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CONSERVATION OF NATIVE FRESHWATER FISHES IN THE MEDITERRANEAN-TYPE CLIMATE OF CALIFORNIA, USA: A REVIEW

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Abstract

The native fish fauna of California, like the faunas of other regions of the world with Mediterranean climate, is declining rapidly: 63% of the 115 taxa are extinct or in danger of becoming extinct. The native fishes fall into three major groups: (1) diadromous fishes and their stream-resident derivatives; (2) large, long-lived freshwater dispersant fishes, mostly Cyprinidae; and (3) small freshwater dispersant fishes in isolated inland habitats, such as desert springs. In this respect, the fish fauna of California bears a closer resemblance to the fish fauna of Europe than it does to that of eastern North America. The native fish fauna is in trouble because most of the precipitation occurs in the northern half of the state or at high elevations, while most of the human need for water is in the southern half of the state, at low elevations. The result has been the construction of dams and reservoirs on every major stream in the state and thousands of kilometres of aqueducts. In addition, poor land use has devastated many drainages, introduced fishes have replaced native fishes, and fisheries have depleted some stocks. Major droughts have exacerbated these problems. Most of the extinct or endangered species are either native to small isolated habitats or to big rivers. The fishes have continued to decline despite conservation efforts using such powerful legal tools as the Endangered Species Act, the California Department of Fish and Game Code, and the Public Trust Doctrine. The poor state of California's fish fauna is a strong indication that many other endemic aquatic organisms, much more poorly known than the fishes, are in trouble as well. Protecting fishes will thus help to protect aquatic biodiversity in California. With this in mind, a general plan for protecting California's aquatic biota is presented. The plan has two main components: (1) legal protection for species in immediate danger of extinction and (2) development of a statewide system of protected waters called Aquatic Diversity Management Areas (ADMAs). For the latter component, a framework is presented that consists of (1) criteria for the design of ADMAs; (2) a system for ranking the suitability of aquatic habitats for protection of the native biota; (3) a classification system for California's waters; and (4) a long-term scheme for protecting aquatic biodiversity statewide.

Keywords: conservation, fish, California.

INTRODUCTION

Nowhere in the world are aquatic faunas declining more rapidly than regions with a Mediterranean climate (Moyle & Leidy, 1992). The basic reason for this is that these regions have limited supplies of fresh water yet are highly favoured by humans as places in which to live. This puts humans in direct competition for water with fish. California is no exception to this rule. Of its 115 native fish taxa, eight (7%) are extinct, 15 (13%) are formally recognized by state or federal governments as in danger of extinction, 27 (23%) qualify for such formal listing, and 22 (19%) may qualify in the near future if present trends continue (Moyle & Yoshiyama, 1992). More kinds of fish are in serious trouble in California than in any other state in the United States, although on a percentage basis states with desert climates (Arizona, Nevada) are similar. The potential loss of much of the native fish fauna of California is global because a majority of the taxa are endemic to the state (60%) or to the region (82%). In addition many of the taxa in trouble have (or have had) high economic value as commercial or sport fishes. Conservation of this fauna therefore presents many problems that have to be solved quickly if the fishes are to be retained and their economic and aesthetic values restored. The purposes of this paper are: (1) to provide an introduction to the natural and human history of California in relation to its fish fauna; (2) to describe the status of the fauna and the causes of its decline; and (3) to present a strategy for protecting the fauna, using a systematic, habitat-oriented approach.

THE NATURAL ENVIRONMENT OF CALIFORNIA

California is the most environmentally diverse politically defined region of North America. This is because of its large size (*c.* 406,000 km^2), long coast line (*c.* 1 350 km), and diverse topography. The biotic communities range from cool rainforests along the northwest coast, where rainfall may exceed 3 000 mm per year, to harsh deserts in the southeast, where large areas receive less than 100 m/year. Throughout the state the climate is essentially Mediterranean in that subfreezing temperatures are infrequent (except at high elevations) and rainfall is highly seasonal. About 80% of the rainfall occurs from November to March; May to September are usually without rain (Karhl, 1978). However, rainfall is highly variable from year to year and extended droughts are common. The most recent lasted 6 years (1986–1992). From the perspective of fish, this means that extreme conditions are frequently experienced and naturally limit distribution and abundance. In coastal areas, high flows are keyed to winter rains, and in the interior to spring snow-melt from the Sierra Nevada and other mountain ranges. Winter and spring are thus principal times of spawning for fishes while summer and fall are times that most often limit populations, when streams and lakes dry up and water temperatures rise.

These harsh conditions limit diversity despite the huge area encompassed by the state (Moyle, 1976; Moyle & Williams, 1990). The 115 taxa include only 63 species, which are further divided into subspecies and, in the case of salmonids, major spawning runs. The native fishes of California fall into three major groups based on ecology and morphology: (1) diadromous fishes and their stream-resident derivatives (usually not distinct at the species level); (2) large, long-lived freshwater dispersant fishes (according to the definition given by Moyle & Cech, 1988), mostly Cyprinidae; and (3) small freshwater dispersant fishes in isolated inland habitats, such as desert springs. In this respect, the fish fauna of California bears a much closer resemblance to the fish fauna of Europe than to that of eastern North America (Moyle & Herbold, 1987).

The names in this review are those accepted by the American Fisheries Society (Robins, 1991).

HISTORY OF HUMAN IMPACT

The Native Americans found California a fairly benign place in which to live and developed surprisingly large populations primarily by hunting and gathering. Fish were a major source of food for many inland tribes, who heavily used the seasonal spawning runs of both anadromous and resident species (Kroeber & Barrett, 1960). Where large lakes, sloughs, and rivers existed, they also harvested resident species throughout the year (Schultz, & Simons, 1973). Tribal fishing rights and traditions to a large extent, regulated the harvests, presumably reducing the probability of both overharvest and intertribal disputes (Kroeber & Barrett, 1960). Thus effects of the native peoples on the fishes were minimal.

The Spanish began exploring California in the 1500s but the first permanent settlement did not occur until 1769 when a mission was built at the present site of San Diego. By 1773, a dam had been built across a local river, crops were being irrigated, and the alteration of California's waterways had begun (Hundley, 1992). Of even greater significance was the introduction of European diseases (which decimated the populations of Native Americans), European annual grasses (which replaced the native perennial grasses), and cattle (which became feral and heavily grazed the landscape). The reduction of fishing pressure by Native Americans was probably more than offset by the increase in seasonality of flows caused by the change in vegetation and by the increase in erosion caused by cattle grazing.

The changes wrought by Spanish settlement, however, seem gentle and gradual compared with those wrought by the massive influx of people to the state starting in the 1850s. This began with the discovery of gold in 1849 in gravels of tributaries to the Sacramento River. In 1853, hydraulic mining was developed, resulting in innumerable diversions of water from rivers to wash gold from streamside deposits. So much debris was flushed down the rivers that runs of chinook salmon *Oncorhynchus tshawytscha* were eliminated and the Sacramento River became nearly unnavigable when the gravel deposits raised river beds 5–7 m. This also resulted in flooding of cities and farmland, so in 1884 hydraulic mining was banned. This signaled the growing importance of farming and commerce in the state's economy and the beginning of large-scale drainage and water development projects that altered the state's waterways more profoundly than the gold mining. In the late 1800s most of the lowlands of the Central Valley were dyked and drained. The largest lake in California, Lake Tulare in the San Joaquin Valley, was drained to create farmland, eliminating commercial fisheries that existed there. The severe and sudden alteration of valley-floor aquatic habitats greatly reduced the populations of native fishes adapted for such habitats, driving two of the most abundant species, thicktail chub *Gila crassicauda* and Sacramento perch *Archoplites interruptus*, to extinction (Moyle, 1976).

In this same period (1850–1900), two other factors were also having a negative effect on native fishes: unregulated commercial fisheries and introductions of non-native fishes. Fisheries for freshwater and anadromous fishes quickly developed to feed the rapidly growing population of California. Virtually all abundant species were captured and sold. Indeed, many of the native fishes were described from specimens obtained from fish markets (Moyle, 1976). The salmon fisheries were most important, however, and the resource was quickly overharvested all along the California coast. In 1882, the catch in Central Valley streams peaked at around 600,000 fish. The salmon catch has continued to decline ever since despite protective regulations and numerous fish hatcheries.

One factor helping to prevent recovery of salmon populations was the introduction of new species of fish following the completion of the transcontinental railroad in 1869. Specially built railroad cars were soon bringing an array of fish and invertebrates to California, as well as their diseases and parasites. Initially, the most successful were species that could thrive in waters altered by the hydraulic mining: striped bass *Morone saxatilis*, American shad *Alosa sapidissima*, and common carp *Cyprinus carpio*. Striped bass populations literally exploded and it became the most abundant fish in the Sacramento–San Joaquin estuary within 20 years of introduction. This species is a voracious piscivore and presumably contributed to the declines of native cyprinids, Sacramento perch, and salmon. Today 51 species of introduced fishes are established in California and native fishes are now gone from many habitats (Moyle, 1976; Baltz & Moyle, 1993).

Introduced species have been successful in California in good part because the natural environment has been so altered. Free-flowing streams have increasingly been turned into reservoirs, regulated streams, and ditches. The enormous changes to California's waterways are the result of a fundamental reality: most of the precipitation occurs in the northern half of the state and at high elevations, while most of the human need for water is in the southern half of the state, at low elevations. The biggest demand by agriculture (which uses 85% of the state's water) occurs in the summer, when precipitation is almost non-existent. The result has been the construction of dams and reservoirs on every major stream in the state (and many smaller ones as well) and aquaducts that deliver water hundreds of kilometres from its point of origin. They allow thirsty crops such as cotton and rice to be grown in desert areas of the Central Valley and a huge metropolitan area (Los Angeles) to flourish in a region with little natural water. The biggest water development projects are the federal Central Valley Project and the State Water Project (SWP). From 1941 to 1982, construction on these projects was almost continuous. When the first dams were built, fish were given little consideration. For example, the closure of Friant Dam on the San Joaquin River in 1945 resulted in the deliberate extirpation of spring-run chinook salmon in the river, which consisted of 50,000 fish in 1946 (Warner, 1991). The last salmon, representing the southernmost race of the species, attempted to navigate the dry river bed in 1950. The era of uninhibited water development ended when the voters of California soundly defeated a proposal to build one last huge canal, the keystone of SWP, partly on the fear that the canal would have too heavy an environmental cost, including the further loss of fisheries (Hundley, 1992). Today, the operations of existing projects are being re-evaluated and some additional water is being allocated for fish and other environmental needs. A key argument being used is that there is enough water for both people and fish, provided human users, especially agricultural users, engage in water conservation.

HISTORY OF CONSERVATION EFFORTS

The earliest conservation efforts to protect fishes centred on commercially valuable species, especially salmon (McEvoy, 1986; Lufkin, 1991). In the late 1800s, laws were passed to restrict catches in rivers, wardens were hired to enforce the laws, and the first fish hatcheries were built. Large numbers of fishes from eastern North America were introduced, in an effort to replace lost fisheries or find species more acceptable to American tastes than most of the native species. Fisheries continued to decline, however. In the early 20th century, previous efforts were increased as state and federal fisheries agencies developed. Most inland commercial fisheries were banned in favour of sport fisheries, although anadromous fishes were still caught in large numbers in the ocean.

In the 1940s, 1950s and 1960s, it was optimistically assumed that fish hatcheries associated with dams would actually increase the numbers of anadromous fishes and that the new reservoirs would create large new sport fisheries, mostly for introduced species. The latter prediction came true (more or less) but not the former. Native non-game fishes were regarded largely as nuisances that invaded the new reservoirs or competed with more desirable introduced species, so large-scale poisoning operations were common (e.g. Pintler & Johnson, 1958). Meanwhile, mechanized logging operations, expanding agriculture, and intense livestock grazing were devastating drainage basins, including those of major spawning streams of anadromous fishes. This was also the era when a small number of biologists undertook life history studies of native fishes which provided the basis for future fish conservation (Moyle, 1976). Despite their efforts, fish populations and fisheries continued to decline.

The environmental degradation caused by the post World War II economic expansion became so obvious by the late 1960s that legislation was passed by the US Congress to protect the environment. For fish, the most significant acts were the National Environmental Policy Act (1969), the Endangered Species Act (1973 version), and the Federal Water Pollution Control Act (1972). Similar laws were also passed by the California legislature. These laws, and others, slowed down the rate of environmental degradation but have been in part counteracted in California by the rapid rate of human population growth and the increased diversion of water from existing water projects. Fish populations have continued to decline and species are removed from official endangered lists only when they become extinct.

Despite the continued downward trend in native fish populations, there are reasons to hope that the trend can be reversed. Increasingly, fish biologists are organizing themselves to force their agencies to protect native fishes and their habitats. The Desert Fishes Council has led the way in protecting fishes of the Great Basin, including pursuing a successful lawsuit all the way to the Supreme Court of the United States (Pister, 1991). The American Fisheries Society filed petitions for endangered listing of two California endemics, winter-run chinook salmon and delta smelt *Hypomesus transpacificus*. State and federal resource management agencies increasingly have as part of their mandate the protection of biodiversity, and well-organized environmental groups are forcing them to follow their mandates. The most effective tools they have used in recent years in California have been the Endangered Species Act (ESA), an obscure section (5937) of the California Department of Fish and Game Code that states that viable fish populations *must* be maintained below dams, and, increasingly, the Public Trust Doctrine. The Public Trust Doctrine is a concept found in law at least back to Roman times. It essentially states that there are resources that belong to the people (such as rivers, wetlands, lakes, fish, and wildlife) that the government must manage for the greatest public good; private use of these resources must be reasonable because they are held in trust for the health and well being of *all* the people (Smith, 1991). The most significant test of this combination of approaches has been the preservation of Mono Lake, an alkaline sink, from the actions of Los Angeles Water and Power, which was diverting all the inflowing streams to provide water for the City of Los Angeles. The Mono Lake Committee and its allies have so far won every major court test on these issues. Efforts are now being made to apply them to the major water projects in the Central Valley.

TRENDS IN NATIVE FISH POPULATIONS

The native fishes of California are in serious decline. In 1988, seven (6%) of the native fish taxa were extinct, 14 (12%) were officially listed as threatened or endangered, seven (6%) were recommended for immediate listing immediate, 44 (39%) were in decline or had very limited populations in the state and 41 (36%) species appeared to be secure (Moyle *et al.*, 1989; Moyle & Williams, 1990). Four years later (1992), the numbers had changed to 7% extinct, 13% formally listed, 23% qualify for listing, 19% in decline, and 37% apparently secure (Moyle & Yoshiyama, 1992). This represents a rising trend in extinct and endangered species, from 24% in the first three categories in 1989 to 43% in 1992. This shift is the result of better information on the status of some species but represents a real shift in status of most of them, as a result of the effects of severe drought on fish populations stressed by human factors.

Seven native fish taxa have been extirpated, six since 1957. The most recent was the High Rock Spring tui chub *Gila bicolor* subsp., which disappeared in 1989 after African cichlids *Tilapia* spp. were introduced into its isolated spring habitat. This subspecies was recommended for listing as endangered in Moule *et al.* (1989). At the present time one native fish taxon is lost from the state about every 6 years. However, only one taxon was added to the official endangered lists in the 4-year period, the winter run chinook salmon of the Sacramento River. Among the species now considered to qualify for listing are longfin smelt *Spirinchus thaleichthys* and green sturgeon *Acipenser medirostris*, regarded as secure in 1989 due to inadequate information. The newly qualified taxa also include four endemic subspecies from Goose Lake, a large alkaline lake on the California–Oregon border that dried up in 1992 from a combination of drought and diversions. The drought has also pushed coho salmon *O. kisutch*, once present in *c.* 540 coastal streams in the state, to a threatened status (Brown & Moyle, 1991). Less than 5 000 wild coho still spawn in the state each year and many of the remaining populations contain less than 25 fish so are probably not viable. Prior to World War II, there were probably at least 200,000 coho spawners each year and they were major contributors to sport and commercial fisheries. A similar situation exists with spring-run chinook salmon, which may have numbered over a million spawning adults in the state at one time and are now down to about four populations totalling less than 2500 fish (Campbell & Moyle, 1991).

CAUSES OF DECLINE

Moyle and Williams (1990) placed potential factors regulating the abundance of native fishes into six categories: (1) natural factors; (2) water projects; (3) habitat modification; (4) pollution; (5) introduced species; and (6) exploitation. For each of the 113 taxa in their study they rated the importance of each category. For declining species, they found that water projects were most important followed by introduced species and habitat modification (from logging, channelization, overgrazing, etc.). They also noted that species rarely declined from one factor alone but usually from the effects of several working in conjunction with one another. For example, many native fishes can thrive in reservoirs created by water projects until introduced species, especially predatory centrarchid basses *Micropterus* spp., become established. Likewise, commercial fishing exacerbates the effects of water projects and poor logging practices on salmon because it removes larger and older fish from the already depleted populations. This means that most chinook salmon returning to California streams are now 3 years old and few are 4 or 5 years old. The elimination of older fish from the population effectively increases the probability that a particular year class of fish in a stream can be eliminated by a natural or human-made disaster because there may not be a back-up group of older fish still present in the ocean.

The importance of the various factors is also shown by the finding that most extinct or endangered species are either native to small isolated habitats or to big rivers (Moyle & Williams, 1990). Small isolated habitats are easy to disrupt with introduced species or habitat alteration. Thus the Shoshone pupfish *Cyprinodon nevadensis shoshone* became endangered when its home spring near Death Valley was tapped as a town water supply and the drainage ditch in which it persisted was polluted with mosquitofish *Gambusia affinis*. All the native fishes (five species) of the Colorado River are extinct or endangered in California because the river is now completely developed. Dams block migrations and release water that is cold and clear (rather than warm and muddy); in addition the reservoirs are full of exotic fishes that prey on the eggs and young of the native fishes (Minckley & Deacon, 1991). In the Sacramento–San Joaquin drainage, the species that are *not* in trouble are those that can thrive in streams of intermediate size, those too small to dam but too large to destroy easily.

The factor that may provide the final push to extinction for many California species is extended drought. When water is scarce, a greater proportion is taken for human use, leaving less for fish at a time when they need it most (e.g. Moyle *et al.*, 1992). The native fishes are actually adapted for surviving extended periods of drought through a combination of life history strategies and physiological tolerances (Moyle *et al.*, 1986). Human interference not only makes droughts more severe by removing much of the water but extends drought conditions by capturing, in empty reservoirs, much of the run-off in the first wet year following a drought. In addition, habitat alterations have left fewer places that can act as refuges for drought-stricken fishes.

A FRAMEWORK FOR PROTECTING CALIFORNIA'S AQUATIC BIOTA

The poor state of California's fish fauna is a reflection of the poor state of aquatic habitats in California in general. It is also a warning that many other endemic aquatic organisms, much more poorly known than the fishes, are also in trouble (e.g. Eng *et al.*, 1990). Protecting fishes will help protect these organisms as well. With this in mind, the author has developed a general plan for protecting California's aquatic biota. The plan has two main components: (1) formal listing, as endangered, of the species in immediate danger of extinction; and (2) development of a statewide system of protected waters, called Aquatic Diversity Management Areas (ADMAs). This plan should be regarded as a regional subset of the global proposal of Nyman (1991).

Protecting endangered species

The federal Endangered Species Act (ESA) is probably the most powerful piece of environmental legislation in the world today. In unequivocal language, it mandates the protection and recovery of species officially recognized as being in danger of extinction in the near future. There are severe penalties for 'taking' an individual of an endangered species ('take' can include destruction of habitat) and federal agencies must comply with endangered species guidelines when issuing permits or providing funding for activities that might affect an endangered species. The decision to list a species as threatened or endangered is supposed to be based purely on biology without economic considerations taken into account, although a listing decision can be overridden by a committee of cabinet secretaries and agency heads. The listing process is slow and complex and the agencies in charge of listing are greatly underfunded, so there is a long backlog of species waiting to be listed. The state of California has an endangered species law based on the federal ESA but with more provisions for 'take'. All petitions to list also have to be approved by a politically appointed Fish and Game Commission, which has been increasingly reluctant to list species.

Not surprisingly, the ESA is under intense attack by special interests that would like to weaken it, because of its perceived negative effects on economic activity. The attacks take many forms and are often veiled in language that seems to suggest ways to make the ESA more effective. One such approach is to suggest that protecting endangered species is not adequate; the act should instead protect endangered ecosystems. The problem, of course, lies in defining what an ecosystem is and what each ecosystem's boundaries are for legal purposes. For most ecosystems this cannot be done easily and the debate about boundaries would probably tie up listing packages for years. One answer to this tactic is to list species in groups that represent ecosystems, an approach favored by the US Fish and Wildlife Service, the main federal agency in charge of endangered species (K. Taniguchi, USFWS, pers. comm.). Thus, the author has recommended listing fishes in five regional clusters, as follows:

(1) Central California: delta smelt, longfin smelt, Sacramento splittail *Pogonichthys macrolepidotus*, spring-run chinook salmon, green sturgeon, Red Hills roach *Lavinia symmetricus* subsp.
(2) North coast: coho salmon, chum salmon *O. keta*, pink salmon *O. gorbusha*, spring-run chinook salmon, summer steelhead *O. mykiss gairdneri*, green sturgeon, longfin smelt.
(3) Interior drainages: Eagle Lake rainbow trout *O. mykiss aguilarum*, McCloud redband trout *O. mykiss* subsp., Goose Lake redband trout *O. mykiss* subsp., Goose Lake sucker (*Catostomus occidentalis lacusanserinus*, Goose Lake tui chub *G. bicolor thalassina*, Goose Lake lamprey *Lampetra tridentata* subsp., Cowhead Lake tui chub *G. bicolor vaccaceps*.
(4) Desert basins: Shoshone pupfish, Saratoga Springs pupfish *C. nevadensis nevadensis*, Salt Creek pupfish *C. salinus*, Amargosa pupfish *C. nevadensis amargosae*, Amargosa Canyon speckled dace *Rhinichthys osculus* subsp., Owens speckled dace *Rhinichthys osculus* subsp.
(5) Southern California: southern steelhead *O. mykiss gairdneri*, Santa Ana sucker *C. santaanae*, Santa Ana speckled dace *Rhinichthys osculus* subsp., tidewater goby *Eucyclogobius newberryi*, Shay Creek stickleback *Gasterosteus* sp.

Protecting these fishes would protect a number of aquatic ecosystems in the state and help to prevent other species, both fish and invertebrate, from becoming endangered as well.

Realistically, it is highly unlikely that all these species will be listed as threatened or endangered, if for no other reason that the agencies do not have enough staff or money to do the evaluations. Listing may also not always be necessary to protect the species. For example, when the USFWS began deliberating about the emergency listing of four endemic Goose Lake fishes, it catalyzed a meeting of local landowners and representatives of state and federal agencies (July 1992). There is now reason to be hopeful that voluntary actions from landowners and increased habitat restoration activities of land management agencies will save these fishes, without having to resort to the more confrontational ESA mandates (G. Sato, Bureau of Land Management, pers. comm.).

Protecting aquatic habitats

The number of endangered species in California is increasing rapidly, as is the number of confrontations on endangered species issues. The best way to avoid creating endangered species is to protect the habitats of native species before they decline to the point where emergency action is needed to keep them from becoming extinct. In this section a framework is provided that allows for the systematic protection of aquatic habitats and the species they contain. This framework is not meant to be a substitute for actions needed to protect species on the verge of extinction but it is designed to help to prevent more species from being added to the list of endangered species.

This framework consists of (1) criteria for the design of Aquatic Diversity Management Areas (ADMAs), (2) a system for ranking the suitability of aquatic habitats for protection of the native biota, (3) a classification system for California's waters, and (4) a scheme for protecting aquatic biodiversity statewide, including the development of a system of ADMAs.

Aquatic Diversity Management Areas are water bodies that have as their top priority for management the maintenance of local biodiversity (Moyle & Sato, 1991; Nyman, 1991; Moyle & Yoshiyama, 1992). Other uses are permitted, but they are secondary to the primary goal. The key to their management is flexibility, recognizing that active management is often needed to maintain or enhance biodiversity. ADMAs are not necessarily pristine environments, but they are usually reasonable approximations of them. ADMAs should be established following the principles of reserve design outlined in Moyle and Sato (1991).

(1) An ADMA must contain the resources and habitats that are necessary for the persistence of species and communities it is designed to protect.
(2) An ADMA must be large enough in area to contain the range and variability of conditions necessary to maintain natural species diversity.
(3) ADMA integrity must be protected from edge and external threats.
(4) An ADMA should have enough interior redundancy of habitats to reduce problems created by localized extinctions of species due to natural processes.
(5) Each ADMA should be paired with *at least* one other ADMA that contains most of the same species but that is far enough distant from it so that it is unlikely to be affected by a regional disaster.
(6) An ADMA should be able to support populations of its biota that are large enough to have low probability of extinction due to demographic and genetic stochasticity.

A rating system for potential ADMAs presented here recognizes the need for managing habitats that range from pristine to degraded, with highest priority being given to assigning ADMA status to the most pristine systems to prevent them from being degraded (Moyle & Sato, 1991). The rating system consists of six classes of waters that form a continuum from best (Class 1) to worst (Class 6).

Class 1. These waters are those that bear the closest resemblance to waters unaltered by the activities of western civilization. A Class 1 water contains a complete set of native biota and has a high degree of natural protection, such as location in an undisturbed watershed or above natural barriers to invasions by exotic species. It can be of any size, but ideally it should contain a high percentage of the regional fish fauna, a diversity of habitats, and enough area to maintain viable populations of the largest and most mobile species. Waters that fit this description are extremely rare and undisturbed watersheds are non-existent.

Class 2. Class 2 waters are not sharply differentiated from Class 1 waters, but they have been more obviously modified by human activity. A Class 2 water should also contain mainly native organisms and have the possibility of being restored to a Class 1 water without unreasonable effort, such as removal of a dam. Class 2 waters will form the backbone of any system of ADMAs because they are numerous and large in size and many occur on public land.

Class 3. These waters appear to be natural, but they have been so modified that the natural biotic communities have been significantly and probably irreversibly altered. Often introduced species are integral parts of these biotic communities. Class 3 waters are unlikely ever to be restored to Class 1 waters. They nevertheless have potential as part of a system of ADMAs because they are often refuges for some parts of the native biota. An example is the reach of the McCloud River (Shasta County) between two dams, much of it contained in a reserve. It contains rainbow trout, riffle sculpin *Cottus* sp., and a native invertebrate and amphibian fauna, but it is missing two key elements: spring-run chinook salmon and predatory bull trout *Salvelinus malma*. It is also home to introduced brown trout.

Classes 4, 5 and 6. These waters are artificial preserves of various sorts. They cannot serve as ADMAs but only as sources of species for restored ADMAs (Moyle & Sato, 1991).

A classification system for California's waters is needed if a state-wide system of ADMAs is to be established on a systematic basis. Moyle and Ellison (1991) have devised a classification scheme for aquatic habitats in California that can be used to focus efforts in aquatic conservation. This classification system contains over 160 categories and is expandable, so if habitats were inadvertently excluded, they can be added. The system focusses on fish (especially on regions of endemism) but includes many fishless habitats as well. Ideally, every habitat type listed in the system should be protected in two or more ADMAs. A single ADMA could, and probably should, include multiple habitats within the classification system, which can also be used to help determine what parts of the biota already are protected under *de facto* ADMAs (e.g., waters in parks and natural areas) and what parts have little or no protection so that limited personnel, time, and money can be used most efficiently. At present, the majority of the habitat of most species does not occur in protected waters (Moyle & Williams, 1990).

A GENERAL SCHEME FOR PROTECTING AQUATIC BIODIVERSITY IN CALIFORNIA

The first step in the process of systematically protecting aquatic biodiversity in California is to identify at least two potential ADMAs in each category of the classification. The characteristics of each potential ADMA can be summarized on one page (Table 1) and compiled into an expandable catalogue. Additional one-page descriptions could be completed by anyone reasonably familiar with a particular body of water that might merit ADMA status. The catalogue of ADMAs is designed to be a source of information for management agencies as well as concerned citizens. The waters initially listed as ADMAs are considered to be *the minimum* needed to protect aquatic biodiversity, not as the only waters so protected. Highest priorities should be given to assigning ADMA status to waters that (1) are unique ecosystems with endemic organisms, such as Eagle Lake (Lassen County) or Cowhead Lake slough (Modoc County); (2) are critical habitats for threatened or endangered species, such as Goose Lake (Modoc County); (3) have Class 1 status (above); and (4) have the right combination of large size, low degree of disturbance, and intact fish assemblages to be the best representatives of a particular aquatic ecosystem, such as Deer Creek (Tehama County).

Once a reasonable catalogue of potential ADMAs is available, agencies charged with environmental protection or environmental groups, such as The Nature Conservancy, will be able to use the information to set conservation priorities and to develop biodiversity-oriented management plans (Moyle & Yoshiyama, 1992).

While the initial ADMA programme is being set up, a long-term programme of biological survey and research should be established. Its goals should include:

(1) Eventual inclusion of *all* bodies of water into an easily accessible data base that would also be usable for planners using Geographical Information Systems.
(2) Systematic surveys of California's fresh waters to find new ADMAs to add to the system (the more duplication of each habitat type, the better). It is particularly important to identify aquatic

Table 1. Aquatic Diversity Management Area catalog entry key

Aquatic Diversity Management Area: Number assigned as entry accepted for catalogue

Site: Name of body of water and location (county is usually enough).

Site number: Number assigned in University of California, Davis stream site data base.

Ichthyological province: As defined in Moyle (1976).

Classification: Class number and title according to Moyle and Ellison (1991). Some sites will have more than one class number.

Boundaries: The boundaries of the system in general terms, usually drainage. The upper boundaries will usually be all tributaries and the watershed itself. The lower boundaries may be indeterminate or defined by natural or human-made barriers.

Native fishes: Common names of all native fishes present.

Description: Description of the water body and its region, including biotic elements.

Status and ownership: Names of government and other landowners. Private landowners not identified specifically. Status is a statement of condition of water.

Type of preserve: The system of Moyle and Sato (1991). In brief: Class 1, pristine; Class 2, modified but could revert to Class 1, as over 75% of the species are native; Class 3, highly modified, probably beyond restoration to Class 1 or 2, but still containing native species.

Degree of protection: System of Moyle and Williams (1990): 1, 0–10% of water body with formal protection; 2, 11–50% with such protection; 3, 51–90%; 4, >90%. This has to be estimated based on how much of the aquatic habitat is designated as being protected.

Management: Suggestions for management.

Acquisition priority: 1, High. All or most of drainage/water on private land and acquisition (or conservation easement) needed soon to protect biodiversity. 2, Slightly lower priority than 1 because some of ADMA already protected or threats to integrity not immediate. 3, Much of ADMA protected but small parcels should be eventually acquired for complete protection. 4, All lands in publically owned or adequately protected.

References: Publications, if any.

Date: Date account prepared   Prepared by: Author habitats that are poorly represented on public lands in order to encourage efforts for acquisition of land or water rights, to develop conservation agreements or to make other arrangements with landowners that would ensure protection of crucial waters.

(3) Regular, repeated surveys of selected waters, including all ADMAs, as an indicator of the overall and regional health of California's fresh waters, using community approaches as recommended by Fausch *et al.* (1990).

(4) Complete taxonomic and genetic studies of all of California's freshwater fishes, focusing initially on rare species with scattered populations (e.g. Modoc sucker) and on widespread species with numerous distinct geographic populations (e.g. tui chub, Sacramento sucker, California roach). This would help develop priorities for management, as discussed by Vane-Wright *et al.* (1991). Given the relatively small number of native species, this goal is achievable in 10–15 years with sufficient funding.

(5) Conduct surveys of other groups of aquatic organisms, focusing especially on groups that occur in habitats without fish, to locate endemic or unusual forms. A good example is the survey of Anostraca by Eng *et al.* (1990). This would assure that fishless ADMAs would be adequately represented in a conservation system.

Ultimately each ADMA would become part of an official statewide ADMA system and would have an agency assigned to monitor and manage it. General management philosophy and guidelines should be established by an interagency committee, but local responsibility for management is important. Ideally each ADMA should also have a voluntary citizens' management/watchdog group associated with it, or at least an individual appointed as the ADMA Advocate. A system of volunteer ADMA protectors is not as difficult to organize as might be thought. Citizens' groups are already springing up all over the state as people realize that waterways they value are being degraded. An angling group, California Trout, systematically appoints members to be 'keepers' of important trout streams. In both cases, concerned citizens monitor the health of the streams and complain loudly (or take legal action) if they observe problems. Another alternative is to have a core of paid, professional stream- or lake-keepers established, whose job would be to monitor and protect waters designated as ADMAs.

A major problem with this conservation scheme is that it largely does not apply to big rivers (Colorado, Sacramento, San Joaquin, Klamath) and their estuaries. The reason for this is that these systems have been so modified by upstream water diversions that they no longer have natural flow regimes, and many of the upstream tributaries that once supported large runs of anadromous fishes have been cut off by dams. In addition, introduced species are predominant in the Colorado and San Joaquin Rivers and to a lesser extent in the Sacramento River. In these systems the best strategy is to manage flows and other conditions to enhance native fish populations. For example, in the Sacramento River, native fishes are still present but they are declining largely because of the combined effects of regulated flows in the river and diversions in the estuary. Winter-run chinook salmon, wild spring-run chinook salmon, delta smelt, longfin smelt, and Sacramento splittail are all in danger of extinction in the system. These species are only likely to be saved if flows are regulated to favour them, especially during spawning and larval rearing periods. Currently, a major re-evaluation of the flow regime in the Sacramento River and its estuary is underway, largely because the biota of the river and estuary are in a severe state of decline (Herbold *et al.*, 1992).

CONCLUSIONS

California has an extraordinarily interesting and diverse aquatic biota, with a high degree of endemicism. The habitats upon which this biota depends are being degraded so rapidly that natural environmental events, such as long-term drought, can push species to extinction or near-extinction. Although there are legal mechanisms available to protect endangered species and habitats they are inadequate to meet the present crisis. Therefore, a more systematic approach to protecting habitats (and the species they contain) is needed, such as the ADMA scheme presented here. While elements of the ADMA scheme have been adopted or are being considered by a number of state and federal agencies in California, this approach will work only if there is also a high degree of involvement in conservation efforts by people at the local level. If government agencies provide the framework for conservation and expert guidance, the ADMA approach can work. Whether or not the political system can overcome the special interests that oppose such conservation efforts, however, is questionable (Reisner, 1986).

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