvested, threatened by disease
Tahoe yellow cress	*Rorippa subumbellata*	High agency interest
Water bulrush	*Scirpus subterminalis*	High agency interest

Table 5-71—General outline for species accounts developed for select focal species.

- Population status
  - Distribution in California, Nevada, and the Lake Tahoe basin
- Ecology
  - Population biology/demographics
  - Life history
  - Reproductive behavior
  - Foraging (behavior/needs)
  - Dispersal behavior
  - Home range (size/characteristics/use)
  - Interactions with other species
  - Research needs
- Habitat relationships
  - Specialist/generalist?
  - Habitat types used
  - Successional stages used
  - Response to natural disturbance
- Effects of human activities (historic/current/anticipated)
  - Impacts on habitat
  - Impacts on individuals
  - Impacts on populations
  - Current management
  - Management objectives
- Conservation
  - Current conservation
  - Conservation objectives
  - Potential conservation efforts

of the species composition of the basin and the distribution of rare plants. Approximately one-quarter of the plant species list is composed of species whose occurrence has not been documented. Uncertainties about plant occurrence in the basin resulted in our creating a plant species list that most likely overestimates the richness of plant species in the basin. Shevock (1996) stated that large portions of the Sierra Nevada remain unsurveyed, and certainly this is true of much of the basin. High elevation species are particularly poorly inventoried. Studies by Smith (1973, 1983) represent the only attempt at a floristic treatment of the basin; they were the earliest and most comprehensive surveys of plants of the basin and neighboring areas. Surveys by Manley and Schlesinger (in preparation) were designed to answer questions about riparian biodiversity patterns rather than to describe the basin's flora, but identified 145 additional plants at 80 sites in the basin. This suggests that additional survey efforts would be highly successful in confirming additional plant species as occurring in the basin.

Nonvascular Plants—Nonvascular plants are possibly the least studied group of organisms addressed here (Shevock 1996). Shevock (1996) highlighted the poor state of knowledge for mosses in the Sierra Nevada. Distributional information for these taxa is typically general (e.g., "western US"), perhaps indicating broad ranges for these species but more likely suggesting incomplete knowledge of species' distributions. These gaps in data make assessments of species potentially occurring in a specific area, such as the basin, especially difficult. The only confirmed records of bryophytes in the basin come from Manley (unpublished data); this is a very short list. The list of potential species we compiled is short also, reflecting the lack of available distributional information on nonvascular plants. Perhaps when the bryophyte flora for California referenced by Shevock (1996) is published, a more definitive list of nonvascular plants in the basin can be derived.

Vertebrates—Some groups of vertebrates are better studied than others; birds have received the most attention, followed by fish, mammals, amphibians, and reptiles. Information on the basin's birds is relatively easy to obtain; the Lake Tahoe basin bird list (Eastern Sierra Interpretive Association ca. 1993) and Orr and Moffitt (1971) provide lists of the basin's bird species, while recent studies, such as Keane and Morrison (1994) and Manley and Schlesinger (in preparation), provide more recent data. Fish also have been well-studied, in part because of the basin's significant sport fisheries. Our information on mammals came primarily from two volumes (Orr 1949; Hall 1995) describing observations mostly over 50 years old, a survey of riparian areas throughout the basin (Manley and Schlesinger in preparation), and two site-specific bat surveys (Pierson 1998; Tatum 1998a, 1998b). Though we can describe the basin's mammal species composition with some confidence, systematic surveys for all mammal species, particularly bats and mid-sized carnivores, would greatly enhance our understanding of the composition, distribution, and population sizes of the basin's mammals. Amphibians and reptiles are more poorly studied than the other vertebrate groups in the basin, reflecting the historical lack of interest in these groups. Only recently have systematic surveys of amphibians been conducted in the basin (Manley and Schlesinger, in preparation; Lehr 1999; Leyse 1999); we are only beginning to understand patterns of amphibian occurrence and occurrences of sensitive amphibian species around Lake Tahoe. Reptiles are the taxonomic group for which there is the greatest discrepancy between the potential species occurrence (CDFG 1998a) and actual records in the basin. Further surveys for herpetofauna in the basin are much needed.

Invertebrates—Over half of the described species on Earth are insects, and many undescribed species are most likely insects (Noss and Cooperrider 1994), yet we know very little about their distributions. Kimsey (1996) and Erman (1996) point out the poor state of knowledge in the Sierra Nevada for terrestrial insects and aquatic invertebrates, respectively. Distributional information for these groups is typically very general (e.g., "western US"), as it is for nonvascular plants, perhaps indicating broad ranges for these species but more likely suggesting incomplete knowledge of species' distributions. In the basin, we were able to confirm the occurrence of many lepidopteran species, but only because they have been relatively well studied. Some studies, such as Manley and Schlesinger (in preparation) have identified additional invertebrate taxa, but the list is far from complete. Kimsey (1996) notes that the status of insect taxa is poorly understood in California except for a few particularly well-studied locations (mainly research and teaching stations), which are still studied at certain times of year only. In the basin, a number of small-scale surveys have been conducted that have addressed some taxa at varying levels of specificity. Invertebrates are particularly troublesome because of the difficulty of identifying genera and species; most are identified to family only. In some cases, invertebrate sampling is conducted during assessments of water quality; for this purpose it is often unnecessary to key aquatic invertebrates below the family level (Mangum 1997). These constraints make it difficult to inventory species and to detect changes in species composition, especially in light of the limited funding and time available for invertebrate studies. However, identification of invertebrates to species is important for understanding the invertebrate fauna; one species is not interchangeable for another in terms of its environmental requirements and its function in ecosystems (Erman 1996).

Fungi—Because fungi are often harvested for food, they are somewhat better known than nonvascular plants. However, fungi are typically under-studied by both managers and researchers. The small number of state-listed and federally listed fungi more likely reflects the lack of information on the state of fungal populations than it does viable populations of all fungal species. The Sierra Nevada Ecosystem Project (SNEP 1996) did not address fungi, apart from a brief treatment of the lichens (Shevock 1996). Only Ryan (1990) and Manley and Schlesinger (in preparation) have surveyed fungal and lichen taxa in the basin, and neither approaches a comprehensive survey. Fungi are an extremely important group of organisms to ecosystem function, as they play a vital role in decomposition and nitrogen fixation and represent food sources for humans and other animals, such as tree squirrels (Alexopolous et al. 1996). Fungi warrant some inventory effort and study in the basin.

What monitoring, conservation, and research activities are most appropriate for the focal species identified?

Focal species represent a wide range of concerns about and interests in species and populations in the basin and appropriate conservation, monitoring, and research activities will vary among focal species. In general, the greater the concern and interest associated with a species, the more support there will be for increased investment. The large number of focal species precluded detailed discussions of conservation and monitoring in relation to each species. Instead, we rated the relative level of concern and interest (i.e., importance) of the criteria for focal species selection (Table 5-72). Species associated with multiple criteria were treated in relation to the criterion with the highest level of importance. Potentially imperiled species received a relative importance of 1, the highest level of importance for monitoring and conserving focal species. The three remaining ecological criteria, along with agency emphasis species, received a relative importance of 2, the next highest level of importance. The remaining cultural criteria received a relative importance of 3, the most modest level of importance. We used these rankings to guide our identification of appropriate monitoring and conservation activities. It is important to note that all focal species are of high concern or interest and that actions taken on behalf of every species will benefit the basin's biological diversity. These rankings are simply intended to help identify appropriate levels of investment. Considerations and recommendations for inventory, conservation, monitoring, and research regarding focal species by criterion, as well as some species-specific recommendations, are discussed below.

Prerequisite Inventory Data

The first step in the conservation and monitoring of any species is to obtain an accurate inventory of its distribution and abundance. Earlier, we discussed data gaps encountered in the identification of focal species. Inventory data are

Table 5-72—Relative level of concern and interest in focal species associated with specific criteria. The relative importance of species associated with each criterion is indicated, with 1 representing the highest level of concern and interest and 3 representing the lowest.

Criteria	Importance
Ecological criteria:	
Potentially imperiled	1
Potentially vulnerable	2
Endemic	2
Exotic, domestic, native pest	2
Cultural criteria:	
Agency emphasis	2
Harvested	3
Watchable	3
Human conflict	3

emphasized here as fundamental information necessary to design meaningful and effective conservation efforts. The thoroughness of the inventory needed will depend on the type of conservation and monitoring activities proposed. Systematic surveys of plant species in the basin would greatly improve our understanding of the composition, distribution, and population sizes of plants in the basin. Surveys to confirm potentially occurring focal species (e.g., subalpine fireweed [*Epilobium howellii*], the Mono checkerspot butterfly) and surveys for Forest Service sensitive vertebrates not currently known to occur (e.g., great gray owls and Townsend's big-eared bats) would be especially helpful. Finally, obtaining a more thorough inventory of species occurrence and distribution in the basin for the lesser known taxa (i.e., nonvascular plants, fungi, invertebrates, herbaceous plants, and bats) would provide a more balanced and comprehensive depiction of biological diversity in the basin and a stronger foundation for conservation efforts.

Conservation

The integrity of the basin's biological diversity would best be maintained and enhanced if conservation measures were developed, adopted, and implemented for biological diversity in the basin. We discuss three types of conservation actions: awareness and education, measures to protect biological integrity, and restoration options. Awareness and education can be achieved in a variety of ways, including concerns highlighted in such publications as this assessment and in workshops, research symposia, campfire talks, web sites, newspaper and radio media, school programs, and the public's involvement in monitoring and conservation efforts. Measures to protect biological integrity entail implementing actions intended to safeguard or mitigate impacts to focal species. Such measures may include disturbance buffer zones around nest sites, maintenance of movement corridors, or relocation of populations. Restoration for focal species can involve specific measures to improve the quality or quantity of habitat (including control of exotic species) or to reintroduce populations of focal species. The more intensive conservation actions also include actions at lower levels; for example, restoration activities are often most effective when accompanied by protective measures and education. Increasing levels of concern about the persistence of a species will merit increasing levels of investment in conservation, from awareness (the lowest level) to highly intensive conservation measures such as guarding all individuals in the wild (e.g., elephants in parts of Africa), to restoration options such as augmenting the population through captive breeding (e.g., California Condor [*Gymnogyps californianus*]) (Figure 5-38). Conservation of biological diversity will be most successful if all three types of conservation actions are employed. Below, we discuss some options for conservation actions.

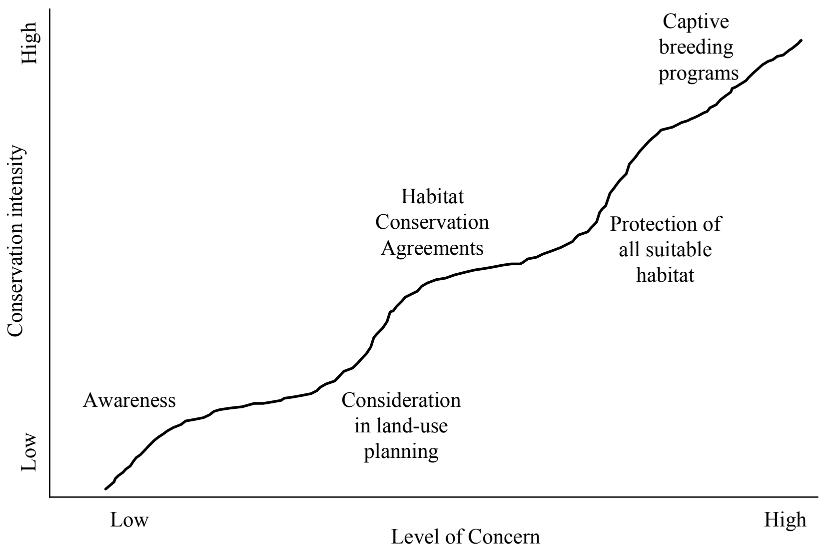


Figure 5-38—Relationship between the level of concern for a species or population and intensity of conservation actions.

We identified opportunities for conservation actions that seemed appropriate for each focal species (Appendix Q). The number of focal species precluded detailed discussion of the actions suggested for each species. Instead, we provide a summary of conservation opportunities identified across all species. Awareness and education measures were appropriate for the most species (n = 127), followed by measures to protect biological integrity (124 species), and finally restoration (21 species) (Table 5-73). Many of the conservation measures, such as habitat protection, could benefit multiple species; only a few species warrant species-specific conservation plans (e.g., bald eagle). Population restoration opportunities included potential reintroductions of one bird (peregrine falcon), one mammal (mountain sheep), two amphibians (mountain yellow-legged frog and northern leopard frog), and one fish (Lahontan cutthroat trout). We also identified the restoration of habitat for native species through the control and/or eradication of 12 exotic species as an opportunity to protect biological diversity. Our treatment of threats and conservation actions is incomplete, but it should serve as a starting point for developing awareness and education programs, measures to protect biological integrity, and restoration of biological diversity in the basin.

Monitoring

Monitoring designed to describe the status of and change in populations and associated habitats of focal species would provide a wealth of information about their potential persistence in the basin and potential threats to their persistence. Developing a monitoring scheme entails identifying attributes to describe populations and habitats and designing and implementing data collection and analysis. Monitoring attributes can consist of direct measures and indirect measures that serve as indicators. Ideally, indicators provide a strong signal about conditions through relatively few attributes. Habitat quantity or quality is often considered a potential indicator of population status. However, it is an indirect indicator and should not be relied on unless local validation efforts can quantify the error

Table 5-73—Summary of conservation actions recommended for focal species.

Type of Conservation Action	Total Number of Species	Number of Species by Taxonomic Group
Awareness/education	127	4 vascular plants 16 nonvascular plants 57 terrestrial vertebrates 16 fish 12 invertebrates 22 fungi and lichens
Measures to protect populations and habitats	124	43 vascular plants 77 terrestrial vertebrates 1 fish 3 invertebrates
Restoration: habitat or environmental features	16	10 vascular plants 5 terrestrial vertebrates 1 fish
Restoration: populations	5	4 terrestrial vertebrates 1 fish

associated with tracking habitat as an indirect measure of population status for individual species in the basin.

The development of a sound monitoring strategy requires careful evaluation of potential attributes (both direct and indirect measures), questions the attributes would address, and design options that accommodate data collection requirements. Here, we simply address options for population attributes that would be appropriate measures of population conditions relative to the level of concern for each species. First we define the range of types of monitoring data and then discuss the appropriate match with each focal species.

General Condition Monitoring—Focal species were identified to prioritize management and conservation efforts based on species specific interests and concerns. Monitoring these species will not necessarily be informative about the status of biological diversity in the basin or general trends in species populations. The identification of focal species that serve as indicators of ecosystem conditions is one approach that would complement the set of focal species currently identified for monitoring. The other approach is to implement a monitoring scheme that tracks trends in many species which together serve to provide information on the general trends of species populations. The ability to accomplish multi-species monitoring is in the process of being developed for species throughout the Sierra Nevada (Manor 1999; USDA 1999c), and preliminary results suggest that some method of general condition monitoring is a powerful approach to addressing trends in biological diversity, particularly in a geographic area as small and well-defined as the Lake Tahoe basin.

Types of Monitoring Data—We identified seven types of monitoring data to aid in differentiating monitoring needs among species groups and individual species: presence, frequency of occurrence, relative abundance, population size, territory occupancy, reproductive success, and population demography (Table 5-74). The higher the level of concern, the greater the investment in monitoring that is appropriate. Monitoring the presence and relative abundance of a species would be commensurate with a low level of concern or with uncertainty about the presence of a species in

Table 5-74—Types of monitoring data for focal species in the Lake Tahoe basin, in increasing order of intensity (adapted from USDA 1999c).

Type of Data	Description
Presence	An assessment of whether a species occurs in the basin. Some species' presence in the basin must be established before conservation actions can be addressed. Presence monitoring is also appropriate for species with a very small portion of their range in the basin.
Frequency of occurrence	An accounting of the proportion of survey sites occupied by a species. Can provide both status and change data. Changes in the number of sites occupied by a species provides a crude measure of trend. Analysis of occupied sites also can provide data on habitat relationships.
Relative abundance	An index of abundance that can allow comparison of abundance among survey sites, and therefore among habitat types, but cannot yield density estimates. Typically, it is based on a count of individuals.
Territory occupancy	Proportion of all known territories that are inhabited by breeding individuals. Also can provide strong information about habitat relationships. Data can include shifts in individuals occupying territories over time.
Population size	Typically an estimate of the number of individuals in the population based on a sample. For animals, mark-recapture techniques are commonly used. For rare species, it may be an actual census of individuals.
Reproductive success	Can be measured in a variety of ways, depending on the species and sampling method. For instance, reproductive success of birds may be determined using the number of eggs laid and young fledged to calculate number of young produced per adult or per egg laid. For plants, can include measures of seed viability and germination rates.
Population demography	Estimation of important population parameters, such as birth rates, mortality, and age structure, that can suggest causes of observed population trends. Most informative for long-lived species. Can enable detection of population trends that less sensitive measures (abundance of individuals, frequency of occurrence) would not detect as quickly.

the basin, whereas monitoring trends in abundance and distribution within the basin would be commensurate with a higher level of concern (Figure 5-39). Monitoring reproductive success or obtaining detailed demographic data would be commensurate with the very highest level of concern. Intensive monitoring would be most effective if accompanied by monitoring at lower levels of investment; for instance, detailed demographic data would be bolstered by estimates of population size.

Population Monitoring—We identified the type of monitoring most appropriate for each focal species (Appendix P). We identified the target data, indicating the type of data we recommended should be collected for each species, and the nontarget data, indicating additional data that would be beneficial to acquire if not requiring excessive additional effort. Designation of data as nontarget is intended to alert those designing and implementing monitoring efforts that these additional data would be helpful if feasible to obtain.

The appropriate types of monitoring data identified for each focal species are summarized in Table 5-75. Data on relative abundance were identified as target for most focal species (114 species), particularly terrestrial vertebrates. Data on frequency of occurrence were identified as target next most frequently (82 species). This type of

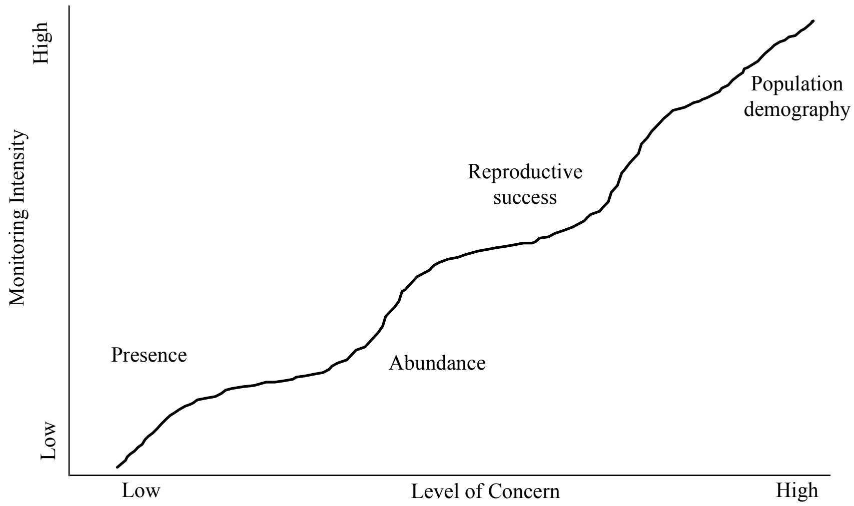


Figure 5-39—Relationship between the level of concern for a species or population and associated intensity of monitoring actions.

Table 5-75—Summary of recommended types of target monitoring data for focal species.

Type of Monitoring Data	Total Number of Species	Number of Species by Taxonomic Group
Presence/absence	67	27 vascular plants 16 nonvascular plants 17 terrestrial vertebrates 7 lichens
Frequency of occurrence	82	19 vascular plants 24 terrestrial vertebrates 11 fish 13 invertebrates 15 fungi and lichens
Relative abundance	114	5 vascular plants 99 terrestrial vertebrates 8 fish 2 invertebrates
Population size	11	6 vascular plants 5 terrestrial vertebrates
Population demography	2	2 fish

monitoring was generally identified for species known to occur in the basin and possessing one or more of the following characteristics: the level of concern was moderate, information on population size in the basin was lacking, or the feasibility of collecting relative abundance data was low. Presence/absence monitoring was identified third most frequently (67 species). Species for which presence/absence monitoring was identified were those with a high level of concern outside the basin but that have not been confirmed to occur in the basin. Monitoring population size was identified next most frequently (11 species), for five raptors and five vascular plants with small populations in the basin, as well as for one noxious weed. Finally, we identified population demographic (age class distribution) monitoring for two species of fish with a high level of concern. Monitoring relative abundance or territory density were not identified as target data for any species but were identified as nontarget data for many species.

We recognize that monitoring efforts are underway for many individual species in the basin, although many of them are restricted to specific areas. We identified monitoring needs at a baseline level for the entire basin, understanding that for some species this level of monitoring would not directly meet the needs or desires of individual agencies or interest groups. Our objective was to identify the basic level of data required to assess the status and population changes of each focal species in the basin, considering current information gaps and the ultimate need to improve our knowledge of the condition and trends of biological integrity in the basin.

Research Opportunities

Our list of research opportunities is intended to highlight key information that would significantly further our understanding of biological integrity and diversity in the basin. Enumerating all research opportunities relating to species and populations in the Lake Tahoe basin would not be possible. The following is a short list of research opportunities:

1. We need to understand the effects of human disturbance on focal species (particularly bald eagle, northern goshawk, and marten).
2. We need to understand the effects of land use practices (grazing, prescribed fire, mechanical thinning) on focal species (especially spotted owl, northern goshawk, willow flycatcher, and amphibians).
3. We need to assess the impacts of brown-headed cowbird parasitism on the reproductive success of the basin's nesting passerines (particularly willow flycatcher and yellow warbler).
4. We need to assess the impacts of exotic fish and bullfrogs on native fish, amphibians, and invertebrates.
5. We need to evaluate parameters likely to influence the success of potential reintroduction of extirpated species and species in imminent danger of extirpation (e.g., mountain yellow-legged frog and Lahontan cutthroat trout).
6. Management of biological diversity in the basin would be informed by research directed at understanding the effects of topographic barriers created by the mountain ranges surrounding the basin on the populations of less mobile species, including testing hypotheses on the potential impact of reduced immigration and emigration rates on the probability of persistence for some species in the basin.

Species and Populations: Conclusions

Our assessment of species and populations in the Lake Tahoe basin exposed the following key findings:

- Biological diversity in the basin has been diminished because of losses of several native species and the establishment of many exotic species. Species extirpations were probably influenced by larger-scale declines, fire suppression, and the basin's topographic isolation. Species additions resulted from direct introductions, fire suppression, an increased level of settlement, increased abundance of large trees, and the basin's topographic isolation.

- Some basic information on the basin's species composition is lacking, especially regarding nonvascular plants, invertebrates, and fungi.
- A multitude of species are of concern and interest in the basin. Many species were of concern for ecological reasons, including extirpated species, listed species, species with population declines, species whose life history characteristics make them vulnerable to future declines, endemic species, and exotic species. Cultural interest species included harvested species, watchable wildlife species, human conflict species, and management agency emphasis species. Most species were of concern for ecological reasons. Because of the differing levels of concern for and interest in focal species, appropriate conservation, monitoring, and research efforts will vary widely among species.
- Many vertebrate species were potentially imperiled because of population declines and range contractions. Although these declines have occurred at larger geographic scales than the basin, attention paid to these species at smaller scales is critical in supporting larger-scale populations.
- Several exotic and ecological pest species occurring in the basin may, in the absence of control, cause future ecological damage, primarily through predation on and competition with native species. In some cases, significant damage may have already occurred. Exotics of particular concern include beavers, trout, bass, bullfrogs, tall whitetop, Scotch thistle, Eurasian watermilfoil, opossum shrimp, and crayfish. Further, several domesticated species, such as dogs, cats, and cows, may negatively affect native species through predation and harassment and may damage local ecosystems through overgrazing and trampling.

Concluding Remarks

This assessment of biological integrity in the Lake Tahoe basin considered a wide array of topics of concern to the public, land managers, and scientists. We addressed three major facets of biological integrity: community structure and composition, the fire regime, and species composition and population characteristics. Most of the issues included historical perspectives, which informed our interpretations of the current status of biological integrity and which may inform future decisions about the desired future condition of biological integrity in the basin.

We were unable to address some topics of equal importance to biological integrity in the basin. For example, a more thorough treatment of terrestrial vegetation types would contribute greatly to improving our understanding of community diversity and landscape dynamics. Similarly, additional Ecologically Significant Areas could be identified by considering some additional criteria (e.g., representativeness) that we were unable to address in the time available. An extended discussion of physical processes in the basin that shape biological diversity and integrity would enrich considerations for conservation and restoration. Finally, our conservation, monitoring, and research recommendations represent a starting point in the process of developing an integrated conservation strategy for biological integrity that addresses management, monitoring, and research.

References

Adams D. P. 1967. Late Pleistocene and recent palynology in the central Sierra Nevada, California. *In* E. J. Cushing and H. E. Wright (eds.) Quarternary Paleoecology. Yale Univ. Press, New Haven, Connecticut. P. 275-301.

Agee, J. K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, DC.

Ahlborn, G. 1990a. California Quail. Pages 168-169 in Zeiner, D. C., W. F. Laudenslayer, Jr., K. E. Mayer, and M. White, eds. California's wildlife, Vol. II: Birds. California Department of Fish and Game, Sacramento, California.

_______. 1990b. Coyote. Pages 284-285 in Zeiner, D. C., W. F. Laudenslayer, Jr., K. E. Mayer, and M. White, eds. California's wildlife, Vol. III: mammals. California Department of Fish and Game, Sacramento, California.

Alexopolous, C. J., C. W. Mims, and M. Blackwell. 1996. Introductory mycology, fourth edition. John Wiley & Sons, Inc., New York.

Allaby, M. 1994. The Concise Oxford Dictionary of Ecology. Oxford University Press, Oxford, England.

Allen, B. 1999. Personal communication. Tahoe Research Group, University of California, Davis, California.

Allessio, L. 1999. Personal communication. Special Use Permit Administrator, USDA Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, California.

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122, USDA Forest Service.

Anderson, K. 1993 Indian Fire-Based Management in the Sequoia Mixed Conifer Forest of the Central and Southern Sierra Nevada. Final Report Executive Summary. Yosemite Research Center, Yosemite National Park Cooperative Agreement. Order number 8027-2-002. 421 pp.

Anderson, M. K., and M. J. Moratto. 1996. Native American land use practices and ecological impacts. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis.

Anderson. H. 1982. Aids to determining fuel models for estimating fire behavior. USFS Intermountain Research Station, Gen. Tech. Rep. GTR-INT-122. 22p.

Andrewartha, H. G., and L. C. Birch. 1984. The ecological web: more on the distribution and abundance of animals. University of Chicago Press, Chicago, IL.

Angermeier, P. L., and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives: protecting biotic resources. Bioscience 44: 690-697.

Anonymous. 1997. A catastrophe for birds. Bird conservation, Summer Nesting 1997:10-11.

Ansley, J. S., and J. J. Battles. 1998. Forest composition, structure, and change in an old-growth mixed conifer forest in the northern Sierra Nevada. Journal of the Torrey Botanical Society 125:297-308.

Arora, D. 1986. Mushrooms Demystified. Ten Speed Press, Berkeley, California.

Atkinson, I. 1989. Introduced animals and extinctions. Pages 54-69 in Western, D., and M. Pearl, eds. Conservation for the twenty-first century. Oxford University Press, New York.

Axelrod, D. I. 1986. The Sierra redwood (Sequoiadendron) forest: end of a dynasty. Geophytology 16:25-36.

Bahro, B. 1999. Fuels officer, Placerville Ranger District, Eldorado National Forest, personnel communication.

Baker, J. R. 1994. Ornamentals and Turf Integrated Pest Management, Insect Note 11. Web Site: http://ipm-www.ncsu.edu/insect_notes/Ornamentals_and_Turf/not11.html North Carolina Cooperative Extension Service, Department of Entomology, North Carolina State University.

Barber, M. C. (ed.) 1994. Environmental Monitoring and Assessment Program Indicator Development Strategy. EPA/620/R-94/XXX. US Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, Georgia.

Barbour, M. G., and R. A. Minich. 1999. California upland forests and woodlands, pp. 161-201. *In* M. G. Barbour and W. D. Billings (eds.), North American terrestrial vegetation, 2nd ed., Cambridge University Press, New York, New York.

Barbour, M. G., J. H. Burk, W. D. Pitts, M. W. Schwartz, and F. Gilliam. 1998. Terrestrial plant ecology, 3rd ed. Addison Wesley Longman, Menlo Park, California.

Barnett, L. 1999. Personal communication. Senior Planner, Tahoe Regional Planning Agency, Zephyr Cove, NV.

Beauchamp, D. A., B. C. Allen, R. C. Richards, W. A. Wurtsbaugh, and C. R. Goldman. 1992. Lake trout spawning in Lake Tahoe: egg incubation in deep-water macrophyte beds. North American journal of fisheries management 12:442-449.

Beauchamp, D. A., E. R. Byron, and W. A. Wurtsbaugh. 1994. Summer habitat use by littoral-zone fishes in Lake Tahoe and the effects of shoreline structures. North American Journal of Fisheries Management 14:385-394.

Beckstrom-Sternberg, S. M., D. E. Moerman, and J. A. Duke. 1995a. The Medicinal Plants of native America Database. http://probe.nalusda.gov:8300/cgi-bin/ browse/mpnadb (ACEDB version 4.3 – data version June 1995a).

_______. 1995b. The Foodplant Database. http://probe.nalusda.gov:8300/cgi-bin/browse/foodplantdb (ACEDB version 4.3 – data version June 1995b).

Begon, M., J. L. Harper, and C. R. Townsend. 1990, 2nd ed. Ecology: Individuals, populations, and communities. Blackwell Scientific Publications, Boston, Massachusetts.

Benoit, L. 1997. Tahoe Regional Planning Agency Memo August, 29, 1997: "Tall Whitetop" Alert. Zephyr Cove, Nevada.

Bezzone, D. 1999. Personal communication. California Department of Fish and Game. Sacramento, California.

Biswell, H. H. 1958. Prescribed burning in Georgia and California compared. Journal of Range Management 11:293-298.

Blackburn, T. and K. Anderson, eds. 1993. Before the Wilderness: Environmental Management by Native Californians. Ballene Press, Menlo Park, California.

Blonski, K. S., and J. L. Schramel. 1981. Photo series for quantifying natural forest residues: southern Cascades and northern Sierra Nevada. National Wildfire Coordinating Grop, GTR PSW-56, Berkeley, California.

Bonnicksen, T. M., and E. C. Stone. 1982. Reconstruction of a presettlement giant sequoia–mixed conifer forest community using the aggregation approach. Ecology 63 (4): 1134–48.

Borror, D. J. and R. E. White. 1970. A field guide to insects: America north of Mexico. Houghton Mifflin Company, Boston, MA.

Botkin, D. B. 1990. Discordant harmonies: a new ecology for the twenty-first century. Oxford University Press, New York, New York.

Bouldin, J. R. 1999. Twentieth-century changes in forests of the Sierra Nevada. Doctoral dissertation, University of California, Davis.

Bradford, D. F. 1989. Allotopic distribution of native frogs and introduced fishes in high Sierra Nevada lakes of California: implication of the negative effect of fish introductions. Copeia 1989(3):775-778.

Brittingham, M. C., and S. A. Temple. 1983. Have cowbirds caused forest songbirds to decline? Bioscience 33:31-35.

Brown, J. H. 1995. Macroecology. The University of Chicago Press, Chicago, IL.

Brown, J. H. and A. C. Gibson. 1983. Biogegraphy. C.V Mosby Co., St. Louis, MO. 643 pp.

Burbridge, A. A., and N. L. McKenzie. 1989. Patterns in the modern decline of western Australia's vertebrate fauna: causes and conservation implications. Biological conservation 50:143-198.

Burns, R. M., and B. H. Honkala (eds.). 1990. Silvics of North America: 1. Conifers. USDA Forest Service, Agricultural Handbook 654, Washington, DC.

Burt, W. H., and R. P. Grossenheider. 1980. A field guide to the mammals, third edition. Houghton Mifflin Company, Boston, MA.

Butt, A. 1999. Personal communication. University of Nevada, Reno, NV.

Caduto, M. J. 1990. Pond and brook: a guide to nature in freshwater environments. University Press of New England, Hanover.

Carlquist, S. 1965. Island life. Natural History Press, Garden City, N.Y.

Carpenter, S. R., J. F. Kitchell, and J. R. Hodgson. 1985. Cascading trophic interactions and lake productivity. Bioscience 35:634-649.

CDFG. 1957. A report on Lake Tahoe and its tributaries: fisheries management vs. trial and error. California Department of Fish and Game. Sacramento, California.

_______. 1998a. California wildlife habitat relationships program database, version 6.0. California Department of Fish and Game, Sacramento, California.

_______. 1998b. California hunting regulations. California Department of Fish and Game, Sacramento, California.

_______. 1999. Rarefind database. California Department of Fish and Game, Sacramento, California.

Cecchettini, R. Personal communication. El Dorado County Animal Control, South Lake Tahoe, California.

Chang, C. 1996. Ecosystem responses to fire and variations in fire regime. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis.

Chatfield, K. 1997. Medicine from the mountains: medicinal plants of the Sierra Nevada. Range of Light Publications, S. Lake Tahoe, California.

Clark, J. L. 1992. California wildlife viewing guide. Falcon Press, Helena, Montana.

Cody, M. L. 1986. Diversity, rarity and conservation in Mediterranean-climate regions. In Soule, M. E., ed. Conservation Biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, MA.

Cole, D. N., and P. B. Landres. 1995. Indirect effects of recreationists on wildlife. Pages 183-202 in Knight, R. L., and K. J. Gutzwiller. Wildlife and recreationists. Island Press, Washington, DC.

Cordone, A. J. 1999. Personal communication. Biologist, Retired from California Department of Fish and Game, Sacramento, California, March 11, 1999.

Cordone, A. J., S. J. Nicola, P. H. Baker, and T. C. Frantz. 1971. The kokanee salmon in Lake Tahoe. California Fish and Game, 57(1):28-43.

Countryman, C. C. 1955. Old-growth conversion also converts fire climate. *In* Proceedings of Society of American Foresters Annual Meeting, 158–60. Portland, Oregon: Society of American Foresters.

Cryer, D. H., and J. E. Murray. 1992. Aspen regeneration in soils. Rangelands 14(4):223-226.

d'Azevedo, L. 1986. Washoe, pp 466-498 in: L. d'Azevedo (ed.), Handbook of North American Indians, vol. 11, Great Basin. Smithsonian Institution, Washington, DC.

Dale, J. W. (ed.). 1996. California forest health in 1994 and 1995. USDA Forest Service, PSW Regional Report R5-FPM-PR-002, Albany, California.

Daly, C. 1995. US monthly precipitation, 1961-90 base period. Oregon State Univ., Corvallis, Oregon. (Digital map layer).

Daly, C. and G. L. Johnson. 1999. PRISM spatial climate layers: their development and use. Short Course on Topics in Applied Climatology, 79th Annual Meeting of the American Meteorological Society, 10-15 January, Dallas, TX. 49 pp. http://www.ocs.orst.edu/prism/prisguid.pdf.

Daly, C., G. Taylor, and W. Gibson, 1997, The PRISM Approach to Mapping Precipitation and Temperature, 10th Conf. on Applied Climatology, Reno, NV, American Meteorological Society, 10-12.

Daly, C., R. P. Neilson, and D. L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology, 33:140-158.

Davis, F. W., and D. M. Stoms. 1996. Sierran vegetation: a gap analysis. Pages 671-689 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Davis, F. W., D. M. Stoms, R. L. Church, W. J. Okin, and K. N. Johnson. 1996. Selecting biodiversity management areas. Pages 1503-1528 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Davis, O. K. 1997. Pollen analysis of a mid-lake core from Lake Tahoe, California: historic vegetation change. Appendix 7.2 *In* D. L. Elliott-Fisk, R. A. Rowntree, T. A. Cahill, C. R. Goldman, G. Gruell, R. Harris, D. Leisz, S. Lindström, R. Kattleman, D. Machida, R. Lacey, P. Rucks, D. A. Sharkey, and D. S. Ziegler. 1997. Lake Tahoe Case Study. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, Addendum. University of California, Centers for Water and Wildland Resources, Davis.

DeByle, N. V., and J. C. Zasada. 1980. Aspen. Pages 96-97. *In:* F. H. Eyre (ed.). Forest cover types of the United States and Canada. Soc. Amer. Foresters, Washington, DC.

Dennis, A. 1995. Calflora computerized database. USDA Forest Service, Pacific Southwest Station, Albany, California.

Derrig, M. 1999. Personal communication. Hydrologist, USDA Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, California.

Desjardin, D. E., 1997. Spring Fungi of the Sierra Nevada. Department of Biology, San Francisco State University, San Francisco, California.

Diamond, J. 1989. Overview of recent extinctions. Pages 37-41 in D. Western and M. Pearl, eds. Conservation for the twenty-first century. Oxford University Press, New York.

Diamond, J. M., K. D. Bishop, and S. Van Balen. 1987. Bird survival in an isolated Javan woodland: island or mirror? Conservation biology 1(2):132-142.

Downs, J. F. 1966. The two worlds of the Washo. Holt, Rinehart, and Winston. New York, New York.

Drost, C. A. and G. M. Fellers. 1996. Collapse of a regional frog fauna in the Yosemite area of the California Sierra Nevada, USA. Conservation biology 10(2):414-425.

Dunn, J. L., and K. L. Garrett. 1997. A field guide to the warblers of North America. Houghton Mifflin Company, Boston.

Eastern Sierra Interpretive Association. No date, ca. 1993. Birds of the Lake Tahoe basin. Pamphlet published in cooperation with USDA Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, California.

Edlund, E. G., and R. Byrne. 1990. Climate, fire, and late Quaternary vegetation change in the central Sierra Nevada. *In* S. C. Nodvin, and T. A. Waldrop (tech cords.), Fire and the Environment: Ecological and Cultural Perspectives. pp. 390-396. USDA For. Serv. Gen. Tech. Rep. SE-69. Asheville, South Carolina.

Ehrlich, P. R., D. S. Dobkin, and D. Wheye. 1988. The birder's handbook: a field guide to the natural history of North American birds. Simon and Schuster, Inc., New York.

Elliott-Fisk, D. L., T. C. Cahill, O. K. Davis, L. Duan, C. R. Goldman, G. E. Gruell, R. Harris, R. Kattelmann, R. Lacey, D. Leisz, S. Lindström, D. Machida, R. A. Rowntree, P. Rucks, D. A. Sharkey, S. L. Stephens, and D. S. Ziegler. 1997. Lake Tahoe case study. Pages 217-276 in Sierra Nevada Ecosystem Project: Final Report to Congress, Addendum. Wildland Resource Center Report No. 40, University of California, Davis.

Elton, C. S. 1958. The ecology of invasions by animals and plants. Methuen & Co Ltd, London.

Engeman, R. M., R. T. Sugihara, L. F. Pank, and W. E. Dusenberry. 1994. A comparison of plotless density estimators using Monte Carlo simulation. Ecology 75:1769-1779.

Erman, N. A. 1996. Status of aquatic invertebrates. Pages 987-1008 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

ESRI. 1994. ARC/INFO GRID version 7 user manual. Environmental Systems Research Institute, Inc., Redlands, California.

_______. 1998. Arc-Info, version 7.2. Environmental Systems Research, Inc. Redlands, California.

FEMAT. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team (FEMAT). 1993-793-071. Washington, DC.: GPO.

Ferguson, S. 1999. Personal communication. Regional Water Quality Control Board, South Lake Tahoe, California.

Ferrell, G. T. 1996. The influence of insect pests and pathogens on Sierra forests. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis.

Ferrell, G. T., W. J. Otrosina, and C. J. Demars, Jr. 1994. Predicting susceptibility of white fir during a drought-associated outbreak of the fir engraver, *Scolytus ventralis*, in California. Canadian Journal of Forest Research 24:402-305.

Filip, G. M., and D. J. Goheen. 1982. Tree mortality caused by root pathogen complexes in Deschutes National Forest, Oregon. Plant Dis. 66:240-243.

Finney, M. A. 1998. FARSITE fire area simulator. Missoula, Montana: Systems for Environmental Management.

_______. 1999. FLAMMAP. Missoula, Montana. Systems for Environmental Management.

Fites-Kaufman, J. A. 1997. Historic landscape pattern and process: fire, vegetation, and environment interactions in the northern Sierra Nevada. Doctoral dissertation. University of Washington.

Foster, M. 1993. Information and Thoughts on the Forest (Eldorado NF) Mushroom Policy, Unpublished document on file with the Eldorado National Forest.

Frankel, O. H., and M. E. Soule. 1981. Conservation and evolution. Cambridge University Press, Cambridge, Massachusetts.

Franklin, J. F., and J. A. Fites-Kaufman. 1996. Assessment of late-successional forests of the Sierra Nevada, pp 627-661. *In* SNEP Science Team, Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Centers for Water and Wildland Resources, University of California, Davis.

Frantz, T. C., and A. J. Cordone. 1966. A Preliminary Checklist of Invertebrates Collected from Lake Tahoe, 1961-1964. Biological Society of Nevada Occasional Papers, No. 8.

_______. 1967. Observations on deepwater plants in Lake Tahoe, California and Nevada. Ecology 48(5): 709-714.

_______. 1996. Observations on the Macrobenthos of Lake Tahoe, California-Nevada. California Fish and Game 82(1): 1-41.

FUNET. 1999. All (in this database) Other insects list (scientific names). Web Site: http://www.funet.fi/pub/sci/bio/life/warp/insects-list.html Finnish University and Research Network, Finnland.

Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. USDA Forest Service, Misc. Pub. No. 1339, Washington, DC.

Gardner, J. V., L. A. Mayer, and J. Hughes-Clark. 1998. The bathymetry of Lake Tahoe, California-Nevada; USGS Open-File Report 98-509.

Gaston, K. J. 1994. Rarity. Chapman & Hall, London.

Gentry, A. H. 1986. Endemism in tropical versus temperate plant communities. In Soule, M. E., ed. Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, MA.

_______. 1992. Tropical forest biodiversity: Distributional patterns and their conservation significance. Oikos 63:19-28.

Gerstung, E. R. 1988. Status, life history, and management of the Lahontan cutthroat trout. American Fisheries Society symposium 4:93-106.

Given, D. R., and D. A. Norton. 1993. A multivariate approach to assessing threat and for priority setting in threatened species conservation. Biological Conservation 64: 57-66.

Goldman, C. R. 1989. Lake Tahoe: preserving a fragile ecosystem. Environment 31(7):7-31.

Goldman, C. R., M. D. Morgan, S. T. Threlkeld, and N. Angeli. 1979. A population dynamics analysis of the Cladoceran disappearance from Lake Tahoe, California-Nevada. Limnology and oceanography 24(2):289-297.

Goodman, D. 1996. Princeton University biology Library Super Taxa for Biological Abstracts and Zoological Record. Princeton University Web Site: http://www.princeton.edu/~biolib/instruct/supertaxa.html, Princeton, New Jersey.

Graber, D. M. 1996. Status of terrestrial vertebrates. Pages 709-734 in Sierra Nevada Ecosystem Project: final report to Congress, Vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Graumlich, L. J. 1993. A 1000-year record of temperature and precipitation in the Sierra Nevada. Quat. Res. 39:249-255.

Greenway, S. H. 1990. Aspen regeneration: a range management problem. Rangelands 12(1):21-23.

Grinnell, J. 1933. Review of the recent mammal fauna of California. University of California publications in zoology 40(2):71-234.

Grinnell, J., J. S. Dixon, and J. M. Lindsdale. 1937. Fur-bearing mammals of California: their natural history, systematic status, and relations to man, Vols. I and II. University of California Press, Berkeley, California.

Hale, M. E. and M. Cole. 1988. Lichens of California. University of California Press, Berkeley, California.

Hall, E. R. 1995. Mammals of Nevada, 2nd ed. University of California Press, Berkeley, California.

Hall, R. In prep. Deep-water plants of Lake Tahoe. U. S. Environmental Protection Agency, San Francisco, California.

Hampton, A. M. 1988. Altitudinal Range and Habitat of Triclads in Streams of the Lake Tahoe Basin. The American Midland Naturalist, 120(2): 302-312.

Hansen, E. M., and Lewis (eds.). 1997. Compendium of conifer diseases. American Phytopathological Society, St. Paul, Minnesota.

Hanson, L. 1999. Personal communication. USDA Forest Service, Plumas National Forest, Oroville, California.

Hanson, T. and E. B. Walker. 1999. Spider Mites on Conifers Oligonychus ununguis (Jacobi). Bugwood Publications No. 98-104. Web Site: http://www.bugwood.caes.uga.edu/vermont/html/spider_mites_on_conifers.html The Entomology and Forest Resources Digital Information Work Group. University of Georgia. Tifton, Georgia.

Harper, J. L. 1981. The meanings of rarity. Pages 189-203 in Synge, H., ed. The biological aspects of rare plant conservation. Wiley, New York.

Hawkins, C . P., J. L. Kershner, P. A. Bisson, M. D. Bryant, L. M. Decker, S. V. Gregory, D. A. McCullough, C. K. Overton, G. H. Reeves, R. J. Steedman, and M. K. Young. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 18(6):3-10.

Hayes, M. P. and M. R. Jennings. 1986. Decline of ranid frog species in western North America: are bullfrogs (*Rana catesbeiana*) responsible? Journal of herpetology 20(4):490-509.

Heyvaert, A. C. 1998. The biogeochemistry and paleolimnology of sediments from Lake

Tahoe, California-Nevada. Ph.D. dissertation, University of California, Davis, California.

Hickman, J. C., ed. 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley, California.

Hill, D. J. 1972. Maidu Use of Native Flora and Fauna. Unpublished.

Hogg, R. B., and E. A. Tanis. Probability and statistical inference, 2nd ed. MacMillan Publishers Co., Inc., New York, NY.

Hunsaker, C. T., J. D. Christman, A. B. Coley, and M. A. Kane. In prep. Ecological sustainability, part 1: issue paper and literature review. U.S. Environmental Protection Agency.

Husari, Sue. 1999. Personal communciation. Assistant Director of Fire, USFS Pacific Southwest Region.

Insera, V. 1999. Personal communication. California-Tahoe Conservancy, South Lake Tahoe, California.

James, G. W. 1915. The Lake of the sky. J. F. Tapley Co., New York.

James, J. W. 1971. Climate and air quality of the Lake Tahoe region, a guide to planning. USDA Forest Service and Tahoe Regional Planning Agency, South Lake Tahoe, California.

Jameson, Jr., E. W., and H. J. Peeters. 1988. California mammals. University of California Press, Berkeley, California.

Jennings, M. R. 1996. Status of amphibians. Pages 921-944 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Jennings, M. R. and M. P. Hayes. 1994. Amphibian and reptile species of special concern in California. California Department of Fish and Game, Rancho Cordova, California.

Johnsgard, P. 1988. North American owls. Smithsonian Institute Press, Washington, D. C.

Johnson, C. 1995. Forest inventory and analysis user's guide. USDA Forest Service, Region 5, San Francisco, California.

Johnson, K. 1999. Personal communication. Tahoe Regional Planning Agency, Zephyr Cove, NV.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental management 5:55-68.

Karron, J. D. 1997. Genetic consequences of different patterns of distribution and abundance. Pages 174-189 in Kunin, W. E., and K. J. Gaston, eds. The biology of rarity: causes and consequences of rare-common differences. Chapman & Hall, London.

Kattan, G. H. 1992. Rarity and vulnerability: the birds of the Cordillera Central of Colombia. Conservation biology 6(1):64-70.

Kattleman, R. 1996. Hydrology and water resources. Pages 855-920 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Keane, J. J. and M. L. Morrison. 1994. Wildlife inventory and habitat relationships in the Lake Tahoe region, 1991-1993. Unpublished final report. California Department of Parks and Recreation, Tahoe City, California.

Keane, J. J. and W. J. Zielinski. In prep. Prioritizing species for conservation in the Sierra Nevada. USDA Forest Service, Pacific Southwest Region, Sonora, California.

Keetch, J. J., and G. M. Byram. 1968. A drought index for forest fire control. Research Paper, SE-38. Asheville, North Carolina: USDA Forest Service, Southeast Forest Experiment Station.

Kilgore, K. J., R. P. Morgan II, and N. B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. North American journal of fisheries management 9:101-111.

Kimsey, L. S. Status of terrestrial insects. Pages 735-742 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Kirkpatrick, J. B. 1983. An iterative method for establishing priorities for the selection of nature reserves: An example from Tasmania. Biological Conservation 25:127-134.

Kittel, T. G. F. 1998. Effects of climatic variability on herbaceous phenology and observed species richness in temperate montane habitats, Lake Tahoe basin, Nevada. Madrono 45:75-84.

Kondolf, G. M., R. Kattelmann, M. Embury, and D. C. Erman. 1996. Status of riparian habitat. Pages 1009-1030 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Kramer, G. 1988. Fresh emergent wetland. Pages 124-125 in Mayer, K. E., W. F. Laudenslayer, Jr., eds. A guide to wildlife habitats of California. California Department of Forestry and Fire Protection, Sacramento, California.

Krebs, C. J. 1978. Ecology: the experimental analysis of distribution and abundance. Harper & Row, New York, NY.

LaLande, J. 1993. Ethnobotanical List for Indians of Southern Oregon. Rogue River National Forest. USDA Forest Service. (note on lisitng – a partial, very incomplete list of major plants used by local native groups)

Landauer, L. B. 1995. The mountain sea. Flying Cloud Press, HI.

Lehr, S. 1999. Personal communication. California Department of Fish and Game, Sacramento, California.

Leiberg, J. R. 1902. Forest conditions in the northern Sierra Nevada, California. US Geological Survey, Professional Paper No. 8, Series H, Forestry, 5. Government Printing Office, Washington, DC.

Leopold, A. 1933. Game management. Charles Scribners Sons, New York, NY.

Levin, S. A. 1992. The problem of pattern and scale in ecology. Ecology 73:1943-1967.

Leyse, K. 1999. Personal communication. Section of Evolution and Ecology, University of California, Davis, California.

Lindström, S., and S. Waechter. 1995. North shore ecosystems project heritage resource inventory, Nevada area. Prepared for EA Engineering, Science, and Technology, Inc., by Far Western Anthropological Research Group, Davis, California.

_______. 1996. North shore ecosystems project heritage resource inventory, California area. Prepared for EA Engineering, Science, and Technology, Inc., by Far Western Anthropological Research Group, Davis, California.

Loeb, S. L. and S. H. Hackley. 1988. The distribution of submerged macrophytes in Lake Tahoe, California and Nevada, and the possible influence of groundwater seepage. Internationale Vereingung fur theoretische aund angewandte Limnologie Verhandlungen 23:1927-1933.

Ludwig, J. A., and J. F. Reynolds. 1988. Statistical ecology. Wiley Interscience, New York, New York.

Lugo, A. E. 1994. Maintaining an open mind on exotic species. In: Meffe, G. K. and C. R. Carroll. Principles of Conservation Biology. Sinauer Associates, Sunderland, MA

MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Monographs in population biology no. 1. Princeton University Press, Princeton, NJ.

MacNally, R., and A. F. Bennett. 1997. Species-specific predictions of the impact of habitat fragmentation: local extinction of birds in the box-ironbark forests of central Victoria, Australia. Biological conservation 82(2):147-155.

Major, J., and D. W. Taylor. 1988. Sierra Nevada. *In* M. G. Barbour and J. Major (eds.), Terrestrial vegetation of California, 2nd ed. California Native Plant Society, Sacramento, California.

Mangum, F. A. 1997. Aquatic Ecosystem Inventory Macroinvertebrate Analysis. USDA Forest Service, Pacific Southwest Region, Eldorado National Forest, Placerville, California.

Manley, P. 1997. Progress report, Sierran provinces assessment and monitoring team. USDA Forest Service, PSW, Albany, California.

Manley, P. N., and M. D. Schlesinger. In preparation. Riparian-associated biota of the Lake Tahoe basin. USDA Forest Service, Pacific Southwest Region, South Lake Tahoe, California.

Manley, P. N., W. J. Zielinski, C. M. Stuart, J. J. Keane, A. J. Lind, C. Brown, B. L. Plymale, and C. O. Napper. In press. Monitoring ecosystems in the Sierra Nevada: The Conceptual Model Foundation. J. Environ. Monit. and Assessment.

Manley, P., and C. Davidson. 1993. Assessing risks and setting priorities for neotropical migratory birds in California. Unpublished manuscript. USDA Forest Service, Pacific Southwest Region, Vallejo, California.

Manor, S. 1999. Optimizing the monitoring of geographic distribution of vertebrates in the Sierra Nevada. Unpublished manuscript. USDA Forest Service, Pacific Southwest Station, Arcata, California.

Margules, C. and M. B. Usher. 1981. Criteria used in assessing wildlife conservation potential: A review. Biol. Conservation 24:115-128.

Margules, C. R., A. O. Nicholls, and R. L. Pressey. 1988. Selecting networks of reserves to maximise biological diversity. Biological Conservation 43:63-76.

Mayer, K. E. and W. F. Laudenslayer, Jr. 1988. A guide to wildlife habitats of California. California Department of Fish and Game, Rancho Cordova, California.

McKelvey K. S., and K. K. Busse. 1996. Twentieth-century fire patterns on Forest Service lands. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis.

McKelvey, K. S. and J. D. Johnston. 1992. Historical perspectives on forests of the Sierra Nevada and Transverse Ranges of southern California: forest conditions at the turn of the century. Pages 225-246 in J. Verner, K. S. McKelvey, B. R. Noon, R. J. Gutierrez, G. I. Gould, Jr., and T. W. Beck. The California spotted owl: a technical assessment of its current status. USDA For. Serv. Gen. Tech. Rept. PSW-GTR-133. USDA Forest Service, Pacific Southwest Station, Albany, California.

Meffe, G. K., and C. R. Carroll. 1994. Principles of Conservation Biology. Sinauer Associates, Sunderland, Massachusetts.

Millar, C. I., and W. B. Woolfenden. 1999. The role of climate change in interpreting historic variability. Ecol. Appl.

Millar, C. I. 1997. Comments on historical variation and desired condition as tools for terrestrial landscape analysis, pp 105-131. *In* S. Sommarstrom (ed.), Proceedings of the sixth watershed management conference, Centers for Water and Wildland Resources Report No. 92, University of California, Davis.

Millar, C. I., M. Barbour, D. L. Elliott-Fisk, J. R. Shevock, and W. B. Woolfenden. 1996. Significant natural areas. Pages 839-853 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Miller, C., and D. L. Urban. 1999. Forest pattern, fire, and climatic change in the Sierra Nevada. Ecosystems 2: 76-87.

Miller, R. G. 1951. The natural history of Lake Tahoe fishes. Ph.D. Dissertation, Stanford University, Palo Alto, California.

Millsap, B. A., J. A. Gore, D. E. Runde, and S. I. Cerulean. 1990. Setting priorities for the conservation of fish and wildlife species in Florida. Wildlife Monographs 111: 1-57.

Milne, L. and M. Milne. 1988. The Audubon Society Field Guide to North American Insects and Spiders. Alfred A. Knopf, New York.

Minnich, R. A. 1986. Snow levels and amounts in the mountains of southern California. Journal of Hydrology 89:37-58.

Minnich, R. A., M. G. Barabour, J. H. Burk, and J. Sosa-Ramirez. 2000. Californian mixed-conifer forests under unmanaged fire regimes in the Sierra San Pedro Martir, Baja California, Mexico. Journal of Biogeography (in press).

Minnich, R. A., M. G. Barbour, J. H. Burk, and R. F. Fernau. 1995. Sixty years of change in California conifer forests of the San Bernardino Mountains. Cons. Biol. 9:902-914.

Montgomery, D. R. and J. M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Washington State Timber/Fish/Wildlife Agreement Report TFW-SH110-93-002, Seattle, WA.

Morey, S. 1988. Bullfrog. Pages 92-93 in Zeiner, D. C., W. F. Laudenslayer, Jr., and K. E. Mayer, eds. California's wildlife, Vol. I: amphibians and reptiles. California Department of Fish and Game, Sacramento, California.

Moyle, P. B. 1976. Inland fishes of California. Universtiy of California Press, Berkeley, California.

Moyle, P. B. 1996. Status of aquatic habitat types. Pages 945-952 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Moyle, P. B., and J. P. Ellison. 1991. A conservation-oriented classification system for the inland waters of California. California fish and game 77:161-180.

Moyle, P. B., R. M. Yoshiyama, and R. A. Knapp. 1996. Status of fish and fisheries. Pages 953-973 in Sierra Nevada Ecosystem Project: final report to Congress, vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. Wiley, New York, New York.

Munz, Philip A. 1968. A California Flora and Supplement. University of California Press. Berkeley and Los Angeles, California; London, England.

Nachlinger, J. L., and N. H. Berg. 1988. Snowpack-vegetation dynamics: mountain hemlocks in the Lake Tahoe area. Western Snow Conference Proceedings:23-34. USDA Forest Service, Kalispell, Montana.

NAMC. 1999. List of taxa found in 90 samples collected within the Lake Tahoe basin; List of all taxa found in 1,135 samples collected in the Sierra Nevada Ecoregion (Olmernik Ecoregion definition). Data query. National Aquatic Monitoring Center, Department of Fisheries and Wildlife, Utah State University, Logan, Utah.

NCSS. 1995. Number cruncher statistical software, version 6.0.12.

NDOW. 1998. General hunting information. Nevada Division of Wildlife, Reno, NV.

Nevers, J. A. 1976. Washeshu. Inter-tribal Council, Reno, Nevada and University of Utah Printing Service, Salt Lake City, Utah.

North. 1998. Personal communication. Research Ecologist, USFS Pacifc Southwest Research Station.

Norton, B. G. 1992. A new paradigm for environmental management. *In* R. Costanza, B. G. Norton, and B. D. Haskell (eds.), Ecosystem health, new goals for environmental management, Island Press, Washington, DC.

Norusis, M. J. 1996. SPSS Statistics 7.0. SPSS inc., Chicago, Illinois.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation biology 4:355-364.

Noss, R. F. and A. Y. Cooperider. 1994. Saving nature's legacy. Island Press, Washington D.C.

Nott, M. P., and S. L. Pimm. 1997. The evaluation of biodiversity as a target for conservation. In Pickett, S. T. A., R. S. Ostfeld, M. Shachak and G. E. Likens, eds. The ecological basis of conservation. Chapman and Hall, London.

Orr, R. T. 1949. Mammals of Lake Tahoe. California Academy of Sciences. San Francisco, California.

Orr, R. T. and J. Moffitt. 1971. Birds of the Lake Tahoe Region. California Academy of Sciences. San Francisco, California.

Paine, R. T. 1980. Food webs: linkage, interaction strength and community infrastructure. Journal of animal ecology 49:667-685.

Palmer, R., ed. 1962. Handbook of north American birds. Volumes 1-5. Yale University Press, New Haven, Connecticut.

Parsons, S. 1999. Personal communication. USDA Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, California.

Pasitschniak-Arts, M. 1993. Mammalian Species, No. 439, Ursus arctos. American Society of Mammalogists.

Patronek, G. J. 1998. Free-roaming and feral cats—their impact on wildlife and human beings. JAVMA 212(2):218-226.

Pennak, Robert W. 1978. Fresh-water Invertebrates of the United States. A Whiley-Interscience Publication, New York

Pepi, J. 1999. Personal communication. Senior Planner, Tahoe Regional Planning Agency, Zephyr Cove, NV.

Perring, F. H., and L. Farrell. 1983. British red data books: 1. vascular plants (2nd ed.). RSNC, London.

Pickett, S. T. A., and P. S. White. 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, San Diego California

Pierson, E. D. 1998. Heavenly Valley Ski Resort - bat habitat survey. Unpublished report. Harland Bartholomew and Associates, Sacramento, California.

Poole, A. F., P. Stettenheim, and F. B. Gill, editors. 1992. The birds of north America. Volumes 1-7. The American Ornithologists Union and the Academy of Natural Sciences of Philadelphia, Washington, D. C. and Philadelphia, Pennsylvania.

Powell, J. A., and C. L. Hogue. 1979. California Insects. University of California Press, Berkeley and Los Angeles, California.

Power, M. E. 1990. Effects of fish in river food webs. Science 250:811-814.

Power, M. E., M. S. Parker, and J. T. Wootton. 1996. Disturbance and food chain length in rivers. Pages 286-297 in Polis, G. A., and K. O. Winemiller, eds. Food webs: integration of patterns & dynamics. Chapman and Hall, New York.

Power, M. E., W. J. Matthews, and A. J. Stewart. 1985. Grazing minnows, piscivorous bass, and stream algae: dynamics of a strong interaction. Ecology 66:1448-1456.

Primack, R. B. 1993. Essentials of conservation biology. Sinauer Associates, Inc., Sunderland, MA.

Rabinowitz, D. 1981. Seven forms of rarity. pp. 205-217 in H. Synge, ed. The biological aspects of rare plant conservation. John Wiley & Sons Ltd., New York, NY.

Rahn, M. 1999. Personal communication. Department of Biology, University of Nevada, Reno, NV.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. Handbook of field methods for monitoring landbirds. Gen. Tech. Rep. PSW-GTR-144. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, California.

Ratliff, R. D. 1985. Meadows in the Sierra Nevada of California: state of knowledge. Gen. Tech. Rep. PSW-84. USDA Forest Service, Pacific Southwest Experiment Station, Berkeley, California.

Raymond, C. E. 1992. A place one never tires of. *In* Stopping time: a rephotographic survey of Lake Tahoe, edited by P. Goin, pp. 11-26. Albuquerque: University of New Mexico Press.

Reed, J. M. 1995. Relative vulnerability to extirpation of montane breeding birds in the Great Basin. Great Basin naturalist 55(4):342-351.

Reed, S. B. 1981. Peregine Falcon nesting habitat management and reintroduction plan for the Lake Tahoe Basin Management Unit. USDA Forest Service, South Lake Tahoe, California.

Reiner, J. 1999. Personal communication. USDA Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, California.

Reveal, J. L. 1981. The concepts of rarity and population threats in plant communities. Pages 41-46 in Morse, L. E., and M. S. Henefin, eds. Rare plant conservation. The New York Botanical Garden, Bronx, NY.

Richardson, R. 1999. Plant Kingdom Characteristics. Lecture Notes Web Site: http://scidiv.bcc.ctc.edu/rkr/botany/lectures/plantkingchar.html, Bellevue Community College, S.E. Bellevue, Washington.

Rodriguez, D. 1999. Personal communication. Forest Botanist, Eldorado National Forest., March 4, 1999.

Rogers, J. H. 1974. Soil survey of the Tahoe Basin area, California and Nevada. USDA Soil Conservation Service, Washington, DC.

Rosenzweig, M. L. 1995. Species diversity in space and time. Cambridge University Press, Cambridge, MA.

Rosgen, D. 1995. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Rowe, T. G., and J. C. Stone. 1997. Selected hydrologic features of the Lake Tahoe basin, California and Nevada. USDI Geologic Survey, Open-file report 97-384. Carson City, Nevada.

Royce, E. B. 1997. Xeric effects on the distribution of conifer species in a southern Sierra Nevada ecotone. Doctoral dissertation, University of California, Davis.

Rucks, P. 1999. "Washoe Cultural Plants" in progress. Unpublished.

Ruggiero, L. F., K. B. Aubry, S. W. Buskirk, L. J. Lyon, and W. J. Zielinski, technical editors. 1994. The scientific basis for conserving forest carnivores: American marten, fisher, lynx and wolverine in the western United States. General Technical Report RM-254. U.S. Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado.

Rundel, P. W., D. J. Parsons, and D. T. Gordon. 1988. Montane and subalpine vegetation of the Sierra Nevada and Cascade Ranges. *In* M. G. Barbour and J. Major (eds.), Terrestrial Vegetation of California: pp. 559-599. Calif. Native Plant Society, Sacramento, California.

Russell, W. H., J. McBride, and R. Rowntree. 1998. Revegetation after four stand-replacing fires in the Lake Tahoe basin. Madrono 45:40-46.

Ryan, B. 1990. Lichen collection from study of air quality in the Desolation Wilderness. Unpublished report and resident collection. U.S. Forest Service, South Lake Tahoe, California.

Savage, M. 1997. The role of anthropogenic influences in a mixed-conifer forest mortality episode. Journal of Vegetation Science 8:95-104.

Sawyer, J. O. and T. Keeler-Wolf. 1995. A manual of California vegetation. California Native Plant Society, Sacramento, California.

Scharf, R. F. 1993. Diseases of Pacific Coast conifers. USDA Forest Service, Agriculture Handbook 521, Washington, DC.

Schluter, D. and R. E. Ricklefs. 1993. Species diversity: an introduction to the problem. *In* Pages 147-158 R. E. Ricklefs and D. Schluter, eds. Species diversity in ecological communities: historical and geographical perspectives. Univ. Chicago Press, Chicago, IL.

Schoener, T. W. 1987. The geographical distribution of rarity. Oecologia 74:161-173.

Schwind, B. 1998. Lake Tahoe basin existing vegetation layer—accuracy assessment. Unpublished document. USDA Forest Service, Pacific Southwest Region, Vallejo, California.

Scott, E. B. 1957. The Saga of Lake Tahoe. Sierra-Tahoe Publishing Co., Pebble Beach, California.

Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, J. Anderson, S. Ciacco, F. D'Erchia, T. C. Edwards, J. Ulliman, and R. G. Wright. 1993. Gap analysis: a geographical approach to protection of biological diversity. Wildlife Monographs 123:1-41.

SFSU. 1999a. Species Checklist of the Order Lepidoptera from the Sierra Nevada Field Campus. San Francisco State University Web Site: http://thecity.sfsu.edu/snfc/lepidop.htm, San Francisco, California.

_______. 1999b. Species Checklist of Fungi from the Sierra Nevada Field Campus. San Francisco State University Web Site: http://thecity.sfsu.edu/snfc/fungus.htm, San Francisco, California.

Shevock, J. 1999. Personal communication. National Park Service, San Francisco, California.

Shevock, J. R. 1996. Status of rare and endemic plants. Pages 691-708 in Sierra Nevada Ecosystem Project: final report to Congress, Vol. II. Wildland Resources Center Report No. 37, University of California, Davis, California.

Shine, R., and R. L. Charnov. 1992. Patterns of survival, growth, and maturation in snakes and lizards. The American Naturalist 139:1257-1269.

Skinner, C. N., and C. Chang. 1996. Fire regimes, past and present. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis.

Skinner, M. W., and B. M. Pavlick. 1994. California Native Plant Society Inventory of Rare and Endangered Vascular Plants of California. Electronic version.

Smith, G. L. 1973. A flora of the Tahoe Basin and neighboring areas. Wasmann Journal of Biology 31(1):1-231 and the University of San Francisco Press, San Francisco, California.

_______. 1983. Supplement to a flora of the Tahoe basin and neighboring areas. Journal of Biology. University of San Francisco, San Francisco, California.

Smith, S. L., J. Dale, G. DeNitto, J. Marshall, and D. Owen. 1994. California forest health: past and present. USDA Forest Service, PSW, R5-FPM-PR-001, Albany, California.

SNEP Science Team. 1996. Sierra Nevada ecosystem project: final report to Congress, Centers for Water and Wildland Resources Report No. 40, University of California, Davis.

Solem, M. 1995. Fire history of the Caribou Wilderness, Lassen National Forest, California. Master's thesis, Pennsylvania State University.

Soule, M. E. and Simberloff. 1986. What do genetics and ecology tell us about the design of nature reserves? Biological Conservation 35:19-40.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment Terrestrial Technical Report. Report 5 of 5. USDA Forest Service, Southern Region, Atlanta, GA.

SPSS. 1993. SPSS professional statistics 6.1. SPSS, Inc., Chicago, IL.

_______. 1996. Statistical Package for Social Sciences. Version 6.0. SPSS Inc., Chicago, Illinois.

Stebbins, R. C. 1985. A field guide to western reptiles and amphibians. Houghton Mifflin Company, Boston, MA.

Stephens, S. L. 1998. Effects of fuels and silviculture treatments on potential fire behavior in mixed conifer forests of the Sierra Nevada, California. For. Ecol. & Mgt. 105:21-34.

Sterling, E. A. 1904. Report on the forest fire condition in the Lake Tahoe Region, California, June 1904. Report on file in the

Forestry Library, University of California, Berkeley.

Stevens, J. 1996. Applied multivariate statistics for the social sciences (third edition). Lawrence Erlbaum Assoc., Publishers, Mahwah, New Jersey.

Stine, S. 1996. Climate, 1650-1850. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis.

Storer, T. A. and R. L. Usinger. 1963. Sierra Nevada natural history. University of California Press, Berkeley, California.

Strong, D. H. 1984. Tahoe: an environmental history. University of Nebraska Press, Lincoln, Nebraska.

_______. 1999. Tahoe: from timber barons to ecologists. University of Nebraska Press. Lincoln, Nebraska.

Sudworth, G. B. 1900. Stanislaus and Lake Tahoe forest reserves, California, and adjacent territory. US Geological Survey, Part V, Forest Reserves, Washington, DC.

_______. 1967. Forest trees of the Pacific slope. Dover Press, New York, New York.

Sullivan, T. P., and D. S. Sullivan. 1982. Population dynamics and regulation of the Douglas squirrel (*Tamiasciurus douglasii*) with supplemental food. Oecologia 53:264-270.

Swetnam, T. W. 1993. Fire history and climate change in giant sequoia groves. Science 262:885-890.

Swetnam, T. W., and J. L. Betancourt. 1992. Fire-southern oscillation relations in southwestern United States. Science 249:1017-20.

Tatum, L. M. 1998a. Cave Rock bat survey. Unpublished report. USDA Forest Service, Humboldt-Toiyabe National Forest, Carson City, Nevada.

_______. 1998b. Addendum to Cave Rock bat survey. Unpublished report. USDA Forest Service, Humboldt-Toiyabe National Forest, Carson City, Nevada.

Taylor, A. H. 1993. Fire history and structure of red fir (*Abies magnifica*) forests, Swain Mountain Experimental Forest, Cascade Range, northeastern California. Can. J. For. Res. 23:1672-78.

_______. 1995. Fire history of the Caribou Wilderness, Lassen National Forest, California. Final Report, Cooperative Agreement PSW-006CA, USDA Forest Service, Pacific Southwest Research Station, Berkeley, California.

_______. 1996. Reconstruction of pre-Euroamerican forest structure, composition, and fire history in the Carson Range, Lake Tahoe Basin Management Unit. Interim Report, Cooperative Agreement 0024-California-95, USDA Forest Service, Pacific Southwest Research Station, Berkeley, California.

_______. 1998. Reconstruction of pre-Euroamerican forest structure, composition, and fire history in the Carson Range, Lake Tahoe Basin Management Unit. Final Report, Cooperative Agreement 0024-California-95, USDA Forest Service, Pacific Southwest Research Station, Berkeley, California.

Taylor, A. H., and C. B. Halpern. 1991. The structure and dynamics of *Abies magnifica* forests in the southern Cascade Range, USA. J. Veg. Sci. 2:189-200.

Taylor, M. 1999. Personal communication. Botanist, Eldorado National Forest, Placerville, California.

Terborgh, J. 1974. Preservation of natural diversity: the problem of extinction prone species. BioScience 24(12):715-722.

Terborgh, J., and B. Winter. 1983. A method for siting parks and reserves with special reference to Columbia and Ecuador. Biological Conservation 27:45-58.

Terrill, S. B. 1983. Woodpeckers. Page 220 in Farrand, J. Jr. The Audubon Society master guide to birding 2: gulls to dippers. Alfred A. Knopf, New York, New York.

TRPA and USDA. 1971a. Fisheries of Lake Tahoe and its tributary waters: a guide for planning. Unpublished report. Tahoe

Regional Planning Agency and USDA Forest Service, Zephyr Cove, Nevada.

_______. 1971b. Wildlife of the Lake Tahoe region: a guide for planning. Unpublished report. Tahoe Regional Planning Agency and USDA Forest Service, Zephyr Cove, Nevada.

TRPA. 1982. Environmental impact statement for the establishment of environmental threshold carrying capacities. Unpublished report. Tahoe Regional Planning Agency, Zephyr Cove, Nevada.

_______. 1986. Resolution of the governing body of the Tahoe Regional Planning Agency adopting environmental threshold carrying capacities for the Lake Tahoe region: Attachment C, resolution No. 82-11. TRPA, Goals and Policies, South Lake Tahoe, California.

_______. 1996. Draft – 1996 evaluation report: environmental threshold carrying capacities and the Regional Plan package for the Lake Tahoe region. Tahoe Regional Planning Agency. Zephyr Cove, Nevada.

UCB. 1999a. Mosses Represented in the UC Herbarium. The Mishler Laboratory, University of California, Berkeley Web Site: http://ucjeps.berkeley.edu/bryolab/Mossfolders.html, Berkeley, California.

_______. 1999b. Morphology of Fungi. Museum of Paleontology Web Site: http://www.ucmp.berkeley.edu/fungi/fungimm.html, University of California, Berkeley, California.

UCR. 1999. The Biology and Management of the Persea Mite, Oligonychus perseae Tuttle, Baker, and Abbatiello (Ascari: Tetranychidae). Web Site: http://www.biocontrol.ucr.edu/mite1.html University of California, Riverside, California.

Udvardy, M. D. F. 1969. Dynamic zoogeography. Van Nostrand Reinhold Company, New York, NY.

United States Forest Service. 1993. California spotted owl Sierran province interim guidelines environmental assessment. USDA Forest Service, San Francisco, California.

United States Park Service. 1992. [How to measure fuel and fire intensity. (look at NAC 180 report)]

Urie, S. 1999. Personal communication. Botanist, Tahoe National Forest, Nevada City, California.

USDA Committee of Scientists. 1999. Sustaining the people's lands: recommendations for stewardship of the National Forests and Grasslands into the next century. USDA Forest Service, Washingon, D.C.

USDA. 1988. Land and resource management plan: Lake Tahoe Basin Management Unit. Pacific Southwest Region, South Lake Tahoe, California.

_______. 1990. Riparian area management: what can remote sensing contribute? USDA Forest Service, Pacific Southwest Region, Vallejo, California.

_______. 1991. Existing vegetation. USDA Forest Service Remote Sensing Laboratory, Pacific Southwest Region, Rancho Cordova, California.

_______. 1995. Forest Service Manual 2080.5 (Effective date November 29, 1995). USDA Forest Service, Washington Office, Washington, D.C.

_______. 1995a. Region 5 Ecology program, unpublished data. USDA Forest Service, Pacific Southwest Region, Vallejo, California.

_______. 1995b. Forest Service Manual: Title 2080 - noxious weeds. USDA Forest Service, Washington, D.C.

_______. 1995c. Forest Service Manual: Title 2600 - wildlife, fish, and sensitive plant habitat management. USDA Forest Service, Washington, D.C.

_______. 1998a. Sierra Nevada science review. USDA Forest Service, Pacific Southwest Research Station, Berkeley, California.

_______. 1998b. Region Five Sensitive Species List (June 10, 1998 Revision). USDA Forest Service, Pacific Southwest Region, Vallejo, California.

________. 1999a. ITIS Hierarchical Report Report Based on Kingdom: Animalia: Mollusca Integrated Taxonomic Information System (ITIS) Web Site: http://www.marine.csiro.au/datacentre/taxonomy/itis-molluscs.htm

________. 1999b. Sierran All Species Information Database, Vol I. Unpublished database developed in support of the Sierra Nevada Framework for Conservation and Collaboration. USDA Forest Service, Pacific Southwest Region, Vallejo, California.

________. 1999c. Monitoring approach proposed for focal species. Unpublished document developed in support of the Sierra Nevada Framework for Conservation and Collaboration. USDA Forest Service, Pacific Southwest Region, Vallejo, California.

________. In preparation. Southern California Mountains and Foothills Assessment. USDA Forest Service, Pacific Southwest Region, Vallejo, California.

USFWS. 1999. Listed Species and Species of Concern that may occur in the Nevada portion of the Lake Tahoe Basin Management Unit. File No. 1-5-98-SP-076. USDI, Fish and Wildlife Service.

USGS. 1994. Development and documentation of spatial data bases for the Lake Tahoe basin, California and Nevada. U.S. Geological Survey water-resources investigations report 93-4182, Carson City, Nevada.

________. 1997. Federal Geographic Data Committee, Vegetation Subcommittee: Vegetation Classification Standards Appendix III; 10.3 Definitions, US Geological Survey Biological Resources Web Site: http://biology.usgs.gov/fgdc.veg/standards/appendix3.htm

________. 1999. Nonindigenous Aquatic Species; *Myriophyllum spicatum* L., US Geological Survey Biological Resources Web Site: http://nas.er.usgs.gov/nas/dicots/my_spica.html.

van Wagtendonk. 1998. Personal communciation, Research Forester, USDI and USGS Western Ecological Research Center

Van Zuuk, K. 1999. Personal communication. Tahoe National Forest, Nevada City, California.

Verner, J. 1988. Aspen. Pages 66-67 in Mayer, K. E., W. F. Laudenslayer, Jr., eds. A guide to wildlife habitats of California. California Department of Forestry and Fire Protection, Sacramento, California.

Verner, J. K. 1980. Bird communities of mixed conifer forests of the Sierra Nevada, pp 198-223. *In* Proceedings of the workshop, Management of western forests and grasslands for nongame birds, USDA Forest Service, GTR-INT-86.

Wallace, A. R. 1860. On zoological geography of the Malay Archipelago. J. Linn. Soc. London 4:172-184.

Weatherspoon, C. P. 1996. Fire-silviculture relationships in Sierra forests. *In* Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis.

Weatherspoon, C. P., and C. N. Skinner. 1999. Fire and fire surrogates: developing a standard experimental design and protocol for a national study of the consequences of fire and fire surrogate treatments. http:/ffs.psw.fs.fed.us. July 21, 1999.

White, P. S. and J. Harrod. 1997. Disturbance and diversity in a landscape context. In: Bissonette, J. A. ed. Wildlife and Landscape Ecology. Springer-Verlag, New York.

Whittaker, R. H. 1975. Communities and ecosystems, 2nd ed. Macmillan, New York.

Williams, G. R., and D. R. Given. 1981. The red data book of New Zealand: rare and endangered species of endemic terrestrial vertebrates and vascular plants. Nature Conservation Council, Wellington, New Zealand.

Wilson, C. L., and W. E. Loomis. 1967. Botany, fourth edition. Holt, Rinehart and Winston, New York, NY.

Worrall, J. J., and T. C. Harrington. 1988. Etiology of canopy gaps in spruce-fir forests at Crawford Notch, New Hampshire. Canadian Journal of Forest Research 18:1463-1469.

Zabel, C. J., G. N. Steger, K. S. McKelvey, G. P. Eberlein, B. R. Noon, and J. Verner. 1992. Home-range size and habitat-use patterns of California spotted owls in the Sierra Nevada. Pages 149-163 in J. Verner, K. S. McKelvey, B. R. Noon, R. J. Gutierrez, G. I. Gould, Jr., and T. W. Beck, eds. The California spotted owl: a technical assessment of its current status. USDA For. Serv. Gen. Tech. Rept. PSW-GTR-133. USDA Forest Service, Pacific Southwest Station, Albany, California.

Zar, J. H. 1984. Biostatistical analysis, 2nd ed. Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Zeiner, D. C., W. F. Laudenslayer, Jr., and K. E. Mayer, eds. 1988. California's wildlife, Vol. I: amphibians and reptiles. California Department of Fish and Game, Sacramento, California.

Zeiner, D. C., W. F. Laudenslayer, Jr., K. E. Mayer, and M. White, eds. 1990a. California's wildlife, Vol. II: Birds. California Department of Fish and Game, Sacramento, California.

________. 1990b. California's wildlife, Vol. III: mammals. California Department of Fish and Game, Sacramento, California.

Zielinski, W. 1999. Personal communication. USDA Forest Service, Pacific Southwest Research Station, Arcata, California.