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Status of Fish and Fisheries

ABSTRACT

Forty kinds of fish are native to the Sierra Nevada; eleven of these taxa are found only in the range. The fish fauna and fisheries of the Sierra Nevada have changed dramatically since the massive influx of Euro-Americans began in 1850. Four broad patterns are evident: (1) anadromous fishes, especially chinook salmon, have been excluded from most of the riverine habitat they once used on the west side of the range; (2) most resident native fishes have declined in abundance, and the aquatic communities of which they are part have become fragmented, although a few species have had their ranges greatly expanded; (3) thirty species of non-native fishes have been introduced into or have invaded most waters of the range, including extensive areas that were once fishless, mainly at high elevations; and (4) Sierra Nevada fisheries have largely shifted from native fishes, especially salmon and other migratory fishes, to introduced fishes. One reflection of these patterns is that of the forty fishes native to the Sierra Nevada, six (15%) are formally listed by the federal and/or state government as threatened or endangered species, twelve (30%) are considered to be species of special concern because they are in trouble statewide and are potential candidates for listing or because they have limited distributions, four (10%) are in decline in the Sierra Nevada but are probably in less trouble than elsewhere, and eighteen (45%) seem to have stable or expanding populations. Among the species that have largely disappeared from the range are chinook salmon, steelhead, and five kinds of native trout. Fisheries for these species have been replaced, in part, by stream fisheries for non-native trout, often of hatchery origin, and by reservoir fisheries. The introduction of trout into several thousand originally fishless lakes at high elevations has greatly expanded fishing opportunities but has also caused declines of native invertebrates and amphibians. Introduction of non-native fish species has also been the single biggest factor associated with fish declines in the Sierra Nevada. However, this factor is intimately tied to major habitat changes and other effects of dams and diversions, as well as habitat changes caused by grazing, channelization, and other streamside activities.

INTRODUCTION

The native fish fauna of the Sierra Nevada consists of forty native taxa. Eleven (28%) of these taxa, including five kinds of trout, are found only in (are endemic to) the Sierra Nevada as defined by SNEP, and most (85%) are endemic to the Californian region of which the Sierra Nevada forms the core. These fish were widespread, abundant, and an important source of food for the Native Americans of the region (Moyle 1976a; Lindstrom 1993). The fish fauna and fisheries of the Sierra Nevada have changed dramatically since the massive influx of Euro-Americans began in 1850 (Moyle 1995). Four broad patterns are evident:

1. Anadromous fishes have been excluded from most of the riverine habitat they once used on the west side of the range.
2. Most resident native fishes have declined in abundance, and the aquatic communities of which they are part have become fragmented; a few have had their ranges greatly expanded as the result of introductions.
3. Thirty species of non-native fishes have been introduced into or have invaded most waters of the range, including extensive areas that were once fishless, mainly at high elevations.

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4. Sierra Nevada fisheries have largely shifted from native fishes, especially salmon and other migratory fishes, to introduced fishes.

This chapter examines these patterns by documenting (1) the original distribution patterns of the native fishes, (2) the current status of native fishes, (3) changes in the distribution and abundance of chinook salmon, (4) the causes of native fish declines, (5) the expansion of populations of non-native fishes, (6) the effect of the changing fish fauna on fisheries, and (7) the conservation implications of the changes.

ORIGINAL FISH DISTRIBUTION PATTERNS

The native fishes of the Sierra Nevada were found in four distinct zoogeographic regions, which shared surprisingly few species among them: (1) the Sacramento–San Joaquin drainage; (2) the Lahontan drainage, consisting of the Susan, Truckee, Carson, and Walker Rivers; (3) the Eagle Lake drainage; and (4) the Owens drainage. Each of these regions had assemblages (communities) of fish species that characterized different environments within the drainage (Moyle 1976a).

The Sacramento–San Joaquin drainage, which includes all watersheds on the west side of the range, had by far the richest native fish fauna, with twenty-two taxa found in the Sierra Nevada (table 33.1). This fauna included three abundant anadromous fishes—chinook salmon, steelhead rainbow trout, and Pacific lamprey—that were important in Native American fisheries. Chinook salmon, with four discrete runs, were particularly abundant and supported large commercial fisheries in the nineteenth and early twentieth centuries. The Lahontan drainage supported only ten native fish species in the Sierra Nevada, but these fish were also widespread and abundant in the low- to middle-elevation rivers and lakes, and were major sources of food for the Native Americans (Lindstrom 1993). Lahontan cutthroat trout were abundant enough to support commercial fisheries in the nineteenth century, especially in Lake Tahoe and Pyramid Lake, Nevada.

Eagle Lake could be regarded as the northernmost part of the Lahontan drainage in the Sierra Nevada because it shares three fish species with the drainage, but it is an independent watershed that also supports an endemic subspecies of rainbow trout. The Owens drainage, in contrast, although also an eastern Sierra Nevada watershed, has its own distinct fish fauna of four endemic species, mostly confined to the Owens River itself. It was separated from the Lahontan drainage by the fishless Mono Lake basin.

All four of the major fish faunal regions shared a common trait with the Mono Lake basin: they were fishless at high elevations. The high-elevation regions were largely fishless (figure 33.1) because of the combination of extensive glaciation during the Pleistocene (which created most of the lakes) and steep topography (which created many barriers to natural fish invasions). In streams, the highest elevations reached naturally by fish (ca. 3,000 m [9,800 ft]) occur either in unglaciated areas in the southern portion of the range (Kern River) or in the more accessible mountain streams on the east side. Only about twenty lakes naturally contained fish (e.g., Eagle, Tahoe, Donner, Fallen Leaf, Independence, Weber, Convict), which is considerably less than 1% of the total. All such lakes were closely associated with streams containing fish and had no barriers to invasion.

In the western Sierra Nevada, the fish reaching the highest elevations were trout, but in some circumstances other species were also found at elevations above 1,500 m (4,900 ft). Coastal rainbow trout, the trout native to most west-side watersheds, were mostly found below 1,500 m. For example, in the Merced River they reached only Yosemite Valley (1,400 m [4,400 ft]), and in the Tuolumne River they did not reach Hetch Hetchy Valley (1,100 m [3,600 ft]). In the Middle Fork of the Kings River, however, trout may have reached elevations higher than 2,200 m (7,200 ft). In the Kern River drainage, Little Kern golden trout reached about 2,400 m (7,900 ft), Kern River rainbow about 2,500 m (8,200 ft), and California golden trout about 3,000 m (9,800 ft). The only native nontrout species found at high elevations on the west side is the Sacramento sucker, which occurred naturally as high as 2,500 m (8,200 ft) in the Kern River.

In the eastern Sierra Nevada, the highest elevations were reached by Lahontan cutthroat trout (more than 3,000 m [9,800 ft]) and Paiute cutthroat trout (2,500 m [8,200 ft]). However, in the Carson, Walker, and Truckee drainages it was not unusual to find nontrout species (Paiute sculpin, Tahoe sucker, speckled dace, Lahontan redside) above 2,000 m (6,600 ft). These fishes also colonized Lake Tahoe (1,900 m [6,200 ft]), Independence Lake (2,118 m [6,950 ft]), Weber Lake (2,065 m [6,775 ft]), and a few other similar lakes. Fish were completely absent from the Mono Lake basin (including all streams), and the Owens River watershed did not historically contain trout. Of the four fishes native to the Owens River basin, only the Owens sucker was found above 1,500 m (4,900 ft), reaching Convict Lake (2,300 m [7,550 ft]), the only lake in the southeastern Sierra Nevada that naturally contained fish.

CURRENT STATUS OF NATIVE FISHES

The forty kinds of fish found in the Sierra Nevada represent twenty-four species. Six of the species can be divided into two to six forms (subspecies or runs of salmon) that can be recognized by their distinctive morphology and life history patterns. Many of the subspecies were originally described as distinct species (e.g., the golden trouts), and most are en-

TABLE 33.1

Native fishes of the Sierra Nevada.

Name	Drainage	Habitat	Status
Kern brook lamprey, *Lampetra hubbsi*[a]	Sacramento–San Joaquin	Lowlands	Special concern
Pacific lamprey, *Lampetra tridentata*	Sacramento–San Joaquin	Anadromus, foothills, lowlands	Declining
Mountain whitefish, *Prosopium williamsoni*	Lahontan	Foothills, high elevations	Stable
Chinook salmon, *Oncorhynchus tshawytscha*			
Spring run	Sacramento–San Joaquin	Anadromus, foothills, lowlands	Special concern
Winter run	Sacramento–San Joaquin	Anadromus, foothills, lowlands	Endangered
Fall run	Sacramento–San Joaquin	Anadromus, lowlands	Declining
Late fall run	Sacramento–San Joaquin	Anadromus, foothills, lowlands	Special concern
Rainbow trout, *Oncorhynchus mykiss*			
Resident rainbow, *O. m. irideus*	Sacramento–San Joaquin	Foothills, high elevations	Stable or expanding; introduced outside native range
Winter steelhead, *O. m. irideus*	Sacramento–San Joaquin	Anadromus, foothills, lowlands	Declining
Eagle Lake rainbow, *O. m. aguilarum*[a]	Eagle Lake	Foothills, high elevations	Special concern
Kern River rainbow, *O. m. gilberti*[a]	Sacramento–San Joaquin	High elevations	Special concern
Little Kern golden, *O. m. whitei*[a]	Sacramento–San Joaquin	High elevations	Endangered
California golden, *O. m. aquabonita*[a]	Sacramento–San Joaquin	High elevations	Special concern; introduced outside native range
Cutthroat trout, *Oncorhnychus clarki*			
Lahontan cutthroat, *O. c. henshawi*	Lahontan	Foothills, high elevations	Threatened; introduced outside native range
Paiute cutthroat, *O. c. seleneris*[a]	Lahontan	High elevations	Threatened; introduced outside native range
Tui chub, *Gila bicolor*			
Lahontan lake tui chub, *G. b. pectinifer*	Lahontan	Lowlands, foothills, high elevations	Special concern
Lahontan creek tui chub, *G. b. obesa*	Lahontan	Lowlands, foothills, high elevations	Stable or expanding
Owens tui chub, *G. b. snyderi*[a]	Owens River	Lowlands, foothills	Endangered
Eagle Lake tui chub, *G. b.* ssp.[a]	Eagle Lake	Foothills	Special concern
Lahontan redside, *Richardsonius egregius*	Lahontan	Lowlands, foothills, high elevations	Stable or expanding
Sacramento hitch, *Lavinia exilicauda exilicauda*	Sacramento–San Joaquin	Lowlands, foothills	Declining
California roach, *Lavinia symmetricus*			
Sacramento roach, *L. s. symmetricus*	Sacramento–San Joaquin	Foothills	Stable
San Joaquin roach, *L. s.* ssp.	Sacramento–San Joaquin	Foothills	Special concern
Red Hills roach, *L. s.* ssp.[a]	Sacramento–San Joaquin	Foothills	Special concern
Sacramento blackfish, *Orthodon microlepidotus*	Sacramento–San Joaquin	Lowlands	Stable or expanding
Hardhead, *Mylopharodon conocephalus*	Sacramento–San Joaquin	Lowlands, foothills	Special concern
Sacramento squawfish, *Ptychocheilus grandis*	Sacramento–San Joaquin	Lowlands, foothills	Stable or expanding
Speckled dace, *Rhinichthys osculus*			
Lahontan speckled dace, *R. o. robustus*	Lahontan, Eagle Lake	Lowlands, foothills, high elevations	Stable
Owens speckled dace, *R. o.* ssp.	Owens River	Lowlands	Special concern
Sacramento speckled dace, *R. o.* ssp.	Sacramento–San Joaquin	Lowlands, foothills	Stable
Sacramento sucker, *Catostomus o. occidentalis*	Sacramento–San Joaquin	Lowlands, foothills, high elevations	Stable or expanding
Tahoe sucker, *Catostomus tahoensis*	Lahontan, Eagle Lake	Lowlands, foothills, high elevations	Stable or expanding
Owens sucker, *Catostomus fumeiventris*[a]	Owens River	Lowlands, foothills, high elevations	Stable or expanding; introduced outside native range
Mountain sucker, *Catostomus platyrhynchus*	Lahontan	Lowlands, foothills, high elevations	Special concern
Owens pupfish, *Cyprinodon radiosus*[a]	Owens River	Lowlands	Threatened or endangered
Threespine stickleback, *Gasterosteus aculeatus*	Sacramento–San Joaquin	Lowlands	Stable or expanding; introduced outside native range
Sacramento tule perch, *Hysterocarpus t. traski*	Sacramento–San Joaquin	Lowlands, foothills	Stable
Prickly sculpin, *Cottus asper*	Sacramento–San Joaquin	Lowlands, foothills	Stable or expanding
Riffle sculpin, *Cottus gulosus*	Sacramento–San Joaquin	Foothills, high elevations	Stable
Paiute sculpin, *Cottus beldingi*	Lahontan	Lowlands, foothills, high elevations	Stable

[a]Taxa endemic to the region.

demic to the Sierra Nevada. This section briefly summarizes the status of each taxon to justify the status ratings (table 33.1). The overall causes of species declines are then discussed.

Species Accounts

The information in the following accounts is derived from California Department of Fish and Game (CDFG) 1992 for threatened or endangered species; Moyle et al. 1996 for species of special concern; and Moyle 1976a, Lee et al. 1980, and Sigler and Sigler 1987 for these and other species. Broad distribution, habitat, and status information is presented in table 33.1.

Kern brook lamprey: This small, nonpredatory lamprey is endemic to Sierran streams of the San Joaquin drainage. Today there are only four to five known populations, mostly below dams and isolated from one another (Brown and Moyle 1993).

Pacific lamprey: This species is anadromous, with a long (four- to seven-year) freshwater larval stage. Large runs

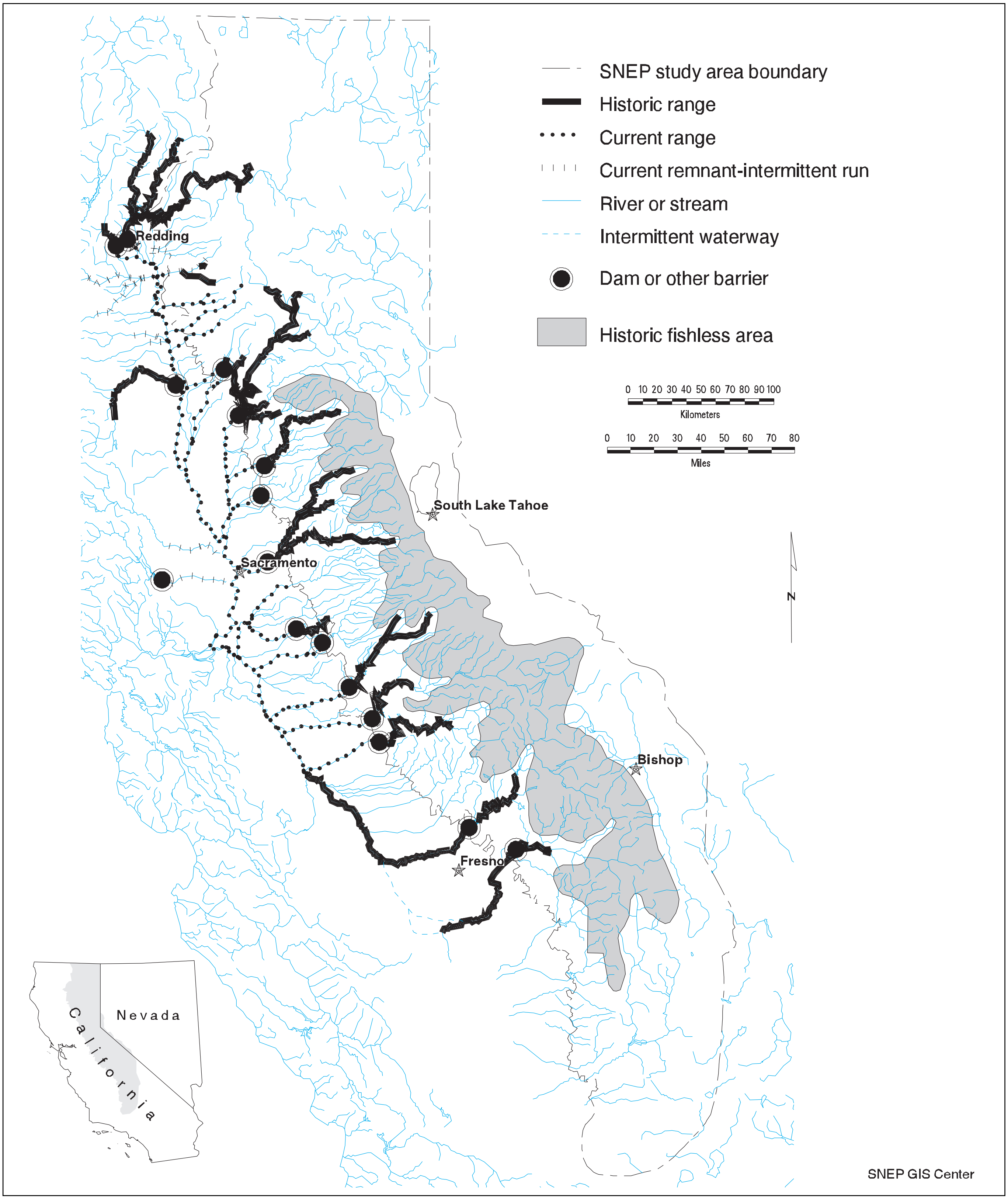

FIGURE 33.1

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 the current and historic distribution of chinook salmon, respectively.

once spawned in most of the same places as chinook salmon, and lamprey populations appear to have declined for reasons similar to those for the salmon decline (e.g., dams). The decline in major prey species, salmon and steelhead, may have been an additional contributing factor. Lampreys still occur in reaches of west-side streams below major dams, and the extent of their decline is poorly documented.

Mountain whitefish: Whitefish are common inhabitants of the larger streams in the Lahontan drainage and Lake Tahoe. There is no evidence of major population declines, and they are subject to a sport fishery.

Chinook salmon: The four runs of chinook salmon were once extraordinarily abundant on the west side, but now the winter run is listed as endangered (state and federal), the spring and late fall runs both qualify for listing, and the fall run is largely supported by hatcheries. The historic distribution and abundance of salmon is treated in a separate section.

Resident rainbow trout: Rainbow trout were, and still are, the most widely distributed fish in the western Sierra. The resident populations were derived from steelhead and occupied all streams up to the highest barrier. Their range was greatly expanded by the transplanting of fish above barriers and the widespread stocking of hatchery fish both into fishless areas and throughout the eastern Sierra Nevada. If distinctive strains of rainbow trout existed in the western Sierra, they seem to have been genetically swamped by interbreeding with non-native strains.

Steelhead: It is likely that anadromous rainbow trout once inhabited most of the streams used by chinook salmon for spawning but ascended higher in the basins and into smaller tributaries. Unfortunately, their historic distribution is poorly documented. Today they are absent from the San Joaquin basin, and their distribution is limited by dams in the Sacramento basin, where the population(s?) are largely maintained by hatcheries. Fish of wild origin that have actually gone out to sea (rather than staying in the river) appear to be less than 10% of the population. It is estimated that 35,000 steelhead return to the Sacramento drainage each year, mostly to the Coleman, Feather River, and Nimbus hatcheries, but the trend is downward (CDFG 1990). In Mill and Deer Creeks, Tehama County, for example, runs of more than 1,000 fish have dwindled to 30 to 40 fish in each stream (Harvey 1995). All runs of steelhead in California, Oregon, and Washington have been proposed to the National Marine Fisheries Service for listing as threatened or endangered.

Eagle Lake rainbow trout: This subspecies is the only rainbow trout population native to the east side. It is unusually long-lived, late maturing, and capable of living in alkaline waters. By 1950, it was nearly extinct, largely as the result of the destruction of its spawning habitat by logging, grazing, and associated activities. It was saved at the last minute by the California Department of Fish and Game through a hatchery rearing program. All fish in the lake are now reared initially in a hatchery and are abundant enough to support a trophy trout fishery. A petition to list the Eagle Lake rainbow trout as a threatened species was denied by the U.S. Fish and Wildlife Service in 1995 because of ongoing efforts to restore its principal spawning stream, Pine Creek.

Kern River rainbow trout: This is a heavily spotted, brightly colored native of the mainstem Kern River. It is one of three subspecies in the complex of distinct "golden trout" forms that evolved in the upper Kern River basin, an isolated region that was mostly not glaciated. Until recently, this form was thought to be extinct as the result of interbreeding with hatchery rainbow trout that had been planted in the river, but it has managed to persist in small numbers. Active attempts to restore its populations are underway.

Little Kern golden trout: This subspecies is native to the Little Kern River basin and at one time was in danger of extinction as the result of invasions by non-native trouts and habitat degradation, especially from grazing. The downward trend in its populations has been reversed as the result of active programs to restore its habitats and exclude non-native trout (outlined in Christenson 1978). It was listed as an endangered species by the U.S. Fish and Wildlife Service in 1970.

California golden trout: The native range of the "classic" golden trout (also known as the Volcano Creek golden trout) was Golden Trout Creek and the South Fork Kern River, but this range has been reduced as the result of competition and predation from introduced trout, especially brown trout. Populations have been further reduced as the result of livestock grazing in the fragile meadow systems through which the streams flow. While the subspecies is in no danger of extinction, because many populations have been established through planting of lakes and streams outside its native range, maintenance of populations in the native range requires active management, including elimination of non-native trout within its native range and elimination of grazing along the streams.

Lahontan cutthroat trout: This was once the dominant trout and predator in streams of the Lahontan drainage as well as Lake Tahoe and other large lakes. It has been replaced throughout its range by non-native trout, except in a few scattered localities, where grazing by livestock often degrades the remaining habitat. It is a federally listed threatened species for which a recovery plan has been developed (Coffin and Cowan 1995).

Paiute cutthroat trout: This federally listed threatened species (upgraded from endangered in 1975) is endemic to the Silver King Creek drainage, Alpine County. It has been extirpated from its native range by non-native trout but survives in several transplanted populations, including one in upper Silver King Creek (Busack and Gall 1981). Grazing, however, continues to have negative effects on the streams in which it lives, and full recovery of populations will require the exclusion of grazing from the riparian zones and meadows (Kondolf 1994; Overton et al. 1994).

Lahontan lake tui chub: The principal native habitat of this plankton-feeding subspecies in the Sierra Nevada is Lake Tahoe, where its populations have presumably been depleted as the result of introductions of plankton-feeding competitors, especially mysid shrimp. However, populations in three reservoirs on the Little Truckee River may also belong to this subspecies.

Lahontan creek tui chub: This bottom-feeding form is abundant in many lowland streams and reservoirs on the east side of the Sierra Nevada and has apparently been introduced into other reservoirs outside its native range.

Owens tui chub: The Owens tui chub is listed as an endangered species by both state and federal governments. Its populations were depleted as the result of diversion of the Owens River, alteration of habitat, and displacement by introduced Lahontan creek tui chubs. Recovery efforts have resulted in populations being established in a number of isolated refugia, although the refugia have to be continually monitored for illegal introductions of predatory game fishes (mainly largemouth bass).

Eagle Lake tui chub: This form is confined to Eagle Lake, Lassen County, where it is a principal prey of Eagle Lake trout. It is extraordinarily long-lived (thirty or more years), an adaptation that has presumably allowed it to survive long droughts in the past, when the lake may have become too alkaline for successful reproduction. A tunnel constructed in the 1920s connecting the lake to Willow Creek keeps lake levels lower than they normally would be and has increased the possibility of an extended drought having a severe impact on the chubs.

Lahontan redside: This small minnow is abundant in streams and lakes in the Lahontan drainage, as well as in Eagle Lake, and it has successfully colonized a number of reservoirs.

Sacramento hitch: The hitch is a large cyprinid species adapted for lowland environments, including low-gradient, sandy-bottomed streams. There are still scattered populations, including one in a Sierra Nevada reservoir (Beardsley Reservoir), but they appear to be gradually disappearing. Brown and Moyle (1993) noted that hitch populations in the foothills in the southwestern Sierra Nevada were few and scattered and that several populations had disappeared in a fifteeen- to twenty-year period.

Sacramento roach: The California roach has numerous isolated and distinctive populations that are poorly described (Brown et al. 1992). The numerous isolated populations in tributaries to the Sacramento River are all considered to be one widely distributed form that is still fairly common and locally abundant.

San Joaquin roach: Like the Sacramento roach, this form is widely distributed in the Sierra Nevada foothills, but the populations in each tributary system have been demonstrated to be distinctive morphologically (Brown et al. 1992). Many of the small populations of this form have disappeared in recent years, a trend that seems to be ongoing (Moyle and Nichols 1974; Brown and Moyle 1993).

Red Hills roach: This undescribed subspecies is one of the most distinctive populations of California roach known (Brown et al. 1992) and inhabits the harsh environment of a few exposed streams in the Red Hills of Tuolumne County. The heavy use of the countryside around its streams for recreation and mining makes this form a possible candidate for endangered species status.

Sacramento blackfish: This blackfish is a lowland species in the Sacramento–San Joaquin drainage that is locally abundant and barely gets up into the streams of the Sierra Nevada.

Hardhead: The hardhead is one of the most specialized species of the Sacramento–San Joaquin fauna and requires clear, cool water in deep pools for its long-term survival. The principal habitats of these fish are in the same stream reaches that are favored for building dams, so their populations have become fragmented. They have become abundant in a few reservoirs (but are absent from most) and will thrive in regulated streams under certain conditions. However, many populations seem to have disappeared or declined in recent years, especially where smallmouth bass have invaded altered habitats, such as in the Kings River and South Yuba River (Brown and Moyle 1993).

Sacramento squawfish: Squawfish are predatory cyprinids that have managed to adapt to the altered conditions of California's rivers and are abundant in many westside streams. Their importance as a predator on salmonids is less than it seems (Brown and Moyle 1981).

Lahontan speckled dace: Speckled dace are the most widely distributed native fish in California and the only species native to both sides of the Sierra Nevada. The robust Lahontan form is abundant and widely distributed.

Owens speckled dace: In contrast to the Lahontan form, the diminutive Owens dace is in danger of extinction as the result of alteration of its small-stream and spring habitats and predation from introduced species. This taxon may actually represent two distinct subspecies.

Sacramento speckled dace: These dace are abundant and widely distributed in the Sacramento Valley, although the southernmost populations (in the Cosumnes River) are very limited in extent and so are in danger of extinction.

Sacramento sucker: The only sucker native to the Sacramento–San Joaquin drainage, this species is widespread and abundant, including in altered habitats. Although it is frequently accused of competing with trout for food and space, there is little evidence that this is true (Christenson 1978; Baltz and Moyle 1984).

Tahoe sucker: This is the common sucker of the Lahontan and Eagle Lake drainages, where it is abundant.

Owens sucker: Another Owens Valley endemic, the Owens sucker is still fairly abundant in its native range and has been introduced into reservoirs in the Mono Lake drainage. Its dependence on altered habitats that contain introduced predatory fishes, however, is a cause for concern.

Mountain sucker: This species frequently co-occurs with Tahoe sucker but is much less abundant. It has disappeared from or declined in much of its native range in the Sierra Nevada in recent decades (Decker 1989). The reasons for this are not clear but may be related to its inability to survive in reservoirs, which occur on most of the rivers to which it is native.

Owens pupfish: This small Owens endemic was once abundant in the sloughs and springs along the Owens River but became endangered when its habitats were drained and altered and exotic predators introduced into them. It is listed as endangered by state and federal governments and persists in only a few small refugia, whose abilities to protect the fish are continually threatened by illegal introductions of game fishes.

Threespine stickleback: This widespread native species is naturally found only in the San Joaquin River in the Sierra Nevada but has been introduced (as a contaminant in plantings of trout) into streams of the Mono Lake basin.

Sacramento tule perch: An unusual, live-bearing species endemic to the Sacramento–San Joaquin drainage, this fish has been largely extirpated from the San Joaquin basin, but it is abundant in much of its original range in the Sacramento basin, including in regulated streams.

Prickly sculpin: Prickly sculpin are primarily a low-elevation species and unusual for a sculpin (Cottidae) in that they can tolerate moderately warm water and become abundant in reservoirs. They are widespread and abundant in the Sacramento–San Joaquin drainage.

Riffle sculpin: This small fish, endemic to California, requires cold water of high quality and is found in many middle-elevation "trout" streams from the Kaweah River north. It recolonizes very slowly the areas from which it has been extirpated. It is missing from a number of streams where it might be expected on the basis of habitat (e.g., the South Yuba River) and so has probably been extirpated and been unable to recolonize.

Paiute sculpin: This is the ecological equivalent of the riffle sculpin in the Lahontan basin. It is widespread and abundant, although it may be locally extirpated as the result of dams and diversions.

Status of Native Fishes

Of the forty fishes native to the Sierra Nevada,

- Six (15%) are formally listed by the federal and/or state government as threatened or endangered species.
- Twelve (30%) are listed as species of special concern by Moyle et al. (1996) because they are in trouble statewide and are potential candidates for listing or because they have limited distributions.
- Four (10%) are in severe decline in the Sierra Nevada but are probably (but not necessarily) in less trouble elsewhere.
- Eighteen (45%) seem to have stable or expanding populations.

Three of the species of special concern (the Owens sucker, Eagle Lake tui chub, and Lahontan lake tui chub) are arguably reasonably secure in their populations, despite their vulnerability to a major drought. But even omitting these species from the concern list leaves nineteen species (48%) with significantly reduced populations and limited distributions within the Sierra Nevada, including all runs of three once-abundant anadromous species (the Pacific lamprey, chinook salmon, and steelhead rainbow trout) and six of the seven taxa of resident native trout. It is clear that the biggest declines in native fish abundance took place between 1850 and 1950, following intensive hydraulic mining, construction of hundreds of dams, and widespread introduction of non-native species. Although conservation efforts or reductions in the rate of habitat change have halted or reversed some declines, many species are still declining. The species in decline are found in all habitats and major drainages of the Sierra Nevada (table 33.1). Increasingly, the causes of continuing decline seem to be related to alteration of stream habitats (through new diversions, grazing, and urbanization) combined with the continued expansion of populations of non-native fishes. Even where declines seem to have been halted (e.g., golden trout in the Kern River basin), only management to prevent the reinvasion of non-native fishes (after eradication) and to restore habitats can prevent declines from starting once again.

Considering that so many of the fish taxa in the Sierra Nevada are threatened or in decline and that thirty species of non-native fish (see table 33.5 later) are established in the waters of the range, it is not surprising to find that the native fish assemblages have also been disrupted or have disappeared from many waters. In streams on the west side of the Sierra Nevada, most fish assemblages lost major components, mainly chinook salmon and other anadromous fishes, following the construction of dams in the nineteenth and early twentieth centuries (see the next section). The disruption of these communities is continuing. For example, in the San Joaquin drainage, the California roach assemblage has disappeared from many areas, including the upper San Joaquin River (Moyle and Nichols 1974), and the squawfish-sucker-hardhead assemblage is increasingly disrupted by reservoirs and introduced species (Brown and Moyle 1993). The most extreme example of loss of fish assemblages, however, occurs on the southeastern side of the range. In the Owens Valley, the original fish assemblage exists only in some tiny refuges especially created for it (Minckley and Deacon 1991).

CHINOOK SALMON DISTRIBUTION AND ABUNDANCE

At one time, millions of chinook salmon spawned in the streams of the western Sierra Nevada, from the Kings River in the south to Battle Creek and other tributaries to the north. In terms of numbers and biomass, they were among the most abundant fish in the streams. They were consequently a major source of energy for stream ecosystems, a major food for the Native Americans, and, after the Euro-American invasion in the nineteenth century, a mainstay of commercial fisheries. In recent years, their continuing decline has been a source of major conflict among various interest groups because their recovery will require major changes in the allocation of scarce resources, especially water. The importance of chinook salmon justifies a separate analysis of the changes in their distribution and abundance through time. This section is a summary of the more detailed analysis by Yoshiyama et al. (1996).

Sierra Nevada Chinook Salmon

The rivers draining the Sierra Nevada were renowned for their chinook salmon production in the nineteenth century, with annual runs of one to three million fish (Clark 1929; Skinner 1962). Even today these rivers are the source of most of the chinook salmon produced in California waters. Between 1980 and 1990, an average of 365,000 Central Valley chinook salmon were harvested annually by commercial fisheries (CDFG 1990). This catch is a fraction of the historic catch (Skinner 1962). Despite occasional years of high catches (e.g., 1995), the catch continues to decline even though the fishery is supported in good part by salmon reared in hatcheries (table 33.2) (Fisher 1994). Equally as dramatic as the decline in numbers of salmon has been the change in their distribution. Dams now block access to most upstream areas that were once major spawning grounds so that virtually all spawning now takes place just above the valley floor.

The main reason that Central Valley rivers, which include those that drain the Sierra Nevada, produced so many chinook salmon is that the salmon showed remarkable adaptations to the local conditions. There are four distinct runs of chinook salmon, more than in any other major river system on the Pacific Coast. Each run takes advantage of conditions that exist in different places and at different times in the drainage. The runs are defined by the times of adult freshwater migration to the spawning areas, the spawning periods, and juvenile residency and downstream migration periods (Fisher 1994). The runs are named on the basis of the season of the upstream spawning migration. The fish making the fall and late fall runs spawn soon after entering the natal streams, while those making the spring and winter runs, in their original natural circumstances, typically held in their streams for two to four months before spawning. Formerly, the runs could also be differentiated on the basis of their typical spawning habitats—spring-fed headwaters for the winter run, high-elevation streams for the spring run, upper mainstem rivers for the late fall run, and lower rivers and tributaries for the fall run. Different runs often occurred in the same stream—temporally staggered but broadly overlapping (Fisher 1994), with each run utilizing the appropriate seasonal stream-flow regime to which it had adapted.

The largest of the four runs were the fall run and the spring run, which were found in most of the major rivers. Fall-run fish historically spawned mainly in the valley floor and foothill reaches (less than 175 m [575 ft] elevation), where they still spawn today. The spring run, in contrast, ascended as high as 1,800 m (5,900 ft), the highest elevation known for any spawning salmon (in Mill Creek, Tehama County). The spring run was originally concentrated in the San Joaquin system, where the fish ascended and used high-elevation streams fed by snowmelt for over-summer holding until the fall spawning season (Fry 1961; F. Fisher, CDFG, conversations with the author, 1995). The winter run was present in the Sierra Nevada region only in Battle Creek (Tehama

County), which has the large cold springs that produce the habitat conditions required by this unique run. These habitat conditions otherwise existed mainly in the upper Sacramento River system (the Little Sacramento, Pit, McCloud, and Fall Rivers). Today winter-run salmon spawn only in the main Sacramento River below Keswick Dam. The late fall run probably was also most abundant in the upper Sacramento River system. However, late-fall-run fish spawned as well in the upper mainstem reaches of the larger rivers such as the American River and the San Joaquin River (Clark 1929; Fisher 1994).

Historic Distribution and Abundance of Chinook Salmon

Early distributions of salmon populations in the Sierra Nevada are not known exactly, due to a lack of scientific or historical records prior to 1850. However, the upstream limits of salmon distributions can often be inferred from the location of natural barriers to migration (e.g., major waterfalls) that exist or formerly existed. It was not until the late 1920s that reliable scientific surveys of salmon distribution in Central Valley drainages were conducted. Reports by Clark (1929) and Hatton (1939) give information on the accessibility of various streams to salmon, and they identify the human-made barriers present at those times. They also give limited qualitative information on salmon abundance. Fry (1961) provided the earliest comprehensive synopsis of chinook stock abundances in Central Valley streams, covering the period 1940–59. Since then, fairly regular surveys of spawning runs in the various streams have been carried out by the California Department of Fish and Game (CDFG 1990, 1993).

Of the four runs of chinook salmon, only the fall run still exists in any numbers (table 33.2). The winter run is listed by both state and federal governments as an endangered species, and the spring and late fall runs are considered to be species of special concern, with threatened species listing proposed for the spring run (Moyle et al. 1996). The principal cause of the decline of these runs has been the elimination of, or lack of access to, suitable habitat for holding, spawning, and rearing. This habitat loss started as soon as Euro-Americans arrived in large numbers to mine gold in Sierra Nevada streams in the 1850s. Numerous hydropower projects appeared in the 1890s and early 1900s, and collectively they eliminated the major portion of spawning and holding habi-

TABLE 33.2

Spawning stock estimates for the four seasonal runs of Central Valley chinook salmon during the period 1967–92, including hatchery returns. Stock estimates of the fall run are given separately for the Sacramento and San Joaquin drainages. The late fall, winter, and spring runs occurred only in the Sacramento drainage during this period, so the values listed for those runs pertain equally to that drainage and to the entire Central Valley. (Modified from Fisher 1994.)

			Central Valley			
Year	Sacramento Fall Run	San Joaquin Fall Run	Late Fall Run	Winter Run	Spring Run	Central Valley Total
1967	157,643	22,785	37,208	57,306	23,840	301,182
1968	191,472	18,742	34,733	84,414	15,360	345,878
1969	268,178	52,212	38,752	117,808	27,447	506,482
1970	201,048	38,097	25,310	40,409	7,672	317,536
1971	193,762	42,996	16,741	63,089	9,274	331,062
1972	138,315	14,748	32,651	37,133	8,652	233,101
1973	263,385	7,895	23,010	24,079	11,967	332,936
1974	229,199	5,607	7,855	21,897	8,281	274,261
1975	187,564	7,825	19,659	23,430	24,044	264,922
1976	190,543	4,673	16,198	35,096	26,786	274,269
1977	184,090	1,050	10,602	17,214	13,951	227,157
1978	153,801	3,161	12,586	24,862	8,358	204,004
1979	222,549	5,087	10,398	2,364	2,960	244,865
1980	165, 041	7,098	9,481	1,156	11,937	197,944
1981	230,176	30,622	6,807	20,041	21,784	314,384
1982	210,975	19,761	4,913	1,242	28,082	274,345
1983	155,145	49,645	15,190	1,831	6,193	243,865
1984	198,517	58,820	7,163	2,663	9,923	284,237
1985	283,622	77,618	8,436	3,962	13,055	394,395
1986	264,212	24,268	8,286	2,464	20,329	324,478
1987	248,440	26,546	16,049	1,997	12,720	307,402
1988	252,542	22,522	11,597	2,094	18,486	307,753
1989	168,925	3,653	11,639	533	12,266	197,216
1990	118,309	1,092	7,305	441	6,630	134,208
1991	126,385	925	7,089	191	5,944	140,343
1992	109,218	3,098	10,370	1,180	2,997	128,495

tats for spring-run salmon well before the completion of the major dams constructed for water supply in later decades. By 1928, Clark (1929) estimated that the amount of salmon-spawning stream habitat had been reduced to about 820 km (510 mi) of river, which he considered to represent a loss of at least 80% of the spawning grounds. The obstructions to the spawners included eleven dams in the San Joaquin system and thirty-five dams in the Sacramento system.

The extent to which salmon (and other anadromous fish) habitat has been lost in the Sierra Nevada can be seen by examining the past and present distributions of salmon in each major river system (figure 33.1; table 33.3). In 1993, the CDFG estimated that the amount of spawning habitat left for salmon and steelhead in the Central Valley system totaled less than 480 km (300 mi) (CDFG 1993). Little of this is in the Sierra Nevada proper. Our estimates, based on the information presented in the stream-by-stream analysis in Yoshiyama et al. (1996), is that only 1,082 km (676 mi) of mainstream habitat remains of the 2,838 km (1,774 mi) originally available to chinook salmon for spawning, a loss of 62%. The actual percentage of spawning habitat lost is higher because in the San Joaquin drainage less than a third of the riverine habitat still accessible is suitable for spawning, and probably less than half of the accessible habitat is suitable in the Sacramento drainage. In addition, many of the smaller tributaries now located above dams were not added into the total of formerly accessible habitat, because it is likely that only small numbers of salmon used them for spawning. Thus, the estimate by CDFG that more than 90% of chinook salmon spawning habitat in the Central Valley drainage has been lost (CDFG 1993) seems reasonable, although the oft-cited estimate that more than 9,600 km (6,000 mi) of habitat were once available for chinook salmon spawning (Clark 1929) is probably high by a factor of three.

Conclusions

Chinook salmon and other anadromous fishes are largely gone from the Sierra Nevada, except where flows are provided for them below major dams at low elevations and in Butte, Deer, and Mill Creeks. This represents a major change in the riverine ecosystems of which they were once part. Not only are

TABLE 33.3

Estimated changes in lengths of streams available to chinook salmon in the major salmon-supporting drainages of the Central Valley.[a]

Drainage	Length (mi) of Stream Historically Available[b]	Length (mi) of Stream Presently Accessible[c]	Length (mi) of Stream Lost (or Gained)[d]	Percentage Lost (or Gained)
Sacramento Valley				
Pit River	93	0	93	100
McCloud River	43	0	43	100
Upper (Little) Sacramento River	53	0	53	100
Battle Creek	35	6	29	83
Antelope Creek	32	32	0	0
Mill Creek	44	44	0	0
Deer Creek	34	38	(4)	(12)
Big Chico Creek	21	21	0	0
Butte Creek	53+	53	>0	>0
Feather River	211	64	147	70
Yuba River	77	21	56	73
Bear River	16	16	0	0
American River	159	28	131	84
Clear Creek	25	16	4	16
Cottonwood Creek	79	79	0	0
Stony Creek	54	~3	51	94
San Joaquin Valley				
Cosumnes River	34	38	0	0
Mokelumne River	69	46	23	33
Calaveras River	~38	38	0?	0?
Stanislaus River	151	46	105	70
Tuolumne River	99	47	52	53
Merced River	99	43	56	57
Upper San Joaquin River	171	0	171	100
Kings River	84	0	84	100
Total	1,774	676	1,098	62

[a]The values for stream lengths originally available and subsequently lost are in most cases minimum estimates, because the full extent of the former salmon distributions is incompletely known. Additional, minor streams such as Thomes, Paynes, Cache, and Putah Creeks and perhaps a dozen others in the Sacramento Valley historically supported salmon runs (Fry 1961)—probably only the fall run and only during wet years when stream flows were adequate. The upstream distribution of salmon in those streams is too poorly known to allow inclusion in this table. Furthermore, current salmon production in those streams is limited because of a number of factors, including low stream flows, habitat degradation, and obstruction by irrigation canal crossings (CDFG 1993).
[b]Lengths of all stream reaches known or presumed to have been traversed or utilized by salmon in the drainage were summed.
[c]Length between the mouth of the stream and the current upstream limit.
[d]Length of stream gained is given in parentheses; this situation applies only to Deer Creek.

TABLE 33.4

Factors contributing to declines of native fishes of the Sierra Nevada region.

Species	Introduced Species	Dams and Diversions	Change in Aquatic Habitat	Watershed Disturbance	Other Factors
Kern brook lamprey	1	3	2	2	1
Pacific lamprey	0	3	2	1	1
Chinook salmon	1	3	2	2	2
Winter steelhead	1	3	2	2	2
Eagle Lake rainbow trout	0	1	1	3	1
Kern River rainbow trout	3	2	1	1	1
Little Kern golden trout	3	2	2	1	1
California golden trout	3	0	2	1	1
Lahontan cutthroat trout	3	3	2	1	1
Paiute cutthroat trout	3	0	2	0	1
Lahontan lake tui chub	3	0	0	0	1
Owens tui chub	3	1	0	0	1
Eagle Lake tui chub	2	0	1	1	1
Sacramento hitch	1	3	1	2	1
San Joaquin roach	2	2	2	2	2
Red Hills roach	2	1	2	3	2
Hardhead	3	2	2	1	1
Owens speckled dace	2	2	3	2	1
Mountain sucker	1	2	1	2	1
Owens pupfish	3	3	3	2	2
Total	40	36	33	29	25

0 indicates that the factor had no known effect.
1 indicates that the factor was of minor importance.
2 indicates that the factor was moderately important.
3 indicates that the factor was of major importance.

the once-abundant juvenile salmon and lampreys no longer part of local food webs, but the disappearance of adult fish has caused a loss of the annual influx of nutrients provided by the decaying carcasses. Attempts to replace the lost fish through the use of hatcheries have been only partially successful; total salmon numbers continue to decline. Achieving the officially stated goal of "doubling" salmon numbers (CDFG 1993) will presumably involve better management of flows in regulated rivers, habitat restoration where possible, and restoring salmon to some areas from which they are now gone (e.g., the American River above Folsom Dam).

CAUSES OF NATIVE FISH DECLINES

The causes of fish declines are multiple and interactive (table 33.4). They also can be quite different for different species and can change over time. In addition, what may be devastating for one species may favor another. Thus, Sacramento suckers and tui chubs do quite well in reservoirs in which most other native fishes cannot survive. The causes of decline can be broken into five broad categories: (1) introduced species, (2) dams and diversions, (3) changes in aquatic habitat, (4) watershed disturbance, and (5) other factors.

Introduced Species

Introduced species of fish have had strong negative effects on the abundance of ten of the twenty species in decline. Of the thirty introduced fish species, ten (33%) are abundant and widespread, eight (27%) are common with somewhat more restricted distributions than the abundant species, and the rest (40%) are rare or peripheral in the range (table 33.5). Introduced species particularly appear to be a problem at high elevations. The reason for this is that seven of the native species are trout characteristic of high-elevation habitats, and six of these trout have been negatively affected by competition, predation, and hybridization by non-native trout, especially brown trout. At lower elevations, predation by non-native fishes, especially centrarchid basses, has also been an important factor in the decline of native species. Hardhead, for example, have declined in response to expanding smallmouth bass populations (Brown and Moyle 1993), while the introduction of largemouth bass into the spring refuges of Owens pupfish, tui chub, and speckled dace continues to be a factor in their decline. Unfortunately, the introduction of new species of predatory fish into Sierra Nevada waters is continuing. Most recently, northern pike (Esox lucius) and white bass have been introduced illegally into reservoirs on the west side. If efforts by the CDFG to eradicate the populations have failed, it is likely that both of these predators will cause further changes to native fish assemblages.

Dams and Diversions

Although introduced species have been identified as a major cause of native fish declines, they often are as much a symptom of the decline as a cause. As a general rule, the more altered a stream or lake is by human disturbance, the more likely it is to become dominated by non-native species (Baltz and Moyle 1993). In many instances, the invasion of introduced fishes has followed habitat changes, especially those created by dams and diversions. Because of the importance of the Sierra Nevada as a supplier of water for California, virtually every stream of any size has at least one dam or diversion on it (Kattelmann 1996). The changes caused by such dams and diversions have been identified as a major cause of the declines of seven of the twenty declining species and as a contributing factor in most of the rest. Reservoirs generally favor exotic fishes, which can then invade both upstream and downstream. Dams and diversions also contribute to declines by flooding habitats, removing water, changing flow regimes, blocking movements and migrations, isolating populations, and causing increased human use of the watersheds. Dams on major rivers have blocked access by spring-run chinook salmon to more than 95% of its spawning and holding areas and have greatly reduced access to spawning grounds of other runs of salmon, steelhead, and Pacific lamprey.

Although Moyle and Williams (1990) identified dams and diversions as the single biggest cause of fish declines in California overall, it is important to recognize that the greatest impacts of dams occur immediately after they are built, when the changes they cause are fully in place for the first time. Thus, most runs of spring-run chinook salmon were eliminated before 1950, following the construction of dams on the major tributaries. However, dams, diversions, and reservoirs have a continued negative effect on native fishes through changes in flow regime and in the physical environment downstream because they block migrations to upstream areas and provide a continuous source of introduced species as predators and competitors to both upstream and downstream reaches. Upstream, these impacts on the isolated remnant populations of native fish are usually less than the effects of other activities in the watershed that alter stream habitats or water quality, such as grazing, road building, and mining.

TABLE 36.5

Introduced fishes of the Sierra Nevada.

Name	Habitat	Elevation[a]	Status
American shad, *Alosa sapidissima*	Anadromous; mainstem rivers; reservoirs and ponds	Low	Uncommon
Threadfin shad, *Dorosoma petenense*	Reservoirs and ponds	Low to middle	Abundant and widespread
Wakasagi, *Hypomesus nipponensis*	Reservoirs and ponds	Low to middle	Uncommon
Kokanee, *Oncorhynchus nerka*	Reservoirs and ponds; lakes	High	Common
Colorado cutthroat trout, *Oncorhynchus clarki pleuriticus*	Lakes	High	Rare
Brook trout, *Salvelinus fontinalis*	Cold-water streams; lakes	High	Abundant and widespread
Lake trout, *Salvelinus namaycush*	Lakes	High	Localized
Brown trout, *Salmo trutta*	Cold-water streams; lakes; reservoirs and ponds; mainstem rivers	Middle to high	Abundant and widespread
Arctic grayling, *Thymallus arcticus*	Reservoirs and ponds	High	Rare
Common carp, *Cyprinus carpio*	Warm-water streams; mainstem rivers; reservoirs and ponds	Low	Common
Goldfish, *Carassius auratus*	Reservoirs and ponds	Low	Uncommon
Golden shiner, *Notemigonus chrysoleucas*	Warm-water streams; lakes; reservoirs and ponds	Low to high	Common
Fathead minnow, *Pimephales promelas*	Warm-water streams; reservoirs and ponds	Low	Common
Channel catfish, *Ictalurus punctatus*	Mainstem rivers; reservoirs and ponds	Low to middle	Common
White catfish, *Ameiurus catus*	Reservoirs and ponds	Low to middle	Common
Brown bullhead, *Ameiurus nebulosus*	Warm-water streams; lakes; reservoirs and ponds	Low to high	Uncommon
Black bullhead, *Ameiurus melas*	Warm-water streams; lakes; reservoirs and ponds	Low to high	Abundant and widespread
Western mosquitofish, *Gambusia affinis*	Warm-water streams; reservoirs and ponds	Low to middle	Abundant and widespread
Striped bass, *Morone saxatilis*	Reservoirs and ponds	Low	Uncommon
White bass, *Morone chrysops*	Reservoirs and ponds	Low to middle	Localized
Sacramento perch, *Archoplites interruptus*	Reservoirs and ponds	Low to middle	Localized
Black crappie, *Pomoxis nigromaculatus*	Reservoirs and ponds	Low to middle	Abundant and widespread
White crappie, *Pomoxis annularis*	Reservoirs and ponds	Low to middle	Common
Green sunfish, *Lepomis cyanellus*	Warm-water streams; lakes; reservoirs and ponds	Low to high	Abundant and widespread
Bluegill, *Lepomis macrochirus*	Warm-water streams; lakes; reservoirs and ponds	Low to high	Abundant and widespread
Pumpkinseed, *Lepomis gibbosus*	Warm-water streams; reservoirs and ponds	Low to middle	Uncommon
Largemouth bass, *Micropterus salmoides*	Warm-water streams; reservoirs and ponds	Low to middle	Abundant and widespread
Spotted bass, *Micropterus punctualatus*	Warm-water streams; mainstem rivers; reservoirs and ponds	Low to middle	Common
Smallmouth bass, *Micropterus dolomieui*	Warm-water streams; mainstem rivers; reservoirs and ponds	Low to middle	Abundant and widespread
Redeye bass, *Micropterus coosae*	Warm-water streams; reservoirs and ponds	Low to middle	Rare

[a]Low elevation is less than 200 m (650 ft). Middle elevation is 200–1,500 m (650–4,900 ft). High elevation is more than 1,500 m (4,900 ft).

Alteration of Aquatic Habitats

Among the many factors affecting aquatic habitats, the most significant in the Sierra Nevada are road building, channelization, grazing, and mining. Road building and channelization are interrelated because hundreds of miles of Sierran streams have been channelized to support roads on their banks. The major transportation corridors in the Sierra Nevada follow streams and are often located in the riparian zones. The most noticeably altered streams are those that are sandwiched between highways and railroads (e.g., North Fork Feather River). However, smaller roads associated with logging, mining, and recreation can also alter streams, especially where they cross; there is a negative correlation between the abundance of roads in a watershed and the integrity of the native stream biota (Moyle and Randall 1996).

The effects of livestock grazing are pervasive throughout the Sierra Nevada, resulting in degraded stream habitats through loss of habitat complexity (by stream-bank alteration and removal of riparian vegetation), siltation, and other effects (Chaney et al. 1990; Menke et al. 1996). The loss of habitat quality and quantity associated with grazing contributes not only to the decline of native fishes but also to the reduction in populations of trout important in stream fisheries (Platts 1991; Dudley and Embury 1995). Mining also contributes to the presence of low fish populations in some areas, mainly through the residual effects (siltation, streambank alteration) of hydraulic mining (Gard 1994), the roads and tailing piles associated with hardrock mines, and the direct and indirect effects of suction dredge mining.

Watershed Disturbance

Cumulative watershed disturbances, as the result of urbanization, logging, grazing, mining, and other factors, have affected most species of fish to some extent, through changes in flow patterns, reductions in flows, and removal of riparian vegetation. These changes can be seen dramatically in Pine Creek (Lassen County), once the principal spawning stream of Eagle Lake trout. Heavy logging and grazing in the drainage, coupled with construction of road and railroad beds across key flowage areas, resulted in the lower reaches of the stream becoming dry much sooner and much more frequently than they had historically, denying adult trout access to spawning grounds and juvenile trout access to the lake (Moyle et al. 1996). Wissmar et al. (1994) found such activities to have caused long-term, cumulative degradation of stream habitats throughout eastern Oregon and Washington, resulting in degradation of fish communities. Similar problems are present throughout the West (e.g., Chaney et al. 1990; Meehan 1991) and the Sierra Nevada (Kattelmann 1996; Menke et al. 1996).

Other Factors

Other factors affecting fish populations include pollution, exploitation, and disturbance. Pollution has played a relatively minor role in fish declines in recent decades because many major sources (e.g., sewage from towns) were cleaned up as the result of the federal Clean Water Act and other regulations. However, pollution may play an increasing role in the future, as atmospheric deposition changes water chemistry and adds toxic materials to the water, especially in the southern portion of the range (Cahill et al. 1996), and as the effects of acid mine drainage and unregulated agricultural pollution (including livestock wastes) accumulate. Exploitation has affected salmon and steelhead populations. It was probably a bigger factor in the past (when salmon canneries were operating) than it is today, although existing commercial and sport fisheries may help to keep anadromous fish populations suppressed, making recovery more difficult. Likewise, the presence of salmon and trout of hatchery origin in streams may interfere with the recovery of wild populations, through behavioral interactions, genetic swamping, and introduced diseases (Steward and Bjornn 1990). Disturbance is a particular problem for anadromous fishes, especially spring-run chinook salmon. Heavy use of streams by rafters, anglers, or dredge miners may disturb fish that are holding or spawning, reducing the success of spawning (Moyle et al. 1996).

Conclusions

The native fishes and fish assemblages of the Sierra Nevada have declined largely as the result of water diversion, introduction of non-native species, and habitat alteration. A number of the species, and consequently the assemblages of which they are part, are likely to become extinct within the next fifty years if present trends continue. Increasingly, the native fish assemblages are found in streams that are isolated from one another by dams or other barriers. As a result, natural recolonization is not possible if a local extinction event occurs. The streams in which native fish assemblages still occur are mostly unregulated and flow through watersheds that are in relatively good condition. Such streams are also likely to support populations of native amphibians and invertebrates. Conservation of the native fish fauna ultimately will require active management of streams and lakes throughout the Sierra Nevada and probably the creation of an aquatic refuge system.

INTRODUCED FISHES IN THE SIERRA NEVADA

At least thirty introduced species of fish have reproducing populations in Sierra Nevada waters; twenty-seven of them are at least regionally abundant and eighteen are widely distributed (table 33.5). In addition, at least seven native species (rainbow trout, California golden trout, Lahontan cutthroat trout, Paiute cutthroat trout, tui chub, Owens sucker, threespine stickleback) have had their ranges expanded through introductions. Most (twenty-two) of the common non-native species are associated with reservoirs or highly altered streams at low to middle elevations, while two (kokanee, lake trout) are associated with large, high-elevation lakes and reservoirs. The two remaining non-native fishes (brook trout, brown trout) are widely distributed in high-elevation lakes and streams, along with introduced populations of rainbow trout and golden trout. The rainbow trout in particular has been widely introduced into streams, lakes, and reservoirs on the east side of the Sierra Nevada, where it (along with other trout) has largely displaced the native cutthroat trout. The other five native species occur in only a relatively few non-native waters.

As was indicated previously, these introduced fishes have had a major negative impact on native fishes in their native ranges, especially at high elevations. These impacts have been well documented in a general sense (e.g., Moyle 1976b, 1986; Li and Moyle 1993), although often only anecdotally in the Sierra Nevada. Ironically, the introduction of the two cutthroat trout subspecies into fishless waters was done because they had been displaced from native waters by introduced trout species. Less well known is the extent and impact of trout introductions into the vast areas of the range that were originally fishless. This section will therefore focus on these introductions and their impacts.

Because the high-elevation regions of the Sierra Nevada are largely within national parks, wilderness areas, and national forests, the hundreds of kilometers of clear-flowing streams and the more than 4,000 transparent lakes they contain are generally considered to be pristine. In fact, these waters are arguably among the most altered ecosystems in the Sierra Nevada. Historically, the single biggest factor altering these systems has been the introduction of trout. Most lakes and streams above 1,800 m (6,000 ft) were fishless until fish planting programs began in the nineteenth century. This section reviews (1) the history of trout stocking, (2) the current distribution of trout, and (3) the impacts of non-native trout on aquatic ecosystems. For more details, see Knapp (1996).

History of Trout Stocking

Although the indigenous peoples of the Sierra Nevada often lived at high elevations, there is no evidence that they moved fish into fishless waters. The upstream limits of fish were determined by natural barriers. This situation changed dramatically with the influx of Euro-Americans in the mid-nineteenth century, who brought with them a love of angling, especially for trout. The first introductions appear to have been transfers of native trout (Lahontan cutthroat trout, coastal rainbow trout, California golden trout) above waterfalls or into neighboring drainages by miners, sheepherders, and other people living in the mountains. Soon, however, non-native salmonids were being planted in the Sierra Nevada: brook trout (1872), brown trout (1872), lake trout (1889), kokanee (1941), Colorado cutthroat trout (1931), and arctic grayling (1930) (Moyle 1976a). Once established, exotic trout were moved to new locations both by private individuals or clubs and by state and federal agencies. Extensive trout planting in Yosemite, Sequoia, and Kings Canyon National Parks was accomplished by the U.S. Army (Christenson 1977). By the 1940s, official stocking of fish was done almost entirely by the CDFG, and today this agency has sole responsibility for stocking trout in the Sierra Nevada. In part because the vast majority of lakes and streams capable of supporting trout already had trout populations, the emphasis of CDFG stocking programs has been to supplement or maintain existing trout fisheries.

Although the fisheries supported in part by stocking programs included those in the national parks, the National Park Service (NPS) began to phase out fish stocking in 1969. This change in policy was a response to the Leopold (1963) report that recommended that "the natural biotic associations within each park should be maintained, or where necessary recreated, as nearly as possible in the condition that prevailed when the area was first visited by white man." A ban on fish stocking became official NPS policy in 1975, but limited stocking occurred in Sequoia, Kings Canyon, and Yosemite National Parks until 1991. Stocking is still permitted in all other waters on federal lands, with the exception of a few waters within wilderness areas that were not stocked prior to each area's designation as wilderness (Bahls 1992). In general, stocking trout in lakes and streams has been based on historic precedents, with little consideration given to the effects of the stocked trout on the native biota (Bahls 1992). Most waters stocked with fish are not regularly evaluated for their fish populations, angler use, or trends in their native biota (Bahls 1992).

It is worth noting that one of the side effects of indiscriminate planting of trout throughout the Sierra Nevada was the introduction of other species of fish either as "contaminants" in the water used for transporting the trout or as bait released by anglers. As a result, threespine stickleback, Owens sucker, and tui chub are present in the Mono Lake basin. Similar anomalous distributions can be found elsewhere in the Sierra Nevada, especially immediately above and below reservoirs or in lakes with easy road access. The exotic fish most commonly established through bait-bucket introductions is probably the golden shiner, which can survive in high-elevation lakes with deepwater refuges in winter and warm, shallow areas in summer.

Current Fish Distribution

All major watersheds of the Sierra Nevada contain introduced populations of trout, but records of exactly which waters contain trout are scattered and incomplete. A guide for anglers, for example, lists about 1,700 lakes with fish in them (Cutter 1984). More than half of these lakes are below 2,400 m (7,900 ft), yet Jenkins et al. (1994) estimate that there are more than 1,000 lakes above 2,400 m alone with fish in them. Existing estimates of the number of waters containing trout are based on interviews with fishery managers (Bahls 1992) or on extrapolations to the entire range from surveys of a small number of waters (Jenkins et al. 1994). Bahls (1992) estimated that 63% of all lakes above 800 m (2,600 ft) contained introduced fish and 52% were regularly stocked. Fishless lakes were generally too small (less than 2 ha [5 acres]) and shallow (less than 3 m [10 ft] deep) to support trout. Such lakes either freeze to the bottom, become depleted of oxygen in the winter, or become too warm in the summer. Jenkins and colleagues (1994) randomly selected thirty high-elevation (more than 2,400 m [7,900 ft]; more than 1 ha [2.5 acres]) lakes from throughout the Sierra Nevada for sampling. They then estimated that, of the 1,404 similar lakes in the range, trout existed in 63%, and the rest were fishless. Golden trout were estimated to occur in 36% of the lakes, rainbow trout in 33%, brook trout in 16%, brown trout in 8%, and cutthroat trout in less than 1%. Although these studies indicate that 60% to 65% of all Sierra Nevada lakes contain trout, the percentage of the larger, deeper lakes containing trout is much higher. This is echoed in the national forests and national parks, where larger, deeper lakes are also more likely to contain fish.

Christenson (1977) estimated that 95% of naturally fishless lakes that were large enough to support trout populations contained fish. To test this hypothesis, a detailed analysis was performed on the only large database available, that maintained by CDFG Region 5 (Knapp 1996). This database contains records of 649 lakes in portions of the Inyo, Sierra, and Toiyabe National Forests, more than 90% of the lakes in the region. Eighty-four percent of the lakes for which there are records lie within wilderness areas, 2% are in a U.S. Forest Service (USFS) Research Natural Area, and 14% are in other areas. The majority of these lakes are at elevations between 3,250 and 3,500 m (10,660 and 11,480 ft), and nearly all are less than 10 ha (25 acres) in area. All the lakes were originally without fish, but today 85% contain trout, 7% are fishless, and 8% are of unknown status. It seems reasonable to conclude that more than 90% of these lakes contain trout. Both fish-containing and fishless lakes occur at all elevations, although fishless lakes are most common at either high (more than 3,500 m [11,480 ft]) or low elevations (less than 2,500 m [8,200 ft]). Lakes containing fish are significantly larger than fishless lakes, which are mostly less than 1 ha (2.5 acres) in area. Of the lakes in this study with fish, 60% contained brook trout, 36% contained rainbow trout, 32% contained golden trout, 5% contained brown trout, and less than 1% contained other salmonids.

Of the 649 lakes, 299 (46%) are still planted on a regular basis by the CDFG, mostly with drops of juvenile fish from airplanes, either annually (35%) or every two years (65%). The principal trout planted are rainbow trout (49%) and golden trout (48%). Despite the regular plants of fish, the 649 lakes in the CDFG Region 5 database are only infrequently surveyed; only 32% were formally sampled for fish in the last ten years, 56% in the past twenty years. These surveys have been only for fish, with no effort made to determine the status of frogs and other native species.

Although lake surveys on non-national-park lands are limited, they are considerably more frequent than stream surveys. Presumably, most streams large enough to support trout contain them, especially if they are downstream of lakes containing trout or immediately upstream of such lakes. In a 1992 survey of 20 km (12.5 mi) of streams in the upper Lee Vining and Mill Creek watersheds (Mono Lake basin), Knapp (1996) found only 2 km (1.25 mi) without fish. It is likely that, as in the case of lakes, more than 90% of stream habitat suitable for trout now supports populations of them.

In the national parks, the percentages of lakes with fish are considerably lower than in areas outside the parks (Knapp 1996). Surveys of lakes greater than 1 ha (2.5 acres) in area in Yosemite National Park in the 1950s indicated that 35% were fishless (although about a third of the fishless lakes had been planted with fish at one time or another), 38% contained self-sustaining populations of trout, 24% had trout populations maintained by stocking, and 4% were of unknown status (Wallis 1952). A survey of 102 lakes in Yosemite National Park with a recent history of fish stocking (Botti 1977) indicated that trout were no longer present in 22% of the lakes and would probably disappear from 22% more following the cessation of stocking. Thus, it can be expected that at the present time about half the lakes in Yosemite National Park greater than 1 ha in area are fishless. This figure is roughly comparable to the frequency of fishless lakes (54%) recorded by Bradford and colleagues (1993) for Sequoia and Kings Canyon National Parks. However, a survey of 104 lakes in the most remote portions of Kings Canyon National Park indicated that only 17% contained trout (Bradford et al. 1994). In general, lakes in the national parks that have self-sustaining populations of fish are likely to be greater than 4 ha (10 acres) in area and likely to be in the most accessible parts of the parks.

For streams, it is likely that conditions in the national parks have not changed much since Wallis (1952) surveyed streams in Yosemite National Park and showed that 22% of 157 streams were fishless (including 2% that had been stocked with fish at one time or another), 58% contained trout populations, and for 20% there was no information. Limited recent data from Yosemite National Park indicate that, overall, at least 60% of all streams still contain trout (Knapp 1996).

Effects of Trout Introductions on Native Aquatic Biota

Trout are generalist predators, consuming whatever prey is available, from invertebrates to fish to amphibians (Moyle

1976a). For stream and lake biotic communities of invertebrates and amphibians that developed in the absence of a top predator like trout, the effects of trout introductions are potentially devastating. In the Sierra Nevada, introduced trout have had negative effects on native trout, amphibians, and invertebrates.

Native Trout

With the exception of rainbow trout and California golden trout, the native trout of the Sierra Nevada have declined in the face of competition, predation, and hybridization from non-native trout. Ironically, one endemic trout, the Paiute cutthroat trout, was saved from extinction because a sheepherder, in 1922, introduced it above an impassable falls on Silver King Creek. The population below the falls subsequently became extensively hybridized with rainbow trout (Busack and Gall 1981).

Amphibians

Amphibians are in decline throughout the Sierra Nevada (Jennings 1996), and introduced trout are one of a number of interacting factors responsible for the decline, especially at high elevations. In general, ranid frogs, bufonid toads, and ambystomid salamanders are less abundant than formerly in or near waters that contain introduced species of fish. It appears that the main mechanism by which trout affect amphibians is through predation on tadpoles, although diseases brought in with the fish may also play a role. The species apparently most affected by fish is the mountain yellow-legged frog (Rana muscosa), which is now found at fewer than 15% of the high-elevation sites at which it was present in 1915 (Drost and Fellers 1994). While the decline in this species is the result of many interacting factors (Jennings 1996), its long-term survival will apparently depend on predator-free lakes deep enough (more than 1.5 m [5 ft]) for the over-winter survival of adults and tadpoles, as well as a predator-free environment for the tadpoles, which take two to three years to mature. In addition, it is likely that the dispersal of this species depends in part on having predator-free streams that can be used as corridors between lakes.

Invertebrates

Introduced trout can affect the composition of zooplankton and benthic invertebrate communities in lakes and of benthic invertebrate communities in streams (Erman 1996). In a survey of seventy-five Sierra Nevada lakes, Stoddard (1987) found that the presence of trout was the best predictor of the zooplankton species present (or absent). As researchers have found in lakes elsewhere, large zooplankton species tend to disappear in the presence of fish because of their vulnerability to predation. The survey by Stoddard (1987) and other surveys indicate that the phantom midge, Chaoborus americanus, may have been extirpated from the Sierra Nevada by trout. This midge has planktonic larvae specialized for living in the larger, low- to middle-elevation lakes, which now universally contain trout. Trout probably have had similar effects on benthic insects, but these effects are much more poorly documented, although it is often noted that the abundance of benthic invertebrates, especially of larger species (caddisflies, mayflies, etc.), greatly declines following trout introductions (e.g., Reimers 1958). Whether or not invertebrate species eliminated from lakes by trout can recolonize a lake in which the trout have disappeared depends on the proximity of the lake to fishless lakes that contain the missing species.

Trout seem to have a less dramatic effect on stream invertebrates than they do on lake invertebrates. However, large, diurnal species may be eliminated from formerly fishless streams once trout are introduced, and the behavior of other species may be altered (Erman 1996).

Conclusions

The introduction of predatory trout into formerly fishless lakes and streams of the Sierra Nevada has caused major changes in the aquatic biota. As a result, relatively few lakes and streams have aquatic communities that are in near-pristine condition. Some invertebrate species may have been eliminated altogether, and a number of native fish, amphibians, and invertebrates have become endangered. The cessation of stocking of hatchery trout in lakes in the national parks has resulted in the partial reestablishment of the assemblages of aquatic organisms native to fishless lakes. Thus, it appears that it is not too late to restore some high-elevation watersheds to a fishless condition in order to restore populations of species sensitive to fish predation. If current trends continue, further extirpations of native organisms from the Sierra Nevada are likely as the result of trout predation in combination with other factors.

SIERRA NEVADA FISHERIES

The main reason that trout and other fish have been widely introduced in the Sierra Nevada is to support sport fisheries. The sport fisheries, including those for native fish, in turn are a major source of support for the recreational industry of the Sierra Nevada, bringing thousands of anglers into the range each summer. For many other people seeking recreation in the Sierra Nevada, catching fish is an important part of their total experience. Five major fisheries can be arbitrarily recognized in the range: high-elevation trout fisheries, wild trout fisheries, catchable trout fisheries, warm-water stream fisheries, and reservoir fisheries. Stock ponds at low elevations are also presumably important in fisheries, but they are largely on private land, and the extent to which they contribute to fisheries is poorly known. Fisheries for anadromous salmon, steelhead, and shad are now largely gone from the Sierra

Nevada and are present primarily in the main river channels at low elevations, mostly outside the SNEP area.

High-Elevation Lake Fisheries

There are about 4,000 lakes in the Sierra Nevada, probably 75% of which are large and deep enough to support trout. Some are accessible by road, but most can be reached only by hiking or similar means. Because the lakes have short ice-free seasons and are mostly in granitic, glacier-scoured basins, they are not very productive. They can support only relatively low densities of trout, and the trout present are usually rather slow growing, rarely exceeding 30 cm (12 in) in length. Aside from roadside lakes stocked with catchable trout, trout in the lakes come from two sources: natural reproduction and plants of small (fingerling) trout, usually by airplane. The majority of naturally reproducing trout populations in the lakes are brook trout, because they can spawn in the lakes. The problem with brook trout is that many populations are made up mainly of stunted individuals, mostly less than 15 cm (6 in) in length (Moyle 1976a). This occurs in part because the lakes are low in productivity, and so the trout have slow growth rates (Reimers 1958). There is presumably intense intraspecific competition among the trout for the limited food resources available in the lakes. In addition, brook trout are fall spawners, and post-spawning adults often have a hard time surviving the winters. Rainbow trout and brown trout often have difficulty maintaining populations in lakes because they require streams for spawning. For this reason, about half of all Sierra Nevada lakes are planted every one to two years with juvenile rainbow trout (Bahls 1992). However, lakes in national parks are no longer planted with trout, a policy decision that was highly controversial at the time it was made (Pister 1977).

A special case of lake fishery is found in Lake Tahoe, where the primary focus is on naturally produced lake trout, although rainbow trout, brown trout, and kokanee salmon are also caught (Cordone and Frantz 1966). Because of the low harvest of the lake's trout fishery (0.27 kg/ha/yr [0.24 lb/acre/yr]), opossum shrimp were introduced into the lake as additional forage. There is no evidence that this introduction improved the fishery, although it did dramatically change the ecology of the lake by eliminating most of the large zooplankton species (Morgan et al. 1978).

Bahls (1992), following a survey of fisheries managers responsible for high-mountain fisheries, characterized the management of high-mountain lakes, including those in the Sierra Nevada, as follows:

> Management . . . can best be summarized as intensive, on-going, and largely indiscriminate stocking. . . . Most regions stock mountain lakes with non-native trout species and with limited or nonexistent survey data upon which to make basic stocking decisions. . . . [There appears to be] little concern for protection of native fish species in lakes or downstream systems, no evident concern for maintaining representative pristine lakes, and no consideration for the effects of trout stocking on the indigenous fauna, aquatic ecosystems, and lake shore. . . . Furthermore, most regions appear to manage fisheries with little understanding of the high lake anglers whom they serve. (P. 191)

Wild Trout Fisheries

Fishing for trout produced naturally in California streams has always been an important recreational activity. California Trout, an angler organization, estimates that about 60% of the more than 150,000 licensed anglers in California fish primarily for trout, with most of the fishing effort concentrated on naturally produced trout (California Trout, unpublished studies). Wild trout are especially important in Sierra Nevada fisheries. Sierra Nevada streams have been estimated to have standing crops of trout 75 mm (3 in) long and longer (mean, 46 kg per ha [41 lb per acre]) that were typical of California streams but lower than those in Rocky Mountain streams (mean, 67 kg per ha [60 lb per acre]) (Gerstung 1973). Wild, catchable-size (longer than 15 cm [6 in]) trout in Sierra Nevada streams average 139 fish per km (224 per mi), with a range of 60–500 per km (100–800 per mi) (Gerstung 1973).

Recognizing that the harvest of trout in California waters was approaching or exceeding the maximum harvest rate (Gerstung 1973) and that a growing segment of the angling community preferred to release most of the fish they caught, the CDFG initiated a wild trout program in 1971. This program, authorized by the state legislature in 1979, allows the CDFG to designate streams and lakes as wild trout waters, in which no catchable-size trout are planted and which have restrictive angling regulations. Fifty such streams and lakes have been designated (Deinstadt et al. 1993), mostly in the Sierra Nevada. Other streams are added to the program on a regular basis, based on their ability to support wild trout fisheries. For example, the Upper Middle Fork of the San Joaquin River has been recommended for addition to the program based on the fact that it supports an average of 964 catchable trout per km (1,606 per mi), one of the highest densities of trout in the Sierra Nevada (Deinstadt et al. 1995). Although most wild trout waters allow a small number of trout to be kept by the anglers, some have catch-and-release fishing only. In either case, large numbers of fish are caught repeatedly over a season, "recycling" the trout. This program is very popular with trout anglers (Deinstadt et al. 1993).

Catchable Trout Fisheries

As fishing pressure increased on roadside streams and lakes in the 1940s and 1950s, the CDFG developed an extensive hatchery system to raise trout to catchable size (15–20 cm [6–8 in]). These fish are planted with the expectation that most will be caught within two weeks of release; at least 50% must be caught for a planting program to be considered successful (Butler and Borgeson 1965). Today, the CDFG supports ten production hatcheries to raise trout, which annually produce about 13 million catchable trout, 1.2 million “subcatchable” trout, and 12.3 million fingerling trout, mostly rainbow trout (Hashagen 1988). The catchable trout are planted in both streams and lakes, while the subcatchable trout (10–15 cm [4–6 in]) are planted mostly in reservoirs (because of higher survival rates). The fingerling trout are planted mainly in high-elevation lakes in the Sierra Nevada. A fairly typical hatchery serving Sierra Nevada streams is the Moccasin Creek hatchery on the Tuolumne River. This hatchery raises more than 1 million catchable rainbow trout each year, which are planted in forty heavily fished lakes and streams in the region, as well as more than 1 million fingerlings for aerial planting in alpine lakes (Groh 1990). The trout produced in such hatcheries presumably account for the bulk of the trout kept by anglers in the Sierra Nevada each year and contribute substantially to the recreational economy of the region.

Warm-Water Stream Fisheries

Warm-water stream fisheries occur in low-elevation streams, especially those with reduced flows due to diversions, and focus on various introduced black basses, sunfishes, and catfishes. In addition, Asian anglers capture common carp as well as various native minnows and suckers for consumption. However, compared to trout fisheries, these fisheries are relatively small, and little information exists regarding them.

Reservoir Fisheries

The creation of hundreds of reservoirs by damming streams throughout the Sierra Nevada has created many “new” habitats for fish and additional fishing opportunities. At high elevations, such reservoirs support mainly trout fisheries, and, because of their accessibility, they are heavily planted with hatchery trout. At lower elevations, warm-water fishes predominate, and these are largely sustained through natural reproduction. As in warm-water streams, the principal fish in angler catches in reservoirs are various bass, sunfish, and catfish species. Because reservoir volumes fluctuate considerably in response to water demands and the amount of water flowing into each reservoir, the fish populations show considerable fluctuation in size. While efforts were made by the CDFG in the 1960s and 1970s to evaluate reservoir fisheries (Calhoun 1966; Horton and Lee 1982), evaluation of fisheries in recent years has been confined to a few reservoirs of special interest (e.g., D. Lindstrom, Pacific Gas and Electric Company, conversation with the author, 1995). However, it is safe to assume that such fisheries are of major importance in the recreational economy of the area.

Conclusions

Recreational fisheries are clearly important in Sierra Nevada lakes and streams, but the intensity of fishing effort tends to diminish with distance from roads. Stream and reservoir fisheries for both hatchery trout and wild trout are important in the Sierra Nevada economy, representing a large chunk of the more than $3 billion contributed annually to the California economy by trout anglers (California Trout, unpublished studies). Although about half of the natural lakes in the Sierra Nevada are regularly stocked with fingerling trout, fishing intensity is not well known for most lakes. Nevertheless, lake fishing is an important part of the backcountry experience for many people. Clearly, an evaluation is needed that balances the economic and recreational benefits of the stocking of backcountry lakes with the biological costs to the local ecosystems.

CONSERVATION IMPLICATIONS

A number of patterns are apparent from the analysis of the status of fish and fisheries in the Sierra Nevada:

- Native fish communities have been disrupted, and the populations of a number of native fish species have been seriously depleted or are in decline.
- Anadromous chinook salmon, steelhead, and lampreys, which were once abundant and widely distributed in the western Sierra Nevada, are no longer important components of most riverine ecosystems in the Sierra Nevada.
- Dams and diversions have greatly altered fish habitats and blocked fish movements throughout the range, with the greatest effects probably occurring before 1950; the habitats they create favor mostly non-native fishes.
- A large percentage of the stream reaches in the Sierra Nevada have been altered to a greater or lesser degree by roads, railroads, grazing, mining, and other factors (Kattelmann 1996); this habitat change has depressed fish populations and continues to do so, but much of it is reversible.
- Trout have been introduced into most high-elevation lakes and streams capable of supporting them and have changed the nature of aquatic ecosystems in the high Sierra.
- Fisheries in the Sierra Nevada are predominantly for introduced fishes, including trout originating in hatcheries.

Obviously, the dramatic changes that have taken place in the fish fauna of the Sierra Nevada reflect dramatic changes in the aquatic ecosystems of which they are part, although our understanding of these changes is limited. It is equally obvious that while many of these changes are likely to be permanent, others are probably reversible, at least in limited areas. If conservation of the remaining native aquatic biota is to be accomplished, protection of the best remaining aquatic habitats will be necessary, as will restoration of the native biota in at least some areas in which it is now reduced or absent. Such protection must be systematic (Moyle and Yoshiyama 1994) and must recognize that there is no time to be lost.

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