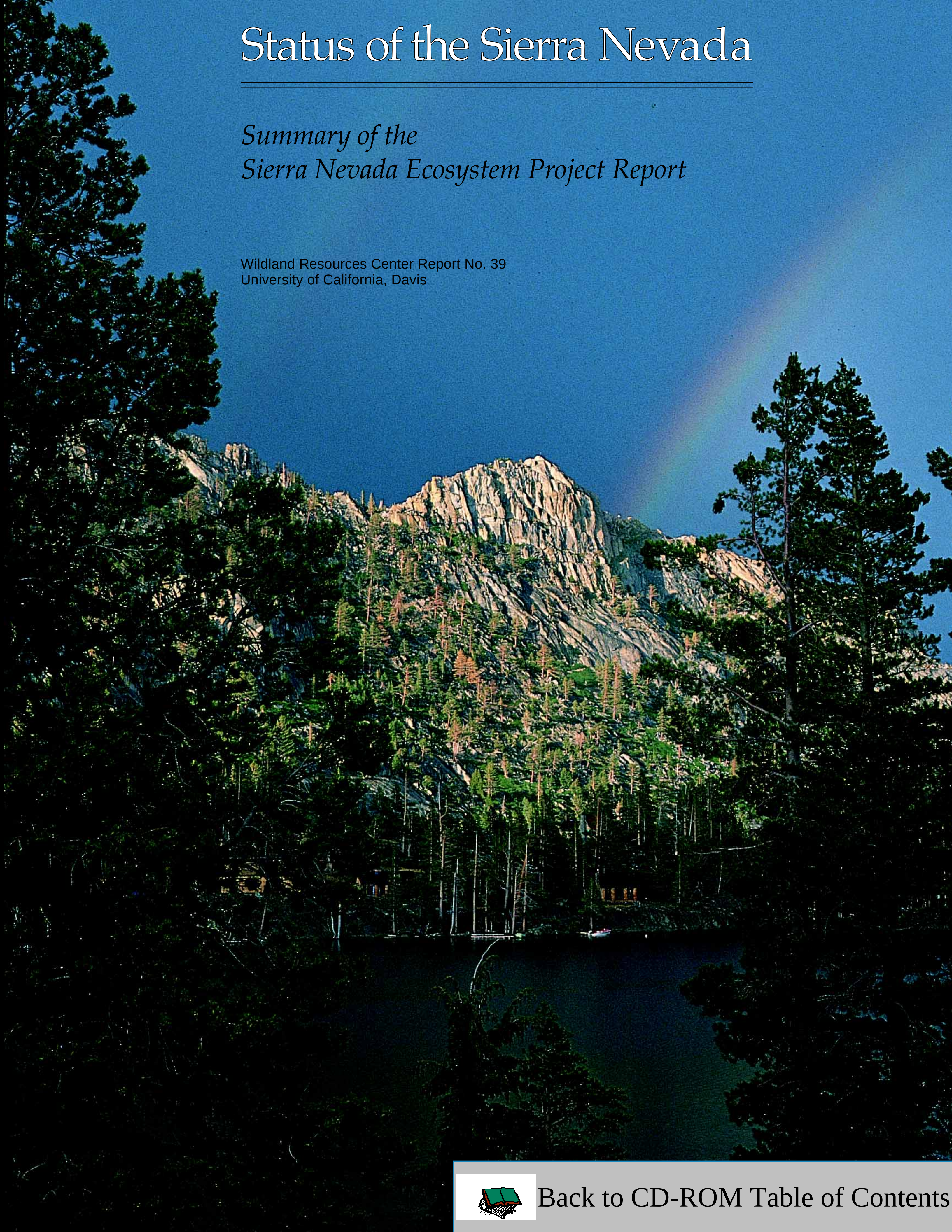
Status of the Sierra Nevada

Summary of the Sierra Nevada Ecosystem Project Report

Wildland Resources Center Report No. 39
University of California, Davis



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CENTERS FOR WATER AND WILDLAND RESOURCES
UNIVERSITY OF CALIFORNIA, DAVIS

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SCOPE AND BACKGROUND

This report summarizes the Sierra Nevada Ecosystem Project (SNEP) completed by the Science Team. It contains a list of critical findings and a summary of the assessments, case studies, and alternative management strategies. The project was requested by Congress in the Conference Report for Interior and Related Agencies 1993 Appropriation Act (H.R. 5503), which authorized funds for a "scientific review of the remaining old growth in the national forests of the Sierra Nevada in California, and for a study of the entire Sierra Nevada ecosystem by an independent panel of scientists, with expertise in diverse areas related to this issue." The U.S. Forest Service augmented support for the study and convened a steering committee to help draft the charge and select the Science Team. The Steering Committee had representatives from the Forest Service, the U.S. Department of the Interior, National Park Service, the University of California, and the California Academy of Sciences, and a member of the National Academy of Sciences.

The Science Team was eventually composed of eighteen team members and nineteen special consultants. In addition, many other scientists worked closely with team members (107 as authors or coauthors of chapters and reports), some throughout the project, and their contributions appear in volumes II and III or are acknowledged elsewhere. Overall management of the project was the responsibility of the University of California Centers for Water and Wildland Resources, through a research agreement with the U.S. Forest Service, Pacific Southwest Research Station.

The project devoted most of its effort to analyzing existing information rather than conducting new studies or experiments. The integration of this accumulated information became a primary objective as we sought a range of options for future directions of management.

Geographic information systems (GISs) formed a primary means of synthesizing data, displaying information, and considering options for further analysis.

The complete report of SNEP is contained in four volumes: Volume I is a summary of the other volumes and contains a presentation of alternative strategies and their implications for the future health and sustainability of the ecosystem.

Volume II contains technical assessments of historical, physical, biological, ecological, social, and institutional conditions in the Sierra Nevada, selected case studies, details on the scientific basis for and methods used in strategies, and references to the literature and data sources.

Assessment reports were guided by five questions: (1) What were historic ecological, social, or economic conditions, trends, and variability? (2) What are current ecological, social, or economic conditions? (3) What are trends and risks under current policies and management? (4) What policy choices will achieve ecological sustainability consistent with social well-being? (5) What are the implications of these choices? All chapters in volume II were reviewed extensively, including anonymous peer review secured by the Steering Committee.

Volume III has late submissions of peer-reviewed papers from volume II, additional commissioned reports, and summary listings of workshops and participants.

Volume IV is a computer-based catalogue of all public databases, maps, and other digitally stored information used in the project. These materials will be listed under the SNEP name and available on the Internet from the Alexandria Project at the University of California at Santa Barbara (http://alexandria.sdc.ucsb.edu/) and the California Environmental Resource Evaluation System (CERES) project of the Resources Agency of the state of California (http://ceres.ca.gov/snep). A directory to the GIS portion and available data from the study is in volume I.

Public involvement was an important component of SNEP (see volume I). Ninety people with diverse interests and responsibilities in the Sierra were assembled as "key contacts." This group met with the team to review progress, ask questions, help in framing scenarios, assist in review of assessments, and plan larger public involvement. The team held smaller work sessions and reported on progress several times at preannounced public meetings called by the Steering Committee. Throughout the study, many team members met with individuals and local and regional groups, presented reports at professional and technical meetings, briefed county, state, and federal agency personnel, and held local workshops. This interaction was vital to the team's progress and helped sharpen its work.

The congressional language and background for this study emphasized that the report was to advise Congress, not to prepare a single plan, a range of options for implementation, or preferred alternatives as in an environmental impact statement process required under the National Environmental Policy Act. The report is a scientific assessment that highlights what is known and presents individual and collective judgments about what this knowledge means for meeting the stated goal of protecting the health and sustainability of the Sierra Nevada while providing resources to meet human needs. Such an assessment leads directly to some of the choices that lie before the public.

To help frame some of these choices, the team chose a small sample of strategies to demonstrate broad choices and implications. The strategies should also educate us on the way parts of the system interact and should lead to a better understanding of unexpected ramifications brought about by human action. No single model of the Sierra that encompasses all interacting parts is possible. We have deliberately chosen several models—mathematical and nonmathematical, quantitative and qualitative—to illustrate our strategies. Models are only one way to organize and display a thought process. Their use is to aid in understanding the implications of choices, in suggesting other choices, and in opening up the territory for informed decision making. This study has shown that options

Contained in this summary is a list of condensed critical findings from the assessments, followed by an overview of the assessments and management strategies from the SNEP reports.

CRITICAL FINDINGS FROM SNEP ASSESSMENTS

Critical findings presented here summarize the most important specific conclusions of the SNEP assessments. Findings are included that indicate the most urgent or important facts revealed in SNEP assessments (volumes II–III), and that relate to environmental policy and management of the Sierra Nevada. These represent *new* findings, findings that *confirm* what has been generally believed about the Sierra, and *emergent* or *synthesizing* ideas that arose from SNEP's integrated analysis of individual reports. The critical findings are presented as conclusions about specific ecosystem components, but they are closely interconnected, and cross-references to critical findings in different sections are numerous—an indication of the close relationship among parts of the Sierra Nevada ecosystem.

❄ CLIMATE CHANGE

Climate Change **During the period of recent human settlement in the Sierra Nevada, climate was much wetter, warmer, and more stable than climates of the past two millennia; successful ecosystem evaluations and planning for the future must factor climate change into analyses.** Many resource assessments and consequent land-use and management decisions have been made under the assumption that the current climate is stable and indicative of recent past and future conditions. Water delivery systems (dams, diversions, anticipated stream flows) in the Sierra have been designed under the recent favorable climate, and fire-management strategies now being planned reflect forest conditions that developed under the current unusually wet climate. Periods of century-long droughts have occurred within the last 1,200 years and may recur in the near future.

❄ PEOPLE AND RESOURCES

Recent Population Growth **Population doubled in the Sierra Nevada between 1970 and 1990; 40% of the population growth occurred in the Sierra portion of just three counties: Nevada, Placer, and El Dorado.** Much of the growth in these counties has been suburban in nature and related to Central Valley metropolitan areas. In addition to an influx of commuters, these foothill areas of high growth have a large fraction of retirees who moved to the Sierra from urban areas throughout California.

Population Forecasts **Official projections forecast that the 1990 Sierran population of 650,000 will triple by 2040.** Some counties are forecast to quadruple to quintuple in population during this period (with the Sierra portions of counties expanding even more), primarily from the expansion of metropolitan areas in the San Joaquin valley. The foothill regions south of El Dorado County are likely to triple to quintuple in population.

Impacts from Population Growth **Population growth and its accompanying effects are causing significant impacts on resources.** These include habitat conversion and fragmentation; invasion of non-native plants and animals; changes in stream flow and ground water due to land clearing and paving; and increases in ground water extraction, septic effluent and wastewater, fire risk, and fire and fuel-management complexity.

Biotic Vulnerability **The oak woodland communities of the western Sierra Nevada foothills are the most vulnerable of the widespread vegetation types as a result of greater access by humans and of their continuing potential for urban development.** Less than 1% of foothill plant communities is in land formally allocated to biodiversity protection; these have been substantially altered by fire suppression. Much of the original extent of these communities has been reduced or altered due to intensive grazing, urbanization (especially low-density residential development), woodcutting, agriculture, mining, conversion to annual grassland, and land development. Severe damage to the foothill riparian zones has greatly diminished the overall viability of the foothill-woodland communities.

Local Mitigation **Some rapidly growing counties that SNEP examined have not collected information sufficient to adequately monitor and forecast impacts of development on biological and social resources. In addition, the current project-level approach to planning does not account for changes in regional or Sierra-wide conditions or address the need for larger-scale monitoring and improvements.** Even when identified as significant impacts under the California Environmental Quality Act, activities have often not been mitigated by local governments. Ecosystem sustainability and population growth require that local Sierran governments develop the capacity to assess, monitor, and mitigate resource impacts related to development and that some mechanism be developed to examine Sierra-wide impacts.

Jobs **The number of jobs has more than doubled in the Sierra Nevada since 1970, but the relative proportion of commodity-producing and service-producing jobs has stayed constant.** Recreation, timber, and agriculture are the three largest employment sectors directly dependent on the ecosystem. In 1990, recreation accounted for 8% of all jobs, timber 4%, and agriculture 3%. Diversification has occurred within each sector.

Personal Income Income earned by commuters, interest, dividends, and transfer payments to retired and other households now constitute more than half the total personal income in the Sierra Nevada. A significant implication of this change is that the regional economies are now less influenced by cyclical fluctuations in local employment from commodity, construction, and tourism sectors than in the past.

Ecosystem-Based Revenues **Water is the most valuable commodity, followed by timber, livestock, and other agricultural products, based on gross revenues. The Sierra Nevada ecosystem produces approximately $2.2 billion worth of commodities and services annually, based on estimates of direct resource values (not the total revenue produced by resource-dependent activities).** Water accounts for more than 60% of that total value, followed by other commodities totaling 20%, and services also totaling 20%. Public timber and private recreation are the largest net contributors of funds to county governments both in total dollars and as a percentage of their total value. Around 2% of all resource values are at present reinvested into the ecosystem or local communities through taxation or revenue-sharing arrangements.

Regional Patterns of Economic Activity **The flow of economic values from the Sierra Nevada provides an empirical basis for assessing how different levels of government, producers and consumers, and employers and employees could be involved in new approaches to ecosystem management.** These regional linkages complicate the application of many rangewide strategies but are powerfully suggestive of future opportunities involving the many stakeholders in ecosystem management.

Community Dependence **Communities in the Sierra Nevada are dependent on the ecosystem for a combination of direct and indirect natural resource benefits, including noneconomic benefits associated with aesthetic and sense-of-place values. Few economies are dependent exclusively on resource-extractive activities (timber, mining, grazing)**.

Timber-Based Employment **Timber industry employment may decline from present levels due to trends of increasing labor productivity within the region and a shift in remanufacturing facilities out of the region.** Timber harvests from federal land will have only a modest impact on trends in local employment. Ecosystem work (fuel management, environmental restorations, etc.) in the forests of the Sierra Nevada can make only a modest contribution to alleviating the effect of the decline on local workers.

Timber Harvests on National Forests **National forest timber harvests have averaged 650 million board feet from 1950 through 1994; the highest level was just over 1 billion board feet in 1988, and the lowest was 227 million board feet in 1994.** Average timber activity differs between harvest amounts and timber sales because harvest depends on variable market conditions and may lag behind sales. In 1964, Sierran national forest timber sales were 1.2 billion board feet, whereas timber harvest was 900 million board feet.

Community Well-Being **One hundred eighty communities were identified in the Sierra: twenty-eight ranked low and thirty-one ranked high in a measure of well-being that includes community capacity and socioeconomic status.** Community well-being is measured by socioeconomic status and community capacity; neither alone is predictive of well-being. A total of 18.5% of the Sierra population live in the twenty-eight communities with a low level of well-being. These communities have on average low socioeconomic status and, due to low community capacity, lack the local resources to take advantage of opportunities that might raise their level of well-being. Sixteen percent of the Sierra population live in the thirty-one communities with a high level of well-being.

Regional Well-Being **Six distinct socioeconomic regions were delineated by transportation corridors, commuting patterns, economies, community identification, and administrative boundaries.** There is considerable variation in socioeconomic status across and within regions in the Sierra. On average, the northern Sierra region has the lowest socioeconomic status and capacity scores of any region. The majority of the impoverished population in this region reside in foothill communities, although there are a number of small, impoverished communities scattered throughout the region. The west-central north region has the highest socioeconomic status and the second-highest average capacity score. Socioeconomic status in the greater Lake Tahoe basin region reflects an unequal distribution of wealth: 40% of the permanent basin population reside in communities with low or very low socioeconomic status, and 47% reside in communities with medium-high to very high socioeconomic status.

Concentration of Low Socioeconomic Status **Sierra residents living in poverty are concentrated in the larger cities and communities.** Half of all Sierra residents living in poverty are found in 11% of the communities. Similarly, half of all children in households receiving public assistance reside in 8% of the communities. Most of these communities are relatively large, with populations greater than 10,000. Nonetheless, residents with low socioeconomic status are scattered throughout the Sierra, in isolated areas as well as pockets within some of the wealthy areas.

❄ INSTITUTIONS

Institutional Incapacities **Many Sierran ecosystem declines are due to institutional incapacities to capture and use resources from Sierran beneficiaries for investment that sustains the health and productivity of the ecosystems from which benefits derive.** The costs of achieving desired objectives for conservation and ecosystem restoration in the Sierra are greater than available resources. Public funding sources (federal, state, and local governments) have not met the need or demand. Current economies are such that money obtained from using Sierran resources (water, timber, recreation, grazing) is inadequate for restoration, conservation, and ecosystem management. Institutions and communities have not effectively informed the public about real costs or responded with creative approaches for funding conservation.

Sources of Institutional Incapacities **Institutional incapacities arise from four primary sources: (1) fragmented control of ecosystems among different jurisdictions, authorities, and ownerships, (2) absence of exchange mechanisms among these entities to sustain rates of investment and cooperative actions that reflect ecosystem values, (3) detachment between those who control ecosystems and communities that depend upon and care for them, and (4) inflexibility in response to rapid changes in population, economy, and public interests.** Existing institutional capacities and arrangements do not adequately support planning and management at the Sierra-wide scale for issues whose natural scales are at that level. Interwoven patterns of private and public land ownership in portions of the Sierra Nevada create conditions that impede the attainment of management objectives because of the difficulty of merging divergent goals across a landscape.

Regionalism **The sources of institutional capacity and of potentials to improve upon capacity differ among the regions of the Sierra, which vary greatly in their institutional as well as ecological, demographic, and economic characteristics.** The pattern of regions in the Sierra (i.e., delineation of number of regions, size, boundaries, and characteristics) also varies by issue, although enough commonalities exist to generally define five or six distinct regions that reflect most issues.

❄ FIRE AND FUELS

Ecological Functions of Fire **Fire is a natural evolutionary force that has influenced Sierran ecosystems for millennia, influencing biodiversity, plant reproduction, vegetation development, insect outbreak and disease cycles, wildlife habitat relationships, soil functions and nutrient cycling, gene flow, selection, and, ultimately, sustainability.** Most vegetation types below the subalpine zone have been highly influenced by and are adapted to regular fire.

Effects of Climate **Climatic variation plays an important role in influencing fire patterns and severity; fires have been most extensive in periods of dry years.** During cool-climate periods of the past centuries, fires were less numerous but larger than during warm-climate periods.

Presettlement Fire Regimes **In most low-elevation oak woodland and conifer forest types of the Sierra Nevada, presettlement fires were frequent, collectively covered large areas, burned for months at a time, and, although primarily low to moderate in intensity, exhibited complex patterns of severity.** Locally severe fires occurred and played an important role in forest dynamics. It is unclear what spectrum and frequency of patch sizes (a few acres to thousands of acres) were created by severe fire; however, contiguous areas of predominately high-intensity fire larger than a few thousand acres almost certainly were much less common than today.

Effects of Suppression **Fire suppression in concert with changing land-use practices has dramatically changed the fire regimes of the Sierra Nevada and thereby altered ecological structures and functions in Sierran plant communities.** Alterations have occurred especially in plant communities historically influenced by frequent low- to moderate-intensity fire.

Fuel Conditions **Live and dead fuels in today's conifer forests are more abundant and continuous than in the past.** Many factors have affected fuel quantities and distribution in Sierran forests, including variation in climate, timber harvest, mining, grazing, human settlement patterns and land-use practices, and nearly a century of fire suppression.

Effects of Logging **Timber harvest, through its effects on forest structure, local microclimate, and fuel accumulation, has increased fire severity more than any other recent human activity.** If not accompanied by adequate reduction of fuels, logging (including salvage of dead and dying trees) increases fire hazard by increasing surface dead fuels and changing the local microclimate. Fire intensity and expected fire spread rates thus increase locally and in areas adjacent to harvest. However, logging can serve as a tool to help reduce fire hazard when slash is adequately treated and treatments are maintained.

Fire Size Trends **The commonly expected consequence of decades of fire suppression—that large, infrequent fires are becoming larger and small, frequent fires smaller—is generally not confirmed by records for twentieth-century Sierran forests.** The central western Sierra Nevada is the only region where evidence exists that this pattern has occurred. This region has experienced the greatest increase in human population, which has affected both the incidence of fire ignitions and the suppression strategies once fires have begun. By contrast, the Plumas National Forest has had no change in the observed size and frequency of fires during this century, and in Sequoia–Kings Canyon National Parks small, frequent fires are larger and large, infrequent fires are smaller than before 1950, that is, the opposite pattern to that in the central western Sierra Nevada. The latter observations are complicated by the active prescribed fire-management program in the parks, the results of which are included in these data.

Fire Surrogates **Although silvicultural treatments can mimic the effects of fire on structural patterns of woody vegetation,**

virtually no data exist on the ability to mimic ecological functions of natural fire. Silvicultural treatments can create patterns of woody vegetation that appear similar to those that fire would create, but the consequences for nutrient cycling, hydrology, seed scarification, nonwoody vegetation response, plant diversity, disease and insect infestation, and genetic diversity are mostly unknown. Similarly, although combining managed fire with silvicultural treatments adds the critical effects of combustion, the ecological effects and fire hazard reduction of this approach are largely unknown.

Urban-Wildlands Intermix **Projected trends in urban settlement—homes intermixed with flammable wildlands—place an increasing number of homes and people at high risk of loss from wildfire unless hazards are mitigated.** Current fuel levels and projected future uses, especially in the west-central Sierra Nevada foothills and lower mixed conifer zones, are incompatible without active fuel management. The presence of homes can force changes in suppression strategies and increase suppression costs.

❄ PLANTS, PLANT COMMUNITIES, AND TERRESTRIAL WILDLIFE

Plant Diversity **Of California's 7,000 vascular plant species, about 50% occur in the Sierra Nevada. Of these, more than 400 species are found only in the Sierra Nevada, and 200 are rare.** Of the geographic regions of the Sierra, the southern is richest in species generally, as well as in numbers of rare species and species found only in the Sierra. The Owens River basin in the eastern Sierra is also an area of rare and unique plant species.

Threats to Plant Diversity **Three plant species marginally within the Sierra Nevada *(Monardella leucocephala, Mimulus whipplei*, and *Erigeron mariposanus)* appear to have become extinct in the last hundred years.** Impacts to plant populations have come largely from settlement, grazing, and fire suppression. Of the habitat types most frequently documented to contain rare and unique species, the foothill woodland and chaparral communities have been particularly damaged and fragmented by changes in agriculture and settlement on the western slopes of the Sierra. Invasion of exotic plant species has been most pronounced in the foothill zone and is associated with livestock grazing in foothill woodlands and grasslands, as well as with settlement patterns.

Vertebrate Diversity **About 300 terrestrial vertebrate species (including mammals, birds, reptiles, and amphibians) use the Sierra Nevada as a significant part of their range, although more than 100 others include the Sierra Nevada as a minor part of more extensive ranges elsewhere.** In total, about 60% of the state's vertebrate fauna occur in the Sierra Nevada to some extent. Only thirteen species are restricted (endemic) to the Sierra in California. Fifteen Sierran species are introduced and not native to the range.

Extinction **Three modern vertebrate species once well distributed in the range are now extinct from the Sierra Nevada: Bell's vireo, California condor, and grizzly bear.** The grizzly bear was directly exterminated by Euro-American settlers. The California condor suffered a series of blows, including the extinction of the Pleistocene megafauna upon which it once fed, elimination of most remaining wild and later domestic grazers, indiscriminate shooting, and, finally, ingestion of lead slugs and collisions with power lines. Bell's vireo lost much of its riparian willow habitat and suffered from cowbird parasitism.

Vertebrate Species at Risk **Sixty-nine species of terrestrial vertebrates (17% of the Sierra fauna) are considered at risk by state or federal agencies, which list them as endangered, threatened, of "special concern," or "sensitive."** By comparison, 30% of the statewide fauna are so listed. Species perilously declining or already at dangerously low populations in the Sierra include bighorn mountain sheep, Yosemite toad, foothill yellow-legged frog, mountain yellow-legged frog, western pond turtle, California horned lizard, willow flycatcher, and olive-sided flycatcher. Barrow's goldeneye (a duck) no longer breeds in the range; harlequin duck and yellow-breasted chat have become rare compared to their presence in historical records. More than a dozen other species of Sierran birds, many of them widespread and common, are steadily declining in abundance.

Loss of Foothill Habitat **Eighty-five terrestrial vertebrate species require west-slope foothill savanna, woodland, chaparral, or riparian habitats to retain population viability; 14% of these are considered at risk.** The number of species actually declining in the foothill zone of the Sierra Nevada is undoubtedly far greater because so much critical habitat has been converted. Many of these species do not rate state or federal listing because their distributions include habitat in other parts of the state.

Loss of Riparian and Old-Growth Habitat **The most important identified cause of the decline of Sierran vertebrates has been loss of habitat, especially foothill and riparian habitats and late successional forests.** In the Sierra, eighty-two terrestrial vertebrate species are considered dependent upon riparian (including wet meadow or lakeshore) habitat; twenty of these are considered at risk. Eighteen species are dependent upon late successional forests; five of these are at risk. Although few Sierran species appear to require closed forest canopies, many more depend upon the presence of large, old trees, snags, and downed logs in all Sierran woodland and forest communities for some part of their life cycle.

Genetic Diversity **Activities occurring in the Sierra Nevada that pose the greatest indirect and direct threats to genetic**

diversity are those that break the chain of natural selection and adaptation. Genetic diversity is distributed within plant and animal populations across the Sierra. It forms the basis for adaptation to changing environments. Losses of regional and local genetic diversity may be precursors to population extinction; once lost, genetic diversity may be irrecoverable. By their nature, timber harvest and forest regeneration have potentially large impacts on diversity, but their impacts can be mitigated by policy. Human-caused activities threatening genetic integrity include severe wildfire, habitat degradation and conversion, landscape fragmentation, introduction of non-native fish, improperly conducted reintroduction of native plant and animal species in ecological restoration, habitat improvement, fire reclamation, and unregulated harvest of special forest products.

Genetic Management **Genetic guidelines that alert managers to activities likely to have genetic consequences and inform managers about preferred management of seeds, plants, mushrooms, animals, insects, and other germ plasm have been mostly lacking, inadequate, or poorly implemented in land management of the Sierra.** An important exception is the policy of the U.S. Forest Service, especially the detailed guidelines for forest tree genetic management, which serves as a model, as well as the genetic guidelines for ecological restoration in the national parks. Without development and implementation of similar guidelines for other taxa and situations, unregulated or uninformed land-use activities will continue to disrupt genetic diversity of Sierran biota.

Community Distribution **Excluding marginal plant communities mainly distributed in the Mojave Desert and Great Basin, the Sierra Nevada encompasses eighty-eight plant community types as defined by California's Natural Heritage Division.** Sierran mixed conifer forest and blue oak woodland are the most extensive types, covering 2,300 and 2,100 square miles, respectively. Sixty-seven types have a mapped distribution greater than 10 square miles. Widespread types exhibit considerable floristic variation from northern to southern ends of the range and are best analyzed on a subregional basis.

Private Ownership of Plant Communities **Many of the foothill community types fall largely within private lands, notably grassland (88% of the mapped distribution on private lands), valley oak woodland (98%), blue oak woodland (89%), interior live oak woodland (71%), and foothill pine–oak woodland (82%).**

Grazing **Livestock grazing has been implicated in plant compositional and structural changes in foothill community types, meadows, and riparian systems, and grazing is the primary negative factor affecting the viability of native Sierran land bird populations.** Twenty-eight percent of Sierran plant communities are potentially grazed over more than 90% of their distribution. Notable among these are black oak woodland, valley oak woodland, blue oak woodland, interior live oak woodland, and east-side ponderosa pine forest. Livestock grazing is currently allowed (if not necessarily used) over 80% of the range (89% of vegetated lands).

Timber Harvest **Six forest types are mostly found on lands available for firewood cutting or timber harvest, including interior live oak (81%), black oak (56%), east-side ponderosa pine (72%), Sierran mixed conifer (67%), Sierran white fir (62%), and lower cismontane mixed conifer–oak (70%).**

Type Conversions **Nearly 800,000 acres of oak woodlands in the Sierra Nevada have been converted to other land uses and vegetation types over the last forty years, a decline of almost 16%.** Major losses from 1945 through 1973 were from rangeland clearing for enhancement of forage production. Major losses since 1973 were from conversions to residential and industrial developments. Exurban migration represents the largest threat to continued sustainability of ecological functions on hardwood rangelands. Maintenance of oak woodlands has high, widespread public endorsement. Oak regeneration (particularly blue oak), once considered a significant problem, appears less an issue outside areas where urban encroachment proceeds. Effective methods have been developed to restore areas denuded of oaks in the past. Voluntary educational programs have made dramatic progress in accomplishing sustainable management practices by ranchers.

❄ LATE SUCCESSIONAL AND OLD-GROWTH FORESTS

Status of Current Late Successional Forests **Late successional old-growth forests of middle elevations (west-side mixed conifer, red fir, white fir, east-side mixed conifer, and east-side pine types) at present constitute 7%–30% of the forest cover, depending on forest type. On average, national forests have about 25% the amount of the national parks, which is an approximate benchmark for pre-contact forest conditions. East-side pine forests have been especially altered.** Human activities, particularly timber harvest, indiscriminate burning in the nineteenth century, and fire suppression in the twentieth century, have drastically reduced the extent of late successional forests through the removal of large trees and woody debris and dense ingrowth of shade-tolerant tree species, leading to greater stand uniformity over large areas and loss of landscape diversity.

Forest Simplification **The primary impact of 150 years of forestry on middle-elevation conifer forests has been to simplify structure (including large trees, snags, woody debris of large diameter, canopies of multiple heights and closures, and complex spatial mosaics of vegetation), and presumably function, of these forests.** By reducing the structural complexity of forests, by homogenizing landscape mosaics of woody debris, snags, canopy layers, tree age and size diversity, and forest gaps, species diversity has also been reduced and simplified. At low elevations along the western boundary, ponderosa pine was preferentially removed, and throughout its range, sugar pine has decreased in abundance first through selection and later by blister rust disease. Although the situation in the Sierra differs from that in forests in the Pacific Northwest, where fragmentation leaves remnant old-growth patches surrounded by large openings, functionally the Sierran forests have been fragmented to a lesser degree by simplification.

Distribution of Late Successional Forests **Four Sierran national parks, Lassen Volcanic, Yosemite, Sequoia, and Kings Canyon, provide most of the remaining large contiguous areas of late successional forests in middle-elevation conifer types.** High-quality, structurally complex late successional middle-elevation forests are proportionately four times greater on national parklands than on adjacent national forest lands. Although the national parks contain large blocks of high-quality late successional forest, similar, if considerably smaller, patches are relatively well distributed throughout the Sierra. However, these late successional forests are at present compromised in many areas by the effects of fire suppression and grazing.

Historic Conditions of Federal Lands **Much of the best of the accessible pine forest was cut before the national forests were created. Many national forest lands were created from the leavings: cutover lands, steep canyon walls, high montane forests, and relatively inaccessible timberlands.** Harvesting of Sierra Nevada forests was largely in the hands of early miners, settlers, and the railroad and timber barons until the forest reserves and national forests were created. Demands for lumber and fuel were coupled with inadequate laws designed to harvest forests and dispose of public lands. The Forest Service proceeded with a large job of land acquisition, often acquiring cutover forest lands of high potential but poor condition, and set about fighting fires, restocking forests, and building a road network for public and commercial access. That road network continues to strongly affect the character of much national forest land.

Continuous Forest Cover **Despite 150 years of Euro-American timber harvest activity in the Sierra Nevada, clear-cut blocks larger than 5–10 acres are at present uncommon in the conifer forests of the Sierra Nevada, and tree cover is relatively continuous.** Aside from clearing for settlement, harvest methods on public as well as private lands have emphasized leaving tree cover. Early large clear-cuts have reforested, and more recent clear-cuts in the Sierra have been small in area and limited in scope.

Forest Mortality **Over the past decade, as they have many times in the past, Sierra Nevada conifer forests have experienced widespread, locally severe mortality caused principally by bark beetles infesting trees stressed by drought, overdense stands, and pathogens.** Along the western slopes, air pollution stress may well have contributed to this extensive mortality. Although fire suppression and forestry practices leading to unhealthy tree densities are implicated in the current die-off, Forest Service records dating back to the beginning of the century reveal that periodic insect outbreaks, often associated with droughts, have killed trees (often just a specific species) over extensive areas of the Sierra Nevada. Tree mortality, even widespread or locally severe mortality, is an inherent component of Sierran forest ecology and an important generator of plant and animal habitats.

❄ RANGELANDS AND GRAZING

Historic Grazing Impacts **Historic unregulated grazing, which ended in the early 1900s, created widespread, profound, and, in some places, irreversible ecological impacts. Foothill habitats have suffered physical and biological damage of many riparian systems and virtual replacement of the native perennial flora by Eurasian annuals.** These introduced species are not ecological equivalents of native foothill species, have displaced many species of plants and animals, and have brought about apparently irreversible changes in ecological function. Grazing has been a pervasive activity throughout the Sierra Nevada for more than 130 years. Even at higher elevations, native rangelands still show consequences of this historic period.

Current Grazing Effects **Current livestock grazing practices continue to exert reduced but significant impacts on the biodiversity and ecological processes of many middle- to high-elevation rangelands even though properly managed grazing (appropriate timing, intensity, duration of use, control of cowbirds, and exclusion from wetlands) can be compatible with sustainable ecological functions.**

Restoration of Upland Rangelands **Increases in native perennial grasses are occurring on some east-side sagebrush-steppe rangelands, but the continuing cheatgrass invasion of these habitats indicates that complete restoration of native plant communities is highly unlikely.** Any continuation of improper grazing practices will surely exacerbate the spread of invasive weeds. Because these rangelands lack the natural capacity to rid themselves of the invasive annuals, active restoration management, with or without the elimination of grazing, will be required.

Restoration of Meadows and Riparian Systems **Easily damaged by improper grazing, montane meadows and riparian systems are resilient relative to restoration of plant cover, but restoration of stream channel shape, system function, and biodiversity may take decades.**

Conversion of Hardwood Rangelands **Human settlement patterns represent the largest threat to continued sustainability of ecological functions on hardwood rangelands.** Major losses of hardwood rangeland habitats have resulted from conversions to residential and industrial developments in the last twenty years. Current land-use trends are unlikely to be reversed by voluntary programs.

Oak Woodland Resiliency **Oak woodlands (particularly blue oak) are much more stable than previously thought; concerns about regeneration are not well founded.** Long-term trends reveal stand structures with recruitment into various size classes and increasing canopy density even under typical livestock management practices. Areas denuded of oaks in the past can be restored with current technology.

❄ WATERSHEDS AND AQUATIC ORGANISMS

Aquatic Habitats **The aquatic/riparian systems are the most altered and impaired habitats of the Sierra.**

Stream Flow **Dams and diversions throughout most of the Sierra Nevada have profoundly altered stream-flow patterns (timing and amount of water) and water temperatures, with significant impacts to aquatic biodiversity.** Native fish populations have been severely reduced or have gone locally extinct, especially at low elevations, primarily as a consequence of dams and introduction of non-native fish species. In contrast, significant changes in flow pattern of larger streams as a result of land-use practices have not been detected. However, high variability in natural runoff and water diversion and storage may mask the ability to detect significant changes.

Riparian Status **Riparian areas have been damaged extensively by placer mining (northern and west-central Sierra) and grazing (Sierra-wide) and locally by dams, ditches, flumes, pipelines, roads, timber harvest, residential development, and recreational activities.** Riparian areas are key Sierran ecosystems that support a diversity of plants and animals not found elsewhere in the range. About 21% of Sierran vertebrates and at least 17% of Sierran plants are associated with riparian and wet areas. Over the range of the Sierra, local impacts have led to a significant widespread problem of riparian fragmentation, with the almost certain loss of important riparian function. Some riparian attributes can recover quickly after a disturbance is removed (e.g., regrowth of plants, energy and nutrient cycling, stream shading); others may require active restoration measures. Greatly altered stream channels take a long time to restore or may be beyond restoration.

Sediment **Excessive sediment yield into streams remains a widespread water-quality problem in the Sierra Nevada.** The main sources of sediments are roads of poor design, location, construction, and maintenance and riparian areas that have been devegetated by logging, fire, grazing, mining, and construction. These problems remain despite attempts at correction. Future population growth will dramatically increase the potential for significant sedimentation problems unless effective mitigation occurs. Preventive practices are much less costly than attempts at rehabilitating damaged sites.

Water Quality **Major water-quality impacts on the Sierra are (1) impairment of chemical water quality downstream of urban centers, mines, and intensive land-use zones, (2) accumulation of near toxic levels of mercury in many low- to middle-elevation reservoirs of the western Sierra, (3) widespread biological contamination by human pathogens (especially *Giardia*), and (4) increased salinity in east-side lakes as a result of water diversions.** Water quality has been measured mostly in places where problems were expected.

Introduced Aquatics **Introduction of non-native fishes (primarily trout) has greatly altered aquatic ecosystems through impacts on native fish, amphibians, and invertebrate assemblages.** Altered habitats are often linked to successful establishment of non-native species. Historically, only about twenty high-elevation lakes contained fish, whereas there are now more than two thousand lakes containing fish. This human-mediated ecological transformation has had severe detrimental impacts on native aquatic invertebrates and amphibians, causing drastic reductions in distribution and population sizes. Merely through cessation of stocking, as many as one-third of the lakes could revert to fishless condition.

Amphibian Status **Amphibian species at all elevations have severely declined throughout the Sierra Nevada.** At high elevations, introduced fish seem to be the primary cause for loss of mountain yellow-legged frog populations throughout historic ranges. Causes for the coincidental decline of amphibians at low elevations are still unknown.

Anadromous Fish **Anadromous fish (chinook salmon, steelhead), once native to most major Sierran rivers north of the Kings River, are now nearly extinct from Sierran rivers.** Dams and impoundments, which block fish access to streams, together with degraded conditions above dams, have led to loss of about 90% of the historic habitat in the Sierra.

Aquatic Invertebrates **Local degradation of habitats has led to significant impacts on aquatic invertebrates, which make up the vast majority of aquatic species in the Sierra Nevada.** The aquatic invertebrate fauna as a whole remains largely unknown, and only a fraction of the species diversity in the range has been identified or studied. In addition to more widely known aquatic habitats, such as streams and lakes, many invertebrate species occur in highly local places such as intermittent streams, ephemeral ponds, fens, bogs, springs, and small wetlands. Many species are known only from single sites. Due to food chain relationships, impacts to invertebrates have significant cascading effects on other animals.

❄ AIR QUALITY

Sierra-wide Status **In northern Sierra Nevada airsheds, and in most remote areas during the winter, air quality is some of the cleanest in the nation and even in the world. Southern airsheds on the west side are heavily impacted during spring, summer, and fall by ozone and small particles derived from Central Valley sources and have some of the poorest air quality in the nation.** Mountain urban areas can be quite heavily impacted by local sources, especially in winter.

Ozone Damage **Extensive ozone damage occurs to sensitive tree species at low and middle elevations in the southwest and central-western slopes.** Peak daily ozone levels at 6,000 feet in Sequoia National Park are essentially the same as for Visalia on the Central Valley floor, while nighttime and early morning levels are sharply higher. Most pollutants originate from the Central Valley and urban/industrial sources in the San Francisco Bay Area. Levels of ozone and most other important pollutants in the Sierra Nevada are either stable or slowly increasing, whereas in many urban areas in California they are improving.

Ozone Standards **The federal ozone standards for human health may be inadequate to protect biota from air-pollution damage.** Ozone injury to Jeffrey pine, one of the most sensitive forest trees, becomes serious when ozone exceeds concentrations of about 0.09 parts per million, which is the California health standard. This level is reached and exceeded in the Sierra Nevada. Thus, although achieving the California standard should protect some forest elements, achieving the federal ozone standard of 0.12 ppm will not.

Smoke **Smoke from managed fires on the average contributes only modest amounts of small particles to human lungs compared with other Sierran sources; winter smoke from woodstoves creates much more severe local air-quality problems.** Future population increases could exacerbate these problems in high-altitude locations such as Truckee and Mammoth Lakes.

Visibility **Visibility is severely degraded for much of the western slope of the Sierra Nevada each spring, summer, and fall by fine-particle sulfates, nitrates, and smoke transported from the Central Valley.**

Dust **Dust storms over the alkali and dry lakes of the eastern Sierra (Mono Lake and Owens [dry] Lake) create severe episodic health hazards to humans and presumably to plants and animals as well, when transported into the White and Inyo Mountains and the Sierra Nevada.** A recent decision on raising the current lake level of Mono Lake should solve this problem, but no effective countermeasures are in place for Owens (dry) Lake.

OVERVIEW OF SIERRA NEVADA ECOSYSTEMS AND ASSESSMENT STATUS

Review of the Sierra Nevada reveals the unfolding process that has shaped the ecosystems. A view of the Sierra is flawed if it considers today's ecological or social environment to be stable: the old-growth forests developed in a different environment from the current one and are headed into a different future. Many of the forests originated under an anomalously wet climate. The developed water systems are based on predictions of flow derived from this unusually favorable period. Snapshots of the present may give misleading pictures of what is needed to support a full range of biotic and human systems in the near and distant future.

If there is natural environmental change, does this give license for humans to act however they like in ecosystems? If ecosystems are always changing, why should it matter if we retain the diversity and function of any specific time and place? It matters because both the *rate* and the *direction* of change in natural systems are extremely important to ecosystem sustainability. Plants and animals, and the ecosystems they compose, evolve and adapt to the gradual pace of most environmental change; that is, they produce the successors who are able to survive and prosper. Humans may make conscious decisions to alter rate and direction of ecosystem change. The important consideration is to make decisions with knowledge of the potential consequences and to understand the context of change in the Sierra Nevada.

Social Institutions

The web of institutions laid across the Sierra by successive generations of Americans is central to an understanding of the mountain range and its future management. This web is the eventual target of the current study, in that the project's assessments and strategies must be absorbed, adapted, and implemented not by the organisms or rocks of the mountain range but rather by the institutions through which human society operates.

Institutions are central elements in the ecology of the Sierra Nevada because they mediate the relationship between the labor and desires of people and the Sierran ecosystems those people use. In a biological analogy, institutions—the governmental and nongovernmental organizations, agreements, and regulations—constitute a key part of the life history strategy that the human species currently uses in the Sierra. Institutions are how people link themselves to other parts of the ecosystem.

Institutions govern not only what people extract from the ecosystem—water, timber, recreation, amenities—but also how they reinvest in the natural capital through actions such as planting trees or restoring habitats. The extent to which institutions and policies "close the loop"—that is, mitigate the environmental impact of human activities—is a critical part of a Sierra Nevada ecosystem assessment.

As institutions regulate the exchanges between people and the ecosystem, they also link people who reside outside the mountain range with the ecosystem within it. Institutions that close the loop by extracting water or reinvesting (for instance, watershed rehabilitation to mitigate for habitat loss) are also closing a loop that passes beyond the Sierra to include urban and agricultural water users in the San Francisco Bay Area, southern California, and the Central Valley. Closing the loop, then, includes identifying and accounting for the values of all stakeholders in the Sierra Nevada, regardless of their locations, and understanding how benefits and costs flow among coupled ecosystems.

Although institutions are part of the ecology of the Sierra, nothing ensures that those institutions perceive the entire ecosystem, much less manage it in a sustainable manner. Heretofore, institutions have largely focused on portions of ecosystems. For instance, for streams on the east side of the Sierra, the Lahontan Regional Water Quality Control Board has jurisdiction over the quality of water, the state Water Resources Control Board over the rights to the water, the state Department of Fish and Game over the trout in the water, and the U.S. Forest Service and the state Department of Forestry and Fire Protection over the trees that grow next to the water. Jurisdictions split along geographic as well as resource lines. The U.S. Forest Service and the National Park Service manage the land along the upper reaches of most Sierran rivers, while private landowners, the federal Bureau of Land Management, municipal utilities, and local irrigation districts manage much of the land along the lower reaches. There are no existing mechanisms to ensure that the sum of the management of the parts of the ecosystem adds up to wise management of the whole ecosystem.

Like all other parts of the Sierran ecosystem, the institutional components change over time in response to larger forces. Population growth and development bring more people into the region, increasing not only the demand for services but also the diversity of values and issues influencing management of the range. The creation of markets for values and benefits that heretofore have been allocated by right or administrative arrangement—water is the preeminent example—upsets many existing arrangements and creates the need for different types of institutions. Interagency and intergovernmental cooperation blurs lines of authority and blunts institutional prerogative but may allow movement in arenas currently stymied by gridlock. Grassroots activism creates new institutions, which compete with existing ones for legitimacy and authority. These driving forces interact in different ways in different regions of the Sierra and force the evolution of institutions.

Future policies and institutions need to transcend their "ecosystem component" status to perceive the Sierra Nevada as a set of ecosystems with links to stakeholders within and outside the range and to manage both extraction and reinvestment to ensure the long-term persistence of the ecosystem and the people that depend upon it.

Rock and Soil

The Sierra Nevada is an enormous deposit of granitic rocks whose exposed slopes are readily visible. The environmental history of the range has been shaped over several hundred million years by varying intensities and forms of uplift, erosion, volcanism, and glaciation. Plate tectonics and climate variations acting at millennial, decadal, and annual timescales interact to influence the intensity of these events and their impacts on the landscape. These diverse geological activities have produced a broad suite of rock formations in the Sierra Nevada, dominated by granitics but including many types of igneous, sedimentary, and metamorphic rocks, with ages from Cambrian (about 500 million years ago) to Quaternary (the past 2 million years). Most evidence suggests that the modern range is about 10 million years old, although very recent and controversial evidence suggests it is much older.

Rocks of the Sierra Nevada interact with climate, topography, surface processes, and biota to create Sierra Nevada soils. Because the Sierra Nevada is underlain by mostly granitic

❄ *SNEP Core Area*

The core area boundary for the Sierra Nevada Ecosystem Project was the area (20,663,930 acres) containing the headwaters of twenty-four major river basins and extending through the foothill zone on the west side and the base of the escarpment on the east side (figure 1). No single boundary adequately defined all the ecological and social components, but watersheds were in many ways the most discernible and most meaningful units in the Sierra and were therefore used by SNEP. At the request of Congress, a larger study area for the project included portions north of the physiographic Sierra Nevada and extensions beyond the core area to the south and east. Appropriate adjustments to these boundaries were considered in SNEP analyses pertinent to the needs of each issue.

Thirty-six percent of the core Sierra Nevada is privately owned. About two-thirds of the land area in the Sierra Nevada is publicly owned (figure 2). Most of that is national forest managed by the U.S. Forest Service, the remainder is largely shared by the Bureau of Land Management and the National Park Service. The state of California and local jurisdictions administer only small pieces within the SNEP study area. Most of the land at high elevations throughout the Sierra is public, as are large proportions of the eastern Sierra. Below about 3,000 feet in the western Sierra, private lands predominate.

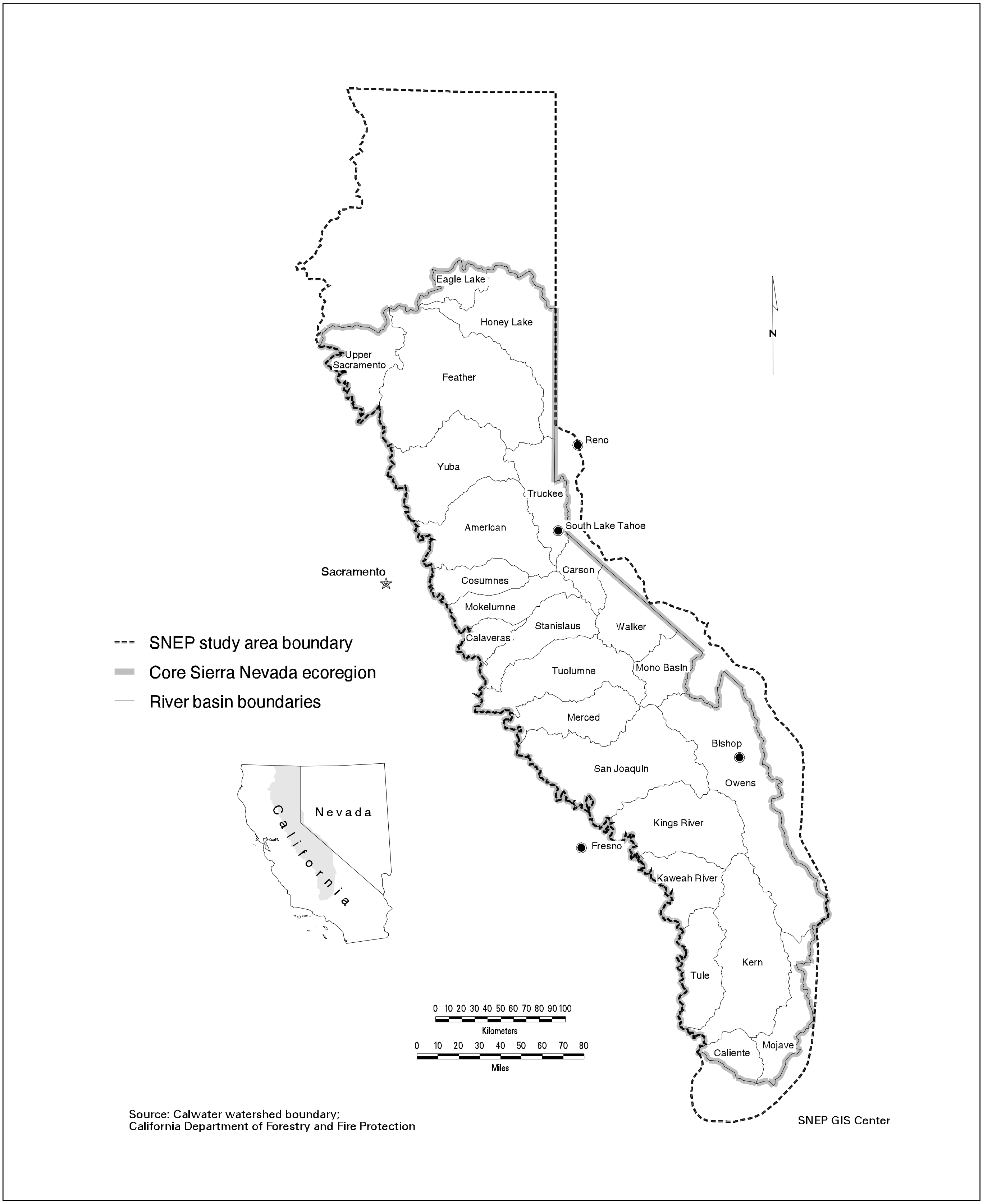

FIGURE 1

Boundaries of the core Sierra Nevada ecoregion, the larger study area, and the river basins used in the SNEP assessments.

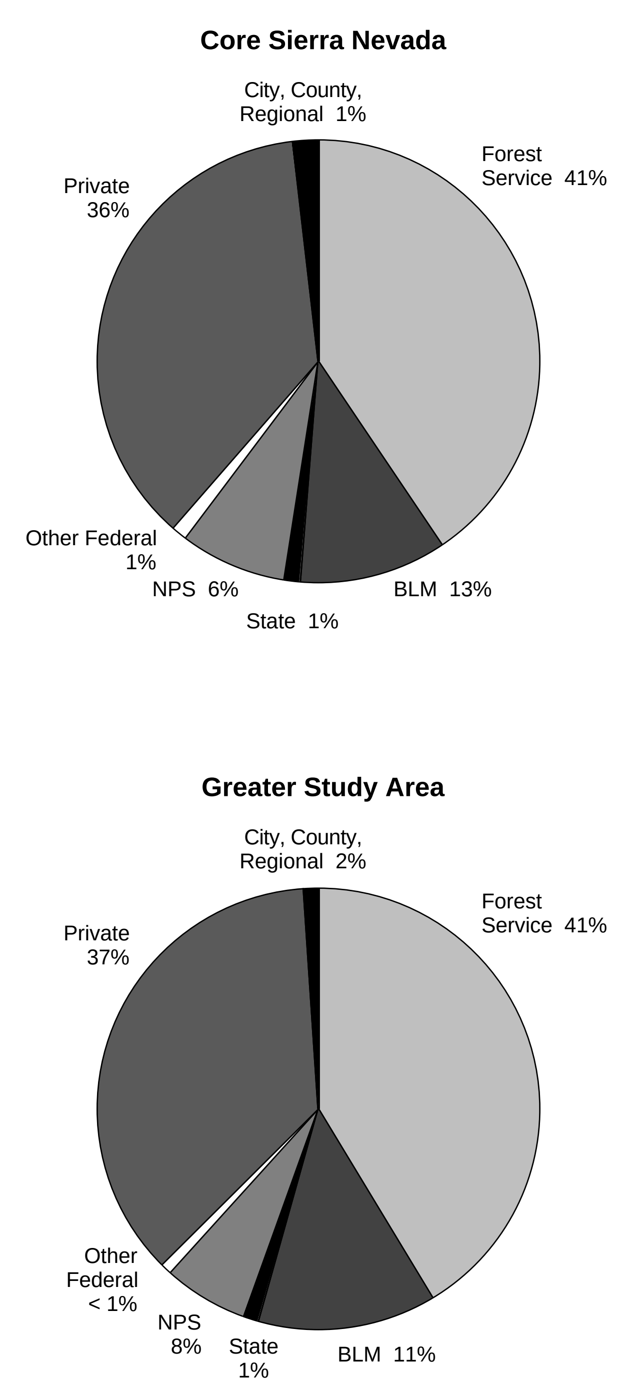

FIGURE 2

Ownership percentages in the core Sierra Nevada ecoregion and the greater SNEP study area.

interact to influence the intensity of these events and their impacts on the landscape. These diverse geological activities have produced a broad suite of rock formations in the Sierra Nevada, dominated by granitics but including many types of igneous, sedimentary, and metamorphic rocks, with ages from Cambrian (about 500 million years ago) to Quaternary (the past 2 million years). Most evidence suggests that the modern range is about 10 million years old, although very recent and controversial evidence suggests it is much older.

Rocks of the Sierra Nevada interact with climate, topography, surface processes, and biota to create Sierra Nevada soils. Because the Sierra Nevada is underlain by mostly granitic rocks, soils that develop from these foundations are thin and rocky. Although the nutrient capital (fertility) of the soil in general over the Sierra Nevada is rather low, the range contains some of the most productive sites for conifers in the world. Soil types form a mosaic across the Sierra, influencing vegetation, erosion, wildlife distribution, water quality, fertility, and a myriad of human uses.

Such a complex geological and soil foundation has dramatic implications for human uses of Sierra Nevada ecosystems. Mesozoic deposits (more than 100 million years old), altered through pressure and heat and exposed through erosion or buried deep underground, form the gold and silver that attracted a rush of miners and began the period of Euro-American settlement. Abundant sediments from ancient seafloors, lake beds, and water-carried deposits create the ore and gravel resources that are the contemporary valuable rocks of the Sierra. Persistent seismic activities, especially along volcanic vents of the eastern escarpment near Mammoth Lakes and Markleeville, are a focus of concern for urban development in these areas, yet those same vents provide geothermal power for existing communities. The rich and fertile soils that have formed on the western edges of the Sierra Nevada continue to support a diverse agriculture that had its origins with the Native American communities that occupied the region.

Volcanic and seismic activity is highly localized but ongoing in the Sierra Nevada. New volcanic craters have been built, vents have erupted, hot springs have formed, faults have slipped, and volcanic-induced mud slides have occurred as recently as the past hundred years in a few regions. Volcanic events will undoubtedly persist as agents of change affecting local ecological and human elements of Sierran ecosystems and demanding local attention.

Climate

Climatic and geological forces are the royal architects of Sierra Nevada ecosystems. Water, wildfire, plants, fauna, and humans are highly dependent on regional climate and local weather. Organisms must adjust (migrate, adapt) or die as climate changes. The current patterns of vegetation, water flow and abundance, and animal distribution in the Sierra are determined largely by cumulative effects of past and present climates. Human development in the Sierra has proceeded during a recent period of relatively wet, warm climate. Patterns of human settlement, perceptions of wildfire, design of water delivery systems, predictions of water availability, future forest and urban planning, and aesthetic expectations about forest condition (size, composition, health of forests) are based largely on conditions of this anomalous climate today and influence how people manage resources. For instance, two extensive droughts, each lasting 100 to 200 years, occurred within the last 1,200 years. During the cold phase of the Little Ice Age (about A.D. 1650–1850), glaciers in the Sierra Nevada advanced to positions they had not occupied since the end of the last major ice age over 10,000 years ago. The period of modern settlement in the Sierra Nevada (about the last 150 years), by contrast, has been relatively warm and wet, containing one of the wettest half-century intervals of the past 1,000 years. Many of the forests that stand today were established under different climates—generally wetter ones—from the present regimes.

The current Sierran climate is dominated by a "mediterranean" pattern of a cool, wet winter followed by a long hot and dry period in summer, with high yearly variability in temperature and precipitation. Precipitation increases and average temperature decreases with increase in elevation. The transition zone of rain to snow is an important determinant of vegetation types, stream dynamics, and human settlement.

The Sierra summits wring water from the winter storms and summer convection systems, leaving the eastern flank progressively drier each mile east. From moist mountain ecosystems at the Sierran crest, the transition to semiarid desert can occur in less than two horizontal miles. Strong gradients of aridity also exist from north to south along the Sierran axis as a result of the location of jet stream and subtropical high pressure cells.

Water

Given strong seasonal Mediterranean patterns, high annual variability of climate, natural aridity of the eastern flanks, and the constant thirst of plants, animals, and burgeoning human communities adjacent to the Sierra, water remains a subject of intense competition for all Sierran biota.

Water partitions the Sierra into twenty-four readily discernible river basins or watershed units. Streams, creeks, and temporary waters define subwatersheds at increasingly smaller scales within these areas. Watersheds at each scale are important to a diverse aquatic biota, including fishes, amphibians, invertebrates, and plants. Aquatic and their associated riparian systems are the most altered and impaired habitats of the Sierra. At middle and low elevations, fish diversity of pre-contact streams was high compared with the present. Chinook salmon and steelhead once ran in most of the major Sierran streams but now have been nearly eliminated from the range due to dams and impoundments, which profoundly alter stream-flow patterns and water temperatures. Decline in other native fish species is also evident, especially at lower elevations. The best indicators of health of the aquatic system may be the group of organisms least known—invertebrates. These small creatures are rarely seen by most people but are central to the functioning of aquatic ecosystems and represent the majority of species diversity. Some species are highly specialized, occurring only in a few wetlands, springs, or small streams.

Extensive and abundant populations of frogs and salamanders once inhabited most Sierran streams, lakes, and wet meadows. Frogs are now missing from many of these habitats. More than 4,000 lakes in the high Sierra—most of them naturally fishless—once supported a diversity of aquatic amphibian and invertebrate species. Non-native fish, introduced for sport fishing, now dominate most of these high Sierran lakes and have radically transformed aquatic ecosystems at the expense of native amphibians and invertebrates. Despite apparent protection of natural resources by wilderness and other reserve area designations, native aquatic biota have suffered extensive local extinctions and are threatened rangewide.

Plants and Vegetation

The Sierra Nevada today is rich in vascular plant diversity, with more than 3,500 native species of plants, making up more than 50% of the plant diversity of California. Hundreds of rare species and species growing only in the Sierra Nevada (endemics) occupy scattered and particular niches of the range. Three native species are believed to be extinct from the range, whereas hundreds of non-native species now occur in the range that were not present before Euro-American settlement.

Vegetation, or the assemblage of plants growing together in an area, is a dominant element of Sierran ecosystems, for ecological functions that plants engage in (e.g., soil aeration) and as habitat and sustenance for other organisms. The distribution of wildlife is closely associated with the distribution of vegetation, and the same is true for less visible and less familiar forms of life such as fungi, bacteria, and insects.

The major vegetation zones of the Sierra form readily apparent large-scale elevational patterns. Unlike aquatic systems, whose dominant Sierran pattern is defined by east-west watersheds, primary vegetation types of the Sierra form north-south bands along the axis of the Sierra. Major east-west trending watersheds that dissect the Sierra into steep canyons form a secondary pattern of vegetation in the Sierra. Diversity of regional and local plant species in the Sierra Nevada is highly influenced by climate, elevation (temperatures), and soil type, and eighty-eight primary vegetation types are recognized. Only part of the Sierran landscape is forested, the rest being meadow, chaparral scrub, woodland, savanna, canyon land, alpine habitat, bare rock, and water. The boundaries of the Sierran floristic province differ from boundaries defined by geology, watersheds, aquatic diversity, or wildlife, especially at the northern and southern edges of the range. Of all the Sierran vegetation types, the foothill plant communities have supported the most native biodiversity and highest human populations during the last few centuries. Now these are most at risk of loss by conversion to human settlement.

On the west side, forest types change from ponderosa pine to mixed conifer to firs with increasing elevations. On the east side, forest types change from piñon pine and juniper to Jeffrey and ponderosa pines and an east-side version of mixed conifer. Straddling the crest is a zone of subalpine and alpine vegetation. Each vegetation type in the Sierra is in itself a mosaic. Small changes in topography, differences in soil and rock characteristics, and the history of disturbance (fire, storm blowdown, insect and pathogen activity, avalanche) contribute to the complex mixture of patches that characterizes Sierran forests. Plant patterns vary not only from place to place in the Sierra but also over time. This complexity at the local scale makes it difficult to map vegetation, to generalize relationships of structure to function, and to assess forest conditions.

Characteristic structure and function develop in Sierran forests as they age. Under aboriginal conditions, fires and other disturbance events regularly burned entire stands of trees, leaving openings that passed through continuous but distinctive phases as they aged. This succession of a forest through time between major disturbances is important for plants and animals that use different stages as habitat. Different ecological functions develop with successional phase in a forest. From seedling colonists to mature forest stands, forests develop in structural complexity and species composition until they reach a stage known as late successional, or more popularly, old growth.

We know most about late successional/old-growth attributes—and the relationships of structure to ecological function—in middle-elevation conifer forests, specifically mixed conifer, red fir, and east-side pine. A dominant feature in middle-elevation forests is the spatial variability that develops as a result of succession in Sierran forests. In these and other vegetation types, wildfire was a frequent characteristic of pre-contact conditions. The vagaries of fire, from low to high intensity, small to large areas, contribute to the great variability that typifies Sierran middle-elevation forests. Each stand passes through its own history, thus developing a distinctive structure. Various events (tree fall, windfall, avalanche, fire hot spots, insect outbreak) create small and large openings in some areas, whereas other areas maintain standing trees (alive and dead) despite disturbance. Patches develop a characteristic structure in their abundances of large, old trees (relicts left after ground fires); multiple age classes of live trees; mixtures of dominant species; snags and downed woody debris of different sizes and degrees of deterioration; closed crown canopy; and layers of vegetation. Collectively the forests containing these patches are highly heterogeneous. The image evoked popularly by the term *old growth*, that is, extensive uniform stands of even-aged, old trees, although descriptive of some Pacific Northwest forests, does not fit the complex and heterogeneous Sierran forests.

Depending on forest type, about 19% of the current distributions of middle-elevation conifer forest types are presently in high-quality late successional condition. National parks contain the major concentrations of these forests, and, proportionately, have about four times as much forest in late successional condition as the Sierran national forests (for west- and east-side mixed conifer, white fir, and red fir). Despite alteration of the national park forests due to fire suppression, forests in the parks represent the best available benchmark for presettlement amounts of late successional forest at these elevations in the Sierra. The most commercially valuable forest types, namely, west-side mixed conifer and east-side pine, are the most deficient in high-quality late successional forests. These types have had the longest and most intense histories of timber harvest.

Despite timber harvest, fires, livestock grazing, and mining, there is still a high level of continuity in middle-elevation forest landscapes. The forest cover at these elevations is relatively continuous, and most forested stands have sufficient structural complexity to provide for at least low levels of late successional forest functions. Fragmentation of forests through patch clear-cutting has been much less common in the Sierra than on federal forest lands in the Northwest. Though forest continuity is high, forest structure has been greatly simplified relative to pre-contact conditions.

Over the past decade, Sierra Nevada conifer forests have experienced widespread, locally severe levels of mortality caused principally by bark beetles infesting trees stressed by drought, overdense stands, and pathogens. Pine and fir forests in the Tahoe Basin and along the eastern slope of the Sierra have been especially affected, although heavy losses in firs have occurred in central-western forests. Along the western boundary of the Sierra, air pollution stress contributes to extensive mortality. Although fire suppression and some forestry practices are implicated in the die-off, outbreaks of similar extent are recorded to the beginning of the twentieth century and appear to be the natural condition.

The oak woodlands, grass savannas, and riparian communities of the Sierra Nevada foothills are the most ecologically transformed terrestrial ecosystems in the range. These communities have been converted at an alarming rate over the last century, first for rangeland clearing and more recently for residential and industrial developments. In the mid-nineteenth century, the perennial herbaceous understory in these communities was virtually replaced by introduced annual Eurasian grasses and herbs whose life history traits differ greatly from those of native species, and those traits create major transformations in ecological function that ripple through the ecosystem. Most areas have been grazed heavily for many years or converted to agriculture. Local firewood collection has reduced the abundance of large, old trees, snags, and fallen logs. Riparian habitats in the foothill zones have suffered proportionately greater reduction than those elsewhere in the range, with species reduction and total removal of vegetative cover in many places.

Animals

About 400 species of terrestrial vertebrates (including mammals, birds, reptiles, and amphibians) use the Sierra Nevada, although only a fraction are restricted to the range. Animals that live in the Sierra Nevada depend greatly on the distribution and quality of vegetation for their habitat and food needs. Many native Sierran species are adapted to habitats maintained by the presettlement fire regime. Although only a handful of species require late successional habitats, many more depend on the presence of large, old trees, snags, and logs in Sierran woodland and forest communities for some part of their life cycle. Late successional and riparian forests are important habitats to wildlife, as are the low-elevation foothill woodland types. In the latter zone especially, conversion of habitat and loss of ecological function have dramatically altered the suite of species that flourish in these communities. A common and important pattern for Sierran birds is their migration up and down slopes, following seasons. When a specific habitat needed for completion of a critical life stage (e.g., foothills for breeding) is disrupted, species may be put at risk even if they are able to use alternative habitat for other needs.

Three modern species once well distributed are now gone from the Sierra Nevada. These are grizzly bear, Bell's vireo, and California condor. Fifteen terrestrial vertebrates now well established in the Sierra are not native to the range. Several of these have had significant detrimental impacts on the ecology of the Sierra and its native species. The most serious effects have been produced by the brown-headed cowbird, which arrived in the range early in the twentieth century. The spread of this nest-parasitizing bird has mirrored the spread of farmland, grazing, clear-cut logging, and suburban development. Cowbirds are implicated or directly charged with the decline of several songbirds in the Sierra Nevada, especially willow flycatcher, Bell's vireo, yellow warbler, and chipping and song sparrows.

The conversion of oak woodlands has had substantial effects on terrestrial vertebrates. This zone once supported some of the highest species densities in the range. Lower elevations in this region provided key habitats to many Sierran species that are short-distance altitudinal migrants. Now many of these habitats are gone or greatly diminished in quality and extent, with concomitant effects on animal species. Loss of riparian habitats in this zone has been especially critical.

Humans in the Sierra

Humans are an integral part of Sierra Nevada ecosystems, having lived and sustained themselves at various elevations in the region for at least 10,000 years. Indigenous populations were widely distributed throughout the range at the time of European immigration. Archaeological evidence indicates that for more than 3,000 years Native Americans practiced localized land management for utilitarian purposes, including animal hunting, forest burning, seed harvesting, pruning, irrigation, and vegetation thinning. These practices no doubt influenced resource abundance and distribution in areas of early human settlement. On a longer timescale, humans may have played a role in the decline of large vertebrates during prehistoric times. Extinction of a large and diverse megafauna throughout western North America, including the Sierra Nevada, at the end of the last major ice age (around 10,000 years ago) coincided with the arrival of humans in North America. Some scientists link these extinctions to overhunting by humans of animals already stressed by changing environments.

Immigration of Euro-American settlers in the early 1800s began a period of increasingly intense resource use and settlement. By the late 1800s, parts of the Sierra had been transformed as a result of intense interest by these immigrants in Sierran resources. For example, grizzly bear and foothill bighorn sheep were driven to extinction locally, and mountain meadows were transformed by the excessive grazing of this period. Agriculture, mining, logging, and grazing activities were extensively practiced in many regions of the Sierra. The need to divert water to support resource extraction and settlement led to a major reordering of natural hydrological processes through a vast network of ditches and flumes. In some areas, impacts from early use of the Sierra created rapid and irreversible changes from presettlement conditions.

By the early 1920s, a new phase of Sierran history was emerging, in which resource use was more regulated and forest and range protection was emphasized. Suppression of fires became a primary goal of federal, state, and private efforts, controls were imposed on the timing and locations of grazing, and timber harvest was systematized under government and industrial forestry programs. Although trends of use have varied over the last 150 years, increasing population pressure and complex demands on Sierran resources pose serious ecological threats in some regions and severe management challenges elsewhere.

Settlement patterns and resource use have historically reflected the export value of Sierra Nevada resources as commodities. The foothills became a focus of early attention for Mother Lode gold deposits, timber, water, and agriculture. An estimated 150,000–175,000 people moved into the Sierra Nevada from 1848 to 1860. The population in 1970 was about 300,000, and by 1990, over 650,000 people were living in the Sierra. About 70% of the current population are located on the west-side foothills of the Sierra Nevada, with other concentrations in the vicinities of the main Sierran highways. Projections suggest that the entire Sierra Nevada will grow in population to somewhere between 1.5 million and 2.4 million residents by the year 2040.

New residents are increasingly drawn by the amenity values of Sierra Nevada resources as they seek a high-quality living environment. Retirees, commuters, and exurban migrants are all coming to the Sierra Nevada at the same time that employment is declining in the traditional resource-extraction industries, changing the social, economic, and ecological fabric of the region. The new residents are decreasingly dependent on resource extraction and increasingly bring outside sources of income into the region. Over the past twenty years, the economy of the Sierra Nevada region, like the population, has more than doubled. The major commodity-based sectors—agriculture, timber, and mining—experienced little or no growth in employment. On a rangewide basis, recreation and tourism provide more jobs and roughly the same total amount of wages as all the commodity-based sectors combined. The economic stimulus from new businesses, commuters, and retirees is now far greater than that provided by all the commodity and recreation-based employment in the region. One of the major implications of this trend is that the economic character of the region is less influenced by the major resource industries and agencies and is becoming more similar to the diverse economy and society of California as a whole.

Community well-being in the Sierra is undergoing transitions consistent with changing settlement patterns and resource uses in the region. About 15% of the Sierra population live in communities with high well-being. More than half of these communities are in the Sacramento commuter counties of Nevada, El Dorado, and Placer. About 20% of the total population of the Sierra live in communities with low levels of well-being. More of these communities are in the northern Sierra than other regions, although scattered communities with low or high well-being exist throughout the region. Some communities, such as the greater Lake Tahoe Basin area, have distinct patterns of unequal distribution of wealth and well-being, with areas of extreme poverty surrounded by communities of wealth and high community capacity.

For many residents, air quality is an important aspect of quality of life in the Sierra Nevada. Air quality varies greatly depending on region. Northern airsheds, with the exception of some local communities where winter woodsmoke creates health hazards, generally are among the cleanest in the nation. Southern airsheds, by contrast, are heavily impacted by ozone and have some of the poorest air quality in the nation. Ozone damage is occurring in conifer forests of middle and high elevations, particularly in the southern western forests. We know little about the levels of ozones and other particulates that are acceptable to biota, but federal standards for humans may be inadequate for some other species. Dust storms over the alkali and dry lakes of the eastern Sierra create episodic health hazards to humans and presumably to plants and other animals as well. Air quality in the Sierra Nevada is at a critical point, with moderate to severe degradation becoming all too often accepted as the status quo. Unlike other areas in the state, the Sierra has ozone levels that are not declining. Except at a few places like Lake Tahoe, Mono Lake, and some urban communities, little effort is being made to address reduced visibility in the Sierra, the source of which primarily is the Central Valley.

MANAGEMENT STRATEGIES FOR ECOSYSTEM SUSTAINABILITY

SNEP developed a number of strategies to address problems found in the assessments. These focus on specific individual ecosystem components of the Sierra Nevada and on combinations of elements. The latter examples illustrate how in practice actual solutions must integrate multiple overlapping components and adapt to local needs and constraints. The strategies are briefly summarized here.

Population and Settlement

The Sierra Nevada is likely to undergo significant land conversion because of population growth over the next half-century. The amount of land converted will depend on the rate of population growth, the spatial pattern of settlement, and the average density of homes. Four alternative futures of settlement over this time period were estimated from models of settlement, existing density options from county General Plans, and population projections from the state Department of Finance.

If current population growth and settlement patterns continue, then half the private land in the Sierra would be settled. If a more compact form of settlement were followed, then the land area occupied would still double from the present amount. If low population growth and compact development were chosen, then little additional land (8% more) would be required, assuming that infill and carefully targeted density transfers are used. Under any future scenario, however, significant changes in land-use and infrastructure policies will be needed to achieve lower impact on critical habitats, especially in the foothill zone, where many unique vegetation types are at risk.

Community Well-Being

Greater reinvestment in ecosystem management and restoration activities may provide an opportunity to improve well-being in some Sierran communities. Such activities are likely to have the most impact on improving well-being in communities that already have a moderate level of community capacity—that is, where the residents have sufficient knowledge and other attributes necessary to take advantage of new job opportunities (almost half of the communities in the Sierra). If greater reinvestment occurs, then the range of ecosystem management activities could be quite large (e.g., monitoring, maintenance and restoration of forest roads, erosion control, mining reclamation, fuels reduction, stand density management). All activities would require a change in reinvestment patterns for natural resource management. Many activities would require significant training (e.g., scientific training for monitoring) or local economic development (e.g., access to capital and vocational training for watershed rehabilitation) to effectively improve socioeconomic status and hence improve well-being.

Other ways of improving well-being include making the link between forest commodity use and local communities. This approach would make products available locally for processing and secondary manufacturing development and provide capital and price incentives for such activities.

Institutions

Strategies are suggested to (1) improve return from beneficiaries of the Sierra to those who will maintain and enhance the ecosystem qualities from which benefits flow, (2) strengthen cooperation among federal, state, and local governments and agencies whose authorities and resources overlap in the ecosystem and strengthen cooperation between the public and private sectors, (3) increase community involvement in the protection and management of Sierran ecosystems, (4) provide legal, regulatory, and financial support to advance such reforms beyond current levels of *ad hoc* spontaneity, (5) take advantage of characteristic aspects of Sierra Nevada regions to leverage progress on issues of regional and rangewide scale.

Fire and Fuels Reduction

SNEP strategies recognize fire as a major ecological process in the Sierra Nevada that exerts profound influences on the evolution of Sierran ecosystems. Today the wildland-urban intermix of homes and flammable fuels, other widespread forest fuel hazards, and the potential for intolerable forest resource damage from major forest conflagrations require overall strategic planning by federal, state, and local agencies and the affected public with attention to cost and benefits of proposed actions. Such planning would seek to (1) avoid further community development in flammable wildlands without mitigating fuel hazards, (2) establish defensible space / fuel reduction zones buffering communities and certain wildlands, (3) identify other resource-threatening intolerable fuel hazards and prescribe mitigation treatment, (4) support a return of managed fire and prescribed wildfire, where practicable, to specific forest areas to provide the natural ecological functions believed necessary for ecosystem health and sustainability, and (5) advocate strong prevention and suppression capability.

Biodiversity Management Areas

The biodiversity management area (BMA) strategy is a forward-looking, scientific conservation approach to efficiently reducing the vulnerability of Sierran biodiversity and conflicting land uses. BMAs are specially designated public or private lands with an active ecosystem management plan whose purpose is to contribute to regional maintenance of native genetic, species, and community levels of biodiversity. The strategy uses mapped information about land ownership, land use, potential impacts to biodiversity, and biological communities to identify biological types (e.g., vegetation types and their associated animal species) most in need of protection and to calculate the most efficient or least-cost solution to providing protection for some predetermined proportion of each such type identified.

Applications of BMA alternatives indicate that satisfactory solutions to represent all plant community types of the Sierra cannot be found that use public lands alone for BMAs, that the contribution of matrix lands (i.e., lands outside the BMAs) is essential to achieving rangewide goals, that a modest degree of overlap with other SNEP biodiversity strategies can be achieved, and that some areas appear especially well suited to serve as BMAs. Certain regions (e.g., the northern Sierra) would require more lands in BMAs to achieve targeted levels of biodiversity protection than others (e.g., regions containing the national parks).

BMA Case Study in El Dorado County

An application of the BMA approach was developed for watersheds in El Dorado County. This case study emphasizes the cooperative, multisector, multijurisdictional nature of effective biodiversity conservation in the Sierra Nevada. In El Dorado County, all adequate BMA solutions required the inclusion of significant private lands, because many important biological communities are almost entirely unrepresented on the public lands. On the other hand, the BMA strategy shows how several of these communities can be included in one watershed to improve the efficiency of the solution.

Areas of Late Successional Emphasis

SNEP analyzed six strategies to counter the major declines in high-quality late successional forests and to enhance forest late successional conditions throughout middle-elevation conifer forests of the Sierra. Each strategy assumes that existing high-quality late successional forests must be retained and expanded to support the full range of organisms and functions into the future, that distribution of late successional conditions across the landscape involves a combination of focus areas and management of matrix land, and that fire is reintroduced into the forest.

The areas of late successional emphasis (ALSE) strategy was developed in detail by SNEP with new simulation models, multiple alternatives, and explicit landscape solutions. The strategy was developed primarily for west-slope forests, specifically mixed conifer and red fir / white fir types on public lands. The strategy stratifies forestland into two landscape categories. ALSEs are large areas (20,000–60,000 acres) with a management emphasis on maintaining forests in late successional conditions. Active management would occur in ALSEs—primarily use of prescribed fire, although some mechanical fuel treatment could be allowed. Fire protection of ALSEs would receive high priority. Matrix lands, those forested areas exclusive of ALSEs, would typically have management objectives other than to attain late successional representation. Restoration of late successional structures in these lands to minimum standards is an essential part of this strategy.

Distributed Forest Conditions

An alternative strategy was developed that distributes rather than concentrates areas of late successional emphasis widely over the landscape. Targeted for east-side middle-elevation conifer forests (but applicable elsewhere), this strategy divides the planning landscape into watershed units of about 5,000 acres. As in the ALSE strategy, the watersheds would be divided into cores and matrix areas. On about 30% of each watershed (about 1,500 acres, but not necessarily contiguous) the main management objective would be to maintain late successional conditions. Additional biodiversity values would be given high priority in core areas, including restoration and maintenance of native plant diversity and genetic diversity.

Emphasis would be on minimal disturbance, although mechanical treatments would be permitted to attain goals.

The remaining matrix areas in each watershed would be available, as appropriate, for more intensive uses. Matrix management would include maintenance of late successional structure and function to the degree possible.

Integrated Case Study for Eldorado National Forest

A forest condition case study was applied to the Eldorado National Forest. It illustrated how seven other SNEP strategies might be integrated in practice and included goals for (1) late successional forest, (2) vegetation and plant communities, (3) wildlife habitat, (4) watersheds and aquatic organisms, (5) fire protection and fire ecological function, (6) community well-being, and (7) private land contribution. This case study incorporated a wide range of strategies to bring an integrated approach for systemwide benefits. Explicit solutions were developed that illustrate the important role of private lands and collaborative planning, adaptive management, and monitoring. They also showed the need for reinvestment to fund ecosystem restoration and management, the risks associated with increased use of fire for fuel reduction, and other implications that emerge from implementation.

Grazing and Rangelands

The grazing and rangelands strategy focuses heavily on educating responsible persons about the undesirable impacts likely to occur if prescriptive and adaptive management techniques are not adopted and continually adjusted through careful monitoring of a suite of proven criteria. Mountain meadows, upland shrublands, hardwood rangelands, and stream/riparian ecosystems each possess restoration needs and capacities that can be enhanced through careful cooperative management. Increased ecosystem functionality and increased agricultural productivity can be complementary goals for many sites in the Sierra Nevada.

Water and Aquatic Organisms

Conditions that lead to deterioration of aquatic and riparian ecosystems vary among the watersheds of the Sierra but sort into three main categories: changes in timing and quantity of flow, disturbance from land-use practices, and changes in biotic communities from non-native organisms. Strategies to improve conditions would begin by clearly identifying the causative agent or interactions that are prevalent in a particular aquatic habitat or watershed.

In some cases, small changes in reservoir releases, water management, or watershed condition could create substantial improvements in the viability of aquatic systems while costing little to those who make the changes (e.g., discontinuation of fish stocking in some high mountain lakes should help restoration of mountain yellow-legged frog populations). In other cases, costly managerial changes may have little biotic effect. There is a need to differentiate among these situations and to identify when voluntary cooperation, compensation, and prescriptive enforcement are likely to work best. Improvement in conditions and use of available funds and expertise could occur by watershed-scale and Sierra-wide coordination, reinvestment, and collaboration among the diverse interests and institutions affecting the aquatic environment.

Air Quality

The air-quality strategy uses existing regulatory standards and remediation technologies to improve specific problems identified. These include (1) reducing ozone levels through rigid enforcement of the current standard of 0.09 ppm peak hourly rate, (2) reducing fine-particle pollution by enforcing current emission standards, particularly related to Bay Area refineries and summer agricultural burning in the Central Valley, and (3) minimizing smoke from Sierra Nevada residential sources while increasing controlled forest burning during spring and fall to avoid catastrophic wildfires.

INSTITUTIONAL INTEGRATION OF ASSESSMENTS AND SOLUTIONS

The strategies examined by SNEP represent responses to problems identified in the Sierra Nevada through the SNEP assessments. The strategies are not fully analyzed alternative management schemes, nor does any one strategy address all aspects of the ecosystem. Rather, they are potential components of regional or rangewide alternatives yet to be formulated. As these strategies are taken together, common properties emerge that SNEP suggests will characterize successful approaches to sustainable management of the Sierra Nevada.

Whole Systems

The strategies collectively consider the Sierra Nevada to be a whole system. Although individual SNEP strategies are incomplete, they show how actual solutions must address not just parts of the system but also the way in which parts interact to create the whole. The full scope of those interactions brings together things hitherto considered separate: core forest areas and matrix, people and nature, regions within and regions outside the Sierra.

The strategies emphasize sustainable management over the entire landscape. For example, the areas of late successional emphasis (ALSE) strategy incorporates management of the lands between core areas of late successional emphasis (i.e., the matrix) and management of core areas themselves. Similarly, the biodiversity management area (BMA) strategy depends largely on the contribution of lands outside the BMAs. The distributed forest conditions strategy proposes that sustainability of late successional forests emerge as a property of entire landscapes, not small reserved portions thereof. Reserves, when discussed, are viewed as part of a larger conservation strategy. Managing the entire landscape for ecosystem sustainability requires that public and private resources and lands be considered together, along with the suite of institutions and rights associated with them.

The diversity of the strategies indicates that addressing whole systems means confronting the full range of system components: physical, biological, and social. The system consists not just of biological structures, such as old-growth stands, but also of ecological functions and human communities—both communities of place within the Sierra and communities of interest elsewhere in the state and nation. SNEP strategies illustrate these components and scales and demonstrate how components could be linked in practice.

The strategies also reveal different scales within the larger Sierran ecosystem. Some strategies respond to regional issues: for example, air quality in the southern Sierra, distributed forest conditions in the eastern Sierra, county buildout on the west slope. Others address truly rangewide concerns: for example the BMAs, ALSEs, and aquatic strategies. The aquatic and air-quality strategies suggest a scale that extends far beyond the range itself.

Finally, the whole system is not static and changes over time. The fire strategy addresses a significant source of change in the Sierra and also emphasizes our uncertainty about the historic scope of fire and the risks associated with its purposeful application. Social dimensions of the mountain range change as well. These dynamics are addressed by the county buildout and community well-being strategies. The nature of change requires that management approaches be flexible enough to learn from and adapt to changing ecological and social conditions.

The view of the Sierra as a whole system, or a web of biological and social influences stretching over and beyond the range and evolving over time, suggests that no easy policy or technical “fix” can be implemented in the Sierra Nevada. Many institutions will absorb, elaborate, and recast SNEP strategies to find solutions. Congressional involvement is essential to recasting policy in the Sierra. Existing federal laws constitute part of the web of influences that has served to bring parties together in search of new solutions. The rest of the web is composed of important state and local institutions and their associated laws and policies, as well as affected parties and stakeholders wherever they live. Considerations of cost, local variation in landscape attributes and their conditions, different patterns of land ownership and human communities, as well as other varying factors argue for flexible program design and implementation.

Collaboration

Collaboration among various agencies, private interests, and the public at large in the Sierra is the most significant principle that emerges from SNEP strategies. As they collaborate, agencies, private landowners, and the public begin to function as interacting parts of a whole system, and the number of ways to balance use and environmental quality increases exponentially. Collaboration may also encourage private landowners to innovate and to develop creative approaches that will accomplish broad ecological goals in advance of regulations. The mix of lands and resources in the Sierra, including intermingled private and public land, required SNEP to assess ecological conditions at appropriate scales and develop strategies at similar scales: for example, accounting for cumulative watershed effects required that solutions be addressed by all watershed stakeholders. These examples suggest that actual strategies must also extend across property or jurisdictional boundaries.

Successful collaboration requires a mix of expertise and considerable institutional support. Mobilization of people and resources and coordination of activities may require collaboration at a local scale, but as activities engage more technical, financial, or legal issues, specialized expertise usually found in state or federal agencies will be required. Collaboration will succeed to the extent that it receives ongoing support from top management and feeds directly into existing budgets, business processes, and agency missions.

Collaboration springs out of perceived mutual interest. State and federal agencies and other interests have experience in collaborating, especially in response to disasters and threats to life and property. A potential for improvements in service and structure of incentives may also lead to collaboration. In the absence of others threats, avoiding potential regulation remains one of the most powerful incentives to collaborating. Decentralizing control and restructuring agencies to focus on clients may greatly enhance effective collaboration.

Careful restructuring of natural resource laws could encourage participation, thereby reducing the temptation to withdraw and increasing the effectiveness of collaboration. The incentive for collaboration diminishes if alternatives provide apparently quicker, albeit incomplete, resolution for individual participants. Bilateral negotiation rather than full collaboration, for example, probably will lead to only partial solutions, perceptions of bad-faith bargaining, and a retreat to adjudication.

Collaboration will collapse if any of the parties attempts to dominate. Like any negotiation, successful collaboration is based on mutual respect for the rights and equity of all participants. This concept is particularly clear in the case of private landowners, for whom equity is generally expressed in terms of land values. It applies as well to public agencies and takes the form of legal authority, budgets, and scope of action. For members of the public, the form it takes is less established but no less important.

Goal Setting

The development of goals is fundamentally a social and political process rather than a technical one. SNEP’s contribution lies in defining important dimensions of goals—for instance, old growth, aquatic biodiversity, community well-being—rather than the goals themselves. Identification of specific goals requires active participation of all stakeholders. Although the need for goals to organize human activity may appear self-evident, the barriers to convening and managing the development of ecosystem goals are enormous. Convening such a process requires common acceptance of the whole ecological and social system, joint understanding of how the system works, and a shared sense of the importance of the values at stake. Lake Tahoe is a good example in that its value is tangible to people, it is related to its watershed through water and sediment flows, and it has loss of clarity as the preeminent problem. Other issues that have a central ecological role and impact on economic value, such as the erosion of biodiversity and fire, may also bring stakeholders together.

Public agencies can incorporate collaborative goal setting into their land-management mission. They are already able to contribute technical, legal, and financial expertise to the goal-setting process, and they are also capable of representing and interpreting rangewide and national perspectives. They can also help to convene the full range of stakeholders needed to address issues, ownerships, and jurisdictional and even cultural boundaries. This process may involve trades and negotiations among participants. In so doing, agencies would not direct the goal-setting activities but rather, within legal and practical limits, participate in a manner that allows stakeholders to achieve common understanding and agreement.

Funding Management and Restoration

The SNEP strategies focus primarily on technical or planning aspects of management and restoration. Generally they do not attempt to specify cost or funding source. The fire and ALSE strategies propose some harvest of timber and biomass. These activities will produce income but may not cover the full cost of the strategies. None of the strategies are likely to succeed unless they look beyond nearby commodity outputs to identify the full range of beneficiaries of their actions and to devise mechanisms to recover a portion of that benefit. For instance, for those activities in the fire strategy that seek to reduce the likelihood of large, severe wildfire, specific beneficiaries that should be included are local property owners, distant metropolitan water consumers, regional air-quality boards, fire-control agencies, and national disaster relief agencies, among others. Successful projects depend on equitable allocation of costs to appropriate beneficiaries and use of appropriate mechanisms to recover those costs.

Arrangements for funding and cost recovery associated with implementation of the strategies will require innovative approaches that might include establishing fees or markets or allocating rights to be traded. Enabling these mechanisms may require legislative involvement even while retaining local flexibility. Equally, legislative proposals to permit local or regional cost allocation and recovery should provide opportunities for site-specific experimentation and further modification as these arrangements mature or as the local and regional conditions and objectives change.

Regional Context

Translation of SNEP strategies into actual policy may proceed more easily through development of regional policies for the different regions of the Sierra. These regions differ in population levels, density, and growth, and in the manner in which they incorporate costs of resource use and environmental risk, governmental coordination, and activism. The pattern of employment, commodity production, and services directly dependent on the Sierra Nevada ecosystem varies greatly across the range; economic linkages clearly define distinct regions within the Sierra. SNEP strategies emphasize different issues in different regions. For instance, the air-quality strategy is important in the southern Sierra, the fire strategy emphasizes the west-central Sierra, and the grazing strategy focuses on the Modoc country and eastern rangelands. Consequently, agencies and other institutions that are critical to the resolution of ecosystem management problems in one region may be much less important in others. Similarly, funding arrangements are likely to vary significantly from region to region. It is, therefore, unlikely that a single model or policy would apply equally well across all regions, except perhaps one that encouraged widespread institutional innovation toward ecosystem stewardship.

Monitoring and Adapting

To determine if the strategies achieve ecosystem sustainability, someone must monitor. To do this requires a commitment to design, finance, and adapt over the long term.

The most effective monitoring programs would generate information on effects at several spatial scales. For instance, the distributed forest conditions strategy attempts to achieve a desired regional condition by implementing treatments incrementally at the watershed level. Monitoring only within watersheds where treatment has proceeded will not answer how well the strategy is achieving the regional condition.

Monitoring a strategy's results relative to its goals is a necessary part of adaptive management. An open process is necessary to build trust; without it, monitoring can fuel conflict rather than reduce it. In many instances, no single agency or group is available that will be considered impartial by all stakeholders, in part because values influence interpretation as well as methods. Building trust in monitoring processes requires agreement on the choice of methods and multistakeholder (or multiparty) involvement. With particularly sensitive issues, all-party participation in monitoring may also be required.

Decision processes must incorporate specific mechanisms for changing the direction of the policy or project. Monitoring data that highlight inadequacies is of little use without a concomitant process for shifting strategies or reallocating resources. The need for institutional flexibility is particularly important. For example, in addressing issues related to the fire ecosystems of the Sierra, unexpected catastrophic fires may quickly change the context of ecosystem management by reducing old growth, degrading watershed condition, or creating new options for fuel management.

The importance of monitoring argues for the establishment of a broadly based convener to facilitate range- and regionwide coordination. Organization of such a group—whether it arises at the local, regional, or Sierra-wide level—must be structured to fit the need. However construed, it ought to be collaborative in nature, be authoritative in charge, and focus on monitoring local conditions for achievement of rangewide goals and strategies. Such a group, for example, could help to assemble information in the year 2000 to examine improvements or changes in the following:

- Quantity and distribution of Sierran old-growth forests
- Status of conditions of concern:
  - ozone levels, local air-quality problems
  - amphibians
  - riparian quality
  - vertebrates at risk
  - community well-being
  - restoration of fire and treatment of fuel conditions
  - trends of native grasses and alien weeds on rangelands
  - foothill habitats
- Other emerging issues

Also inherent in the strategies is a need for a central caretaker of information to develop and maintain data pertinent to rangewide monitoring and planning. A manager would have responsibility for organizing and synthesizing local databases as part of rangewide systems and would ensure coordination of distributed databases. Decentralized input of information, as well as access to existing data sets, could be obtained through the Internet, with public access available on-line or through public terminals at libraries and other public locations. Decentralized information also would facilitate a system whereby public agencies and others could provide appropriate tools and expertise, together with training on how to employ these technologies, that would enable local governments, other public agencies, and individual citizens to use these sources of information in ecosystem planning and monitoring.

Optimism for the Future

SNEP assessments reveal a great wealth of knowledge, expertise, and involvement in the ecological integrity of the Sierra. The concern of many individuals and groups for the region's future is of long standing and well known. Less publicized is that, in some areas, people with strong ties to the region have already joined together to assess environmental conditions and to create dynamic regional strategies for resource management and environmental stewardship. In the process, diverse communities are being engaged in the search for solutions. As dialogues about collaboration begin to occur across ownerships and jurisdictions, one can anticipate the development of further solutions to issues that are best observed and addressed at the landscape or watershed scale.

After many years of attempting unsuccessfully to "declare" various natural resource policies, agencies now realize that no single optimal policy can be delineated, much less implemented. Local and regional approaches to problem solving, however, are complementary to central planning and can make positive contributions to ecosystem conservation. Regional and subregional delineation, as it occurs, will further involve shared responsibility, power, and leadership by individuals and groups who are quite capable of working with public resource agencies to develop solutions to many resource management problems. Agencies can learn from people while not abdicating responsibility for ensuring that the public interest is protected. Public enthusiasm can make an enormous difference. If the energy and optimism now present in the region and in the larger Sierra community can be embraced, society will gain a great opportunity to move resource policy forward in the Sierra. On the other hand, if public concern and awareness are not channeled into current efforts to address the environmental issues in the Sierra, many institutions and individuals who now willingly give their time and energy to this cause may become discouraged and turn away from collaborative efforts.

SNEP's research, assessments, and strategies offer confidence that a change in approach to management of natural resources and ecosystems is possible, desirable, and indeed already under way in parts of the Sierra. The next phase in improving environmental quality in many areas of the Sierra involves less focus on redrawing jurisdictional boundaries or enacting more stringent mandates and more focus on building coalitions and stronger communities.

THE FUTURE

This study, like other major ecosystem assessments, raises our understanding to a new level. In the process, many new questions and uncertainties are revealed. Weaknesses in how existing knowledge has been used become apparent. The need to know and to use knowledge wisely is unending. The need to refine the delicate relationship between how we use and extract resources from the Sierra Nevada and how we live in the mountain range will continue. The Sierra Nevada is also a treasure for those who live around the nation and the world. Its future condition involves this wider interest.

With the end of this project a new process begins. The people must examine the ideas and test them against their own sense of validity and need for change. Several major themes are present in this report.

First, we have identified problem areas and offered some alternatives for addressing them. In some cases, problems have emerged because of unintended outcomes of use of resources and, in others, because of a change in social values. Left unresolved is the question of whether our society has the will and the capability to correct such problems. Implementation of new approaches or possible solutions is the responsibility of the public and its institutions. The beginning is to acknowledge that problems exist: willing minds and able hands can find solutions.

Second, most of the problems of the Sierra can be solved, although the timescale and degree of solution will differ depending on the problem. For example, economic conditions, wildlife habitat, forest structure, and community well-being are restorable. Reduction of damaging air pollution could occur in a matter of days, but restoration of complex forest structure might take a century and recovery of degraded river channels, even longer.

One problem that is irreversible is loss of species and loss of distinct populations of species. There is a well-known parable about wisdom: does the wise person eat the seed corn or plant the seed corn? Plant, of course, for the future. But if one is already starving, the outcome will be the same regardless of the choice. Options exist now for charting the course toward restoration. Failure to use these options increases the chance of irreversible loss and reduces the range of options available over time.

Third, because our understanding of complex human communities and ecological systems is never perfect, all strategies for improvement are in some ways experiments. Learning as we go and adjusting as necessary work best when we give as much care and planning to measuring the response to new management strategies as we do to implementing them. Changes in our agencies and institutions will be necessary to adjust this balance between measuring outcomes and implementing new management. Monitoring designs that compare different approaches among agencies and private landowners could have the added value of collaborative efforts, sharing of resources and expertise, and more efficient testing of alternatives. The blessings of abundant resources may have allowed us to temporarily avoid the questions of sustainability and to establish highly independent resource agencies. The future may not allow the luxury of either.

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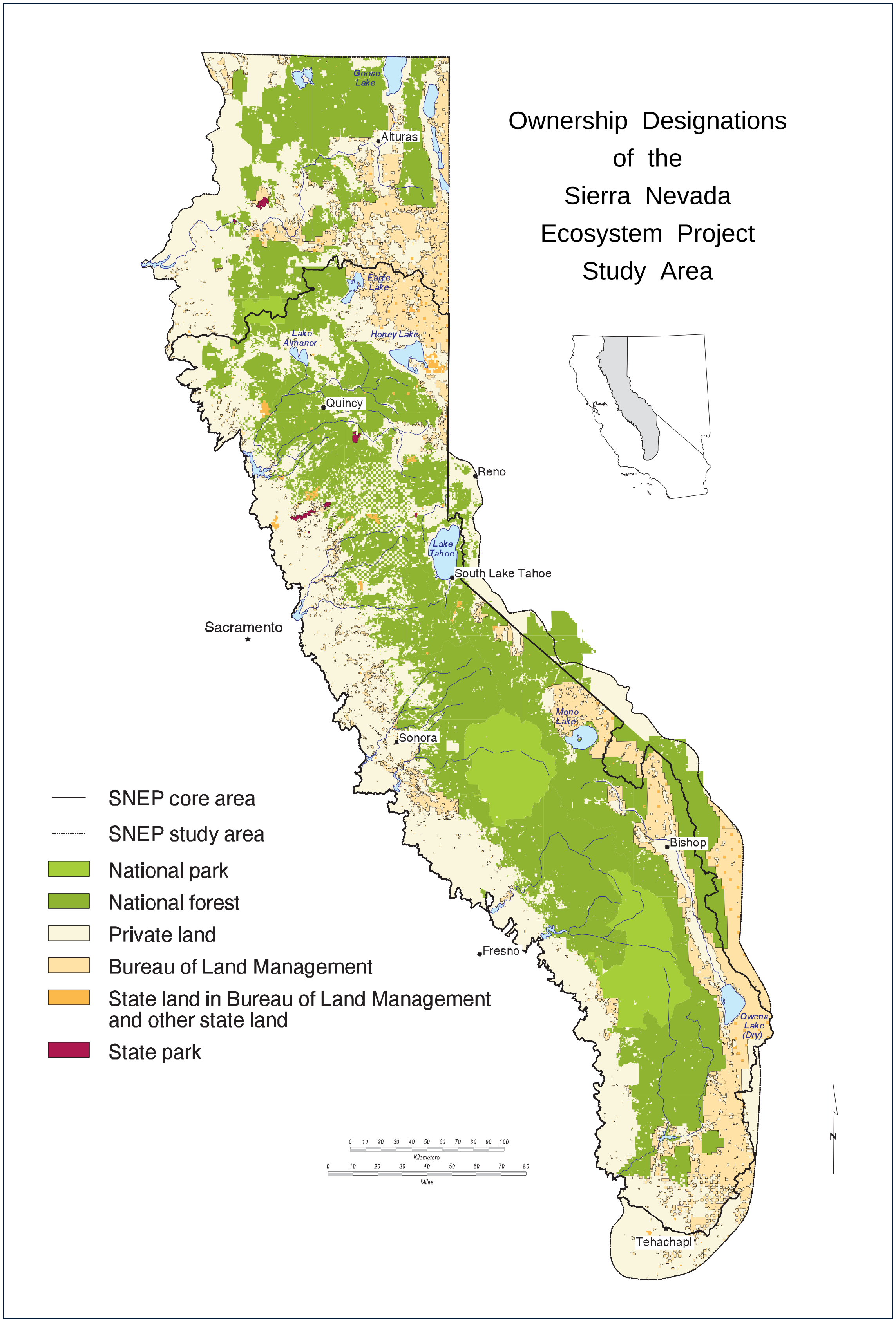

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