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Assessment Summaries and Management Strategies

Sierra Nevada Ecosystem Project
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CHAPTER 8

Watersheds and Aquatic Biodiversity

❊ CRITICAL FINDINGS

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.

Riparian Status Riparian areas have been damaged extensively by placer mining (northern and west-central Sierra) and grazing (Sierrawide), and locally by dams, ditches, flumes, pipelines, roads, timber harvest, residential development, and recreational activities.

Sediment Excessive sediment yield into streams remains a widespread water-quality problem in the Sierra Nevada.

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.

Introduced Aquatics Introduction of non-native fishes (primarily trout) has greatly altered aquatic ecosystems through impacts on native fish, amphibians, and invertebrate assemblages.

Amphibian Status Amphibian species at all elevations have severely declined throughout the Sierra Nevada.

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.

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.

ASSESSMENT

California's economy derives enormous benefits from water diverted from the streams, rivers, and lakes of the Sierra Nevada. A major cost associated with these benefits has been deterioration of the biotic integrity and sustainability of the aquatic systems, as reflected in declines in the distribution and abundance of native aquatic and riparian organisms. Water determines the distribution and abundance of many plants and animals throughout the Sierra Nevada by shaping and providing habitat. Lakes and streams support rich communities of native organisms both in the water and in adjoining riparian areas. These water bodies also support cities, farms, and industries within and distant from the mountains. That water was critical for development of the mining economy that dominated California for years after the gold rush. The Sierra Nevada has provided high-quality water for natural communities for millennia and for modern society for more than half a century. But in less than twenty years the risk of *Giardia* has spread to such an extent that virtually everywhere in the mountains one can no longer casually drink from a stream or lake, and concern for other microorganisms, such as *Microsporidium*, in water supplies is growing. Development of streams and other resources of the Sierra Nevada over the past 150 years has met the downstream demands of society throughout California but has impaired the quality and availability of water for both ecological and social needs in many parts of the mountain range.

Aquatic Ecosystems

Aquatic and riparian habitats are linked in direct and complex ways and are fundamentally dependent on natural flows of water. Natural supplies of water and its constituents (mineral particles, solutes, organic matter, biota) are highly variable over time, changing markedly between seasons and between years and over space. The native biota is well adapted to these seasonal patterns and extremes, but Californians have not been satisfied with the natural distribution of water and have engineered extensive control over the waters of the Sierra Nevada. Hydrologic processes have been further modified by side effects of the development of other natural resources of the Sierra Nevada. As human activities have altered characteristics of streams (such as volume of water, flood peaks, duration of low flows, seasonal timing, sediment supply, amounts of nutrients and organic matter, and water temperature) aquatic and riparian ecosystems have been forced to change. Other ecological changes have been deliberate, such as introduction of exotic species (e.g., brook trout, bullfrog), conversion of streams to lakes, and conversion of riparian zones to roads and structures.

In many respects aquatic systems have shown remarkable resilience. Vegetation along many streams gutted by mining has returned. Agencies are beginning to recognize the special nature of riparian areas, and some are developing practices intended to protect in-stream and associated resources.

❊ *A Past View of Resources in the Lahontan Region*

"A discussion of the economic value of the fishes of this region and any consideration of methods of propagation and protection must begin and end with the assumption that agricultural and manufacturing interests are of paramount importance. A considerable and constantly increasing amount of the flowing water must be used first for power and then for irrigation, and when any measure intended for the protection of fishes is found to seriously interfere with the working of power plants or the demands of agriculture it will have to be abandoned."

John Otterbein Snyder, Fish Biologist
Bulletin of the U.S. Bureau of Fisheries 1915/16

Present-day water projects at least recognize that the aquatic system requires some flows to exist. And some fisheries agencies personnel are becoming attuned to the needs of all organisms rather than the special management of a few. Nevertheless, the net results of a century and a half of these disturbances to the Sierra Nevada are greatly simplified and impaired aquatic ecosystems. Aquatic and riparian habitats have been severely altered and continue to deteriorate, leading to the loss of native species, ecosystem functions, and services to human society.

Invertebrates

The best indicators of the health of the aquatic system of the Sierra Nevada may be the group of organisms we know the least about—invertebrates. These small creatures are rarely seen or considered by most people, but they are central to aquatic ecosystems because they consume algae and organic matter and become food for fish, birds, mammals, amphibians, and reptiles. These organisms represent a great diversity of species. Species restricted to the Sierra Nevada (endemic) in two major groups of aquatic insects, the caddisflies and the stoneflies, were estimated for this report to be 19% (of 199 species) and 25% (of 122 species), respectively. A wealth of evolutionary, ecological, and biogeographical information is contained in Sierra aquatic invertebrates. Some species are highly specialized and are found only in a few wetlands, springs, or small streams. When these limited habitats are altered, their dependent invertebrates are likely to disappear.

Shifts in composition of invertebrate communities suggest changes in aquatic habitat or water quality, and invertebrates have been used to assess changes for many years. The great diversity of aquatic invertebrates makes them an especially valuable tool for monitoring almost any kind of aquatic habitat. The invertebrate fauna of the Sierra Nevada has probably changed dramatically since the 1850s because of major changes in habitat and some species have become extinct. However, few species-level inventories of aquatic invertebrates exist for the Sierra, and the distribution of most species is poorly known.

Fish

Native fishes are much better known than their invertebrate food supply and are also at risk from changes in water availability and quality, habitat alteration, and introduction of exotic species. Of the forty species of fishes native to the Sierra Nevada, six are formally listed as threatened or endangered and twelve others are candidates for listing. Four other fishes are in decline within the Sierra Nevada but are less threatened elsewhere. Less than half of the native fish species of the Sierra Nevada have secure populations. The long-term causes of the declines are introductions of exotic fishes, dams and diversions, alterations of stream channels, and watershed disturbance (grazing, mining, roads, logging, etc.). These different problems occur throughout the range and usually operate in combination to degrade and dissect aquatic habitat. This habitat fragmentation, in turn, allows piecemeal extirpation of local populations.

Chinook salmon are a principal example of the drastic declines in native fishes of the Sierra Nevada. In the ninteenth century, more than a million salmon spawned annually in the streams of the west slope, with some ascending to an elevation on 6,000 feet. However, the curtain of dams across the Sierra Nevada rivers blocked access to about 90% of the original spawning habitat (figure 8.1). Consequently, spring-run chinook salmon, present in less than 10% of their original numbers, have been virtually eliminated from the Sierra Nevada except for those spawning in a few undammed tributaries to the Sacramento River (such as Deer Creek and Mill Creek).

Fish are one of the most intensively managed components of the ecosystems of the Sierra Nevada. Occasional transfer of fish in buckets in the 1800s has exploded into hatchery production of millions of fish and mechanized stocking at hundreds of sites throughout the range. At least thirty non-native fishes have become established in the Sierra Nevada, and ten of these exotic species are now widespread and abundant. Before the active manipulation of fisheries, most of the Sierra Nevada above 6,000 feet lacked any fish fauna. Hundreds of miles of streams and almost all of the more than 4,000 natural lakes of the Sierra Nevada were dominated by invertebrates and frogs until widespread trout introductions began in the ninteenth century. Trout are now present almost everywhere in the range that is capable of supporting them. In Sequoia, Kings Canyon and Yosemite National Parks fish stocking was terminated in the lakes in the 1980s. Recent regional surveys show that trout have disappeared naturally from 29–44% of these previously stocked lakes. Many high-elevation lakes

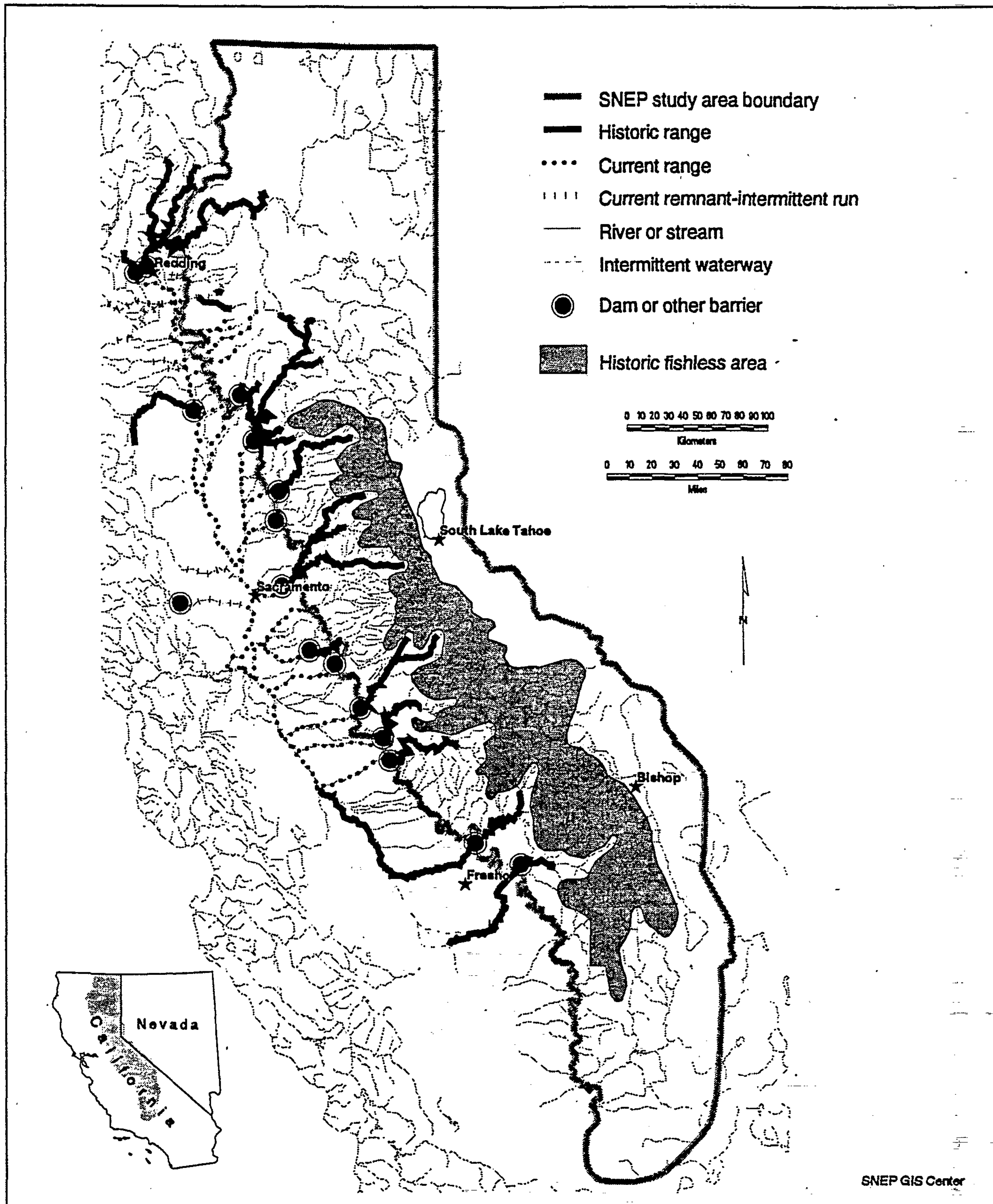

FIGURE 8.1

Two major changes in Sierra Nevada fish distribution. The shaded area shows streams and lakes that historically were without fish but that now mostly contain them. The dotted and heavy lines show current and historic distrubution, respectively, of chinook salmon. (From Volume II, Chapter 33.)

outside the national parks are still regularly planted with trout to support recreational fisheries. This artificially maintained fishery provides substantial angler use, and fishing in the high-elevation lakes remains a major objective of those who visit these sites. Nevertheless, the predatory trout have greatly altered lake and stream ecosystems, resulting in local and rangewide changes in species assemblages of aquatic invertebrates. Introduced trout are also a factor contributing to the decline of some native amphibians, in particular the mountain yellow-legged frog, whose former distribution is almost perfectly coincident with the former fishless zone (figure 8.2). Further, the widespread use of fish poison for fisheries management in Sierra streams and lakes for more than forty-five years has had undetermined impacts on nontargeted organisms.

Amphibians

Amphibians have suffered sharp declines in abundance, distribution, and diversity throughout the Sierra Nevada and elsewhere. Half of the twenty-nine native amphibian species are at risk of extinction because of declining populations or

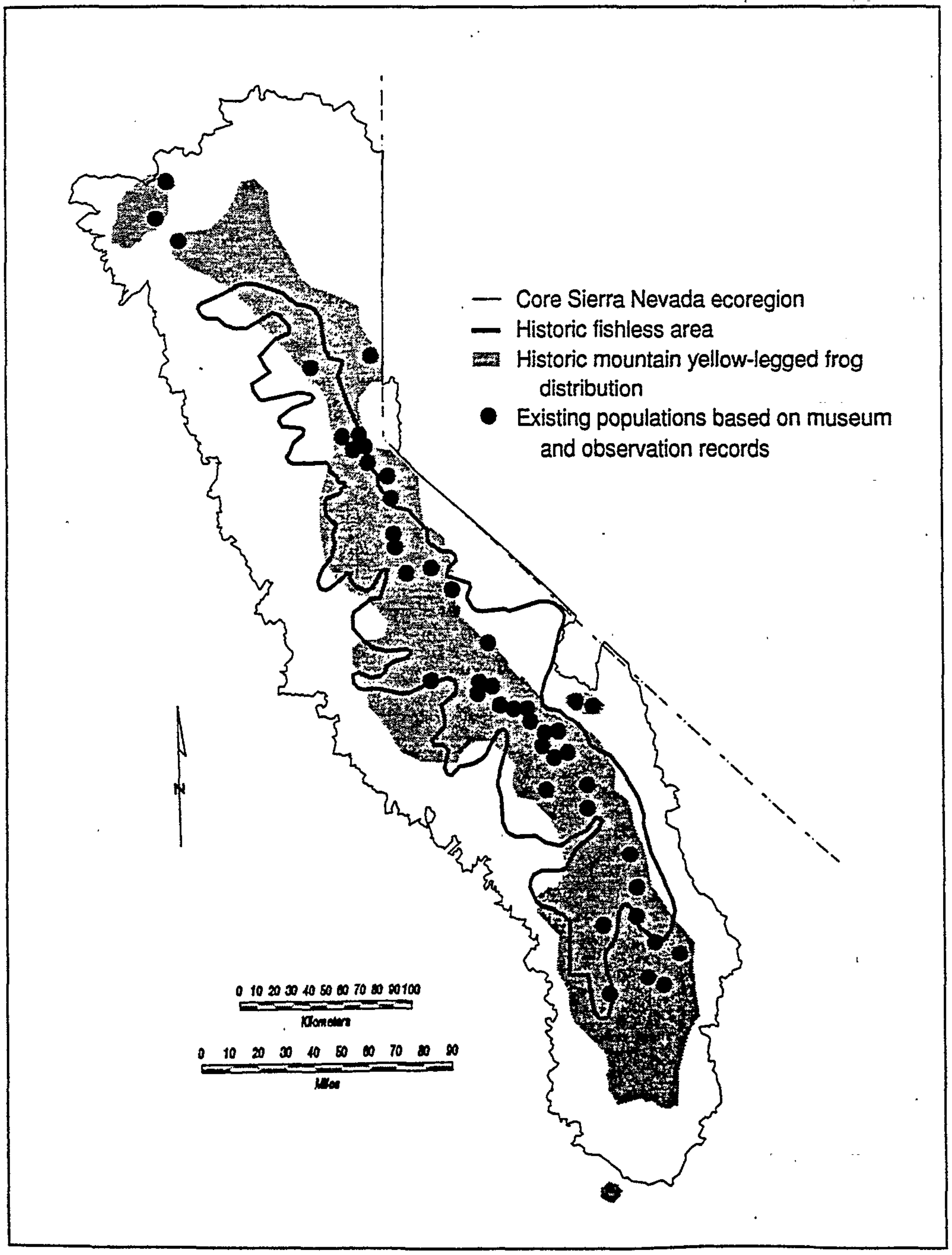

FIGURE 8.2

Decline of Mountain yellow-legged frog and association with historic fishless area in the Sierra Nevada. Current known populations of frog are shown as dots compared to the frog's former range, which closely coincided with the historic fishless area. Most lakes in the historic fishless area now contain populations of non-native fishes, which were introduced for sports fishing and are implicated in the decline of mountain yellow-legged frog. (From volume II, chapter 32.)

❆ *Deer Creek Watershed Conservancy*

"Spring-run Chinook salmon and Steelhead once occurred in many streams throughout the Central Valley. Today these incredible fish occur in only a few Sacramento Valley streams, including Deer Creek. The important populations are monitored to ensure their continued existence. The survival of these fish has depended on the caring stewardship of property owners within the watershed and their future will rely upon continued responsible management of the land."

Deer Creek Watershed Conservancy, Vina, California

(Photo by Peter B. Moyle)

very limited distributions. The Breckenridge Mountain slender salamander, absent in all recent searches, is already considered extinct. Species in danger include eight of the twenty salamanders and seven of the nine frogs and toads. Of the fourteen endemic amphibians in the Sierra, twelve are in danger of extinction. The decline of frogs is particularly alarming because they are now missing from a wide variety of habitats, ranging from alpine lakes to foothill streams. Populations of several frog species formerly stretched in a continuous band from north to south in a specific range of elevations for each species. There are also waters where native amphibians are still surviving. In the foothills, these tend to be small streams that have a dense riparian canopy, that are free of introduced species, and that have not been disturbed by grazing and other impacts. At high elevations, populations are found in clusters of fishless lakes and streams in remote areas. These observations show that populations of most amphibians, especially frogs, are no longer connected but exist as isolated groups that are highly vulnerable to extirpation. Current ecological theory strongly suggests that species such as these depend upon linkages among the populations that collectively span great distances or elevations. Fragmentation and extirpation without hope of recolonization may lead to local, then regional, then Sierra-wide, extinction of amphibian species if present trends continue.

Aquatic Habitats

The decline of native fishes and amphibians and changes in aquatic invertebrate assemblages in the Sierra Nevada largely reflect the deterioration of aquatic and riparian habitats. They have been altered by development of water and other resources. Of sixty-seven types of aquatic habitat categorized in the Sierra Nevada, almost two-thirds (64%) are declining in quality and abundance, and many are at risk of disappearing altogether. Factors contributing to this deterioration are many and cumulative. The health of any part of an aquatic system depends on all the influences of the channel network and watershed upstream of that point. In spite of better land-use practices, excessive sedimentation continues to be observed and documented in site-specific analyses, even though systematic, rangewide monitoring is lacking. Implementation of newer practices designed to prevent sedimentation (practices officially designated as best management practices under the federal Clean Water Act) may be too recent for positive results to be observed in some systems. But the close associa-

❃ *Watershed Risk Assessment*

Potential for soil erosion was classified for watersheds in the Eldorado National Forest (only a small portion is shown in figure 8.3). Remote sensing and geographic information systems produced data on slope, vulnerability to soil erosion, and amount of bare ground. Threshold values were estimated for each factor. Figure 8.3 shows those regions (based on map units of 0.22 acres) where no factor, one factor, two factors, or three factors exceeded threshold. The resulting map points to likely problem locations and to areas where mitigation or restoration projects would be most effective in reducing the cumulative effects of natural and human-induced watershed changes. (From volume II, chapter 54.)

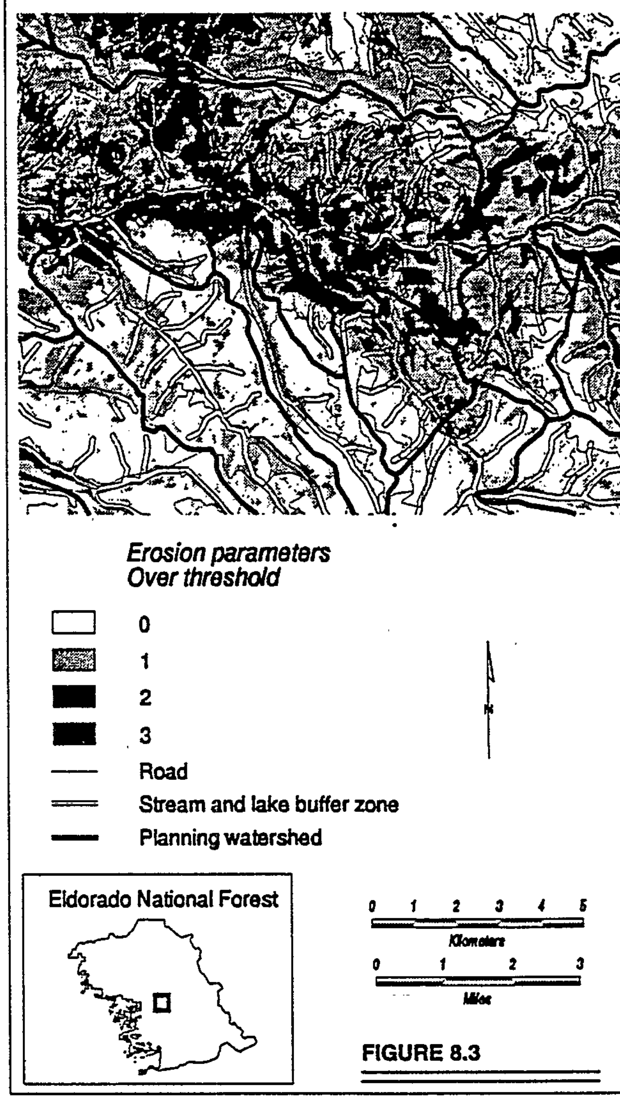

FIGURE 8.3

tion between roads and sedimentation and the pervasive nature of roads within the streamside corridor mean that chronic problems may be persistent and difficult to overcome.

The land areas near water bodies (riparian areas, stream and lake management zones, etc.) are crucial as habitat for a large group of species. Approximately 17% of Sierran plant species, 21% of the vertebrate species, and almost 100% of aquatic invertebrate species in streams are closely associatedwith or dependent on riparian or wet areas. This area also yields essential inputs of food, nutrients, wood structure, and energy to the aquatic system and buffers the effects of land use. Thus it provides several vital functions: special terrestrial habitat, aquatic structure, energy/food resources, and buffer. It is also the region to which historically it was easiest to gain access (roads), and it is fundamentally attractive to cattle grazing. Overgrazing and livestock concentration in riparian zones has altered stream morphology and vegetative composition in many areas throughout the Sierra Nevada. Intense grazing has been so widespread that few ungrazed reference sites exist for comparison. Riparian protection is recognized in current state and federal land-use management policies and has expanded in the past two decades; for example, clear-cut logging to a stream margin was practiced into the 1970s. Nevertheless, existing standards still do not adequately provide for sufficient land area or describe appropriate management for maintenance of all the vital functions. Small aquatic habitats (e.g., springs, intermittent streams) are more affected by adjacent land use than are larger streams and lakes, yet they generally fall under lower standards of protection. Wetlands and springs in the Sierra Nevada have been modified by water development, road construction and drainage, grazing, and residential development at large scales (e.g., Tahoe Keys) and on individual parcels. Foothill areas below about 3,300 ft appear to have the

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greatest loss of riparian vegetation of any region in the Sierra Nevada. In addition to land disturbance, creation of large reservoirs has submerged about 600 miles of riparian corridors along larger rivers, further fragmenting riparian habitat.

Direct modification of streams by dams, diversions, and channelization projects has had major, permanent impacts on larger streams and associated riparian zones where most of these projects have been built. Dams and water diversions of all sizes affect most watersheds in the Sierra Nevada (figure 8.4). Placer and hydraulic mining in the 1800s devastated streams and riparian zones, which are now partially recovered. But dredging operations were only the initial disturbance to which more recent impacts have been added. If population growth occurs as projected, new pressure is likely to be intense to extract local sources of stream gravel for roads and building.

Recovery and Restoration

Although few changes other than extinction are irreversible in an absolute sense, many environmental modifications can be considered to be effectively irreversible. Most structures, such as large dams, canals, residential developments, and highways, are permanent for practical purposes. However, impacts from permanent structures can often be reduced by changes in use of the structures or by creative mitigation. Other persistent impacts, such as unsurfaced forest roads and agricultural fields, can be removed or mitigated, and ecological functions of the site can be restored with sufficient investment. Cessation of chronic disturbances, such as grazing or trampling in riparian areas, seasonal water diversions, and stocking of nonreproducing fish, will allow natural recovery of different aspects of an ecosystem at varying rates. For example, wet-meadows converted to dry terraces above an incised stream as a result of overgrazing may not recover even over a century without active restoration work. Riparian vegetation tends to become reestablished within a few years after chronic disturbance is eliminated, but readjustment of channel morphology to a natural shape may require decades. Although disturbances such as a single timber harvest or a fire can have severe short-term effects, natural recovery from them generally occurs at a much faster rate than recovery from chronic disturbances.

Knowledge Base

The knowledge base for improving water allocation and implementing sound watershed management in the Sierra Nevada is notably weak. Economic values of water in different uses are not well established. Information about water demand and historic water rights is not easily accessible. Records of water quality and sediment yield are available at very few sites throughout the mountain range. Rates of natural and accelerated erosion have not been measured at many locations in the Sierra Nevada. The impacts of various water and land management practices are not quantified or even known in some cases. In the few cases where long-term, rangewide surveys exist, such as grazing transects in wet meadows on the national forests, data have not been summarized until now. The effectiveness of best management practices and restoration techniques are largely untested. In general, the basic data for sound decision making about improving water and watershed management are lacking. Specific habitat requirements of most riparian-dependent terrestrial vertebrate species are poorly documented, and general surveys of species distribution for most aquatic invertebrate species are missing. Adequate monitoring of natural processes, impacts, mitigation, and restoration could provide a much better basis for water resources planning and administration. Inadequate information is currently a major constraint on improvements in water and land management.

In summary, the aquatic/riparian systems are the most altered and impaired habitats of the Sierra. Species losses and changes in species assemblages have been accelerated in aquatic and aquatic-connected habitats. Frogs, in particular, have been declining at an alarming rate in recent years. Native fish and other assemblages have been fragmented by water projects. Many aquatic species are either listed as threatened or endangered or will be candidates for listing if present trends continue. The declines were especially severe during the first hundred years of water development, starting with hydraulic mining. Although declines have subsequently slowed in most cases, many continue and there is little evidence of long-term improvement in the status of aquatic organisms.

Restoration, better management, and research are needed to recover lost habitat, prevent further loss, and monitor efficacy of management. Suggested solutions are outlined in the strategies and in the individual assessments of volume II.

STRATEGIES FOR IMPROVING WATERSHEDS AND AQUATIC BIODIVERSITY

Goals

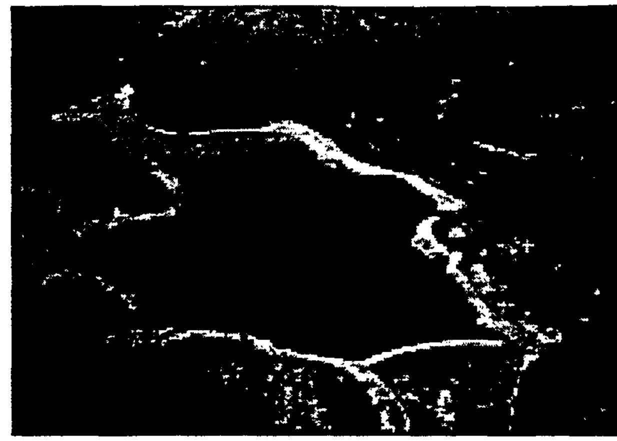
Strategies for improving watersheds and aquatic biodiversity have two goals:

- Improve the biotic integrity and sustainability of aquatic habitats and ecosystems in the Sierra Nevada. This goal implies that protection, management, and restoration of watersheds is needed to maintain natural hydrologic and ecological processes.
- Secure long-term social and economic benefits of a dependable supply of clean water from naturally-functioning watersheds.

❀ *Mercury Contamination*

"Anthropogenic mercury is present in the aquatic biota throughout the historic Sierra Nevada gold region. Higher mercury regions include the highest densities of active dredging operations, which also correspond to the greatest historical mining. Bioavailable mercury shows amplification through the food chain. Although the absolute concentrations in rainbow trout presently are well below existing health standards, fish from some reservoirs in this region have markedly higher mercury than those in upstream rivers."

D. G. Slotton, S. M. Ayers, J. E. Reuter, and C. R. Goldman, Technical Completion Report, Davis: University of California Water Resources Center, 1995.



Upper-elevation reservoir on the Middle Fork Yuba river. Jackson Meadows Reservoir, Tahoe National Forest. (Photo by Richard Kattelmann.)

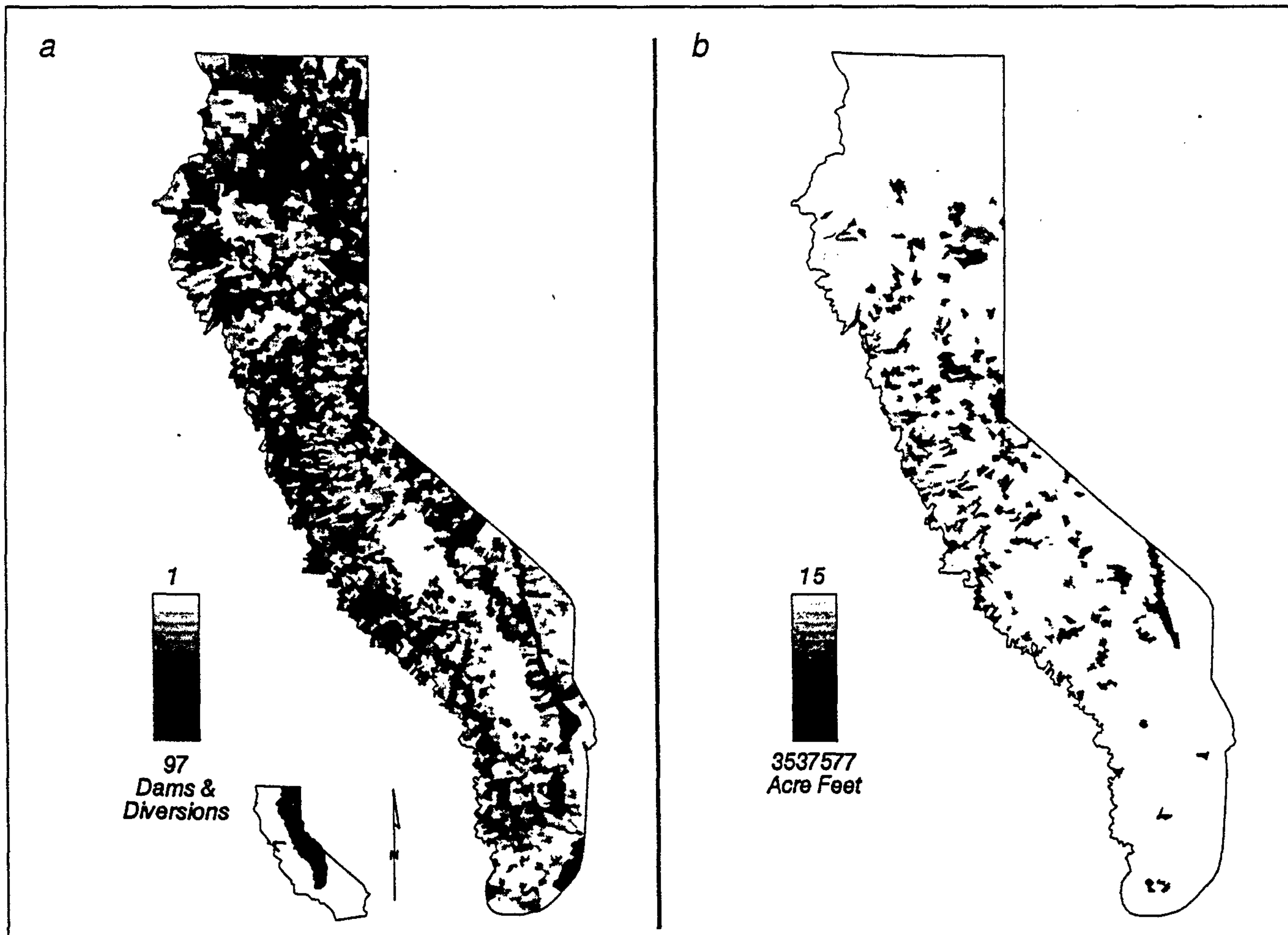


FIGURE 8.4

Relative density of dams and diversions in planning watersheds (*a*) and reservoir capacity in watersheds of the SNEP study areas (*b*). (From volume II, chapter 36.)

Functional riparian areas provide vital habitat for many terrestrial and aquatic organisms, large wood and food to a stream, and buffer land use. Sagehen Creek, Tahoe National Forest. (Photo by Jerry Morse.)

Possible Solutions

Conditions that lead to deterioration of aquatic and riparian ecosystems vary among different watersheds in the Sierra Nevada, but all river basins have been altered to some degree. Therefore, an optimal strategy for preventing further degradation includes all watersheds of the range but recognizes their differences. Such a strategy involves a mixture of approaches from protecting "the best of what is left" to restoring highly degraded systems. In addition to implementing long-term local and regional strategies, there is a need to prevent loss of species and habitats in the short term. There are also opportunities to reestablish chinook salmon and other native species of fish and amphibians to areas where they have been lost because of water development or introduction of exotics. Restoration of the functions of aquatic and riparian habitat where they are identified as impaired will support the recovery of imperiled species.

Watershed Focus

Problems and opportunities for solutions come from analysis on a watershed-by-watershed basis unless there are easier or more effective ways of doing so. A watershed approach allows connections to be made between upstream actions and downstream consequences and benefits. Evaluation of the health of individual streams and their watersheds could identify particular problems and their causes. Reduction of the adverse impacts of land disturbance (e.g., erosion, stream bank instability, loss of riparian habitat, loss of large woody debris and its recruitment) requires cooperation among citizens' groups, regulatory agencies, private landowners, and public land managers within a watershed. The Central Valley and Lahontan Regional Water Quality Control Boards may occupy the logical position to provide oversight and coordination of local watershed efforts. Alternatively, creation of regional boards with an ecosystem management focus might be considered to address problems that are connected across watersheds, such as restoration of native frog populations.

Restoration of Stream-Flow Pattern

In watersheds where water management activities degrade water quality and aquatic biodiversity, improvement may be possible by altering some aspects of reservoir or diversion operations. In general, restoring some semblance of a natural stream discharge regime (such as increasing minimum flows or peak flows) is beneficial to aquatic health. Voluntary adjustments in operations, greater use of conjunctive water-use practices, changes in timing and volume of releases from reservoirs during relicensing, and more stringent enforcement of the Fish and Game Code provide mechanisms for improving streamflows.

Reserve Systems and Management Practices

In watersheds where the principal problems are caused by land disturbance, there is a wide spectrum of possibilities, with different mixes being appropriate in different river basins. A reserve strategy of protected watersheds might be necessary to sustain and improve the few remaining areas of relatively natural flows or high biological integrity (e.g., Deer and Mill Creeks, Tehama County; Clavey River; North Fork Calaveras River; Middle and South Forks Kings River; North and South Forks Kern River). A system of protected areas could be maintained with variable mixes of public and private controls appropriate to each watershed, including economic incentives to landowners for protection of unique or unusual areas. In addition, it is critically important to apply locally-adapted best management practices to all lands to minimize soil loss and impacts on aquatic systems.

Institutional Innovations

New policies and institutional mechanisms must be designed to recognize the ecological importance of riparian areas, minimize further disturbance and fragmentation, and provide incentives and funding for restoration activities. On public lands, a well-supported and financed effort is needed to relocate roads, campgrounds, and other incompatible uses out of riparian areas.

Improved riparian and in-stream protection can be achieved by designing variable-width buffers that recognize the dependent terrestrial community habitat requirements, energy and food supplies, and management-influence areas adjacent to aquatic systems. Existing data combined with GIS technology allows layout of such buffers as a first step until more refined information is obtained on-site. Continued efforts to rewater dry and near-dry channels below diversions could proceed through enforcement of existing laws and changes in in-stream flow requirements during relicensing of hydroelectric projects. Changes in road location and grazing management practices are needed to avoid further damage to mountain meadows and spring systems. Existing regulatory approaches to wetlands conservation require better coordination among agencies, local governments, and citizens' groups.

Restoration of Native Species

Runs of anadromous fish could be restored where feasible (e.g., San Joaquin River below Friant Dam and the Kings River below Pine Flat Dam) by maintaining adequate flows through altering reservoir release schedules, improving physical habitat, and improving water quality. There is also potential to restore salmon and steelhead above major dams wherever large expanses of suitable spawning habitat still exist (e.g., American River). Restoration of native species, especially amphibians, to some of their original range could be accomplished by controlling competing exotic species in carefully selected areas and avoiding new introductions. As a tradeoff with recreational fishing, artificial stocking could cease in about a third of the high mountain lakes, where native frogs are under extreme threat from introduced fish, and the lakes could be allowed to revert to a fishless state.

Water-Use Payments

A possible funding source for expanded watershed and restoration activities is the beneficiaries of both the water-supply system and watershed management. A diversion tax on water is one possibility. Such a tax would be similar to severance taxes on minerals and yield taxes on timber, which have a long history in some jurisdictions. Taxes on diverted water as low as $1–10 per acre-foot would generate from $20 million to $200 million for stable long-term funding. A trust fund or conservancy could then finance watershed improvements and monitoring throughout the Sierra Nevada.

Monitoring

A major long-term commitment to collecting, analyzing, and evaluating physical, chemical, and biological indicators of the status of aquatic systems is needed. The Central Valley and Lahontan Regional Water Quality Control Boards could be the coordinators of such a program. Cooperators could include the Department of Water Resources, U.S. Geological Survey, U.S. Natural Resources Conservation Service, National Biological Service, federal land management agencies, the California Academy of Sciences, the University of California and other colleges and universities, local governments, water agencies, landowners, and citizens' groups. To provide adequate geographic coverage throughout the Sierra Nevada, dramatic improvements in efficiency over current data collection efforts would be necessary.

Implications

The economy of California largely depends on high-quality water originating in the Sierra Nevada and diverted to distant locations. Hydropower generated from falling water has been extensively developed throughout much of the mountain range. Watersheds with continuous vegetative cover and healthy riparian areas provide the highest-quality water which requires little or no treatment for human uses. The connection between watershed condition and downstream quality is rarely recognized by water users. Almost none of the high economic value of water at its end use is returned to the source area. If maintaining and restoring the conditions contributing to water availability and quality becomes an objective, then some of the value of water would need to be reinvested in the source areas. Other institutional changes in water allocations could lead to more efficient water delivery to higher-valued uses at lower environmental costs.

Watershed management is an alternative means of organizing agencies and coordinating between agencies and citizens' groups. Within each river basin, one existing management agency could assume leadership in organizing watershed efforts, or different organizations could cooperate in a mutually acceptable framework. The regulatory and adjudicative regional water quality control boards may be subdivided along watershed lines so as to facilitate such organization. In some cases, small changes in watershed management could create substantial improvements in aquatic systems at small cost to those who make the changes in other cases, costly managerial changes may have little biotic effect. There is a need to identify when voluntary cooperation, compensation, and prescriptive enforcement are likely to work best.

The primary criteria for measuring success of improved water and land management are improvements in the status of imperiled species and in water quality, especially sediment. Maintenance of populations of aquatic and riparian species that are currently stable, and nondegradation of currently high water quality are other important criteria. The success of new institutional arrangements and funding mechanisms could be evaluated on an efficiency and equity basis, but the status of aquatic ecosystems should be the basis for assessing new programs.