5 Reconciling Ecosystems: Reversing Declines in Native Species

CALIFORNIA DEPARTMENT OF WATER RESOURCES

Food grows where water flows.

Congress created dust bowl.

No water = no barley = no beer.

People are more important than fish!

Signs along rural California highways, early 21st century

Free-flowing water in California has generally been regarded as something to extract, pollute, contain, or otherwise modify for human use. Not surprisingly, given California's rapidly growing human population and economy, wild organisms that depend on natural streams, wetlands, and lakes are in sharp decline, reflecting a decline in the quality and abundance of natural aquatic habitats. These losses bear witness to California's history of large-scale land and water development with scant concern for environmental needs (Chapter 1). Only since the 1970s has California really addressed the negative consequences of water and land development. For example, the construction of Friant Dam in the 1940s dried up long sections of the San Joaquin River and only recently has a monumental effort begun to restore flows (and fish) to the river. Recent efforts to recreate the San Joaquin River—albeit in a much reduced and controversial form—reflect a growing understanding that free-flowing waterways have high economic, aesthetic, and environmental values.

In this chapter, we (1) document the decline in California's native fish species, as indicators of deterioration of aquatic environments, (2) describe valuable ecosystem services that are being lost as a result of this deterioration, (3) discuss three general conservation strategies—reservation, restoration, and

A Chinook salmon, swimming upstream.

reconciliation—to create long-term solutions, (4) focus on reconciliation as a way to deal with major environmental problems, and (5) discuss legal means to achieve reconciliation. Then, we provide some guidelines for crafting policies and regulations to reconcile human and environmental uses of water.

Fish Versus Water Supply: The Fish Are Losing

The best documented indicators of declining aquatic environments in California are fish (Moyle and Williams 1990; Moyle 2002; Howard and Revenga 2009). Of 129 kinds of native fish in California, 5 percent are extinct, 24 percent are listed as threatened or endangered species, 13 percent are eligible for listing today, and another 40 percent are in decline (Figure B). In other words, over 80 percent of the native fishes are extinct or imperiled to a greater or lesser degree. The number of imperiled species is increasing rapidly. Since the first statewide assessment in 1985, fish species have been listed under state and federal Endangered Species Acts (ESAs) at a rate of about one species per year, with 31 listed by 2010. Most native fishes are endemic only to California (60 percent) or to the interstate waters of California, Nevada, and Oregon (19 percent). Thus, their decline is largely due to factors in California, mostly related to human water and land management.[1] Clearly, environmental management actions in recent decades have been far from sufficient to reverse these declines.

An analysis by Richter et al. (1997b) indicates that the loss of freshwater biodiversity in the western United States primarily results from altered hydrologic regimes, pollution (especially nonpoint source pollution), and invasions of alien species. Three quite different examples illustrate this well: Chinook salmon, delta smelt, and pupfish (Moyle 2002).

Chinook Salmon

Chinook salmon (*Oncorhynchus tshawytscha*) once dominated the Central Valley's rivers, as well as the Klamath, Eel, and other larger coastal streams. Statewide, it is likely that 3 million to 4 million large (9- to 90-pound) fish returned to spawn each year after two to four years in the ocean. The salmon returned in distinct runs, named for the time of year they entered fresh water: fall, late-fall, winter, and spring. The runs for each river and for each season

1. Declines in fish populations, of course, are also caused by natural factors such as droughts and weak upwelling in the coastal ocean. But the fish have always made it through such conditions in the past. What has changed is the human modification of habitats, which now exacerbate, or make it much harder to recover from, natural causes of decline.

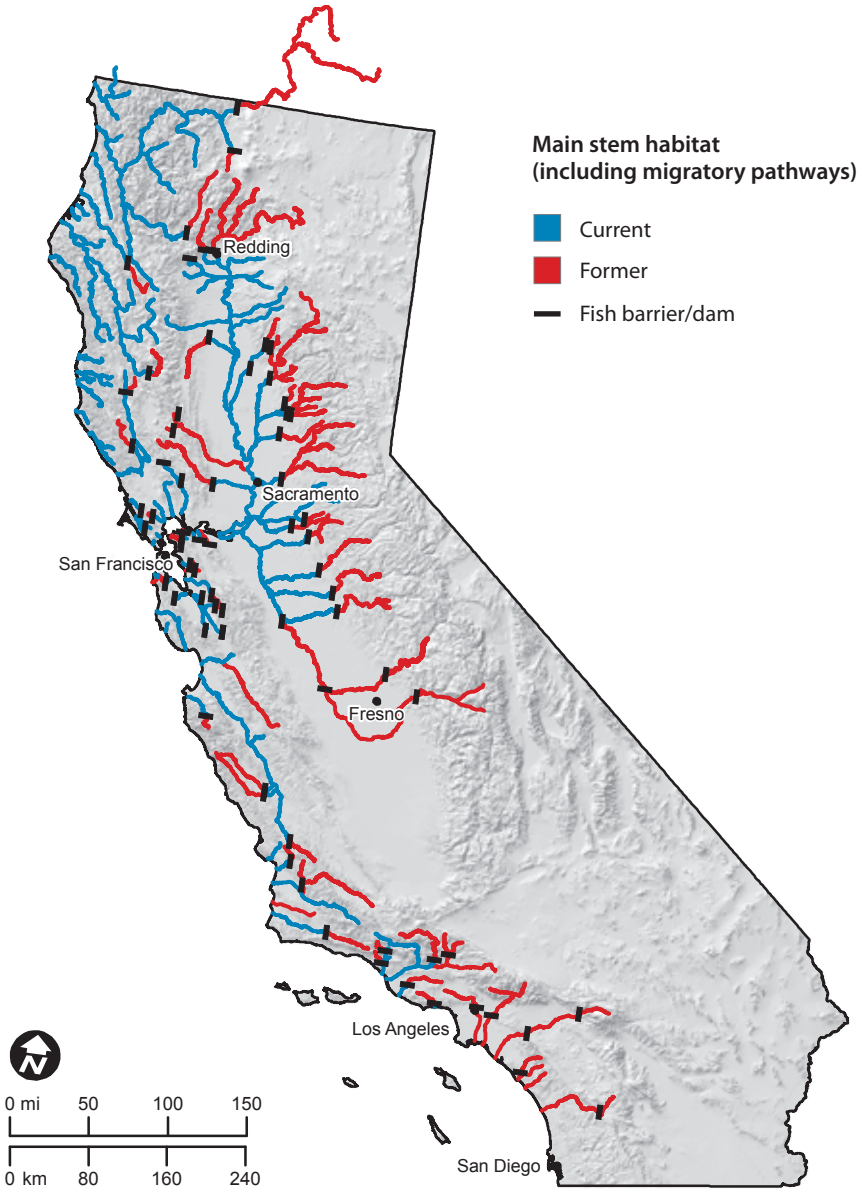
were genetically distinct, reflecting a long history of adaptation to California's diverse environments. The diversity of the spawning runs and life histories meant that virtually all accessible habitats in the larger rivers were saturated with fish, with migrating or spawning adults found somewhere in the state during most months of the year.

Today in the Central Valley alone, the winter run is listed as endangered, the spring run as threatened, and the late-fall run as "special concern" (qualified for listing). The Central Valley fall-run population, which sustained the commercial and recreational salmon fishery for decades, has collapsed (fewer than 40,000 fish in 2009) and could be considered for listing. In addition, some local runs are now extinct, such as the spring and fall runs in the San Joaquin River. Although many factors have contributed to the decline of salmon, the biggest single cause was construction of dams, starting in the late 19th century. California's dams, large and small, denied winter-run Chinook access to *all* their upstream spawning and rearing areas, barred spring-run Chinook and late-fall Chinook from more than 90 percent of their upstream spawning areas, and kept the fall run from perhaps 70 percent of their historical spawning and rearing areas (Yoshiyama et al. 2001). Likewise, in the Klamath and Trinity Rivers, dams denied salmon access to hundreds of miles of spawning and rearing streams (Hamilton et al. 2005) (Figure 5.1).

Unfortunately, dams are not the only problem, just the biggest. Salmon declines have been exacerbated by levees that deny access to floodplain rearing habitats, alteration of flows and habitat in estuaries, sedimentation from mining and logging, pollution from agricultural and urban sources, introduction of alien predators and competitors, water diversions, and general decline of habitat and water quality. These factors make the salmon more vulnerable to natural episodes of adverse conditions, such as drought in fresh water and reduction in coastal upwelling and other conditions in the ocean (Moyle, Israel, and Purdy 2008; Lindley et al. 2009).

In the Central Valley, most salmon and steelhead runs have persisted because cold water released from dams in summer (principally for irrigation) replaced some of the lost upstream habitat and because of hatcheries, constructed to mitigate lost habitat. Winter-run salmon now spawn at locations far below their natural habitat, where water is maintained at required cold temperatures by the release of cold water stored in the very dam (Shasta) that bars them from their far-larger natural spawning grounds. Hatcheries focused on sustaining fisheries primarily by rearing fall-run Chinook salmon, especially following

Figure 5.1
Dams and diversions have cut off access to high-quality spawning and rearing habitat for salmon and steelhead



SOURCE: Moyle, Israel, and Purdy (2008).

NOTE: The map includes only habitat in larger rivers and major tributaries; the actual number of miles of stream cut off is much higher than shown.

the construction of Shasta Dam in the 1940s. Hatcheries annually produce millions of juvenile salmon, which, until recently, provided several hundred thousand adult salmon each year for the fishery and returns to the rivers, hiding in part a long-term decline in wild salmon abundance (Yoshiyama et al. 2000).

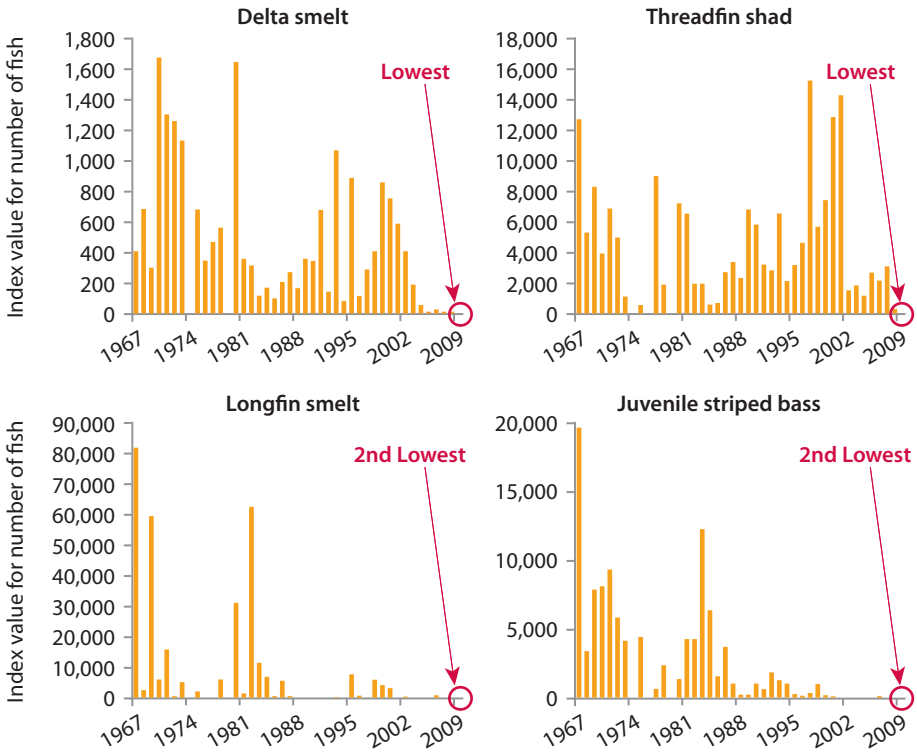
The hatchery strategy has had other, unintended consequences. Hatchery fish appear to have replaced naturally spawning salmon, rather than supplementing them as originally intended (e.g., Williams 2006). As a consequence, in the Central Valley, Chinook salmon have lost much of their genetic and ecological diversity.[2] The descendents of hatchery fish are less fit for survival in the wild, especially under adverse conditions such as those created by increased diversion of water, poor water quality, alien species, and less favorable ocean conditions. The result has been a collapse of fisheries and the creation of salmon populations whose abundance now increasingly depends on the hydrologic serendipity of a series of wet years combining with favorable ocean conditions (Lindley et al. 2009).

Delta Smelt

The delta smelt (*Hypomesus transpacificus*) is the most controversial endangered fish species in California today because it is a small endemic fish that lives in the hub of California's water distribution system, the Sacramento–San Joaquin Delta. Court decisions have required some reduction in exports to protect smelt populations, so the smelt have become scapegoats for major cutbacks in water deliveries to farmers in the southern Central Valley, even when the principal cause is drought (Hanak et al. 2010). Delta smelt are extremely vulnerable to changes in their habitat because they are found only in the upper San Francisco Estuary, have a mostly one-year life cycle, have a low reproductive rate, and depend on zooplankton in open water for food (Bennett 2005). Until the early 1980s, delta smelt were one of the most abundant fish in the upper estuary, but their population abruptly crashed, resulting in their listing as a threatened species in 1993 (Moyle 2002). Their decline, which hastened again in the early 2000s, coincides with increased export pumping from the Delta, as well as the decline of other open-water, or pelagic, fish species (Figure 5.2) (Feyrer, Nobriga, and Sommer 2007; Sommer et al. 2007).

2. On genetic diversity, see Williamson and May (2005) and Barnett-Johnson et al. (2007); on ecological diversity, see Carlson and Satterwaite (2010).

Figure 5.2
Populations of the Delta's open-water fish species have plummeted



SOURCE: California Department of Fish and Game.

NOTE: The graphs report the indices for the fall midwater trawl.

The delta smelt's importance in affecting the timing and volume of Delta exports has caused some to seek a single cause of their decline other than water exports. This presumes that if such a cause can be found and fixed, delta smelt would recover and exports could continue or even increase. Single causes often suggested include entrainment in the export pumps of the southern Delta, predation by alien species such as striped bass, reduction in food supply by alien clams, the effects of ammonium from sewage treatment plants, the toxic effects of pyrethroids and other agricultural chemicals, and blooms of toxic algae. The problem with the single cause theories is that any or all of these factors can affect smelt populations at one time or another or in one place or another. As

Pupfish in desert environments are highly vulnerable to extinction from competition for water resources. Photo by Jacob Katz.

Bennett (2005) and Moyle and Bennett (2008) show, the problems facing the smelt are systemic: Since the 1980s, there has been a *regime shift* in the Delta ecosystem, so it functions less like an estuary (with strong upstream-downstream gradients) and more like a confused lake, with channels dominated by rooted aquatic plants and regular movement of water across the Delta, toward the pumps. This environment is increasingly hostile to the estuary-adapted smelt, making the smelt more vulnerable to such factors as toxins and food supply reductions (Moyle et al. 2010).

Pupfish

Pupfish (*Cyprinodon*) are the opposite of salmon and smelt in almost all respects. Pupfish are small (1–2 inches long) and spend all of their short lives (6–18 months) in the warm springs and river backwaters of southeastern California deserts (Moyle 2002). Of the eight varieties of pupfish native to California, one is extinct, two are listed as endangered, and the rest are considered highly vulnerable to extinction because their distribution is limited to deserts where water is in high demand. Thus, the Owens pupfish (*C. radiosus*) became endangered after the City of Los Angeles developed the Owens River and its hydrologically connected groundwater for municipal supply, altering most pupfish habitat. Likewise, desert pupfish (*C. macularius*) became endangered because of alterations of the Colorado River through dams, diversions, pollution from

agricultural return water, and groundwater pumping. The Tecopa pupfish (*C. nevadensis calidae*) went extinct when the warm springs it inhabited were converted to a spa. Pupfish also are exceptionally vulnerable to predation by introduced fishes, which thrive in human-altered waterways as well as in pristine desert spring pools.

Other Aquatic Species

Studies in Europe and other countries indicate that little-studied mollusks, aquatic insects, and other aquatic organisms face problems similar to those of native fishes (Balian et al. 2008). This is no doubt the case in California as well, reflecting the altered state of freshwater environments. Loss of aquatic biodiversity is a worldwide crisis regarded as more severe than the destruction of rainforests because it is so pervasive (Moyle and Leidy 1992; Helfman 2007; Magurran 2009). California is arguably on the leading edge of global freshwater faunal endangerment in terms of threats to the entire fauna, so solutions here (or a lack thereof) can provide examples with global implications (Leidy and Moyle 1998; Howard and Revenga 2009).

Bringing Fish into Water Management: Ecosystem Services

There are many reasons to protect desirable fish and other organisms, including their potential scientific and medicinal benefits, their effects on other species of plants and animals that inhabit the same ecosystem, and stewardship for its own sake (Norton 1987; Rolston 1994).[3] These values—including the idea that it is wrong to allow species to go extinct through human actions—are expressed in the federal Endangered Species Act of 1973. Historically, the design, construction, and operation of California's water supply and flood management infrastructure were based on promoting economic development, principally through traditional uses of water for agriculture, manufacturing, and urban activities. The evolution of societal values, exemplified by the Wild and Scenic Rivers Act, the Endangered Species Act, and the Clean Water Act, changed how water has been allocated and delivered for these traditional economic

3. Desirable species are defined here as mostly native fishes that require an ecosystem that functions like the original ecosystem. Desirable species therefore are indictors of ecosystem "health," and maintaining or increasing their abundance can be a goal of management. Thus, in the Delta, the native delta smelt, tule perch, and Chinook salmon are desirable species because they thrive in a functioning estuary. The striped bass, an alien species, can also be regarded as desirable because it also requires a functioning estuary to persist, and it supports a valuable fishery (see Moyle and Bennett 2008).

uses (Chapter 1). This societal change has created ongoing tension between the economy and the environment, where allocations of environmental water or investments in habitat for organisms are viewed as "costs" associated principally with regulatory compliance, without recognizing corresponding benefits.

As discussed in Chapter 2 (Box 2.3), these perceptions stem, in part, from failure to adequately incorporate the value of *ecosystem services*—benefits that ecosystems provide to humans—in assessments of water-related activities. Ecosystems are important not only to support specific species, but also for the broader set of services they provide (Daily et al. 2009). As highlighted by the National Research Council (2005) and the Environmental Protection Agency (EPA) Science Advisory Board (2009), explicit monetary and nonmonetary evaluation of ecosystem services provides the best approach for translating various management actions into how they affect human welfare.[4] By bringing to light the high value of services provided by natural systems, such an approach can guide water resource design, implementation, and operation, leading to better stewardship of the environment (Arthington et al. 2009). Systematic evaluation of services improves the analysis of tradeoffs and complementarities among alternative uses of ecosystems by a wide range of stakeholders. Finally, and perhaps most significantly, clearly articulating linkages among ecosystem functions, the services of such functions, and how these services affect human well-being is necessary to move beyond the simplistic and misleading "farmers versus fish" perception that often dominates public debate over water management (Hanak et al. 2010).

There are many examples of complementarities, where restored or conserved ecosystem functions support native biodiversity while enhancing social and economic values (Brauman et al. 2007). In California water management, such mutually beneficial actions are perhaps best illustrated by efforts to manage floods. As described further in Chapter 6, modern approaches to flood management seek to store and convey water on floodplains and bypasses, rather than relying exclusively on dams and levees to "control" high flows.

4. Strict adherence to using ecosystem service valuation in benefit-cost evaluation of projects may produce undesirable results. For most projects, provisioning services are both more easily quantifiable and often of higher monetary value than other services. Thus, a benefit-cost evaluation can favor large, capital-intensive projects, such as dams and levees that maximize agricultural and urban water supply and hydropower, at the expense of poorly monetized regulating, cultural, and support services, such as benefits to species and open space (Box 5.1). In addition, many current and projected projects are specifically designed to restore ecosystem functions damaged by historical water management activities. Typical examples include reservoir reoperation to support cold water fishes, dam removal, the restoration of degraded physical habitat in rivers and streams, and the creation of wetland habitat. Since these do not often improve high-value provisioning services, they may not meet the ecosystem services-based benefit-cost test. Yet such projects are often essential for restoring ecosystem function.

Components of this approach include setback levees that increase the area inundated in wet seasons; flood bypass areas that divert flows onto floodplains, usually through weirs; and changes in reservoir operation that promote increased frequency and duration of floodplain inundation. Box 5.1 describes some benefits and costs from expanding floodplains. Done properly, this approach to flood control simultaneously restores a valuable array of ecological characteristics that support native species while providing a range of other valuable services (Opperman et al. 2009). Reintroducing seasonal inundation often restores the productivity of food webs to support native fishes within, around, and downstream of the floodplains. Floodplain inundation can also reestablish wetland and riparian woodlands and the array of native animal and plants that rely on them.

5.1

Ecosystem services and floodplain restoration

Many ecosystem services that improve human well-being arise from restoring floodplain functions. This restoration also can have significant costs. The challenge in ecosystem service valuation is to systematically compare these tradeoffs and identify actions with the greatest benefit. Some of the costs and benefits are discussed below, using the classification system from the Millennium Ecosystem Assessment (2005) (see also Box 2.3).

Provisioning services. Benefits include increased production of commercially harvested fish, increased operational flexibility for water supply, increased groundwater recharge, and more flexibility to adapt to climate change. Costs include loss of traditional economic land uses (including urban development and farm activities that are incompatible with seasonal flooding) and potential reductions in water supply from higher evapotranspiration and required releases to maintain floodplain ecosystem function.

Regulating services. Benefits include reduced flood stage and associated reductions in flood damages or costs to upgrade flood infrastructure, reduced maintenance for flood infrastructure, improved habitat for aquatic and riparian wildlife, improved water quality resulting from nutrient cycling, improved soil fertility, lower air temperatures, and improvements in air quality. Costs include maintaining flooded regions, controlling invasions by nonnative plants and animals, and compensating landowners for flood losses.

Cultural services. Benefits include increased native biodiversity, ecotourism and recreation, open space, education opportunities. Costs include increased oversight and patrolling of recreation areas.

Wintering snow geese on the Yolo Bypass. The bypass provides valuable ecosystem services in addition to flood protection. Photo by California Department of Fish and Game.

A prime example of this approach in action is the Yolo Bypass (Sommer et al. 2001). Initially designed to provide flood protection to Sacramento residents, the area supports seasonal agriculture, diverse habitat for fish and waterfowl, and recreational areas for bird-watchers, anglers, and hunters. Recently, interest has grown in expanding the aquatic ecosystem functions of the area, while also managing the floodplain for groundwater recharge. Any expansion in the flooded area will need to consider potential losses of agricultural or other economic activity and compensate landowners accordingly.

General Strategies for Recovering Freshwater Biodiversity

The provision of ecosystem services requires healthy ecosystems, usually characterized by high levels of native biodiversity, as indicated by the abundance and diversity of native fish species. However, any strategy to protect native freshwater fishes and their ecosystems must be simultaneously local, regional, and statewide because of the enormous environmental diversity in the state and the high degree of local endemism (Moyle and Yoshiyama 1994). Protection of pupfish, smelt, and salmon require radically different approaches that are best taken under an umbrella strategy for maintaining the array of aquatic diversity statewide.

Although the state and federal Endangered Species Acts allow for ecosystem-based management strategies through federal Habitat Conservation Plans (HCPs) and state Natural Community Conservation Plans (NCCPs), these efforts are usually undertaken in response to crises, not to prevent them. As the number of listed species increases, so will the number of crises, including conflicts among actions to protect listed species. To maintain biodiversity into the future, a general ecosystem-based conservation strategy will be needed that both prevents crises and deals with ongoing ones. Here, we discuss such a strategy and highlight some examples of the approach. The obvious state agency to take the lead in developing and implementing such a strategy is the Department of Fish and Game (DFG), working closely with the State Water Resources Control Board (SWRCB). The relevance of both agencies was illustrated when the state legislature required that each agency come up with criteria to provide freshwater flows through the Delta to reverse the trends in delta smelt and other endangered species (Box 5.2).

5.2

Flows for the Sacramento–San Joaquin Delta

The Sacramento–San Joaquin Delta Reform Act of 2009 (Senate Bill X7-1) directed that the SWRCB come up with recommendations for new flow criteria for the Delta ecosystem (State Water Resources Control Board 2010b). The board, citing its responsibilities under the public trust doctrine, developed flow criteria, mainly to protect endangered fish, without attempting to balance water needs for other purposes. The board concluded that there was good scientific evidence that higher flows were needed, although the exact amounts were controversial. Key recommendations were that flows needed for ecosystem function were (1) 75 percent of unimpaired Delta outflow from January through June, (2) 75 percent of unimpaired Sacramento River inflow from November through June, and (3) 60 percent of unimpaired San Joaquin River inflow from February through June. Depending on how these flow recommendations were implemented, they would greatly reduce Delta export pumping, with perhaps greater reductions for upstream and indirect diversions from the Delta.

The new law also required that DFG come up with "quantifiable biological objectives and flow criteria for the species of special concern in the Delta" (California Department of Fish and Game 2010a). DFG proceeded to do so for 34 species, mostly threatened or endangered plants, insects, fish, birds, and mammals. The DFG flow recommendations are very similar to those of the SWRCB. The two agencies are in general agreement that current water management provides inadequate flows through the Delta to sustain the endangered species, especially fish.

A general conservation strategy will need to combine three distinct approaches: reservation, restoration, and reconciliation. Although the first two have a role in conservation, in today's world most species are most likely to be protected through reconciliation, which recognizes how completely humans dominate the natural world (Rosenzweig 2003). These approaches differ from more technological approaches, such as artificial propagation (e.g., fish hatcheries, captive breeding programs) that have often been relied on with little success.

Reservation

Reservation is the strategy of protecting species in relatively pristine areas (reserves or preserves) where natural processes dominate, isolated from most interference from human activities. This strategy is reflected in language such as "protecting the best of what is left" and, for salmon streams, protecting "salmon strongholds." Although protecting the most pristine areas is highly desirable, few pristine areas remain and they are small in total area, so they cannot protect most biodiversity.[5] For protecting aquatic organisms, an added difficulty is that entire watersheds must be protected because stream processes and fish movements, from headwaters to stream mouth, are interconnected. Thus, small watersheds are more likely to be eligible for reserve status than large ones, where the economic costs of designating a reserve are also likely to be larger. Overall, few opportunities exist for establishing fully functioning aquatic reserves in California, although some possible examples exist, such as the Clavey River, a relatively pristine tributary to the Tuolumne River, and much of the Smith River, by the Oregon border. Some small de facto reserves exist, such as Salt Creek, completely within Death Valley National Park, or Elder Creek, Mendocino County, completely protected within the University of California's Angelo Coast Range Reserve.

Restoration

Restoration returns a damaged ecosystem to a more desirable condition, ideally requiring minimal continued human intervention to sustain its desirable species and characteristics. A restored system generally bears a close resemblance to the original system. For aquatic systems, restoration under this narrow definition is most likely in streams and other water bodies that are not damaged

5. Information in this paragraph draws from Moyle and Yoshiyama (1994) and Moyle and Randall (1998).

irreversibly by dams, diversions, channelization, and other changes. Ideally, restoration efforts also should encompass an entire watershed. Dam removal is often a major component of large-scale restoration projects, but the effects of removal can be complex and hard to predict (see the next section). A major problem with aquatic restoration efforts in California is that most waterways contain alien fish species, invertebrates, and amphibians that can interfere with native species. The most adaptable alien species rarely disappear after major restoration efforts.

Even in a region as large as the Sierra Nevada, few opportunities exist for real watershed restoration; most opportunities are at high elevations and require eradication of alien species (Moyle and Randall 1998). Thus, the Dye Creek watershed, Tehama County, is entirely within The Nature Conservancy's Dye Creek Preserve. Despite its remarkably intact riparian woodland and abundance of native fish and frogs, full restoration will require eradication of nonnative green sunfish, bullfrogs, wild fig trees, and pigs, all possible but very difficult (especially pig removal). Knapp, Matthews, and Sarnelle (2001) document how removing trout from Sierra Nevada lakes that were originally fishless not only brings back endangered frogs but recreates an aquatic ecosystem that interacts with the surrounding terrestrial ecosystem.

Reconciliation

Reconciliation recognizes that humans so completely dominate the planet that conservation of species and their habitats depends on integrating native ecosystem functions into ecosystems shaped by human activity. Such ecosystems are often largely new in many aspects of their structure and function and require continual human management. For example, maintaining native fish in rivers below dams in California requires not only minimum flow releases from the dam but releases with appropriate temperatures and volumes on a schedule that follows the natural flow regime. Thus, restoration flows in Putah Creek in Solano and Yolo Counties are less than 5 percent of the annual natural flow volume, but because the flow regime follows the natural seasonal pattern, a group (assemblage) of native fishes dominates much of the creek (Marchetti and Moyle 2001). Alien fishes remain but in low numbers in native fish reaches. Native birds and plants also have benefited from the flow regime, but active removal of invasive shrubs and trees has been required in some areas, and bird populations have been enhanced through the use of bird houses (Truan 2004).

The creek is a narrow ribbon of habitat in an agricultural landscape. The habitat looks "natural" but requires continual human input to keep it that way. Putah Creek is thus a reconciled waterway that supports many native species.

One of the best-known "restoration" efforts in California is Rush Creek, a tributary to Mono Lake. Rather than being a restoration project, Rush Creek is actually a good example of a reconciliation project. Rush Creek had been allowed to dry up completely through diversion to support Los Angeles's Owens Valley Project (Chapter 1). Following a key court decision, diversions were reduced, and extensive channel improvements and re-vegetation efforts were undertaken to restore the stream and its riparian habitat. This effort also restored the trout fishery, which, in fact, was the main legal reason for restoring the stream. Ironically, Rush Creek was originally without fish, so the restored stream supports populations of nonnative rainbow trout and brown trout, which undoubtedly have had effects on the reconciled ecosystem (Kondolf 1998).

The San Joaquin River "restoration" effort noted in this chapter's introduction is also an attempt at reconciliation. The reconciled river—roughly 150 miles from Friant Dam to the Merced River confluence—will support two runs of Chinook salmon, a natural assemblage of native fishes, and birds and mammals requiring riparian habitats once the new flow regime is established. But the ecosystem will bear only modest resemblance to the original river ecosystem. Much of the channel will be between levees, and nonnative fish, amphibians, and invertebrates will dominate some sections, especially those that still receive agricultural drain water. Yet there will be a living river again, flowing down the once-dry streambed.

A common aspect of these three examples of reconciliation is the presence of alien species as significant parts of the ecosystem. The aliens include not only fish species but also invertebrates such as clams, crayfish, and scuds (small shrimplike crustaceans), as well as plants, which may have replaced native species or else have added complexity to the ecosystem. Most of these species cannot be eliminated, because they are fully integrated into the ecosystem and some, such as brown trout in Rush Creek, may even be considered desirable species. Thus, management plans for reconciled ecosystems must first include designation of which desirable species should be the focus of management and then determine which alien species can be lived with and which species will require control measures. Reconciled ecosystems usually require continuous management.

A Systematic Approach to Protecting Aquatic Biodiversity in California

California has 140 major types of aquatic ecosystems, distinguished by zoogeography, endemism, and geomorphology (Moyle and Ellison 1991). For broadest protection of the state's aquatic biodiversity, each ecosystem type requires at least one protected/managed example, including unique systems such as Mono Lake and the upper McCloud River. An important reason for such protection is that, given the nature of California's environment, most of the ecosystem types are likely to support endemic species, including many species of invertebrates and plants. Unfortunately, even the best examples of most of these ecosystem types have already been altered by humans, many irreversibly, so the basic reconciliation strategy is to designate selected examples for protection and management of their remaining natural values, including endemic fish and invertebrates. Ideally, multiple examples of each type (or the most valued types) should be protected to provide redundancy (Moyle and Sato 1991). Where possible, the examples should be protected as reserves or restoration areas, but in reality most protected systems will need to be compatible with fairly sustained human use and will require adaptive management approaches to sustain desirable characteristics in a rapidly changing world.

Reconciled aquatic ecosystems of diverse quality, from a native biodiversity perspective, will necessarily dominate conservation programs in the future. However, strategies to protect aquatic biodiversity still typically focus on increasingly ineffective strategies such as setting up relatively small protected reserves or finding areas that can be restored to near-pristine conditions.[6] In an effort to use largely reservation and restoration strategies as a basis for conservation, Moyle and Yoshiyama (1994) and Moyle (2002) recommended a five-tiered approach to prevent further loss of aquatic biodiversity in California, with each tier requiring a different, increasingly difficult, scale of action:

1. Protect endangered species and their habitats.
2. Maintain habitats that support clusters or assemblages of native species with similar habitat requirements; the clusters often contain species that are or could be listed under state and federal ESAs.
3. Protect distinctive habitats such as spring systems or isolated small streams.

6. See, for instance, Nyman (1999) and Chadderton, Brown, and Stephens (2004).

4. Manage watersheds in wildlands for natural characteristics as much as possible.
5. Recognize bioregions (large areas with common natural features and common flora and fauna) and develop landscape-level strategies for maintaining biodiversity within them.

Moyle (2002) thought that under this approach, watershed protection and management (Tier 4) was likely to pay the greatest dividends in native biodiversity persistence in the long run. Unfortunately, this is extremely difficult to accomplish, given the scale of effort needed, because there are few watersheds of any size that do not suffer from heavy human use. Using a set of semi-quantitative criteria specifically designed for the Sierra Nevada, Moyle and Randall (1998) ranked nearly 100 watersheds according to their conservation value, as part of the Sierra Nevada Ecosystem Project. The most highly ranked watersheds would qualify for reservation or restoration. The rankings have been largely ignored, because highly ranked watersheds seemed obvious to most people and were already receiving attention (e.g., Deer Creek, Box 5.3) while the scores of some low-ranking watersheds were disputed by people who lived

5.3

Balancing reservation, restoration, and reconciliation in Deer Creek

Deer Creek, Tehama County, is a tributary to the Sacramento River with high aquatic conservation value (Moyle and Randall 1998). The aquatic ecosystem is largely dominated by a complex assemblage of native fish species (including threatened spring-run Chinook salmon and Central Valley steelhead) and amphibians. Although the creek has no major dams, there is a diversion on its lower reaches, which also are partially channelized to protect agricultural fields. Most of the watershed is a patchwork of public and private timber and grazing lands, with limited public access (partly because of its rugged topography). In the foothill reach, the creek flows through the Ishi Wilderness Area. Close to the headwaters is a large meadow system being restored from the effects of grazing, after being acquired by The Nature Conservancy as part of its Lassen Foothills Project. One small tributary, Cub Creek, is protected by Lassen National Forest as a Research Natural Area. The watershed is a patchwork of land with different degrees of protection and intensity of use. But the natural values of the watershed are largely maintained by private landowners (mostly ranchers and timber companies) through the Deer Creek Watershed Conservancy, with some assistance from public funds. The result has been that Deer Creek continues to support a flora and fauna dominated by native species (e.g., Baltz and Moyle 1993).

there (e.g., South Yuba River).[7] Thus, Tier 5, bioregional management, becomes the most likely general strategy for maintaining aquatic biodiversity, using reconciled ecosystems and waterways, mixed with a few reserves and restoration sites.

The reality is that the characteristics of aquatic areas likely to qualify for reservation or restoration are so demanding that few such areas exist or can be established (Table 5.1). This does not mean California should give up on them; just the opposite is true. Aquatic ecosystems that bear close resemblances to unaltered systems will become increasingly valuable, for protection of rare plants and animals and as a source of material for improving reconciled ecosystems. At the same time, the aim should be to manage as many reconciled systems as possible in ways that protect remaining native biodiversity, while maintaining a close resemblance in structure and function to undisturbed ecosystems. This approach not only will enhance biodiversity, but will provide society with valuable ecosystem services such as clean water and recreation.

Pragmatically, any effort to systematically protect aquatic biodiversity will include watersheds with conservation values ranging from high to low, with low-scoring watersheds being more integrated into human dominated landscapes (Doppelt et al. 1993). Such an effort will also need some form of groundwater management because many California streams have springs as sources and many

Table 5.1
Which approach for which ecosystems?

Characteristic	Reservation	Restoration	Reconciliation
Size	< 50 km^2	< 50 km^2	> 50 km^2
Hydrologic regime	Natural	Natural or restorable	Altered
Diversity of aquatic habitats	Low	Low	Low to high
Natural biological integrity (biodiversity)	High	Restorable to high	Low to high
Percent native fish species	100	90–100 or restorable	Various
Percent native riparian species	100	75–100	Various
Dominance of alien species	None	Low	Low to high
Importance of rare habitats	High	High	Low to high
Importance of endangered species	High	High	Low to high
Compatibility with human usage	Low	Low to moderate	Moderate to high
Protective management required	High	High	Adaptive

SOURCES: Characteristics of reserved or restored ecosystems are from Moyle and Yoshiyama (1994); Nyman (1999); and Moyle (2002).

NOTE: In reality, the three basic management strategies each represent part of a spectrum of actions, albeit a spectrum dominated by reconciliation.

7. P. Moyle, unpublished observations.

stream reaches can go dry if groundwater contributions are lost as a result of excessive aquifer pumping (Howard and Merrifield 2010). Given limited conservation dollars, some kind of prioritization for protecting and managing aquatic ecosystems is inevitable, and it is preferable that this be done explicitly. The highest investments would be in areas with the greatest potential for maintaining natural values, usually determined by some measure of native biodiversity. This would include larger reserve and restoration areas, reconciled systems that most resemble historical systems, and unique human-dominated ecosystems with significant natural values, such as the Sacramento–San Joaquin Delta (see below). The Nature Conservancy's Lassen Foothills Project is a good example of where investment is going into reconciled ecosystems with high natural values, resulting in significant ecosystem protection (Box 5.3). On the other hand, the Salton Sea may be an example of misplaced priorities for conservation dollars (Box 5.4).

5.4

Should the Salton Sea be saved?

The Salton Sea, at 35 miles long and 9 to 15 miles wide, is the largest "lake" in California. It was created in 1905 when the entire Colorado River broke through a small irrigation diversion and flowed into a desert depression, the Salton Sink. By the time the flow was shut off (1907), the sink was filled with water (Hundley 2001). Initially, it was an extraordinarily productive ecosystem, producing huge numbers of fish and supporting vast flocks of migratory and breeding waterfowl. Over the years, the sea became increasingly salty, although it was kept from reaching lethal levels for fish by inflows of heavily polluted irrigation and urban drainage from both the United States and Mexico. However, as less fresh water flowed into the sea because of more efficient water use, salinities increased which, combined with other factors, caused massive die-offs of fish and birds (Hurlbert et al. 2007). Elaborate schemes to "save" the sea by diking, pumping, and drying some areas have been proposed, at great cost in money and water (www.saltonsea.water.ca.gov). This is a case where "no action" might be the best alternative, especially if it allowed more water to be returned to the river to "restore" wetlands in Mexico's Colorado River delta. That delta, now largely dry, was once a major, productive ecosystem that supported many of the same bird species that now use the Salton Sea. It can be argued that saving the Salton Sea and restoring the Colorado River delta are independent issues, but they both depend on water from the overallocated Colorado River. Most water reaching the lower river is diverted for cities and agriculture. Although myriad legal issues are involved in water allocation in this region, a process to prioritize allocation of the little water available for ecosystem purposes would seem beneficial.

The Salton Sea is rapidly becoming too saline to support fish and many other kinds of life. Photo by David McNew/Getty Images.

The coordination of ecosystem reconciliation with local, regional, and statewide objectives will require considerable attention by local entities. Local leadership is often provided by local watershed groups (Putah Creek, discussed above) or regionally active conservation groups (e.g., The Nature Conservancy—Box 5.3). These groups typically work with local interests to reconcile other water and land uses and native ecosystems. Although such efforts are helpful, they might be greatly expanded and made more coherent with state and national objectives through creation of regional stewardship authorities, discussed in more detail in Chapter 8. These authorities could coordinate local ecosystem reconciliation activities in conjunction with other water and environmental management activities.

Reconciling the Delta

The examples of Putah Creek, Rush Creek, and the San Joaquin River described above are reconciliation efforts that rely principally on reintroducing water into existing stream channels that are then modified to improve ecological performance. For much of California, particularly in heavily urbanized areas or areas that have been intensively farmed, the physical changes to the landscape are so great that reconciliation efforts involve the development of wholly new, even novel ecosystems. Perhaps the best example of this is in the Sacramento–San Joaquin Delta.

The Delta was historically a 700,000-acre tidal freshwater marsh. Reclamation of land from the marsh involved constructing 1,100 miles of levees and then

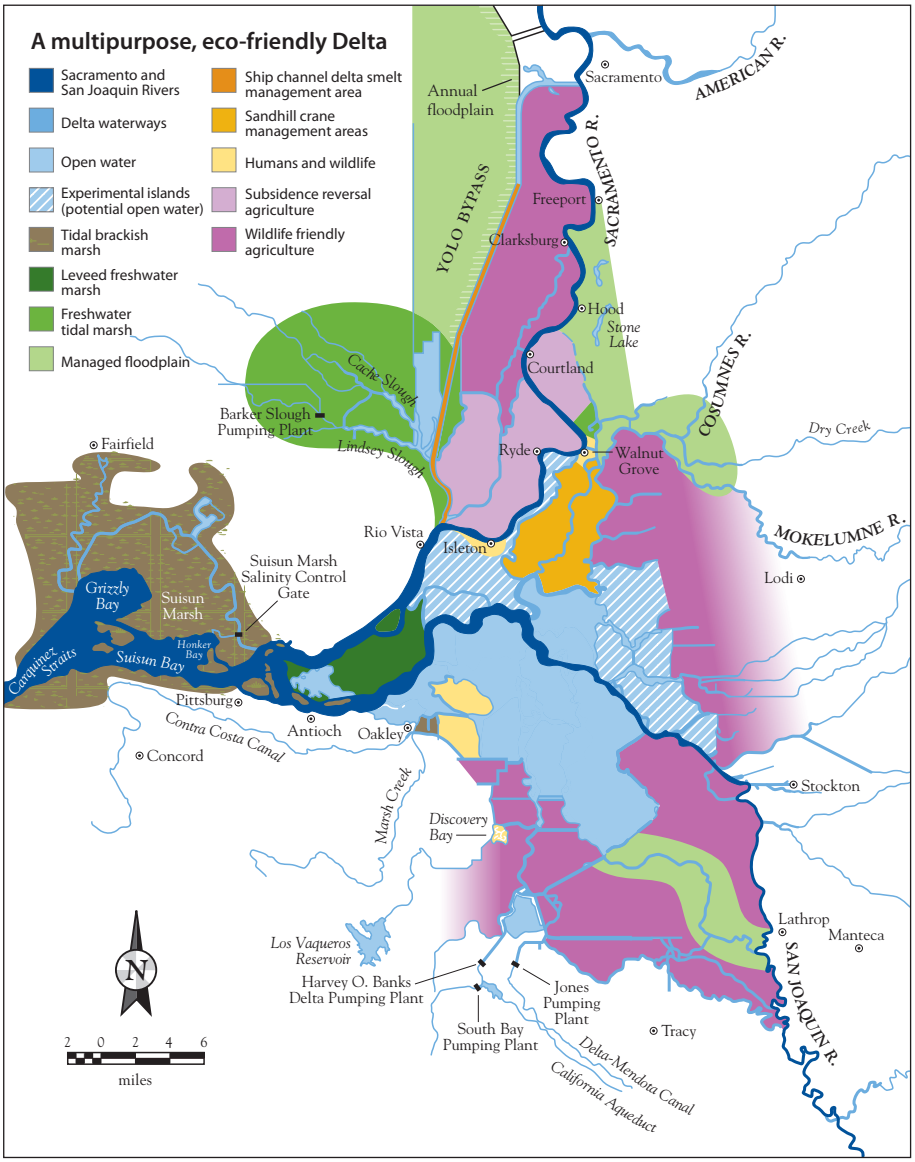
draining the lands behind them to allow crop production. Cultivation caused the land behind the levees to sink, principally as a result of oxidation of the Delta's peat soils. This process removed more than 2 billion cubic yards of soil from the Delta, creating deeply subsided islands—many more than 25 feet below sea level—surrounded by a network of fragile levees. As discussed throughout this book, and examined in detail in Lund et al. 2007, 2010, fixing the Delta to balance ecological and water supply goals is essential for California water management. But the Delta cannot be restored. There is insufficient fill or funds to bring all marshes back. Moreover, given the new blend of native and alien species, restoring the Delta to its original physical condition would not restore its historical biological condition.

The only alternative for the Delta is a reconciliation strategy that blends the needs of humans and the ecosystem in a landscape and hydrology that has irreversibly changed. One concept of a reconciled, "eco-friendly Delta" is shown in Figure 5.3. This new Delta, described in more detail in Lund et al. 2010, seeks to accommodate inevitable future changes (higher sea level, earthquakes, additional permanently flooded islands, and changing inflows as a result of climate shifts), seeks to maintain substantial and profitable agricultural use of Delta lands in ways that support native wildlife, and creates or improves aquatic habitats and functions needed to support desirable fish species (tidal marsh and open water habitat, along with variable hydrology and salinity). Most important, this reconciled Delta is strikingly different from the historical Delta. It supports new, novel habitats (flooded islands) that have no natural equivalent, as well as species of plants, invertebrates, and vertebrates from all over the world.

Reconciliation Strategies

Conservation by reconciliation requires actions that create better conditions for desirable species, usually by partially reversing previous large-scale actions by humans. Reconciliation actions do not bring back pristine or even historical conditions; rather, they create environments that support the long-term existence of native species, recovery of endangered species, and provision of ecosystem services. A list of potential actions appears in Table 5.2, along with a summary of positive and negative aspects of each tool from an environmental management perspective. Here, we present expanded examples of four important reconciliation actions: reducing contaminants, reducing the effects of alien species, reoperating or removing dams, and changing fish hatchery operations.

Figure 5.3
A reconciled, "eco-friendly" Sacramento–San Joaquin Delta would have multipurpose land and water uses



SOURCE: Lund et al. (2010).

NOTES: The map shows land and water use in a reconciled "eco-friendly" Delta. This conceptual Delta accommodates rising sea level and declining levee reliability by allowing flooding of islands (Suddeth, Mount, Lund 2010), creating new fresh and brackish water marsh habitat and floodplain habitat, promoting agriculture that provides habitat for wildlife, and restricting urbanization.

Table 5.2
Some tools for reconciling aquatic ecosystems

Tool	Positives	Negatives
Dam removal	Access to upstream areas, reduced alien species, improved downstream habitat	Loss of control of flows, especially cold water; loss of barriers to invasion
Dam reoperation	Flows to favor native species, downstream habitats	Reduction in water for other environmental purposes; requires habitat restoration as well
Estuary ecosystem-based management	Improved survival of estuarine-dependent species, including salmonids in both Delta and coastal systems	Reduced abundance of some desirable species, especially game fishes
Fisheries management improvement (including law enforcement)	Improved populations of many ecologically important species (salmon, sturgeon, etc.)	Tendency to substitute short-term actions for long-term changes
Floodplain recreation and management	Improved spawning and rearing habitat for native fish species, including salmon	Less water available for other environmental purposes in some years
Hatchery reoperation; conservation hatcheries	Improved survival of wild salmon and other fish; extinction prevention	Reduction in total salmon and steelhead numbers (temporary)
Invasive species prevention, eradication, management	Reduced "surprises" in ecosystem management; improved populations of native species; fewer listings of threatened and endangered species	Creation of public attitude that all alien species are bad, when many serve important ecosystem functions
Nonpoint source pollution reduction	Increased abundance and diversity of fish species, improved water quality for humans and other species	May result in reduced flows if polluted water sent elsewhere
Public education	Improved ecosystem function because of greater public engagement	People can love favored places to death
Scientific studies and monitoring expansion	Better understanding leads to improved management	Lack of complete information provides reason to delay taking action
Urban and industrial waste discharge improvement	Increased abundance and diversity of fish species, improved water quality for humans and others	Loss of some nutrients for ecosystems
Water diversion management (fish screens, etc.) improvement	Reduced loss of fish and aquatic life to diversions; improved stream flows; fewer "hardened" banks	Overoptimistic expectations of positive effects on fish populations
Watershed-based citizen groups (support)	Groups can be local "watchdogs" for stream alteration; monitoring; conducting habitat restoration; local education	Danger that restoration efforts can be misdirected without proper expertise
Watershed and stream habitat improvement	Improved terrestrial and aquatic habitats for native species; improved fish populations	Species tradeoffs, such as reductions of nonnative game fishes

Table 5.2 *(continued)*

Tool	Positives	Negatives
Wetland and riparian restoration and management	Increased habitat for aquatic and riparian organisms including fish and birds	Reduced dryland habitats
Wildland management (logging, fire, grazing, etc.) improvement	Reduced sediment in rivers, improved riparian cover, can counter effects of climate change	Increased frequency of fire; reduced populations of nonnative game animals (pigs)

NOTES: The positives and negatives are environmental, not economic. The most potent negative arguments—not noted in the table—relate to short-term costs of implementing measures.

Reducing Contaminants

No laws have made California's waterways more habitable for fish and usable by humans than the Clean Water Acts of 1972 and 1977 and their state counterpart, the Porter-Cologne Act of 1969. These statutes set high water quality standards to make all waters swimmable and fishable by regulating discharges of pollutants into navigable waterways. These regulations led to the construction of improved sewage treatment plants statewide, as well as general reductions of discharges from factories and other "point" or fixed sources. The result was a dramatic improvement of water quality, as once feculent rivers and estuaries became usable for recreation again and capable of supporting fisheries. This success story, however, has been limited for several reasons:

- Nonpoint source pollutants from agriculture and urban areas, including pesticide and nutrient runoff, continue to cause problems. Agricultural runoff, the biggest nonpoint pollution source in California, is still loosely regulated, with farmers in most regions required to comply only with best management practices (Chapter 6).
- "Legacy" contaminants from previous eras, such as heavy metals and PCBs, are causing problems in some waterways; their presence can greatly delay or increase the costs of large-scale environmental projects (e.g., removal of dams with mercury in reservoir sediments) (Chapter 3).[8]
- Thousands of new, unregulated chemicals are present from many sources, especially pharmaceuticals and personal care products. The chemicals, labeled Constituents of Emerging Concern, can be harmful in barely detectable concentrations (Chapter 3; Guo et al. 2010).

8. PCBs (polychlorinated biphenyl) were widely used as fluids in transformers, capacitors, and coolants. Because of PCB's toxicity and classification as a persistent organic pollutant, PCB production was banned by Congress in 1979. Toxic effects include endocrine disruption and neurotoxicity.

- Population growth has increased wastewater volumes and pollution loads, even though discharge concentrations are lower.
- Increasing water diversions reduce the ability of natural flows to dilute pollutants. Spills of oil and chemicals occasionally occur, as material is moved across and along streams and rivers by pipelines, trains, and trucks.

These factors sometimes result in direct kills of fish and invertebrates, as happened in the Southern Pacific Railroad Cantara spill of metam sodium in 1991, which killed most organisms in the upper Sacramento River above Shasta Reservoir (Hanemann 1992). More often the harm is more subtle, manifesting as increased mortality rates of small juvenile fish weakened by exposures; failures of eggs to hatch because of contaminants passed from the mother; tumors and other environmental diseases; or feminization of male fish, reducing reproductive capacity (Adams 2002). Similar effects can occur in humans exposed to contaminants, so treating water for drinking has become more complex and expensive. To help address these multifaceted problems, the State Water Resources Control Board and regional boards have set water quality standards (e.g., minimum dissolved oxygen levels, maximum temperatures, sediment loads) for most California streams and estuaries, based on § 303(d) of the Clean Water Act, but the standards are increasingly difficult to meet (Chapter 6; Mumley et al. 2003).

Legacy effects of mining are particularly worrisome because most large sites continue to leach toxic metals into the environment, even if treated by the U.S. Environmental Protection Agency as Superfund Sites. Thus, Sulfur Bank Mine on the edge of Clear Lake (Lake County), abandoned in the 1950s, continues to add mercury to lake food webs (Eagles-Smith et al. 2008). Likewise, Iron Mountain Mine on the Sacramento River continues to leach large amounts of copper, cadmium, and zinc into Keswick Reservoir on the river and has considerable potential for disaster from a catastrophic failure of Spring Creek Dam, an earthen structure that holds back a concentrated soup of toxic leachates (Mount 1995; Brown and Moyle 2004). Water emerging from the mine is the most acidic ever measured.[9] The mine and reservoirs are now the subject of one of the largest remediation efforts ever attempted, using federal stimulus funds under the American Recovery and Reinvestment Act of 2009.

9. The pH –3.6 (http://toxics.usgs.gov/topics/rem_act/iron_mountain.html).

Although there are no easy solutions to these problems, reduction of contaminants will likely require:

- Continuing investments in new water and sewage collection and treatment facilities;
- Reducing inputs of contaminants of emerging concern into waste streams and waterways by changing the availability, use, disposal, and treatment of these chemicals by individuals and corporations;
- Managing and reducing nonpoint source pollutants from agriculture and other sources, such as city storm drains;
- Managing watersheds to reduce sediment from logging, road-building, and other land-altering actions;
- Undertaking large-scale efforts to reduce the legacy effects of past human actions, especially mining; and
- Making large investments in education, regulatory agency staff, and enforcement staff to prevent and reduce future problems.

A common theme of the above actions is the continued need for money to pay for remediation, to benefit human and ecosystem health. The Sacramento region, for example, is facing costs of $800 million to upgrade its sewage treatment plant to remove ammonium, which has negative effects on the Delta ecosystem, and another $1.2 billion in other upgrades (www.sacdeltasolutions.com/pdf/costs-v-benefits.pdf). Although many of the costs of remediation will need to be met by increases in fees to wastewater dischargers, creative financing will also have to be considered, such as a surcharge on products containing contaminants of emerging concern to pay for cleanup costs and research to reduce their use. A model for this might be the surcharge California has instituted to cover the costs of safely disposing of electronic waste (Chapter 7).

Reducing the Effects of Alien Species

All aquatic and terrestrial environments in California contain alien species, many of which have altered habitats and contributed to the decline of native species (Chapter 3). Aquatic environments seem particularly susceptible to alien invasions. For example, the San Francisco Estuary contains at least 250 alien species, with the number increasing by four to five new species per year (Cohen and Carlton 1998). Several of these species, such as the overbite clam, Brazilian waterweed, and the fish species Mississippi silverside and largemouth bass, have

contributed to major ecosystem changes that threaten native species. Similar problems have been recorded for habitats as diverse as North Coast rivers, Sierra Nevada lakes, desert springs, and Southern California creeks.

For aquatic systems, fishes are the best-studied alien species. Alien fishes have been introduced in large numbers, they often dominate California's aquatic ecosystems, and many are important game fishes. In their review of fish introductions into California, Moyle and Marchetti (2006) found that 50 of 110 species known to have been introduced became established. Introductions were made to directly benefit humans for food, sport, biological control, or forage for other fish, or as by-products of such human activities as aquaculture, shipping, fishing, and movement of water through canals. These introductions include some of the fish species most familiar to the California public: various sunfishes, basses, and catfishes, as well as common carp, goldfish, brown trout, and mosquitofish.[10]

Many of these familiar fish species were intentionally distributed into the state's many isolated watersheds by fisheries agencies in the 19th and early 20th centuries (Moyle 2002). In addition, species native to some watersheds have been moved to others, especially rainbow trout and Sacramento perch. These introductions, while done for noble reasons (e.g., improve fishing, provide food, mosquito control), have often imposed unanticipated harm on native fish and fisheries (Moyle, Li, and Barton 1986). Introductions of trout into hundreds of alpine lakes have caused the collapse of native amphibian populations (e.g., Knapp, Matthews, and Sarnelle 2001) and likely declines of native birds (Epanchin, Knapp, and Lawler 2010), while introductions of alien trout species into streams of the eastern Sierra Nevada have nearly eliminated native cutthroat trout. In the lower Colorado River, predation by alien fish species keeps native minnows and suckers from spawning successfully, resulting in extinction for species not maintained by hatcheries. Redeye bass, adapted for small streams, have basically eliminated native fishes in streams where they were introduced (e.g., Cosumnes River, Santa Margarita River). In the Eel River, invasion of Sacramento pikeminnow has suppressed the recovery of salmon and steelhead populations (Box 5.5). To prevent a similar disaster by alien northern pike to

10. Scientific names of species mentioned in this section are overbite clam (*Corbula amurensis*), Brazilian waterweed (*Egeria densa*), Mississippi silverside (*Menidia audens*), largemouth bass (*Micropterus salmoides*), common carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), brown trout (*Salmo trutta*), western mosquitofish *(Gambusia affinis*), rainbow trout (*Oncorhynchus mykiss),* Sacramento perch (*Archoplites interruptus),* cutthroat trout (*O. clarkii*), Sacramento pikeminnow (*Ptychocheilus grandis*), redeye bass (*Micropterus coosae*), northern pike (*Esox lucius),* mud snail (*Potamopyrgus jenkins*i), tule perch (*Hyterocarpus traski*), hitch (*Lavinia exilicauda*), Chinook salmon (*Oncorhynchus tshawystscha*), coho salmon (*O. kisutch*), California roach (*L. symmetricus*), zebra mussel (*Dreissena polymorpha*), quagga mussel (*D. rostriformis*), and Shimofuri goby (*Tridentiger bifasciatus*).

5.5

Alien species, floods, dams, and salmon in the Eel River

The Eel River is the third largest watershed in California, flowing into the ocean just south of the city of Eureka. It flows through the steep, highly erodible hills of the Coast Ranges. The watershed was originally covered with forests of redwood and Douglas fir. The only major dams in the system are Scott Dam (Pillsbury Reservoir, 1930) and Cape Horn Dam (1908) on the main stem, which together form the Potter Valley Hydroelectric Project. This project produces power and diverts some water to the Russian River.

During the 19th and early 20th centuries, in wet periods with good ocean conditions, the Eel River probably supported runs of well over a million salmon and steelhead (800,000 Chinook salmon, 100,000 coho salmon, and 150,000 steelhead), with about half that number in less favorable years (Yoshiyama and Moyle 2010). In the 1930s to early 1950s, the river attracted salmon and steelhead anglers because of the abundance of large fish. Today, the river supports, on average, about 3,500 fish total (±1,000) per year (1,000 Chinook, 500 coho, 2,000 steelhead). Present numbers are more than a 99 percent decline from historical abundance, with no sign of improvement. So, what happened?

From 1860 to 1960, a continuous, if slow, decline of fish resulted from overfishing and watershed disturbance from logging, grazing, and road-building. Disturbance of the fragile soils and rocks on steep hillsides resulted in fine sediment filling in gravel spawning areas and loss of rearing habitat in forested tributaries, stream edges, and the estuary. At the same time, Scott and Cape Horn dams prevented migration to parts of the watershed on the main stem of the Eel, as did reduced flows from the diversions to the Russian River. Habitat degradation and loss of fish intensified after World War II as logging increased and became mechanized with virtually no regulation, making hill slopes more susceptible to erosion. Then came the great storms and floods of 1955 and 1964, which, acting on a highly disturbed landscape, caused massive landslides and erosion. In most stretches, the river became shallow, meandering across an open plain of sediment, with little habitat for salmon and steelhead. This alteration created excellent habitat for the predatory Sacramento pikeminnow, introduced in the early 1980s into Pillsbury Reservoir, apparently by fishermen using juveniles as bait (Brown and Moyle 1997). The new conditions were also perfect for California roach, a small introduced minnow favored as prey by pikeminnow. Thus, the damage done to the watershed by logging, grazing, and dams became exacerbated by natural off-the-charts rain events, setting it up for invasion by a predatory alien. The pikeminnow spread rapidly through the watershed, preying on roach, lampreys, and small salmonids. The large population of predatory fish continues to suppress salmon and steelhead populations. Undoing some of the damage by removing Scott and Cape Horn Dams (Box 5.6) probably would not benefit salmonids much until a way is found to control pikeminnows. Some recovery of salmonids will occur, however, if watersheds, especially those in the coastal fog belt, are allowed to return to the stable, complex cold water habitat that pikeminnow tend to avoid.

Central Valley salmon populations, the Department of Fish and Game spent millions of dollars eradicating the illegally introduced pike from two reservoirs on the Feather River (Moyle 2002).

Today, fisheries agencies in California no longer condone introduction of species and actively oppose bringing new species into the state, although planting trout in some alpine lakes is still approved. All new introductions, therefore, result either from illegal introductions by anglers and aquarists or as a by-product of other activities, such as the transport of mud snails on the boots of anglers or the introduction of tule perch, shimofuri goby, and Sacramento hitch into Southern California reservoirs by way of the California Aqueduct.

Invasive alien species clearly can undo or diminish habitat management actions taken to protect desirable fishes, including releasing more water from dams. New disruptive species are still becoming established in California with a high enough frequency to cause alarm. For instance, quagga and zebra mussels have just invaded California and they have considerable capacity to alter ecosystems and disrupt water project operations by clogging canals and intakes. The cost for their control may run into the hundreds of millions of dollars, as it has in the eastern United States and Europe (Leung et al. 2002).

Because problems with aquatic invasive species cut across agency and jurisdictional boundaries, regulation and control actions must be coordinated with at least 14 state agencies and numerous federal agencies, with the Department of Fish and Game taking the leadership position (California Department of Fish and Game 2008). A comprehensive policy, with funding for enforcement, monitoring, and research, is needed to reduce the effects of alien species that are already present as well as the likelihood and effects of new invasions. Such a policy should include such actions as:

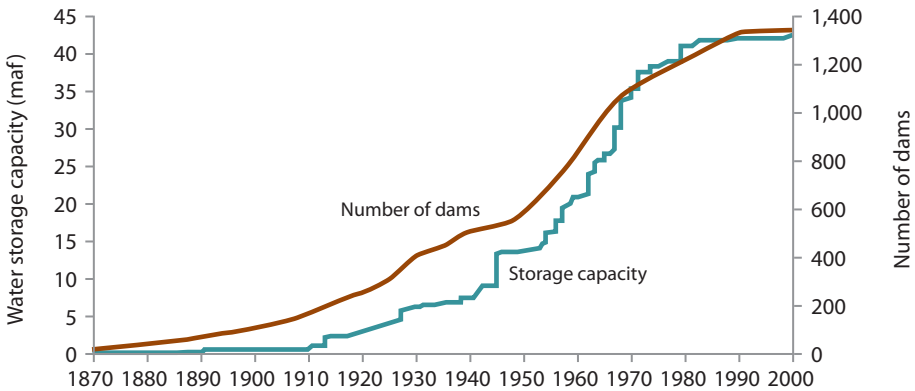
- Adopting the 163 prioritized actions recommended in DFG's (2008) *California Aquatic Invasive Species Management Plan* as well as the recommendations to manage invasive species made by the Ecological Society of America (Lodge et al. 2006);
- Requiring that agencies aggressively act to prevent new invasions, such as including 24-hour inspections of boats at the California border and enforcing no-tolerance limits for alien species in the ballast water of ships and other vectors;

- Creating and enforcing an approved ("white") list for pet, aquaculture, and bait organisms allowed for sale; permissible organisms would lack characteristics of successful invaders (Moyle and Marchetti 2006); and
- Creating an invasive species response team, with DFG as the lead agency, to react quickly to new, potentially harmful invasions, modeled on the oil spill response team; the team would require regular funding and sufficient authority to rapidly act when needed (California Department of Fish and Game 2008).

Reducing the Negative Effects of Dams

California has thousands of dams and diversion structures, each one contributing to loss of aquatic ecosystem function in some way. The dams range from small earthen dams on seasonal waterways, which create ponds for local use, to large dams, such as Shasta and Oroville, which are central to California's water supply system. Dam construction on free-flowing streams began in California in the 1850s, accelerated during the late 19th century in response to demands of hydraulic mining and logging, and peaked from 1900 to 1982 as irrigated agriculture and urban areas developed (Yoshiyama, Fisher, and Moyle 1998) (Figure 5.4).

Figure 5.4
Dam construction increased rapidly during California's Hydraulic Era



SOURCE: Authors' calculations using data from the California Department of Water Resources Division of Dam Safety.

NOTES: The figure shows dam construction and storage capacity from 1870 to 2000. Of dams built between 1850 and 1869, only 17 exist today, with a total storage capacity of 0.034 maf.

Today roughly 1,400 dams are large enough for state safety regulation (Chapter 3). Combined, these dams can impound up to 42 million acre-feet of water, or about 60 percent of the state's average annual runoff (Chapter 2; Mount 1995). Most dams were built with little consideration for their effects on fish, although legally they were required to provide adequate flows for fish downstream of the dam or fish passage around it (Box 1.3). As noted above, dams have dramatically reduced salmon and steelhead habitat in the state.[11] This loss of habitat is a major cause of fishery declines and endangerment of native species.

For salmon and steelhead, the main historical mitigation method has been hatcheries (discussed below), which have largely failed to sustain fisheries (Williams 2006; Moyle, Israel, and Purdy 2008). Recently, increased attention is being paid to either removing dams that harm fish or modifying their operations to improve fish habitat.

Reoperation of dams

The reoperation of dams is often seen as a means to help restore native ecosystems and species below dams while maintaining most economic benefits of one or more dams within a river system. Many researchers have developed methods to establish "environmental flows" in regulated rivers (Richter et al. 1997a; Tharme 2003; Acreman and Dunbar 2005). A particularly useful approach has been application of the natural flow regime concept, which can shift fish and invertebrate populations in a regulated river toward a diverse community of favored species, without requiring large amounts of water (Poff et al. 1997). The natural flow regime for Putah Creek, described above, features a permanent base flow, spring spawning flows for native fishes, and a fall pulse flow for salmon (Moyle et al. 1998). The success of this project, which was based on application of § 5937 of the Fish and Game Code (Box 1.3), formed the basis for the flow regime being applied to restoring the dry San Joaquin River.

The Federal Energy Regulatory Commission (FERC) relicensing process for dams with a hydroelectric component provides a major opportunity for reconciling ecosystems with the operation of dams (Gillilan and Brown 1997). Today, California is in a period of FERC relicensing, with approximately 150 FERC-licensed dams scheduled to be relicensed over the next 15 years. The

11. As shown above (Figure 5.1), dams or reduced flows exclude Chinook salmon from over 1,000 miles of former habitat (Yoshiyama et al. 2001). Likewise, dams on the Klamath River deny access of salmon and steelhead to several hundred miles of upstream habitat (Hamilton et al. 2005).

original licenses were granted 30 to 50 years ago, when there was little concern for the effects of dams on fish and stream ecosystems. FERC is now more willing to require changes to dam operations as requested by federal fisheries agencies. Thus, the agreement to remove four dams on the Klamath River began in the FERC relicensing procedure, in which the agencies requested that the dams be modified to allow voluntary passage of anadromous fish. Economic analyses suggested that removal was less costly (Box 2.4).

Adding new environmental flow requirements below FERC dams during relicensing is particularly important because the U.S. Supreme Court has ruled that releases from such dams are exempt from state laws such as § 5937 of the Fish and Game Code (*California v. FERC* 1990). Yet even with likely changes to the operation of FERC-regulated dams, there will still be hundreds, perhaps thousands, of dams that do not provide adequate flows for fish, as required under § 5937 of the Fish and Game Code and potentially other laws (such as the public trust doctrine and the reasonable use doctrine of the state constitution). The following actions should be taken to better integrate the presence and operation of dams in reconciled or restored native ecosystems. New regional stewardship authorities could coordinate these activities, liaising with the Department of Fish and Game as the lead state agency and working with the State Water Resources Control Board and local agencies and water users to:

- Create a database of *all* dams in California, to determine the extent to which dams modify California streams and do not comply with state law.
- Require flow releases for fish below all dams that currently do not comply with the law.
- Reexamine flow releases below all large federal, state, and local dams to determine if they should be modified to be more compatible with environmental management goals.
- For series of dams on tributaries to large rivers (e.g., dams on the Stanislaus, Tuolumne, and Merced Rivers), find ways to operate flow releases in a coordinated manner, to increase downstream benefits to fish.
- Improve methods for determining environmental flows, and the monitoring that should follow setting of flow releases, so that they are more likely to create conditions favorable to fish.

- Assess, below all dams, how reductions in flow have altered habitat quality and develop and implement mitigation measures (e.g., gravel enhancement for spawning).

Dam removal

Roughly 600 dams have been removed across the United States over the past 20 years, and California has been a national leader in the number of dams removed (Pohl 2003; Doyle and Havlick 2009; Heinz Center for Science, Economics, and the Environment 2002). So far the dams being removed are small, such as mill dams on streams in the eastern states or sediment-filled diversion dams in the west, such as Seltzer Dam on Clear Creek in Shasta County (Poff and Hart 2002). Such dams typically have little or no value for water supply, hydropower production, or flood control but have large effects from blocked fish passage (Heinz Center for Science, Economics, and the Environment 2002). They can also be relatively inexpensive to remove. Age contributes to dam removal: small, older dams sometimes have reservoirs filled with sediment, are subject to failure, no longer effectively serve purposes for which they were intended, and require significant rehabilitation to function well again.

However, large functioning dams also are being examined for removal because of the potential to contribute to recovery of endangered fish populations, especially anadromous fishes such as Chinook salmon and steelhead. Such removals are controversial because of the high costs of dismantling these structures, loss of hydropower and water supply, and uncertain benefits to fish (Stanley and Doyle 2003; Quiñones et al. 2011). Thus, the proposed removal of three hydropower dams on the Snake River, a tributary to the Columbia River, has generated huge arguments over cost and benefits, with fish biologists on both sides of the issue (National Research Council 1996; Gregory, Li, and Li 2002). Nevertheless, removal of two medium-size dams on the Elwha River in Washington State is scheduled to begin in 2011 (www.nps.gov/olym/nature-science/elwha-ecosystem-restoration.htm).

Although any dam removal is likely to be controversial, new approaches are being developed to systematically evaluate costs and benefits. Because dams both impair river systems and provide economic benefits, decisions on removal are rarely easy, in part from lack of a systematic, scientific decision-making process (Poff and Hart 2002). Kuby et al. (2005) applied a multiobjective optimization model to examine a network of 150 dams on the Willamette

River Basin in Oregon. Their preliminary results suggest that removing just 12 dams would have high benefits to salmon, with low loss of hydropower. Such a regional approach is especially promising because it recognizes that many river systems have multiple dams, often operated jointly. A joint evaluation can help determine where economic and ecological values are highest. A regional approach is particularly needed in California, where coordinated management of geographically extensive and diverse water sources is necessary. Null and Lund (2006) found that regional solutions and reservoir reoperation would allow removal of the O'Shaunessy Dam in San Francisco's Hetch Hetchy system, restoring an upstream river valley, albeit at considerable cost and with little benefit for native fish species.

Pejchar and Warner (2001) provide 36 questions that to help assess whether a dam merits removal, and they recommend systematically evaluating all dams using these criteria. The questions fall under seven general headings (pp. 566–67):

- "Is the dam currently degrading habitat quality and quantity?"
- "Will removal of the dam restore habitat quality and quantity?"
- "Is the dam fulfilling its original intended function?"
- "Does the dam pose a current or potential safety hazard to human lives and property?"
- "Is there stakeholder support for dam removal?"
- "Would the Endangered Species Act play a role in dam removal?"
- "Is funding available [for removal]?"

The economic values for retaining the dam also should be considered. Dams with low economic values for traditional purposes and good potential based on the above criteria are likely to be excellent candidates for removal. Some sizable dams would meet most criteria for removal (Box 5.6). The complexity of dam removal suggests that it should be accomplished within a larger regional ecosystem reconciliation context, even though the agency owning the dam should be responsible for removal. Regional stewardship authorities could be charged with such coordination and with convening an interagency group with appropriate expertise.

One factor that challenges demand for dam removal (including removal of Klamath dams) is the increasing demand for hydropower as "clean" energy. The roughly 400 hydropower plants in California currently produce about

5.6

Low-hanging fruit? California dams ripe for removal

Matilija Dam, Ventura River. Built in 1947, its reservoir quickly filled with sediment, making it nonfunctional. It blocks access of endangered southern steelhead to key spawning and rearing areas. The sediment also is needed to slow beach erosion. The dam has been lowered but cost of removal has stalled the removal process.

Rindge Dam, Malibu Creek. Same problems as Matilija Dam.

San Clemente Dam, Carmel River. Regarded as seismically unsafe, this dam is slated for removal rather than repair, to allow better access of endangered steelhead to upstream spawning and rearing areas. The cost of removal is estimated at $83 million, with sediment removal from behind the dam a major factor.

Englebright Dam, Yuba River. Built in 1941 to contain debris from gold mining, it blocks access of salmon and steelhead to the three forks of the Yuba. It is now about half full with sediment. Water supply, power, and recreational benefits of the dam are relatively small, but large amounts of mercury in the sediments complicate sediment removal.

Dwinnell Dam, Shasta River. Dwinnell Dam provides water for a small irrigation district and town and creates a small warm reservoir (Shastina) at the center of a large (1,200+) second-home/retirement-home subdivision. The dam diverts cold water and blocks access of endangered salmon runs to prime spawning and rearing habitat. Removal of the dam could restore the Shasta River, allowing it to become the most salmon productive of all tributaries to the Klamath River.

Iron Gate, Copco 1 and 2, and J.C. Boyle Dams, Klamath River. This sequence of four hydroelectric dams blocks access of endangered salmon and steelhead to cold water in the river and upper basin. Although the power revenue generated is considerable, the fish are in desperate condition and removing the dams may be more cost-effective than providing passage over them. These dams are slated for removal as part of a settlement among the power company, fisheries agencies, Indian tribes, and environmental groups, concluded in early 2010 (Box 2.4).

Martis Creek Dam, Martis Creek (Truckee River). The U.S. Army Corps of Engineers considers this flood control dam as one of the most unsafe dams in California. The dam also causes problems for fish by dividing the creek into two sections and warming up the creek below the dam, although the dam affects only extreme high flows.

Removal of Matilija Dam would improve habitat for endangered southern steelhead. Photo by Jacob Katz.

15 percent of the state's electricity, although much of this energy is from power plants at a handful of large multipurpose dams (Chapter 2; www.energy.ca.gov/hydroelectric/). Hydropower generally requires a dam or a way to divert water to run it through a powerhouse. Although most run-of-river hydropower dams are small and store little water, they can still block fish access to upstream areas and significantly reduce flows and water quality immediately downstream. Although some increases in hydropower output can be achieved with more efficient operation and modernization of existing facilities, pressure to construct more small dams, especially on high-gradient streams, is likely to continue.

Funding dam removal

More dams will be removed in California as environmental and safety benefits become more apparent. But because removal costs are high, especially on large dams, a source of funding is needed. A retirement surcharge on all existing dams may be a suitable way to fund these removals. If removing some dams to aid fish recovery reduces pressures to remove the remaining dams, such a fee could be a cost-effective form of environmental mitigation, albeit one that encourages specialization of river uses. Dam removal or replacement is an inevitable part of the cost of any dam, just as remediation of mining sites is part of the cost of mining (but often is not paid for by mining interests). Today, most dam removal projects are at the expense of taxpayers, not those who benefited directly from decades of dam operation.

Dams have finite lifetimes, even if such lifetimes are very long. Some California dams have had useful economic lives as short as 25 years (e.g., Matilija Dam, Ventura River, Box 5.6), and others will likely provide significant storage capacity for more than a thousand years. Nevertheless, as a matter of ensuring intergenerational equity and providing proper incentives for decisionmaking, the operation of a dam should generate revenues to fund the eventual retirement of the dam and rehabilitation of the dam site (Palmieri, Shah, and Dinar 2001). Similarly, California's Surface Mining and Reclamation Act requires that mine operators set aside a bond sufficient for restoring the mine site after operations have ceased.

Few examples exist of policies that address funding for dam retirement. One example is the Penobscot River Restoration Trust, which has bought three dams from Pennsylvania Power and Light with the intention of eventually removing them (www.penobscotriver.org/). Funding sources for the purchase include private fundraising and federal grants. The trust may use proceeds from the sale of power from the dams to help pay for dam removal. The funding proposal for removal of the Klamath dams includes $200 million from electricity ratepayers (mostly in Oregon) and public funding from California to cover up to $250 million in additional costs.[12] The water bond now slated for the 2012 ballot includes provisions to cover California's public funding obligations for this deal. To set up an alternative structure that relies on dam retirement fees for dam owners and beneficiaries, rather than on taxpayer funds, removal or repair of existing low-value or unsafe dams could be used to help estimate the costs and appropriate fee levels.

Dams will continue to be a major factor altering rivers and other waterways in California, and reoperation or removal of dams will be major ways to improve habitat for fish and other aquatic organisms into the indefinite future.

Salmon and Steelhead Hatcheries

When dams were built and blocked salmon and steelhead spawning streams throughout California, the decline in fisheries was largely regarded as the price of progress. The negative effects were recognized, however, and the legal code of California, even in the 19th century, contained a law that said owners of dams must provide passage over dams for fish or provide sufficient flows below dams to support fish populations. The law was generally ignored. Although this law

12. The decision to rely on taxpayer funding if costs exceed $200 million was based on a desire to minimize rate shock to customers (Public Utility Commission of Oregon 2010). The secretary of the Department of the Interior must estimate costs and determine whether to proceed by March 2012.

Chinook salmon trying to enter Nimbus Fish Hatchery. Hatchery salmon can overwhelm less abundant wild salmon. Photo by Peter Moyle.

remains on the books (as § 5937 of the Fish and Game Code; Box 1.3), it continues to be widely ignored, with notable recent exceptions of actions restoring flows to Rush Creek, Putah Creek, Trinity River, and the San Joaquin River. One factor that made it easy to ignore this and other salmon and steelhead protection laws was the idea that fish hatcheries (starting in 1872) could replace upstream spawning and rearing habitat (Yoshiyama 1999).

Hatcheries can be regarded as a reconciliation strategy because their goal is to release fish back into the wild, maintaining populations large enough to support fisheries. However, hatcheries are a strategy that has not worked well. They allow salmon and steelhead to be taken from the wild, spawned artificially, and have the fertilized eggs kept under controlled conditions. After a few months, small juveniles (alevins) hatch and are then reared in troughs or ponds for three to eighteen months. The assumption is that hatcheries do better than nature by greatly increasing the survival rates of embryos and juveniles, enabling millions of small fish to be released into streams every year. Thus, it should be possible to replace many miles of lost spawning and rearing habitat with a few hatcheries. The failure of this approach is indicated by the fact that of the 20 kinds of salmon and steelhead in California most endemic to the state, 16 are in serious trouble and some are on the verge of extinction (Moyle, Israel, and Purdy 2008). Even the Central Valley fall-run Chinook salmon—the mainstay of the hatchery program—has experienced major declines in abundance in recent years, causing fisheries to be closed or curtailed.

There are two general reasons why this has happened. First, hatcheries evolutionarily select for genetically uniform fish that thrive in hatcheries but do poorly in the wild, especially when environmental conditions are not optimal. Second, so many hatchery fish are produced that even with poor survival they can reduce the survival of wild fish, through competition for limited resources, predation, and hybridization (Williams 2006). Thus, when huge numbers of fat, unwary, hatchery juvenile salmon are suddenly released into rivers below dams, they can literally overwhelm the small and timid wild fish, pushing them from their rearing habitats and making them more vulnerable to predation. Such interactions can exist at all phases of the life cycle, including during ocean feeding and on the spawning grounds. In addition, because only a few returning adults are needed to provide spawners for hatchery production, in theory harvest rates on fish from a hatchery population can be extremely high. Because fishermen cannot tell hatchery salmon from wild salmon, much less distinguish hatchery salmon from individuals from endangered runs, the harvest rates of wild salmon then become unsustainable, further decreasing their numbers.

The reliance on hatcheries has left salmon and steelhead spawning in Central Valley rivers, and most likely in the Klamath and other coastal rivers, overwhelmingly of hatchery origin with a much more genetically homogeneous population (Lindley et al. 2009). Such fish are presumably less adapted to persisting through adverse conditions in both fresh and salt water (e.g., physiologically less capable of surviving on less food, more sensitive to changing ocean conditions, less able to avoid predation). The recent collapse of the Central Valley fall-run Chinook salmon population, for example, may result from a low diversity of responses to unfavorable ocean conditions (Lindley et al. 2009). Hatchery fish essentially lack the resilience and adaptability to persist for long in the real, rapidly changing world (Schindler et al. 2010; Carlson and Satterwaite 2010). Even with many fish being produced from hatcheries, the long-term result is likely to be loss of the fish and the fisheries they support. This loss of returning salmon causes serious damage to stream and riparian ecosystems that depend on the annual influx of salmon nutrients and breaks the implicit promise made to fishermen and coastal communities that dams would not destroy their livelihoods.

Californians must decide whether they want salmon around in the future, beyond a few boutique runs maintained at great expense in a Disneyland atmosphere. Maintaining diverse salmon and steelhead populations will require a radical rethinking of attitudes and policies that will improve flow regimes

and habitats below dams, in conjunction with a comprehensive retooling of hatchery management. Such major steps should be taken in the context of a broader reconciliation strategy for salmon and steelhead, probably funded by surcharges on dam beneficiaries and managed by the Department of Fish and Game. Some possible changes:

- Recognize that most hatcheries maintain fisheries, not wild salmon and steelhead. Therefore, hatcheries should be located in places where released hatchery fish interfere minimally with wild fish (e.g., close to the coast), using fish so domesticated that they have few interactions with wild fish.
- Employ specially managed restoration and recovery hatcheries to keep populations from going extinct while habitat restoration is in progress.
- Improve flows below all dams on streams that historically supported anadromous fishes.
- Increase access to former spawning areas above dams through dam removal, installation of volitional passage structures (e.g., fish ladders), and similar actions.
- Engage in large-scale stream restoration to improve habitats for spawning and rearing of salmon and steelhead.
- Protect and enhance sources of cold water for stream flows, from spring systems to cold water pools of reservoirs.
- Develop intensive fish management strategies that favor wild salmon and steelhead, starting with marking all hatchery fish to distinguish wild from hatchery individuals, as is done in the Pacific Northwest. The strategy should emphasize the "portfolio effect," which maintains a diversity of life history strategies to buffer against environmental variability (S. Carlson, UC Berkeley, personal communication; Schindler et al. 2010).
- These same policies should apply, where appropriate, to native nonanadromous fish species.

Reconciliation and Environmental Laws

A reconciliation strategy for native species and their ecosystems requires a great deal of management and operational flexibility, along with considerable

political and financial support. Changing environmental conditions, arrivals of new invasive species, and incorporation of new knowledge into management all require the ability to adjust course through time. The management of species is governed by numerous laws that provide guidance and, in some cases, severe restrictions on management. Three of these laws— the federal Clean Water Act and the state and federal Endangered Species Acts—can potentially constrain options for managing ecosystems in a changing world.

The Clean Water Act

Section 303(d) of the federal Clean Water Act requires that the SWRCB (usually through the regional boards) set water quality standards throughout California to support beneficial uses. By establishing total maximum daily loads (TMDLs) of pollutants, the board seeks to limit pollution entering the waters from all sources, including nonpoint sources. The goal is to protect and to restore water quality to meet a variety of economic, recreational, and ecological uses.

The same regulations prohibit the board from revising water quality standards in any way that would degrade existing water quality. These antidegradation regulations are targeted at those waters that meet or exceed current standards. Their purpose is to protect pristine and relatively unimpaired waters and to prevent backsliding once water quality objectives are met.

Managing changes in conditions consistent with the antidegradation regulations will be challenging for state and federal regulators. In the case of the Delta and many upstream water bodies, it may not be possible to protect all existing designated uses. Sea level rise will make it increasingly difficult to maintain salinity standards in the Delta with reservoir releases; a severe earthquake could have even more severe effects on salinity levels in the Delta (Lund et al. 2010). Regional warming of the Sierra Nevada will cause water temperatures in streams to exceed state standards (Null et al. submitted). This risk is especially acute for some species of fish, such as the various species of smelt that inhabit the Delta and salmon and steelhead throughout the state, which require relatively cool water flows during migration and spawning (Chapter 3).

It may become necessary in the future to adopt a policy of stream specialization, by which some streams are managed principally to protect fish and others are managed principally for water supply. In the former, water quality standards would focus on maintaining flows, temperatures, and other water quality criteria to protect fish habitat; in the latter, where changes in hydrologic conditions are likely to overwhelm current standards, the emphasis would be

on maximizing water available for agricultural and urban use (or perhaps for hydropower generation).

The antidegradation requirements of the Clean Water Act were enacted in 1977, before the concept of changing climate conditions had become mainstream science. Congress therefore did not consider the likely consequences of climate warming on stream flows, water quality, and water supply. Although EPA's antidegradation regulations provide some flexibility for states to lower water quality standards "to accommodate important economic or social development in the area in which the waters are located," any such change must "assure water quality adequate to protect existing uses fully" (U.S. Environmental Protection Agency *Water Quality Regulations* § 131.12(a)(2) undated (e)).

Indeed, EPA has explained that "no activity is allowable under the antidegradation policy which would partially or completely eliminate any existing use. . . . Water quality should be such that it results in no mortality and no significant growth or reproductive impairment of resident species. Any lowering of water quality below this full level of protection is not allowed" (U.S. Environmental Protection Agency undated (d)). Accordingly, California would be prohibited from lowering water quality standards in any individual river (or other body of water) governed by the antidegradation laws if the change could harm native fish species or eliminate fish as a designated use.[13]

Under these constraints, the SWRCB and regional boards' only option is to try to ensure the protection of *all* existing fish species, regardless of the futility or costs of doing so. This dilemma may ultimately merit congressional review to reconsider the restrictions of existing antidegradation regulations and to modify the antidegradation policy to allow California and other states to alter water quality standards or eliminate designated uses where such changes are needed to facilitate reconciliation and adaptation in the face of the hydrologic realities of climate warming. The new regulations should not lightly permit the lowering of TMDLs or the elimination of designated uses. But where state water quality regulators can demonstrate either that it is futile to try to maintain a particular designated use or that water quality adjustments are necessary as part of a broader reconciliation strategy to improve the overall

13. The EPA regulations do allow states to set different standards for cold water and warm water fishes (U.S. Environmental Protection Agency *Water Quality Regulations* § 131.10(c) undated (e)). Thus, in some situations, it may be permissible for California regulators to conduct a use attainability analysis that would allow a degradation of water quality to protect warm water, but not cold water, fish species. However, for the reasons stated in the text, this change would not be permitted if it would harm an existing cold water fish species.

protection of designated beneficial uses, the law should be flexible enough to enable such changes.

The Endangered Species Acts

The federal and state Endangered Species Acts have become focal points in many of California's water controversies because they may require water to be allocated to fish (and other aquatic species) that previously was allocated to agricultural and urban uses. The number of species being listed under state and federal ESAs in California is increasing (with removals from the list rare), which suggests that most water decisions in the future, large and small, will involve one or more endangered species, especially fish (Chapter 3). With few accommodations and rare exceptions, the Endangered Species Acts prohibit the taking of species that are on the verge of extinction and place severe restrictions on human use of the species' critical habitat. The overriding mandate of the statutes is to ensure the survival and propagation of listed species, regardless of the costs or benefits to human endeavors. Endangered species controversies are usually acute, because by the time a species becomes threatened or endangered, the ecosystem it inhabits is often so degraded that it may be impossible to restore either the species or the ecosystem to its former state.

The resulting water shortages and lowering of water supply reliability raise questions of fairness and efficiency of allocation. In some cases, water users have responded with lawsuits challenging implementation of the statutes or claiming that the regulatory disruption of water supplies is a taking of property or a breach of contract.

Yet the statutes have protected native species that otherwise could have become extinct. In California, these species include several kinds of salmon and steelhead that migrate through the Delta, green sturgeon, delta smelt, and various pupfishes and minnows (Taylor, Suckling, and Rachlinski 2005). Moreover, in two of California's most complex and long-standing water controversies—the Delta and the Klamath River—the regulatory mandates of the ESAs have spurred broader environmental protection and reconciliation efforts.

Looking ahead, endangered species administration, and possibly the laws themselves, will need to adapt to meet several key challenges. Three aspects of the acts, in particular, will bedevil California water management in the future: the tendency of agencies to focus on single-species management, historical focus on single actions and single sources of stress, and the potential need for endangered species triage.

Single-species management

The heart of the federal ESA lies in §§ 7 and 9. Section 7 requires that all federal agencies consult with either the U.S. Fish and Wildlife Service (USFWS) or the National Marine Fisheries Service (NMFS) to ensure that federal actions do not jeopardize the existence of species protected under the act or harm critical habitat. Section 9 prohibits anyone from "taking" an endangered species without a permit, including modifying habitat in a way that could lead to injury or death of an endangered species.[14] Under § 10, however, the government can grant an "incidental take permit" to any persons who wish to take an action that may incidentally take a species, if they prepare an adequate Habitat Conservation Plan. The California ESA does not require consultation, but it prohibits taking of a listed species unless authorized by an incidental take permit from DFG.

Because these laws focus on preserving individual species on the brink of extinction, this sometimes leads to conflicts with efforts to manage other species (National Research Council 1995; Rosenzweig 2003). These conflicts have played out in the biological opinions covering coho salmon and two species of suckerfish in the Klamath Basin (National Research Council 2004) and are the focus of considerable attention and litigation within the Delta.

Despite the focus in practice on individual species, both the state and federal ESAs allow comprehensive, multispecies management actions that can address, at least in part, the problems of single-species management. The HCP process of § 10 of the federal act and the NCCP program of the state act allow regulators and regulated parties to negotiate a long-range habitat management plan to recover listed species (Presley 2011; Thompson 1997b). California has substantial experience on land with regional HCPs or NCCPs that encompass multiple species and a large area of habitat. Development of regional HCPs or NCCPs is a complex task that can require years of scientific study and negotiation. As of mid-2010, only eight NCCP's had been approved in California (many of these are also regional HCPs); most have been relatively simple in scope; all have focused on terrestrial systems not affected by water management (California Department of Fish and Game 2010b).

To date, the vast majority of HCPs nationwide, and NCCPs in California, have focused on land conservation and protection of terrestrial species. Of the 127 HCPs approved from January 1, 2001, through July 31, 2003, for example,

14. Although the "take" prohibition of § 9 applies only to species listed as "endangered," by rulemaking the USFWS and NMFS have extended this proscription to most threatened species as well under § 4(d) of the act.

only seven dealt with aquatic environments (Thompson 2006). Several HCPs in the past decade, however, have addressed the protection of salmon and steelhead, as well as other fish species, threatened by the modification of rivers and streams in the Pacific Northwest. These HCPs have focused on Portland's Bull Run watershed, hydroelectric projects on the mid-Columbia, Tacoma's Howard Hanson Dam, and Seattle's Cedar River watershed.

At the time of this writing, California's largest and most complex HCP-NCCP effort is under way. Known as the Bay Delta Conservation Plan, its purpose is to develop a comprehensive habitat management plan for the Delta. The basic goals of the plan are to recover numerous listed species while allowing for continued export of water through the State Water Project and Central Valley Project.[15] The complexities of this plan are extraordinary, including the large and diverse array of urban, agricultural, and environmental interests involved in negotiations. Unfortunately, the basic goals may be impossible to achieve, given recent recognition by the SWRCB and Department of Fish and Game that much higher flows through the Delta are needed if populations of endangered fish are to recover (Box 5.2). If this basic problem can be overcome, the plan could become a national model for HCPs in aquatic ecosystems. If not, the problems of the Delta are likely to continue to deteriorate, to the detriment of both the ecosystem and the people who depend on it.

Multiple stressors

A long-standing problem of the federal and state ESAs has been their focus on responding to particular projects and proposed actions, and the resulting failure of the USFWS and NMFS to adequately account for and address the many sources of harm to protected fish species. Instead, the focus has been on factors easily controlled by the act—mostly water operations linked to federally authorized projects that are subject to the interagency consultation requirements of § 7. The fisheries agencies routinely emphasize restrictions on how water is managed by these projects, regardless of other factors that limit recovery (although flow *is* often a "master variable" that interacts with other stressors). As agency personnel involved in these consultations routinely point out, their options under § 7 consultations are limited to federal actions and other activities authorized or funded by the United States. For fish, this aspect of the act tends to warp priorities for habitat management away from

15. Bay Delta Conservation Plan documents can be found at http://baydeltaconservationplan.com/default.aspx.

comprehensive ecosystem approaches to simply managing flows. Not only does this focus create high potential for controversy, as regulated water users resent the nonconsideration of other actions, it also reduces the prospects for success in maintaining native species.

The agencies' tendency to focus on those actions subject to § 7 has played out repeatedly in California, particularly in the Klamath Basin and the Delta. In both cases the biological evidence is clear and abundant: The decline of listed species is caused by multiple stressors, some of which are not directly affected by federal project operations and facilities (National Research Council 2004; Brown and Moyle 2004). There is authority under both the federal and state ESAs, as well as state and federal water quality laws, for the fisheries agencies and the SWRCB (and the regional boards) to take a broader approach to the problem of multiple stressors. Yet, to date, the agencies have not been successful in addressing the multiple-stressors problems outside the HCP-NCCP process, in part because of their unwillingness to exercise the broader authority they possess (Hanneman and Dyckman 2009). A recent action by the Central Valley Regional Water Quality Board suggests some movement in this direction. In October 2010, the board issued a draft permit to the Sacramento Regional Wastewater Treatment Plant to clean up discharges, especially ammonium, that harm the Delta ecosystem.

Managing changing conditions

As with the Clean Water Act, the ESAs were enacted before legislators and policymakers recognized the risk of climate change. The focus of the acts is on protecting habitat critical to the survival of species and to reducing actions that could lead to "take" of species. The statutes did not anticipate that changing conditions might make it unfeasible to preserve and recover all species in the future. Increasingly, scientists are recognizing that ecosystems of the future in any given place may be quite different from those today, requiring different management strategies to protect endangered species (e.g., West et al. 2009). Even if a particular species is unlikely to survive because of changes in temperature, arrival of invasive species, or loss of potential habitat from sea level rise, the law lacks provisions that allow regulators to make tradeoffs or to prioritize ecosystem investments that might ensure the survival of one species over another—a form of endangered species triage.

For example, the largest and most genetically distinct population of spring-run Chinook salmon in the Central Valley (listed as a threatened species) lives

in Butte Creek, Tehama County. Studies by Thompson et al. (submitted) indicate that climate change will cause increases in water temperature that will drive the population to extinction within 80 years, if not sooner. It is unclear how this population can be saved without transferring it to a new location (e.g., the San Joaquin River). But the rarer a species becomes, the more difficult it becomes to take such risky conservation measures as relocation.

Given the pace and nature of change in California's aquatic ecosystems caused by climate warming, it is certain that this issue will become prominent in water resource management. The issue of delta smelt and coho salmon, two fish species that may be destined for extinction as self-sustaining wild species despite heroic efforts to save them, is explored in Box 5.7.

Under the federal Endangered Species Act, there is only one means of formally allowing the extinction of a species. Section 7 of the act authorizes convocation of the Endangered Species Committee, a cabinet-level, interdepartmental group that is colloquially known as the "God Squad" because it has the power to authorize other agencies to take actions likely to jeopardize the continued existence of a species. Through an elaborate process, the committee can grant an exemption for a specific federal action if it determines that (1) no alternative actions would save the species, (2) the benefits of the action outweigh the benefits of actions to save the species, and (3) the action is in the public interest. If the committee issues an exemption, the statute also requires that participating agencies employ "reasonable mitigation and enhancement measures" to attempt to preserve the species. These measures may include "live propagation, transplantation, and habitat acquisition and improvement."

Although the federal ESA thus allows for relaxing its protection in highly limited circumstances, it does so in a manner that presumes (and requires) that all feasible efforts be undertaken to attempt to keep the species alive. The act does not contemplate—even in its God Squad exception—that there may be circumstances in which the best policy is to allow some species in some rivers or estuaries to become extinct because the alternative is fragmented, inconsistent, and possibly futile efforts to preserve *all* species that may put every species at greater risk of extinction. The God Squad exemption process was established to address intractable conflicts between species preservation and economic activity rather than conflicts among species protection strategies. It therefore is ill-suited to the dilemma of biological triage discussed here. The California ESA has no provision comparable to the God Squad (or any other means of addressing the problem discussed here).

5.7

Must we think about species triage?

The number of species that qualify for listing as threatened or endangered under the federal and state Endangered Species Acts is increasing rapidly. Flow reduction and alteration caused by water project operations, pollution loading from municipal and industrial use, return flow from irrigated agriculture, sedimentation from logging, alien species introductions, pollution from abandoned mines, and now climate warming have increased stresses on California's aquatic species and reduced or altered their habitat. The problem is especially severe in fresh water, as the rapid increase in threatened fishes in California indicates (Figure I.2). The question thus arises: Can we save all species? Stated more bluntly: Should we devote large amounts of resources to try to save species that may become extinct no matter what we do?

The two species of fish most likely to become extinct in the wild are coho salmon and delta smelt. Bringing coho salmon back from brink will likely require massive investments in restoring watersheds up and down the California coast, especially those with sources of cold water in the summer (Moyle, Israel, and Purdy 2008; National Marine Fisheries Service 2010). Delta smelt are confined to the San Francisco Bay and Delta Estuary and are currently the center of a major conflict over how much freshwater inflow the species needs to persist.

If extinction in the wild of species such as coho salmon and delta smelt is determined to be inevitable, then serious consideration of hitherto unthinkable options may be required. One option involves biological triage in which listed species deemed the least likely to survive projected inevitable changes are taken off species-specific life support. The purpose would be to allow aquatic systems to be managed to better protect the more resilient (but still declining) species in human-dominated ecosystems, using resources available for conservation in the most cost-effective manner. Under this scenario in the Delta, Chinook salmon, green sturgeon, and splittail would be favored for conservation actions. In coastal streams, the focus would be on Chinook salmon, steelhead, and cutthroat trout, which have less demanding cold water requirements than coho salmon. The regulatory focus then could shift from species-by-species protection, to ecosystem-based management designed to maximize the ecological services provided to the ecosystem as a whole. A major problem with this approach, however, is the "shifting baseline," in which species allowed to go extinct slip from societal memory and the next endangered species also becomes seen as expendable. Eventually all the species become, one at a time, subject to the same triage process. Thus, triage is an ugly idea and should be invoked only after extraordinarily careful analysis and under powerful regulations.

In the future, the federal and state governments may need to consider creating an Endangered Ecosystem Committee that, in contrast to the federal Endangered Species Committee, would have authority to allow federal and state agencies, in protecting entire ecosystems, to triage species that are unlikely to survive even with massive governmental and private intervention. Relying on the best available science, the committee would evaluate (1) the probability of survival of listed species in a given ecosystem, (2) the probability that other species in the system will be listed without significant change in management, and (3) effects of proposed management actions on both types of species. The committee could then determine which management actions would have the greatest benefit to the most species and to the ecosystem as a whole. Agencies whose actions could otherwise violate the federal and state ESAs would be able to petition for an exemption if they furnished an appropriate plan to manage the ecosystem for overall habitat, species protection, and enhancement.

The time to adopt a limited policy of species triage is not here yet. But there is a need to anticipate this dilemma of species protection. Properly designed and prudently administered, endangered species triage might allow the fisheries agencies and other environmental regulators to focus on integrated ecosystem management and aggregate species recovery, without the statutorily mandated diversion of inordinate resources (and political capital) to species with low probabilities of long-term persistence. Many coastal salmon populations, for example, are likely to persist only as small, "boutique," highly subsidized runs (Lackey, Lach, and Duncan 2006). Mandatory devotion of substantial resources to conserving these species may both be futile and detract from the recovery of other species that are on the verge of extinction.

Managing with Uncertainties

We began this chapter with the premise that the environment has generally been short-changed in water management. Society has overlooked the many economic and social benefits of environmental water and has therefore been reluctant to manage water for environmental purposes. There is also a tendency to think that California's water system can just be modified in many small ways to preserve native species—the best indicators of the environmental quality of the state's aquatic systems. In some ways this is true, in that many small changes will be important to the success of species and ecosystem recovery efforts. However, success will often require far more radical and strategic changes in water and

land use, including increasing flows in rivers, reconnecting floodplains with rivers, and removing dams. This means that creating more favorable conditions for aquatic biodiversity and the ecosystem services of free-flowing water will be difficult, expensive, and time-consuming. The difficulty is compounded by the high uncertainty of success for specific actions, given ecosystem complexity, gaps in knowledge of how to manipulate many key processes, and, most important, continuing change in climate, invasive species, and other conditions in California (Chapter 3). As a result, a flow regime or water quality target that seems adequate today may not provide the same services in 20 to 30 years. Aiming at a moving target in semi-darkness means that there will be many misses. We recommend using these basic guidelines for making decisions related to improving environmental conditions given this uncertainty:

- Use the principles of adaptive management as expressed by Holling (1978), Lee (1993), and others, which treat management actions as experiments, with appropriate hypotheses, documentation, monitoring, and knowledge integration and experimental design using modeling.
- Work *with* environmental variability rather than trying to fight it (Beechie et al. 2010; Moyle et al. 2010).
- Understand what desirable species require. Most aquatic species are highly adaptable, within limits. So understanding the limits is important, especially in relation to climate change.
- Be willing to accept large-scale change to ecosystems. Humans now irreversibly dominate California's ecosystems. To support native organisms and ecosystem services, it is necessary to think in terms of creating "new" ecosystems that may differ greatly in appearance from existing and pre-development systems (West et al. 2009).
- Focus on preventive actions where possible to avoid such unpleasant surprises as invasions of new species, effects of new toxins, and imperilment of additional species.
- Be explicit about the likely outcomes of large-scale management actions, including statements on uncertainties (Beechie et al. 2010).
- Base decisions on a strong program of solution-oriented scientific research and monitoring, to provide a reliable source of knowledge, recognizing that increased knowledge can also bring increased

uncertainty (Healey, Dettinger, and Norgaard 2008). Yet decisions can and must be made despite uncertainties.

- Involve local watershed groups to generate community support for projects, to act as environmental watchdogs, and to provide energy and labor for restoration projects.

It is becoming apparent that current environmental management will ultimately cause the loss of species and native biodiversity, through timid and incoherent management of ecosystems. More ambitious efforts at reconciling native ecosystems with a major and even predominant human presence will sometimes lose those species with low probabilities of survival, but a well-considered and energetic approach will offer a better chance of sustaining more native species.

Working Toward Reconciliation

The development of water supply, flood control, and hydropower throughout California has degraded aquatic and riparian ecosystems for native species. Today, only a handful of the state's rivers, streams, lakes, and estuaries are relatively unaffected by water management activities. These changed ecosystems are less capable of supporting native biodiversity, as indicated by the declining populations of native fish species, most of which are found only in California. The ever-increasing number of fishes listed under the federal and state Endangered Species Acts means that water decisions in California will be increasingly constrained by the need to save and recover native fishes.

Current approaches to address the decline in native fish species are not working. To improve effectiveness and reduce future conflicts, a multipronged effort focusing on reconciliation is needed. This will involve new approaches and new policies at the federal, state, and local levels and substantial financial investments. To more effectively design, implement, and improve ecosystem reconciliation efforts, it will be necessary to revitalize and focus scientific and technical efforts. Although basic research will remain important, more focused, solution-oriented efforts are needed. At the state level, the effort also will require real leadership, beginning with the governor and the legislature, although most of the on-the-ground decisions related to management will likely be made by the Department of Fish and Game and the state and regional water boards, supported by numerous other agencies including the Department of Water

Resources, the Department of Forestry and Fire Protection, and the Department of Food and Agriculture. New regional stewardship authorities could help coordinate state, local, and regional actions at the scale of watersheds (Chapter 8).

Today, management to support endangered species is often simply viewed as a cost to water operations and is generally undervalued as a result. To create a more accurate picture, water and land development projects should consider the economic value of the many services that healthy ecosystems provide and their contribution to human well-being, as well as the benefits to endangered species. This reconciliation approach is also compatible with continuing changes in California's economy, which is becoming less dependent on water as an input into economic growth (Chapter 2). A range of activities can be considered reconciliation strategies, including levee setbacks to promote floodplain inundation, nonpoint source pollution reduction, invasive species management, and more. Dams, one of the main causes of aquatic species decline, should be a central focus of reconciliation strategies, including dam reconstruction, reoperation, and in some cases removal.

Reconciliation strategies, however, are constrained by current environmental laws. Most significant are the state and federal laws for clean water and endangered species protection. The federal Clean Water Act and the state Porter-Cologne Act prohibit the state from allowing water quality to decline in ways that affect existing beneficial uses. Under a reconciliation strategy, the best option for the state or the ecosystem is not necessarily to maintain existing uses but rather to adjust to changing conditions. For instance, reimposing variability to suppress invasive species and support native species would likely harm some current beneficial uses and be incompatible with current legislation (Moyle et al. 2010). This is likely to be a major issue as climate change and invasive species alter ecosystems and may require amendment to the statutes.

The current implementation of state and federal Endangered Species Acts constrains reconciliation activities in three ways: They concentrate on single-species management, instead of ecosystem-based approaches; they focus on project operations that are federally authorized or funded rather than addressing multiple sources of ecosystem stress; and with one rarely used exception in the federal statute (the God Squad), they have no provision for allowing species to go extinct, whether as part of a species triage strategy or as a result of changing conditions, such as climate warming. The first two of these problems can be addressed with more flexible approaches under existing law. The third problem may eventually require amendment of the statutes.

There are many ways to make California's natural environment better for the coming generations. Here, we have presented some that are both ambitious and doable. One option that we do not like to consider is continuing to stumble along on the same dark path. If management continues as it is today, California will see the disappearance of iconic fish species such as salmon and steelhead from most of the state's waterways. Aquatic environments will become increasingly homogenized, supporting mainly nonnative, tolerant species such as common carp, red shiners, swamp crayfish, tubifex worms, and semi-domesticated ducks. The cost of such services as provision of clean water to drink, places to swim, and fish to eat will rise, or these services will become increasingly unavailable, at the cost of human health, wealth, and well-being. California has long borrowed from its environmental future and the debt is coming due. Paying this debt now will create a more livable, sustainable, and prosperous state. Putting this debt payment off until later will be much costlier, as the natural environment that makes California special slips away.