Protection of Aquatic Biodiversity in California:

A Five-tiered Approach

By Peter B. Moyle and Ronald M. Yoshiyama

ABSTRACT

Aquatic biodiversity is being lost at an even more rapid rate than terrestrial biodiversity, especially in arid regions such as California. In the United States, it is increasingly obvious that the Endangered Species Act of 1973 (ESA) cannot adequately deal with this loss. To help solve this problem, we have developed a five-tiered approach for aquatic conservation in California that should be applicable to other regions as well: (1) immediate ESA listing of species likely to be extirpated in the next 20 years; (2) implementation of restoration-oriented management strategies for clusters of declining species that inhabit the same habitats or drainages; (3) creation of a system of drainages and habitats called Aquatic Diversity Management Areas that provides systematic, statewide protection of aquatic biodiversity; (4) designation of a system of key watersheds, starting with seven pilot watershed projects that represent a diversity of challenges; and (5) development of schemes for bioregional landscape management. If this approach, or one like it, is not adopted soon, extinction rates of aquatic organisms in California most likely will accelerate. The hierarchical approach to conservation proposed here, with its focus on watersheds as the most practical unit of aquatic conservation, should have widespread applicability.

The accelerating rate of extinction of plants and animals and the consequent loss or severe alteration of ecosystems is a worldwide crisis. The problem is particularly severe in aquatic environments (Tudge 1990; Allan and Flecker 1992; Cairns and Lackey 1992), especially in arid regions (Minckley and Deacon 1991; Moyle and Leidy 1992). In North America, a high proportion of the species that are either extinct or in danger of extinction are aquatic organisms (Master 1990; Allan and Flecker 1992). For fishes alone, Williams and Miller (1990) calculated that 28% of the known freshwater fish species in North America are extinct or in serious trouble. Moyle and Leidy (1992) estimated that the figure was approximately 20% for all freshwater fishes worldwide. In regions with Mediterranean climates, where large human populations compete with aquatic organisms for limited supplies of fresh water, 60% to 80% of the native fish species are either extinct or in danger of extinction within the next 50 years (Moyle and Leidy 1992). The situation with aquatic invertebrates and plants is presumably just as bad, or worse, but their biology and status are poorly known, leaving fishes to stand as surrogates for aquatic biodiversity in general (Moyle and Yoshiyama 1992). Unfortunately, given the dramatic decline in amphibian populations worldwide (including California), even fishes may not reflect the true extent of aquatic biodiversity loss (Wake 1991).

In California, the loss of aquatic biodiversity is occurring at an accelerated rate because of the state's burgeoning human population and the extreme extent to which water development has already taken place (Moyle and Williams 1990; Moyle 1993). Among its 115 native fish taxa, nine are extinct, 16 are formally listed as threatened or endangered, 26 qualify for such listing, and 26 have the potential to qualify for listing soon (Moyle et al., in press). The taxa in decline are not just obscure, highly localized endemics but include widespread species that once supported substantial commercial and sport fisheries, such as spring-run chinook salmon (*Oncorhynchus tshawytscha*) (Campbell and Moyle 1991) and coho salmon (*O. kisutch*) (Brown et al., in press). This pattern is found throughout the western United States (Nehlson et al. 1991; Minckley and Deacon 1991).

When populations of a species reach the point where the species is in danger of extinction, or where fisheries for it are being closed, the restoration process becomes controversial and expensive.

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Controversy can become particularly acute when a species is formally listed as threatened or endangered under the federal Endangered Species Act of 1973 (ESA), because the ESA is one of the strongest environmental laws ever written (Orians 1993). For example, the March 1993 listing of the delta smelt (*Hypomesus transpacificus*) as a threatened species has generated major controversies about both the ESA and water policy in California; the smelt is endemic to the Sacramento-San Joaquin Delta, from which a high percentage of the water is diverted south for agricultural and urban users (Moyle et al. 1992). While the ESA is a powerful tool for the conservation of aquatic species, relying on it has several disadvantages: (1) the act comes into play only when a species is on the verge of extinction and recovery is likely to be extremely difficult; (2) the necessarily uncompromising nature of many of the act's provisions automatically generates confrontation about implementation; (3) measures to protect listed species have precedence over measures to protect unlisted species, even though the unlisted species also may be in severe decline; (4) measures to save listed species are likely to focus on "quick fixes" and technological solutions, such as transplants and captive rearing, rather than on ecosystem protection measures; and (5) the number of species qualifying for listing in places such as California exceeds the ability of state and federal agencies to handle the complex listing process for all species, at least under current staffing and funding levels (N. Kanim, U.S. Fish and Wildlife Service, personal communication).

To reduce these problems with the ESA, as well as to provide a framework for the protection of aquatic biodiversity in California, we propose a five-tiered system of conservation:

(1) Immediate listing under ESA, and/or under the equivalent state act, of species likely to be extirpated from California within the next 20 to 30 years (Moyle and Yoshiyama 1992).

(2) Development and implementation of management strategies for clusters of declining species that inhabit the same habitats or drainages. The strategy could include formal, simultaneous listing of all species in the cluster.

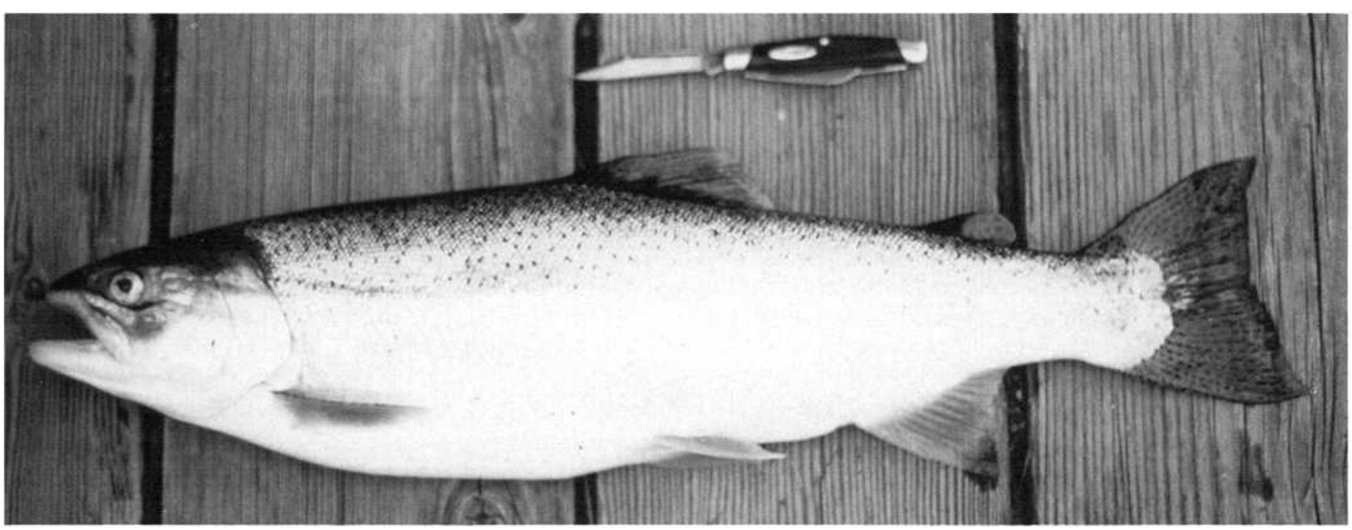
(3) Development and implementation of a system of protected drainages and habitats called Aquatic Diversity Management Areas (ADMAs) to provide systematic, statewide protection of aquatic biodiversity.

(4) Designation of key watersheds throughout the state for special management and restoration activities to protect and enhance biodiversity.

(5) Development of bioregional schemes for landscape (ecosystem) management. While we have developed this strategy specifically for California, we believe it is applicable to other regions as well, especially in the western United States.

Tier 1: Endangered Species Listing

The advantages of listing a species under the ESA, or under the equivalent (if weaker) state act, are that the species then has strong formal protection and a recovery plan. Of the 26 fish species that qualify for listing in California (Moyle and Yoshiyama 1992), however, we would recommend only nine for *individual* listing: longfin smelt (*Spirinchus thaleichthys*), Sacramento splittail (*Pogonichthys microlepidotus*), tidewater goby (*Eucyclogobius newberryi*), Eagle Lake rainbow trout (*Oncorhynchus mykiss aquilarum*), coho salmon (*O. kisutch*), Red Hills roach (*Lavinia symmetricus* subsp.), McCloud redband trout (*O. mykiss* subsp.), Owens speckled dace (*Rhinichthys osculus* subsp.), and Shay Creek stickleback (*Gasterosteus aculeatus* subsp.). The latter four taxa are recommended because they occur in relatively small



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Eagle Lake rainbow trout is one of many rare fish species that would benefit under a proposed Aquatic Diversity Management Area system, which offers more ecosystem-based protection.

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Upper Pine Creek, a potential Aquatic Diversity Management Area in Lassen County, used to be the principal spawning grounds of Eagle Lake rainbow trout but is now inaccessible to the fish. Watershed restoration is beginning and should benefit other aquatic species in the drainage.

isolated habitats, usually by themselves. Petitions for endangered listing of Sacramento splittail and longfin smelt have already been filed by the Natural Heritage Institute (on behalf of the American Fisheries Society and various environmental and fishing groups) because these species will join the already-listed delta smelt and winter-run chinook salmon to make a species cluster whose listing would help to protect the entire San Francisco estuary (NHI 1992). The tidewater goby was proposed for endangered species status by the U.S. Fish and Wildlife Service (USFWS) in December 1992, because it is rapidly disappearing from the many coastal lagoons it once inhabited (C. Swift, personal communication). The Eagle Lake rainbow trout is recommended for listing because its existence has depended on rearing in fish hatcheries for 40 years while restoration of its major spawning stream has been neglected until recently (Moyle and Yoshiyama 1992).

Coho salmon represent a special problem. Ideally, they should be managed together with other declining anadromous species, but their decline is so severe and widespread (including Washington and Oregon) that individual listing is justified to prevent, or at least slow, the continuing extirpation of local populations. In California, coho salmon have evidently disappeared from nearly half of the streams in which they once occurred (Brown et al., in press). Various efforts to develop coastwide management strategies for coho have so far not been productive. The Pacific Rivers Council plans to submit a petition for listing coho salmon soon (D. Bayles, personal communication).

We do not yet recommend for individual listing the remaining 17 species, either because they should be treated as part of species clusters or because of special management considerations in the cases of spring-run chinook salmon and Cowhead lake tui chub (*Gila bicolor vaccaceps*). For spring-run chinook salmon (both Sacramento and Klamath populations), a petition for listing has not been filed in order to allow a proactive, cooperative process to work. A Spring-run Chinook Workgroup has been formed, headed by representatives of commercial fishers, to develop a recovery plan for the salmon. If state and federal agencies do not agree to implement this plan, then a formal petition for listing will be filed (J. Rosenfield, Sierra Club Legal Defense Fund, personal communication). Likewise, a petition has not been filed for Cowhead Lake tui chub because the single population of this species occurs primarily on a private ranch; listing of the subspecies might disrupt ongoing efforts to work with the landowner to save it (G. Sato, Bureau of Land Management, personal communication).

Tier 2. Management Clusters

One of the major criticisms of the ESA is that the act protects only species rather than ecosystems, although its preamble refers to species protection as a tool to protect ecosystems. While protecting ecosystems (all organisms and their interactions in a defined area or set of conditions) is obviously desirable, defining the ecosystem to be protected or determining its boundaries are very difficult (LaRoe 1993; Orians 1993). One solution is to select special management groups of species that seem to have broadly similar ecological requirements and that coexist in limited geographic areas. The assumption behind this solution is that if a number of species are protected simultaneously, the ecosystem of which they are part will also be protected, including threatened organisms of which our knowledge is limited.

For California fishes, Moyle and Yoshiyama (1992) developed five regional clusters from among the 26 species recommended for potential listing as threatened or endangered. Moyle et al. (in press) recognized that some of the regional clusters were too broad to develop effective ecosystem recovery plans, and they instead recommended use of 15 more localized clusters (Table 1). Each cluster contains only species that coexist on a regular basis; they include not only species recommended for listing but species already listed as threatened or endangered, declining species recommended for "special concern" status, and species not yet in serious trouble but indicative of special habitat conditions. While Moyle et al. (in press) dealt only with fishes, they recommended the clusters be expanded to include other aquatic vertebrates (especially amphibians) and invertebrates (Erman and Nagano 1992).

Two strategies use the cluster approach to protect threatened ecosystems. One is to formally list some or all of the species in the cluster; the other is to develop a management or recovery plan without formal listing. In the latter case, the threat of listing may be the club that creates cooperation among affected agencies, landowners, and organizations to implement the plan.

Formal listing is needed in cases where extinction is imminent for some species in the cluster, and emergency measures are needed to prevent further loss of ecosystem components. One reason for listing an entire cluster, although some members of the cluster may be in more serious trouble than others, is that protection of one species under the ESA can mandate measures that will harm unlisted species in the cluster. For example, managing the flows of the Sacramento River for the endangered winter-run chinook salmon may reduce the amount of water needed to support the other three runs of chinook salmon in the river, all of which are declining (Moyle et al., in press). In addition, reserving water in upstream reservoirs to provide river flows for winter-run chinook salmon may reduce options available to provide the fresh water needed for fishes of the Sacramento-San Joaquin estuary. The USFWS recognized this dilemma and, following the 1993 listing of delta smelt as a threatened species, has appointed a Delta Native Fishes Recovery Team, with this paper's senior author as its leader. The team will develop a recovery plan that includes the smelt plus seven other declining fishes in the estuary (Table 1). The charge of the team is to "address the Delta ecosystem as a whole, considering the declines of other native fishes in addition to delta smelt, that may require active management to restore sustainable populations" (M. L. Plenert, USFWS, personal communication). A major problem with this approach is that actions to protect delta smelt legally will have precedence over actions to protect nonlisted species. Thus, one justification for petitioning USFWS to list longfin smelt and Sacramento splittail as additional endangered species in the estuary is that such listings provide a stronger legal foundation to a multispecies or ecosystem approach to management of the estuary (NHI 1992; Fiedler et al. 1993).

Occasionally, listing clusters of species may be necessary when the fishes in the cluster are all threatened by one major factor, even if the species are not all parts of the same ecosystem. For example, the formal listing of all species of fish (and endemic invertebrates) in the springs and streams of the Death Valley region is recommended by Moyle and Yoshiyama (1992) because most depend on the outflows of springs fed by deep, ancient aquifers. The water in these aquifers is being mined for local farmers and is proposed to be mined on a massive scale by the city of Las Vegas (McPhee 1993). Such mining may dry up many, or all, of the spring sources (Moyle et al., in press).

Ideally, the listing of species clusters should be avoided if possible to reduce the confrontational situations that often result, where more money may be spent on legal fees than on recovery efforts. However, the threat of listing clusters of species under the ESA may be needed to provide the motivation to undertake ecosystem recovery efforts. An example of cooperative arrangements to protect a species cluster is the ongoing attempt to restore the

Table 1. Examples of California native freshwater fishes arranged in clusters requiring coordinated management for ecosystem-level management strategies. The status after each name is coded as follows: 1, formally listed as threatened or endangered under ESA; 2, qualifies for threatened or endangered under ESA, according to Moyle and Yoshiyama (1992); 3, species of special concern, according to Moyle et al. (1993); 4, Watch list species according to Moyle et al. (1993); 5, abundant but may be declining (5*).

Sacramento-San Joaquin estuary

1. Delta smelt (*Hypomesus transpacificus*) (1)
2. Longfin smelt (*Spirinchus thaleichthys*) (2)
3. Sacramento splittail (*Pogonichthys macrolepidotus*) (2)
4. Chinook salmon (*Oncorhynchus tshawytscha*)
   Winter run (1)
   Fall run (5*)
   Late-fall run (3)
   Spring run (2)
5. Green sturgeon (*Acipenser medirostris* (2)
6. River lamprey (*Lampetra ayersi*) (3)

Goose Lake

1. Goose Lake lamprey (*Lampetra tridentata* sp.) (2)
2. Goose Lake tui chub (*Gila bicolor thalassina*) (2)
3. Goose Lake sucker (*Catostomus occidentalis lacusanserinus*) (2)
4. Goose Lake redband trout (*Oncorhynchus mykiss* sp.) (2)
5. Pit sculpin (*Cottus pitensis*) (5)

Eagle Lake

1. Eagle Lake rainbow trout (*Oncorhynchus mykiss aquilarum*) (2)
2. Eagle Lake tui chub (*Gila bicolor* sp.) (4)
3. Tahoe sucker (*Catostomus tahoensis*) (5)
4. Lahontan redside (*Richardsonius egregius*) (5)

Death Valley

1. Amargosa Canyon speckled dace (*Rhinichthys osculus* sp.) (2)
2. Amargosa pupfish (*Cyprinodon nevadensis amargosae*) (2)
3. Saratoga springs pupfish (*Cyprinodon nevadensis nevadensis*) (2)
4. Salt Creek pupfish (*Cyprinodon salinus salinus*) (2)
5. Cottonball Marsh pupfish (*Cyprinodon salinus milleri*) (1)
6. Shoshone pupfish (*Cyprinodon nevadensis shoshone*) (2)

Southern Coastal

1. Threespine stickleback (*Gasterosteus aculeatus*)
   Shay Creek (*G. a.* subsp.) (2)
   Unarmored (*G. a. williamsoni*) (1)
   Partially plated (*G. a. microcephalus*) (5*)
   Fully plated (*G. a. aculeatus*) (5)
2. Santa Ana sucker (*Catostomus santaanae*) (2)
3. Santa Ana speckled dace (*Rhinichthys osculus* sp.) (2)
4. Arroyo chub (*Gila orcutti*) (3)
5. Southern steelhead (*Oncorhynchus mykiss gairdneri*) (2)
6. Tidewater goby (*Eucyclogobius newberryi*) (2)
7. Pacific lamprey (*Lampetra tridentata*) (5*)

fishes of Goose Lake, a large alkaline lake that straddles the California-Oregon border. The lake and its tributaries contain four endemic fishes (Moyle 1976, Table 1). In 1992, after a prolonged drought, Goose Lake dried up. As the lake desiccated, USFWS staff began a status review of the four species, preparatory to recommending emergency listing as endangered, based on species accounts in Moyle and Yoshiyama (1992) and observations of local biologists (N. Kanim, USFWS, personal communication). However, the listing was held in abeyance while the Goose Lake Fishes Working Group (an informal association of regional biologists) worked with local landowners, interest groups, university biologists, and representatives of land management agencies to see if alternatives to listing could be found (G. Sato, Bureau of Land Management, personal communication). Cooperation of the landowners has been essential for protection of the fishes because most of the possible refuges for the fishes are on private land or on public land leased for grazing. The efforts of the working group proved to be very successful in demonstrating that (1) there was a general willingness to cooperate with recovery efforts, (2) more refuges exist for the fishes than previously supposed, and (3) funding was available for stream restoration and other recovery programs (G. Sato, BLM, personal communication). If these positive trends continue, formal listing of the four Goose Lake fishes may not be necessary because the Goose Lake ecosystem will be on the road to recovery (N. Kanim, USFWS, personal communication).

Tier 3: Aquatic Diversity Management Areas

While protecting species clusters is a means to protect ecosystems, for the most part this protection is likely to come only after most members of a cluster qualify for threatened or endangered status, as has happened with the Goose Lake ecosystem. Thus, protection of ecosystems using species clusters will be done on a crisis-by-crisis basis, much as the protection of species is currently accomplished under ESA. To reduce this problem and to truly protect biodiversity, ecosystems and habitats must be protected on a systematic basis, before they are so degraded that their constituent species become endangered.

Traditionally, protection of local biodiversity has centered around setting up preserves and refuges. Preserves are areas set aside to protect naturally functioning communities of native organisms to ensure the survival of species in their proper evolutionary context by minimizing human effects. Unfortunately, preserves tend to be thought of as museums that freeze current conditions and exclude all human use. Conceptually, they are based on equilibrium models of ecology that are increasingly being replaced by more dynamic (stochastic) models (Fiedler et al. 1993). Refuges, in contrast, are areas intensively managed for a select group of species, such as waterfowl, or areas set aside to protect economically important or endangered species without much concern for maintaining native biotic communities (Williams 1991). In practice, areas labeled "preserves" and "refuges" run the gamut from highly artificial environments to highly protected natural areas. The two terms are used rather loosely, often meaning different things to different agencies and people. Therefore, we use in their place the term *Aquatic Diversity Management Area (ADMA)* (Moyle and Yoshiyama 1992; Moyle 1993).

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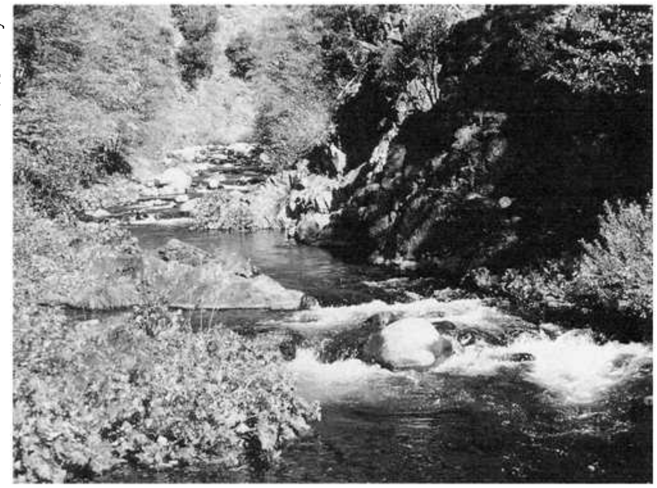

Deer Creek in Tehama County, a stream containing intact native fish fauna, is one of the last refuges for spring-run chinook salmon in central California. Efforts are underway to protect the stream as a key watershed and the salmon as a potentially endangered species.

An ADMA is a water body that has as its top management priority the maintenance of local biodiversity. Other uses are permitted, but they are secondary to the primary goal. The key to an ADMA's maintenance is flexibility, recognizing that active management is often needed to maintain or enhance biodiversity and that an ADMA is likely to change through time (Fiedler et al. 1993). ADMAs are not necessarily pristine environments, but they are usually reasonable approximations of them. Although ADMAs could encompass large watersheds, in practice most will be relatively small (< 50 km^2) and located on lands managed by one governmental agency or landowner (e.g., The Nature Conservancy). They are roughly equivalent to the Significant Natural Areas used by the California Department of Fish and Game (CDFG) (K. Barteloni, CDFG, personal communication). We recognize that the small size of most ADMAs will, in the long term, violate many of the rules of ADMA design discussed below. We therefore regard an ADMA system as providing medium-term (<100 yr) protection for aquatic biodiversity until a functional system of watershed and landscape management is in place.

Characteristics of ADMAs

The characteristics of ADMAs given below are derived from the debate of how nature preserves should be designed (Moyle and Sato 1991). Unfortunately, most of the debate about preserve design has centered on terrestrial systems and has paid little attention to the special problems of protecting aquatic environments. Therefore, the six criteria listed here are those used for the design of preserves in general, although they are discussed in the context of aquatic systems (Moyle and Sato 1991).

(1) An ADMA must contain the resources and habitats necessary for the persistence of the species and communities it is designed to protect. This criterion assumes all life history stages of all organisms (not just fish) are known, a degree of knowledge that is simply not available. Therefore, design of an ADMA should be based on the largest and most mobile species on the assumption that their habitat needs will also encompass those of lesser known species. This means ADMAs will largely be based on the needs of fish, amphibians, and macroinvertebrates, including migratory species present for only part of their life cycles, and on the needs of conspicuous riparian organisms (trees, birds, mammals).

(2) An ADMA must be large enough to contain the range and variability of environmental conditions necessary to maintain natural species diversity. An ADMA that is too small will ultimately fail in its purpose even if all the correct environmental conditions are present. Small ADMAs are extremely vulnerable to natural and human-created disasters, but the actual size of an ADMA will depend on the biota being protected. A spring biota may require only a few hundred square meters, whereas a riverine biota may require several thousand square kilometers, encompassing much of a drainage. ADMAs should also have their water sources protected, including aquifers, stream headwaters, or lake tributaries. Streams and their associated riparian corridors are particularly difficult to include in ADMAs because of their unidirectional flows, dendritic drainages, and variable nature (Naiman et al. 1993). Stream ADMAs thus need to include tiny, intermittent headwaters as well as changing conditions downstream that permit the existence of longitudinal faunal zones (which often shift in location from year to year).

(3) ADMA integrity must be protected from edge and external threats. Reducing edge and external threats are continual challenges to designers of natural areas. Edge threats result from the gradient of habitat quality between the ADMA interior and the unprotected regions outside. The sharper the gradient, the more likely the ADMA will suffer from habitat degradation and invasions of unwanted species. Species characteristic of edge habitats are typically good invaders that thrive in altered habitats, such as green sunfish (*Lepomis cyanellus*), common carp (*Cyprinus carpio*), and bullfrogs (*Rana catesbeiana*). External threats do not recognize boundary lines, and they include such factors as pollutants, diseases, and introduced species. External threats pose a particularly severe problem for ADMAs

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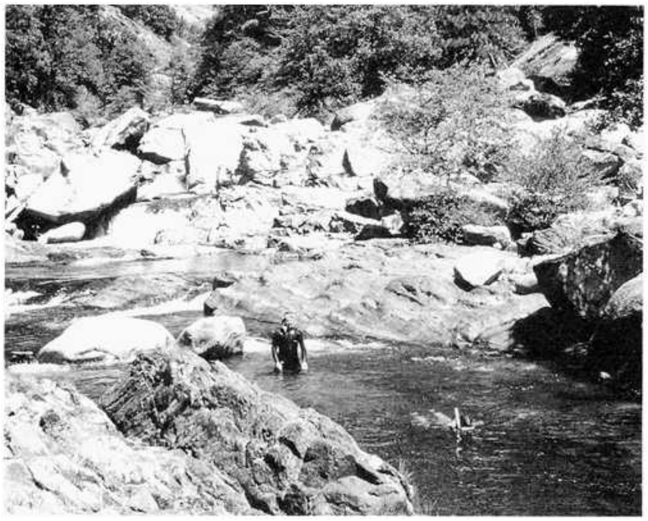


University of California-Davis graduate students snorkel survey the Clavey River, Tuolumne County, an example of a key watershed. The river is the most pristine large tributary stream in the San Joaquin river drainage and contains only native fishes.

because agents that affect the biota in any part of a drainage may eventually be carried by the water throughout its entirety (Moyle and Sato 1991). A particularly insidious external threat to aquatic systems is the pumping of groundwater from aquifers distant from the springs and streams that the aquifers feed. Thus, pumping of groundwater in Nevada may eventually dry up springs essential for the survival of pupfish (Table 1) and spring snails (*Hydrobiidae*) in California.

Edge and external threats will always be problems for ADMA management and can be reduced by creating wide terrestrial buffer zones around each ADMA, protecting water sources and upstream portions of the watershed containing an ADMA, and constructing barriers to prevent invasions of unwanted species. Ideally, barriers should block entry of non-native species but not of native migrants. For California streams, often the best barrier to invasion is a natural flow regime, because native species are generally well adapted to living under the fluctuating conditions (Baltz and Moyle 1993).

(4) *An ADMA should have interior redundancy of habitats to reduce the effects of localized species extinctions due to natural processes.* This somewhat reiterates criterion 2, but the need for local redundancy cannot be overemphasized. Aquatic species frequently occur as small populations in narrow habitat types where populations come and go in relation to natural events and demographic processes. Adequate local redundancy therefore will allow recolonization to occur quickly and naturally. For lakes and springs, this means the entire body of water will need protection. For streams, a network of two or more tributaries of each order should be included in the ADMA.

(5) *Each ADMA should be paired with at least one other ADMA that contains most of the same species but is far enough distant that both are unlikely to be affected by a regional disaster.* Large disasters—volcanic eruptions, earthquakes, pesticide spills, forest fires—can fundamentally alter much of the integrity of an ADMA. Therefore, sources of species must exist for the biotic reconstruction of affected ADMAs, if necessary. For streams, this means creating ADMAs in separate drainages with similar characteristics and biotas. For species inhabiting temporary ponds, this may mean protecting ponds at widely separated localities. Thus, the Conservancy fairy shrimp (*Branchinecta conservatio*), endemic to central California, is well protected because The Nature Conservancy has several widely separated vernal pool preserves in Tehama, Merced, and Solano counties (Eng et al. 1990). Greater replication of ADMA types increases the chances for long-term survival of the native organisms. However, some ADMAs will not be replicable if they contain highly localized endemics (e.g., desert springs with pupfish subspecies, Goose Lake).

(6) *An ADMA should support populations of organisms large enough to have a low probability of extinction due to random demographic and genetic events.* Small populations of organisms can become extinct as the result of natural fluctuations. Small populations also can experience "genetic bottlenecks" that greatly reduce genetic variability and, consequently, their ability to adapt to local environmental changes. This is particularly a problem in setting up stream ADMAs, where fish and invertebrate populations may frequently be driven to low levels by extreme floods or droughts. Under natural conditions, populations from different streams eventually mix again—something that is not possible in an isolated ADMA unless enough of a drainage is included to permit natural recolonization events (Zwick 1992). For some California fishes, localized extinctions caused by artificial isolation are already occurring (Brown et al. 1992).

A Rating System for Potential ADMAs

The fresh waters of California vary widely in their suitability as ADMAs, and very few contain all their native organisms in a protected, natural environment. Many are highly degraded and contain only fragments of their native biota. The ideal ADMA is a pristine environment, but realistically most will have been altered by humans in some manner, some severely so. If highly altered habitats are all that are available to protect certain species, they should be included in a system of ADMAs and efforts made to restore them to more natural conditions. Such ADMAs, however, will probably always contain an incomplete native biota along with introduced species. A rating system developed by Moyle and Sato (1991) recognizes the need for managing habitats that range from pristine to degraded, with highest priority given to designating the most pristine systems as ADMAs to prevent their degradation. This system is essentially a triage system because it scores habitats and ecosystems according to their importance in protecting biodiversity. It consists of a continuum five classes of waters (Table 2).

Creating an ADMA System

The purpose of ADMAs is to protect aquatic biodiversity for 50 to 100 years. ADMAs are needed to ensure we have the Leopoldian pieces available for ecosystem restoration, when and if our society changes its dominant value system and decides to live with nature rather than constantly contending with it (Snyder 1990). ADMAs should also serve as standards against which degradation of other areas can be measured. For these functions to be realized on a statewide basis, a system of ADMAs must be established that includes representatives of as many habitat types as possible, such as the 160 types described in Moyle and Ellison (1991).

The first step in the process of systematically creating an ADMA system is to identify, if possible, at least two potential ADMAs in each category of the classification system and to create a catalog that describes these ADMAs. A single ADMA could, and probably should, include multiple habitats within the classification system. The catalog of potential ADMAs would be a source of information for management agencies and for concerned citizens. Waters initially listed as ADMAs are considered to be *the minimum* needed to protect aquatic biodiversity—not the only waters so protected. Highest priorities are 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 habitat for threatened or endangered species; (3) have Class 1 status; and (4) have the right combination of size, low degree of human disturbance, and intact fish assemblages to be one of the best representatives of a particular aquatic ecosystem, such as Indian Creek (Tehama County) with its intact community of native fishes, amphibians, and reptiles.

Table 2. Rating system for Potential Aquatic Diversity Management Areas (ADMAs). The categories form a continuum, rather than being discrete.

Category	General Characteristics and Management Purpose
Class 1 waters.	Bear the closest resemblance to waters unaltered by modern human activities, contain a complete set of native biota, and have a high degree of natural protection. Ideally, each contains 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. Rare. Examples: Elder Creek (Mendocino Co.), Salt Creek (Inyo Co.). Management goal: keep as pristine as possible, recognizing that some biotic change is inevitable or necessary.
Class 2 waters.	Modified by human activity but contain mainly native organisms and have reasonable potential to be restored to Class 1. Numerous and often occur on public land; will form the backbone of any ADMA system. Examples: Eagle Lake (Lassen Co.); Indian Creek, a tributary to Antelope Creek (Tehama Co.); and vernal pools on a TNC preserve (Solano Co.). Management goal: maintenance of natural diversity and prevention of further degradation, but allowing potentially compatible uses (low-impact recreation, selective logging, nonriparian grazing).
Class 3 waters.	Appear natural, but their biotic communities have been significantly and probably irreversibly altered; introduced species often integral components. Unlikely ever to be restored to Class 1 but can be refuges for native species or migration corridors for anadromous species. Extremely vulnerable to change and cannot be relied upon for long-term preservation of species. Examples: stream sections between dams (lower McCloud River, Shasta Co.), reservoirs that support native fishes (Britton Reservoir on the Pit River, Shasta Co.), or highly altered streams (lower Putah Creek, Yolo and Solano counties). Management goals: maintenance of supplemental populations and gene pools, sources of organisms to stock restored waters, and "wild" areas that can sustain fairly heavy public use.
Class 4 waters.	Artificial aquatic refuges created and/or managed for protecting species that otherwise would likely become extinct. Simulate original environments of the species of concern; require continuous management and monitoring; should be regarded as temporary solutions for saving species or for providing back-up populations for species with limited wild populations. Example: Soda Springs Lake (Inyo Co.), formerly an ornamental pond for a resort and now the major habitat of the Mojave tui chub, which has been extirpated from its native habitats. Management goal: short-term back-up for ADMAs. However, may inadvertently select for phenotypes or genotypes poorly adapted for reintroduction into the wild.
Class 5 waters.	Artificial refuges with no attempt to recreate natural conditions (ponds and tanks). Reproduction of the species is largely controlled by humans, and individuals are often selected (albeit not deliberately) to survive under a narrow range of conditions so may be poorly adapted for reintroduction into the wild (Echelle 1991). Example: Dexter National Fish Hatchery, New Mexico, where fishes native to the lower Colorado River (which borders California) are reared for reintroduction into the river.

The ADMA catalog should indicate the parts of the aquatic biota already protected under de facto ADMAs (e.g., waters in parks and natural areas) and the parts that have little or no protection, so that limited personnel, time, and money can be used most efficiently for aquisition and management. As many ADMAs as possible should be incorporated into established systems of protection such as the Research Natural Area system on U.S. Forest Service land.

This system is essentially a triage system because it scores habitats and ecosystems according to their importance in protecting biodiversity.

While the ADMA program is being set up, a long-term program of biological survey and research should also be established. Although our knowledge of potential ADMAs is limited, a research program should not be regarded as a substitute for taking action, as happens so often in resource conservation (Ludwig et al. 1993). The goals of this program should include

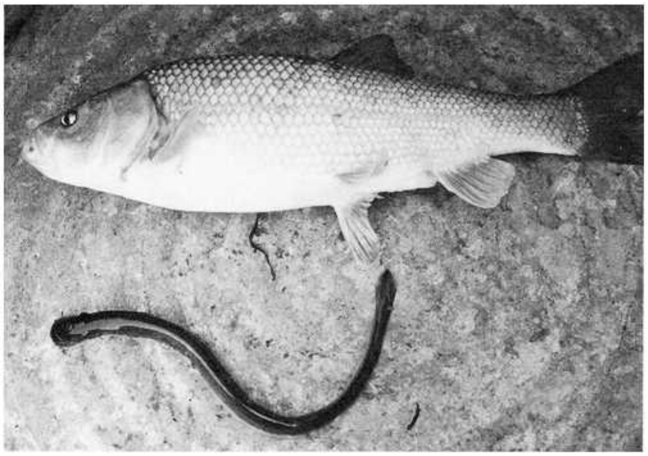
- Eventual inclusion of *all* bodies of water into an easily accessible data base that could be incorporated into Geographical Information Systems. Such a data base has been instituted at the Natural Heritage Division of the California Department of Fish and Game but is very incomplete.
- Systematic surveys of California's fresh waters to find new ADMAs to add to the system. The more duplication of each habitat type, the better for long-term biodiversity protection (Quinn and Hastings 1987; Quinn and Harrison 1988). Particularly important is the identification of aquatic habitats that are poorly represented on public lands in order to encourage acquisition of land or water rights, to develop conservation easements, or to make other arrangements with landowners that would ensure protection of crucial waters.
- Regular, repeated surveys of selected waters, preferably ADMAs, to reveal trends in overall and regional health of California's fresh waters, using community approaches as recommended by Fausch et al. (1990).
- Complete taxonomic and genetic studies 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 and ADMA aquisition, as discussed by Vane Wright et al. (1991). Given the relatively small number of native species, this goal is achievable in 10 to 15 years with sufficient funding.
- Conduct surveys of other groups of aquatic organisms, focusing especially on groups that occur in habitats without fish to locate endemic or unusual forms (e.g., the survey of Anostraca by Eng et al. 1990). This would ensure that fishless ADMAs would be adequately represented in a conservation system.

Ultimately each ADMA should become part of an official statewide ADMA system with a general management philosophy and guidelines established by an interagency committee. Presumably, having a single state agency assigned to coordinate monitoring and management of the individual ADMAs will be necessary. However, local responsibility for management of each ADMA is important because of the need for flexibility, management strategies adapted to local conditions, and local support of management activities. Many of the potential management techniques are discussed in Minckley and Deacon (1991) and Stroud (1992). Ideally, each ADMA should have a voluntary citizens' management/watchdog group associated with it, or at least an individual appointed as the local ADMA advocate. Another alternative would be to establish a core of paid, professional stream keepers whose job would be to monitor and manage waters designated as ADMAs (Cronin 1992).

Tier 4—Key Watersheds

A system of ADMAs by itself will not protect California's aquatic biodiversity in the long run because the ADMA system is a fragmented one, with pieces scattered across California and mostly unconnected. Such fragmentation of aquatic habitats ultimately leads to loss of biodiversity through local extinctions without recolonization (Zwick 1992). What an ADMA system will do, as will protecting endangered species singly or in clusters, is provide a minimum level of biodiversity insurance until we can manage biodiversity on a broader scale. As Noss (1992) states, "Biodiversity can be conceived of as a nested hierarchy of elements at several levels of biological organization. Familiar levels of organization are genetic, population-species, community-ecosystem,

It will be necessary to have a single state agency assigned to coordinate monitoring and management of the individual ADMAs.



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A Goose Lake lamprey was feeding on a Goose lake tui chub when this chub was captured. The two species are part of a group of fishes endemic to Goose Lake, Modoc County, (and Lake County, Oregon) on which conservation efforts are being focused.

and landscape. Generally, as the level of organization ascends from gene to landscape (and beyond, to biosphere), so does the spatial scale at which these elements occur." The first three tiers of biodiversity protection only provide for protection at the lowest levels of this nested hierarchy within a short time frame. Real and lasting protection, however, can occur only at higher levels of organization (Franklin 1993), represented by the fourth and fifth tiers of this system. To be truly successful, biodiversity protection must be integrated within a landscape management approach to environmental protection based on the understanding that human health and well-being are tied to environmental health (Noss 1992; Barnes 1993).

Watersheds are logical landscape units on which to focus conservation efforts (Reeves and Sedell 1992; Naiman et al. 1993). In California, the Department of Water Resources has divided the state into hydrologic basins that can be used as a basis for watershed-oriented landscape management. In each of these hydrologic basins, one or more key watersheds should be designated, if possible. *Key watersheds* are defined as representative watersheds more than 50 km^2 (20 mi^2) in area that are still dominated by native organisms and natural processes or that have high potential to be restored to such a condition. The management goal for these watersheds is to ensure natural processes are allowed to continue with minimal human interference.

Our concept of the key watershed follows the one developed for the Pacific Northwest by Johnson et al. (1991), who defined it as "a watershed containing (1) habitat for potentially threatened species or stocks of anadromous salmonids or other potentially threatened fish or (2) greater than 6 square miles with high quality water and fish habitat" (Thomas et al. 1993). G. H. Reeves and J. R. Sedell have developed a rationale for watershed management and an analytical framework for interdisciplinary watershed analysis (Thomas et al., in press). Watershed analysis is the necessary predecessor of key watershed management because "it develops and synthesizes information on physical and biological processes and conditions. It also analyzes social values, uses, and perceptions as they apply to a specific landscape" (Thomas et al., in press). Thomas et al. (in press) make specific recommendations for key watersheds on federal land in the Pacific Northwest, including a number in northwestern California that would fit well into the ADMA scheme.

In many respects, key watersheds are simply large ADMAs, but their separation from the ADMA tier is a recognition of the greatly increased difficulty of developing coherent, ecologically-based management schemes for large areas under multiple ownership. It is also a recognition that development of a system of key watersheds may hold the greatest hope for long-term maintenance of aquatic biodiversity.

To begin developing a system of key watersheds, we suggest experimental basin/watershed management programs be established in drainages where

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The McCloud River redband trout is one of a number of potentially endangered trout subspecies whose protection will help preserve unique alpine ecosystems.

significant interest in large-scale management already exists. Seven potential watersheds are

(1) Deer, Mill, and Antelope creeks, Tehama County—three adjacent drainages that contain the last spring-run chinook salmon populations in the Sacramento drainage. These streams are still dominated by native fishes and have a high proportion of the drainages in public ownership (Baltz and Moyle 1993).

(2) Eagle Lake, Lassen County—a large, alkaline lake dominated by native fishes including two endemic forms (Moyle et al. 1993). The principal tributary to the lake is Pine Creek, which has its headwaters in a wilderness area next to Lassen National Park. Most of the Eagle Lake drainage is publically owned.

(3) Goose Lake, Modoc County—an immense, shallow lake containing four endemic fishes and a largely undescribed invertebrate fauna. Most of the land around the lake is privately owned, but the headwaters of the tributaries primarily are on public land. Cooperative efforts are already underway to develop protection plans for the fishes (G. Sato, BLM, personal communication).

(4) Wooley Creek—a major tributary to the Salmon River in the Klamath River drainage (Siskiyou County) that is famous for its water clarity and runs of spring-run chinook salmon and summer steelhead. The drainage is entirely within Klamath National Forest and is recommended as a key watershed by Thomas et al. (in press).

(5) South Fork of the Eel River, Mendocino County—a north coast drainage largely devastated by poor logging practices. The river nevertheless still contains protected tracts of old growth forest in state parks and a reserve of The Nature Conservancy. It also has probably the largest remaining population of wild coho salmon in California (Brown et al., in press).

(6) The Cosumnes River, El Dorado County—a highly disturbed drainage but distinguished by being one of the few drainages flowing into California's Central Valley without a major dam. The Nature Conservancy is organizing an effort to find ways to better manage and restore the entire drainage, or parts of it, for its natural values (D. Martinez, personal communication).

(7) San Gabriel River, Los Angeles County—the principal refuge for native fishes of the Los Angeles basin (Table 1). Native fishes are concentrated in the headwaters, which largely flow through public land, but the main river flows through urban areas. Increasing interest in the fisheries and amenity values of urban streams could provide an opportunity to use this system as a prototype for the rejuvenation of other urbanized waterways in California.

These seven drainages are important for native aquatic organisms and represent the wide range of problems that need to be resolved before watershed-level management practices can be implemented. Successful resolution of these problems could provide models for other efforts to protect key watersheds throughout the state.

Tier 5—Landscape Management

Ideally, the first four tiers of biodiversity protection proposed here should be imbedded in much broader regional schemes of land management that recognize the importance of protecting biodiversity and natural processes. Such "bioregional" planning processes have begun in some areas, most dramatically in the Pacific Northwest (Thomas et al. 1993; Thomas et al., in press). Similar efforts are now beginning in California for the Klamath River basin (R. Garrett, USFWS, personal communication) and the Sierra Nevada range (P. Aune, U.S. Forest Service, personal communication). While further discussion of these efforts is beyond the scope of this paper, we emphasize that the difficulties and uncertainties of undertaking such large-scale measures should not be a deterrent for doing so, because time is short (Ludwig et al. 1993). In the words of Franklin (1993): "Biodiversity is not a 'set-aside' issue that can be physically isolated in a few, or even many, reserves. . . . We must see the larger task-stewardship of *all* the species on *all* of the landscape with every activity we undertake as human beings—a task without spatial and temporal boundaries."

Applicability to other Regions

The approach to aquatic conservation outlined in this paper was designed specifically for California with its Mediterranean climate, high degree of endemism, and extremely rapid loss of aquatic biodiversity. It is therefore most directly transferable to other parts of the western United States and to arid regions of the world that have similar problems (Moyle and Leidy 1992). However, the hierarchical approach to conservation advocated here, with its focus on watersheds as the most practical unit of aquatic conservation, has widespread application (Noss 1992; Reeves and Sedell 1992). Currently, the Tier 1 component is widely used in the United States, and application of Tiers 2, 4, and 5 is now being attempted in a few regions, including California. However, the intermediate step of an extensive ADMA system (Tier 3) is needed to link short-term (Tiers 1 and 2) and long-term actions (Tiers 4 and 5). Development of a system of ADMAs and key watersheds in regions that do not yet have large numbers of endangered aquatic species could reduce the rate of habitat degradation and biodiversity loss. Such a system could also be the foundation for regional landscape management with great benefits to human health and well-being.

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