WORKING PAPER, Center for Watershed Sciences, November 2010

Rapid decline of California's native inland fishes

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Word count: 5956

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Abstract: *Degradation of freshwater ecosystems is a global crisis best understood through intensive study of well-studied regional faunas. A quantitative protocol was used to determine conservation status of all 129 freshwater fishes native to California. Seven (5%) are extinct; 34 (26%) qualified for listing as endangered or threatened species; 32 (25%) were rated as imperiled, qualifying as California Species of Special Concern, with potential for listing; 34 (26%) rated being on a watch list and 22 (17%) were found to be relatively secure. Of 31 species officially listed under federal and state endangered species acts, 17 (55%) clearly qualified for listing under our criteria and 12 (39%) were rated as species of special concern. Conversely, of 34 extant species with the lowest ratings under our criteria, only 17 (50%) were officially listed. Climate change, area occupied and anthropogenic threats had the largest negative impact on status. Of the 15 categories of anthropogenic threats analyzed, those most likely to diminish status were alien species, agriculture and dams. Overall, 83% of California's freshwater fishes are extinct, endangered, or in decline, a 16% increase since 1995 and a 21% increase since 1989. The decline seen in California's inland fishes is probably typical of declines in areas that are less well documented, indicating a strong need for better methods of conservation of freshwater ecosystems.*
Key words: Threat assessment, conservation status, biodiversity, risk, endangered, imperiled

Introduction

Extinction in freshwater environments is a world-wide crisis (Moyle & Williams 1990, Saunders et al. 2002, Dudgeon et al. 2006) which is poorly documented (Strayer & Dudgeon 2010). Loss of biodiversity seems to be occurring more rapidly from fresh water than from any other broad habitat (Jenkins 2003, Dudgeon et al. 2006). Driven by recent global assessments of mollusks (Bogan et al. 2008), crabs (Cumberlidge et al. 2009), amphibians (Stuart et al. 2004), and dragonflies (Clausenitzer et al. 2008), the number of freshwater species on International Union for the Conservation of Nature (IUCN) Red Lists has more than tripled since 2003 (Darwall et al. 2008). Nevertheless, the best-studied indicators of the problem remain freshwater fishes (Magurran 2009) which account for about one-third of all described vertebrates, with roughly 13,000 species (Helfman 2007; Lèvêque et al. 2008). In 1992, 20% of the world's freshwater fish fauna was estimated to be extinct or in serious decline (Moyle & Leidy 1992). Less than 20 years later, 37% of the 3,481 freshwater fish species evaluated globally by IUCN were regarded as extinct or imperiled (Vié et al. 2009), although the database is likely biased towards declining species. At the continental scale, 46% of 1,187 described freshwater and diadromous fish species native to North America are extinct or imperiled or have one subspecies or distinct population that is imperiled (Jelks et al. 2008) and about 2.4 species are going extinct per decade (Ricciardi & Rasmussen 1999).

While large-scale assessments spotlight the global extent of the crisis, severity and causes are best understood with intensive studies of regional fish faunas because status can be repeatedly, systematically, and quantitatively documented over relatively short time periods. In this paper, we analyze status of California's native freshwater fishes, comprised of 129 taxa which are reasonably well documented (Moyle 2002, Moyle et al. 2008, Moyle et al. 2010a,b). Their status was previously analyzed in 1989 (Moyle & Williams 1990) and 1995 (Moyle et al. 1995). Here, we use a quantitative protocol to determine conservation status of each species, independent of official agency designations, in order to answer the following questions:

1. What is the status of California's inland fish fauna?
2. Are the fishes continuing to decline?
3. What factors are most strongly associated with conservation status?
4. Do our assessments reflect official status designations?

The inland fishes of California

California's large size (411,000 km^2), length (1400 km and 10 degrees latitude) and diverse topography result in diverse habitats, including 50 isolated watersheds in which fish have evolved independently (Moyle & Marchetti 2008). For most of the state, the climate is Mediterranean; most precipitation falls in winter and spring, followed by long dry summers. This results in rivers that have high annual and seasonal variability in flows (Mount 1995) and native fishes adapted to hydrologic extremes. Of 129 native inland fishes (defined as those breeding in fresh water) currently recognized, 63% are endemic to the state. An additional 19% are found in one adjacent state (Appendix 1, which includes scientific names of fishes mentioned). Thus California's fishes fall within political and zoogeographic boundaries that largely coincide, important for a bioregional assessment (Moyle 2002).

Conditions in California have produced an unusual number of anadromous fishes (24%) as well as fishes that thrive in isolated environments such as desert springs, intermittent streams, and alkaline lakes. Most fishes live in rivers of the Central Valley and North Coast, areas with the most water and most diverse aquatic habitats. Recent genetic and taxonomic studies have underscored the distinctiveness of California fishes and increased the number of taxa from 113 in 1989 (Moyle and Williams 1990) to 129 in the present study.

Most California rivers have been dammed and diverted to move water from places of abundance to places of scarcity, where most Californians live (Hundley 2001). Not surprisingly, native fishes have been in steady decline since the mid-19th century, although the first formal evaluation of their status was not conducted until 1989. At that time, 6 species (5%) were regarded as extinct, 15 (13%) were formally listed as threatened or endangered, and 51 (43%) were regarded as imperiled (Moyle & Williams 1990). Although only one extinction was recognized in intervening years, numbers of listed and imperiled species steadily increased so that in 1995, the numbers were 18 (16%) listed and 51 (44%) imperiled (Moyle et al. 1995). Today, the numbers are 30 (23%) listed and 70 (54%) imperiled, meaning that 83% of California's native fishes are now imperiled or extinct (Moyle et al. 2010) (Fig. 1).

Methods

The methods used in this paper are similar to those in Moyle and Williams (1990) who determined species status by quantifying expert opinion in assigning numeric scores to threat categories. The present methods are both more comprehensive and more transparent, making them easier to duplicate. Also, whereas Moyle and Williams (1990) accepted official agency designations for threatened and endangered species, we assigned status of each of 129 taxa based on their score from our protocol, making each species' status directly comparable to all others.

Sources of information

Taxa used were those defined as species under the federal Endangered Species Act of 1973, so includes species, subspecies, Evolutionary Significant Units, and Distinct Population Segments recognized by one or more agencies. Information on biology and status of each species was derived from detailed reviews in Moyle et al. (1995), Moyle (2002), Moyle et al. (2008) and Moyle et al. (2010 a, b), additional reports and papers from intensive literature searches, and by personal communications with biologists working with each taxon. All species accounts underwent extensive peer-review by species experts. In a few cases, information was updated by field investigations by the authors. The status of each species is as of January 1, 2010.

Quantitative evaluation of status

Species status was determined using seven metrics scored on a 1-5 scale (Table 1) where 1 was a low score indicating major negative impact on status and 5 was a high score, indicating either no or a positive impact on status. Scores were assigned according to a rubric which was standardized to each threat category (Table 2). Metrics were designed to capture risk factors faced by freshwater fishes while keeping redundancy among metrics to a minimum. Principal component analysis revealed relatively equal weighting of all seven metrics on the final status scores (eigenvectors for principal component one: area occupied, 0.322; adult population, 0.398; intervention dependence, 0.405: tolerance 0.341: genetic risk 0.406; climate change 0.381: anthropogenic threats 0.382) suggesting the metrics were relatively independent of one another. For each species, the seven criteria were averaged to produce an overall score with likelihood of near-term extinction increasing as scores decreased. Fishes with scores between 1.0 and 1.9 were regarded as being in serious danger of extinction, while those scoring 4.0 to 5.0 were regarded as reasonably secure. Species with scores between 2.0 and 3.9 were generally in decline or had naturally small isolated populations. The scores only apply to California, so species with wide distributions and high abundance outside the state (e.g., chum and pink salmon) might receive low scores within the state.

Metrics used to score taxon status

1. *Area occupied*. We assumed that extinction threat was lower for species spread over many watersheds than for those with limited distributions. Inland fishes were scored by number and interconnectedness of large watersheds

occupied. Anadromous fishes were scored on number of watersheds occupied (Functionally Independent Populations, Lindley et al. 2004, 2006).

2. *Estimated adult abundance*. In general, the more individuals in a population, the more likely it is to persist through time. However, quantitative population estimates are rare, especially for non-game fishes (Jelks et al. 2008). We therefore used order-of-magnitude estimates of mature individuals as proxy for population size (Table 1).

3. *Dependence on human intervention for persistence***.** This metric scored how dependent a species was on direct human intervention for its continued survival. Thus, Eagle Lake rainbow trout received a score of '1' because it is completely dependent on artificial propagation for its persistence, while rough sculpin scored a '4', because it needs only continued protection of its spring-fed streams (managed for trout fisheries) to maintain abundance.

4. *Environmental tolerance under natural conditions***.** This metric measures overall physiological tolerance in relation to existing conditions in a species' range. A species may have fairly broad physiological tolerances in the laboratory but if it lives in a region (e.g., southern California) where habitat conditions such as temperature naturally approach limits of that tolerance, its environmental tolerance is scored lower.

5. *Genetic risks***.** This metric incorporates two concepts, hybridization and genetic bottlenecks. Hybridization with a related species, especially an introduced species, can result in sterility, reduced fitness and swamping of native genomes (Perry et al. 2002). Similarly, interbreeding between artificially propagated (hatchery) and wild individuals can reduce fitness of offspring (Araki et al. 2009).

In order to avoid over-weighting impact of small population size on status, genetic impacts of small population size were not considered here. However, low genetic variation from hatchery management and/or other past reductions of effective population size may increase extinction threat (e.g., reduce the ability of species to adapt to environmental change) irrespective of current population size and so was considered under this metric.

6. *Vulnerability to climate change.* Climate change is already having effects as reflected in rising water temperatures and more variable stream flow; such effects are only likely to increase. Vulnerability to future climate change was determined by examining geographic range of each species, its isolation (potential for finding refuges), and types of water it inhabits. Species considered to have low vulnerability included those with broad thermal tolerances and those living in aquatic environments shielded (at least for now) from climate-driven change, such as spring-fed systems with constant sources of water (e.g., bigeye marbled sculpin and Saratoga Springs pupfish).

7. *Anthropogenic threats.* We rated fifteen major categories of anthropogenic factors likely to drive extinction risk as having no, low, medium, high or critical effect, based on available information for each species (Table 3). For some species, only a single threat was critical (e.g., hybridization for California golden trout), but for most species, number as well as severity of threats contributed to our final score (Table 2). We judged any species with even one critical rating as being in danger of extinction in the near future. The 15 threats are summarized below.

Anthropogenic threats

*Large dams***.** Dams and their reservoirs had large impacts on status if they blocked a considerable amount of range, caused major changes to physical habitat, or changed water quality and quantity. We regarded dams as having a low impact if they were present within the range of the species but their effects were beneficial, small, or poorly known.

Agriculture. Effects of agriculture are high if agricultural effluent polluted waterways of major importance to the species, if diversions severely reduce flow, if large amounts of silt flow into streams from farmland, if pesticides have significant impacts, and if other agricultural factors directly affect waters in which a species lives. We regarded agriculture as having a low impact if it was not pervasive in the species range or was not known to be causing significant changes to a species' habitats.

*Grazing***.** We separated livestock grazing from other agriculture because its effects are widespread on range and forest lands throughout California. Impacts are high where stream banks are trampled and riparian vegetation removed, resulting in incised streams, drying of adjacent wetlands, and lowering of water tables. Removal of vegetation can also result in increased siltation, higher water temperatures, and decreased summer flows. Impacts are low where grazing has minimal effects, as described above.

*Rural residential***.** As California's human population grows, people spread across the landscape, often settling in diffuse patterns along or near streams. Rural development results in water removal, streambed alteration (to protect houses, create swimming holes, construct road crossings, etc.), and pollution (especially from septic systems). We rated such housing as having high impact where it is abundant and unregulated and causes major changes to streams. Where such housing is present but scattered, the effects are usually low.

Urbanization. Humans alter streams that flow through urban areas to reduce flooding and acquire water. Pollution is pervasive, from sewage, runoff, and storm drain discharges, as is streambed alteration. Generally, the more a city encompassed the key waters of a species, the higher we rated effects of urbanization on it.

*Instream mining***.** The most severe instream mining in California took place during the 19th and early 20th centuries when miners buried (through hydraulic mining), excavated, and dredged riverbeds for gold. We often gave the legacy effects of this mining medium or high ratings. Similar scores were given to species affected by legacy effects of instream gravel mining, which creates large pits in streambeds and alters stream banks. Such mining is largely banned (in favor of mining off-channel areas) today. Impacts of contemporary recreational and professional suction dredge mining also resulted in some intermediate ratings.

*Mining***.** Tailings of hard rock mines are often present in streams and mine drainage causes pollution, mostly from abandoned mines. We also included legacy effects of mercury mining, used to process gold in placer mining, here. We scored threats as high where major mines, even if abandoned, have toxic tailings poiseld on edges of waterways (e.g., Iron Mountain Mine near Redding). Our low threat scores usually came from situations where old mines are present but effects on biota of nearby streams are not evident.

*Transportation***.** Historically, river banks were favorite places to construct roads and railroads. Many rivers and creeks have them running along one or both sides, often confining stream channels and causing pollution from vehicle emissions, waste disposal, and accidents. Also culverts and other road modifications can restrict fish movements. Dirt roads often become hydrologically connected to streams, increasing siltation, changing local flow regimes, and seriously damaging aquatic habitat. Our ratings were based on how much a species depended on streams altered by roads and how severe the alterations were.

Logging. Timber harvest is a major use of forested watersheds which support high abundances of fish, including anadromous salmonids. Logging was relatively unregulated until mid-20th century, resulting in major degradation of streams. Legacy effects include incised streams with silt-bottomed reaches and less large wood to provide structure. Although better regulated today, logging is still a pervasive activity resulting in siltation of streams, reduced complexity of habitat, and other alterations. We gave high threat ratings to species dependent on streams degraded by either legacy or contemporary effects of logging. Low threat ratings were given where such effects are of small significance.

Fire. Wildfires are part of California's natural landscape but human activities have increased their intensity and frequency. A fish species that faces high threat from fire is one whose range can be largely affected by catastrophic wildfire, through increased erosion, increased temperature, and spilled fire-fighting chemicals and other materials. We assigned low threat to fishes that live in areas where fires occur but for various reasons, such as low fuel load, have minimal impact on streams.

*Estuary alteration***.** Many California fishes depend on estuaries for at least part of their life cycle. All their estuaries are highly altered by human activity, including siltation, pollution, diking and draining, and removal of sandbars between the estuary and ocean. Thus, the more estuarine-dependent a fish species is, the more likely we were to assign it a high threat rating.

*Recreation***.** Recreational use of streams has greatly increased with the human population. We found recreational effects usually to be low, although they are often concentrated when stream flows are low. We rated recreation effects as high when a taxon depends on streams that are heavily disturbed (e.g., by off-road vehicles) or contains enough boaters and swimmers to disturb spawning or holding (e.g., salmon and steelhead).

*Harvest***.** We rated legal and illegal harvest effects as high for fishes known to be subject to overharvest, especially large species (e.g., sturgeons) or species that become isolated and therefore easy to catch (e.g., summer steelhead). For most native resident fishes, legal harvest is rarely an issue, so scores were low.

*Hatcheries***.** Most fishes are not supported by fish hatcheries but for those that are, hatchery fish often have negative effects on wild populations through competition for space and food, direct predation, and loss of genetic diversity (Moyle 2002). We rated severity of these effects based in part on hatchery dependence and/or known interbreeding between wild and hatchery populations.

We regarded conservation hatcheries that focus on rare species as having low impacts because of their efforts to reduce hatchery effects as much as possible.

*Alien species***.** Non-native species are present in every California watershed and their impacts on native species through hybridization, predation, competition, and disease are often severe (Moyle & Marchetti 2008). We rated species high in this category if there were major direct or indirect impacts of alien invaders. We rated them low if contact with aliens was infrequent or not known to be negative.

Certainty index

Because quality, amount and reliability of information varied among species, we developed a certainty index for our scores, on a 1-4 scale, where we scored status evaluations as follows:

1. Based on expert opinion (including our own) with little hard data.
2. Based on expert opinion supplemented with limited data and reports.
3. Based on extensive reports found mainly in the gray literature
4. Based on reports from multiple sources including peer-reviewed literature.

This index is mainly used to let managers know risks involved in making management decisions based on our results.

Results

Of 129 freshwater fishes native to California, seven (5%) are extinct with scores of zero; 34 (26%) qualify for immediate listing as endangered or threatened species (scores of 1.0-1.9); 32 (25%) had scores of 2.0-2.9 and could be considered for listing (California species of special concern); 34 (26%) had scores of 3.0-3.9 so rate as needing to be on a watch list; 22 (17%) are relatively secure (4.0-5.0) (Figure 1). The average status score of all extant taxa was 2.7. The certainty ratings (1-4) of our status evaluations averaged 2.7 out of 4.0 (SD 1.2), with 66% of accounts based on extensive literature (4.0) and only 5% based mainly on professional judgment (1.0).

Of 31 species currently listed as endangered or threatened under federal and/or state endangered species acts, 17 had status scores of 1.0-1.9 and 12 had scores of 2.0-2.9 (94% total). Listed species made up half the 34 species with status scores of 1.0-1.9 and 44% of extant species with scores <2.9.

The metrics most often resulting in status scores of 1 or 2 were climate change (62% of species with such scores), anthropogenic threats (56%) and area occupied (55%). In contrast, fishes with scores of 4.0 and above had large populations, wide distributions, and high tolerance of environmental change. The anthropogenic threats that had the most species with critical or high scores were alien species (34%), dams (24%) and agriculture (18%) (Appendix Table 2). Twenty-five species (19%) had at least one critical rating, indicating high likelihood of extinction in the near future, while 63 species (49%) received at least one high rating. The most high ratings awarded to a single species was six. All species had different combinations of threats by kind and severity.

Discussion

What is the status of California's freshwater fish fauna?

In 1989, only 14 species were formally listed as threatened or endangered (Moyle & Williams 1990). Today, with seven extinct species, 31 species formally listed, and about one additional species being listed every two years, the native fish fauna of California is clearly in serious decline by official standards. However, our analysis indicates that the decline is more severe than recognized, with 107 (83%) of native fishes imperiled or extinct. Assuming all species that scored 2.9 or less are on the path towards extinction, then 66 (54%) of 122 extant fishes are seriously imperiled, with another 34 (25%) in decline or otherwise without a secure future. The basic cause of decline is a growing human population that enjoys living in a mild Mediterranean climate where water is in short supply, especially in the dry summer season or during periods of drought. This shortage results in most waterways being dammed, diverted, polluted, or otherwise altered, with the additional threat of frequent invasions of alien fishes (Moyle 2002, Moyle & Marchetti 2006). The highly endemic fishes of the region are especially vulnerable to change because so many are confined to limited geographic areas or to habitats where conditions are naturally stressful. However, even many wide-ranging species (e.g., all salmon species and steelhead rainbow trout) are imperiled (Moyle 2002, Moyle et al. 2008). Native species that have managed to thrive under altered conditions are those that have naturally large ranges, broad habitat requirements, high tolerance of adverse conditions, and an ability to become part of new fish assemblages that include alien species (e.g., Tahoe sucker, Sacramento pikeminnow).

Are the fishes continuing to decline?

Today, 83% of California's freshwater fishes are imperiled or extinct, a 16% increase since the last assessment in 1995 and a 21% increase since 1989. The increase is partly the result of improved information, but declines of most species are also real, as illustrated below by coho salmon, Central Valley fall Chinook salmon, delta smelt, Clear Lake hitch, and Sacramento perch.

Coho salmon are native to hundreds of coastal streams from Monterey Bay north to the Oregon border and once supported sport and commercial fisheries (Moyle 2002). In the 1940s, estimated numbers of adults spawning in California streams were 200,000 to 400,000 (Moyle et al. 2008) (Figure 2). They were regarded by Moyle and Williams (1990) as being in sharp decline but still common. Subsequent studies documented their rapid disappearance from their native streams throughout the state and by 1996 both ESUs present in California had been listed under the ESA. Our analysis scored status of the Central Coast ESU as 1.1 and the Southern Oregon Northern California Coast ESU as 1.7. The 2010 federal ESA recovery plan (NMFS 2010) for California coho salmon is consequently more an extinction prevention plan than a real plan for recovery.

Central Valley fall Chinook salmon is an ESU that historically made up the largest run of salmon in the Sacramento and San Joaquin River basins, with runs once estimated to be around a million fish annually; recent adult populations have been 200,000 to 400,000 fish. Moyle and Williams (1990) considered it to be abundant and perhaps even increasing in abundance. However, its status score here is 2.0, because of a recent precipitous population crash (Moyle et al. 2008) which is apparently the indirect result of the ESU being almost entirely fish of hatchery origin (Barnett-Johnson et al. 2007). The ESU may be effectively extinct as a wild population.

Delta smelt are endemic to the San Francisco Estuary and require fresh water for spawning (Moyle 2002). In the 1970s, they were still one of the most abundant fish in the upper estuary but declined rapidly so that Moyle and Williams (1990) indicated they merited listing as a threatened species. They were listed as threatened by both state and federal governments in 1993. Nevertheless, their decline has continued as the result of major environmental changes to the upper estuary related to increasing water exports (Bennett 2005), despite major efforts to curtail mortalities in recent years. With a one-year life cycle, they may be on verge of extinction and accordingly were given a score of 1.4.

Clear Lake hitch are a minnow species endemic to Clear Lake, a large natural lake in the Coast Range of California (Moyle 2002). Although the lake has been highly altered for human use and has been heavily invaded by alien species, hitch are one of the few native species that persisted; Moyle and Williams (1990) found them to be abundant but possibly declining. However, dramatic reduction in numbers of individuals in spawning streams, presumably related to the expanding population of piscivorous Florida largemouth bass (*Micropterus floridae*) in the lake as well as continued environmental degradation, resulted in a status score of 1.9.

Sacramento perch were once one of the most abundant fish in the Central Valley and subject to commercial fisheries in the 19th century (Moyle 2002). Today they are extirpated from their native range largely from competition and predation by introduced centrarchids (Crain and Moyle 2010). They have persisted only because they have been introduced into scattered reservoirs and lakes in other parts of California and the western USA. However, many introduced populations are now gone and others are located in waters that are not secure (Crain & Moyle 2010). Moyle and Williams (1990) indicated concern about its decline but thought it did not merit listing as threatened. Because so many populations have disappeared or declined since then, it scored 1.6 for status.

What factors are most strongly associated with conservation status?

The fundamental causes of the declines have their roots in the 19th and early 20th centuries when unrestricted mining, logging, and wetland conversion, combined with wide-scale dam building, severely altered most rivers, lakes, and estuaries. In addition, 50 species of alien fishes were successfully introduced, many of them better suited to altered environments than native species (Moyle & Marchetti 2006). Nevertheless, each native species has its own idiosyncratic response to this changing environment, as a result of its natural characteristics interacting with changes occurring in its particular habitats. Our analyses showed that each imperiled species has its own combination of stressors but most common were factors reflecting large-scale landscape changes (dams, agriculture, logging, urbanization, Appendix Table 2). An issue common to all species is climate change, which we rated as important factor affecting our final status score for each species.

Increases in water temperatures and variability in stream flows will become an increasingly important limiting factor for most species, but especially those relying on streams with perennial flows of cool (<20-22°C) water. Thus a systematic conservation approach has to deal both with broad issues and those particular to each species.

Do our assessments reflect official status designations?

Most (94%) listed species scored in our two lowest status categories, indicating that our scoring system made reasonable determinations. However, only half of 34 species scoring below 2.0 are presently listed as are just 35% of those scoring 2.0-2.9. Two listed species scored >2.9, northern California winter steelhead ESU (3.3) and rough sculpin (3.4). The steelhead is clearly in decline but is still fairly widely distributed; it is also closely associated with coho salmon and other listed species. The rough sculpin was one of the first fishes listed under state law, when little was known about its distribution and biology. Subsequent studies have indicated it is fairly widespread in spring streams of the Pit River watershed and is even expanding its range in reservoirs (Moyle 2002). However, recent genetic studies suggest rough sculpin is actually two disjunct populations (A. Kinziger, pers. comm. 2010), perhaps species, which might qualify for listing if treated independently.

An important aspect of our evaluation system is rating of information quality (certainty) on which each determination is based, to enable managers to determine which species need more study. Most of our species status determinations were based on strong published evidence. However, species with both low status scores and low certainty scores should be re-evaluated for status frequently.

Beyond California.

Global climate change is likely to increase fish extinction rates as competition with humans for increasingly scarce water intensifies, stream flows become more variable, and water quality, especially temperature, changes. For coldwater fishes, thermal refuges may disappear from streams in many areas, leaving no place to escape unfavorable conditions. The patterns of decline we see in California have been documented in freshwater fishes in other arid climates (Moyle & Leidy 1992, Aparicio et al. 2000, Maceda-Veiga et al 2010). However, we suspect that the decline of California's inland fishes is likely characteristic of freshwater fishes and their ecosystems worldwide. As better information and similar systematic approaches are employed in other regions, we predict more imminent extinctions will be detected than are presently appreciated. Given trends of rapid decline that we have documented, however, it is likely that many species will be lost before effective conservation plans can be implemented. There is therefore no time to be lost in designing and implementing conservation plans for freshwater biota worldwide.

Acknowledgements

Funding was provided by the California Department of Fish and Game and by the David and Lucile Packard Foundation, the Stephen Bechtel Fund, and the Resources

Legacy Fund as part of the Delta Solutions program at UC-Davis. We appreciate the support and help of DFG biologists Kevin Shaffer, Russ Bellmer, Glenn Yoshiyoka, and Steve Parmenter. This analysis would not have been possible without information and review provided willingly by dozens of biologists statewide, making this a true community effort.

Supporting Information

List of all freshwater fishes native to California and their conservation status (Appendix 1) and percentage of extant fishes affected at different levels by 15 categories of anthropogenic factors that threaten fishes are available as part of the online article. The author is responsible for the content and functionality of these materials. Queeries (other than absence of the materials) should be directed to the corresponding author.

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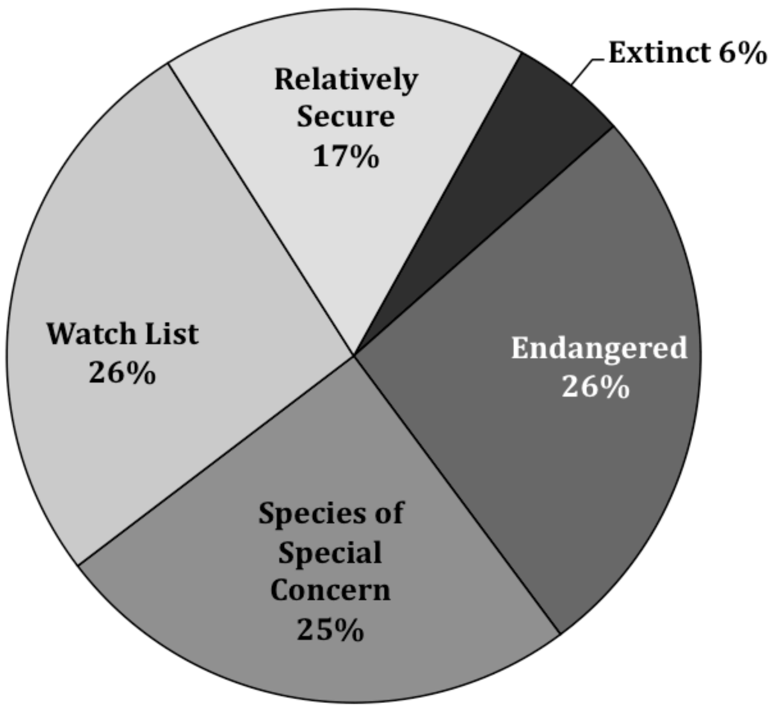
Figure 1. 2010 Conservation status of fishes (N = 129) native to inland waters of California, where extinct = globally extinct or extirpated in the inland waters of California; endangered = highly vulnerable to extinction in its native range, approximately equivalent to IUCN threat level of *endangered* or *critically endangered*; species of special concern = could easily become endangered if current trends continue, approximately equivalent to IUCN threat level of *vulnerable*; watch list = populations in decline or highly fragmented, approximately equivalent to IUCN threat level of *near threatened;* Reasonably secure = no extinction threat for California populations, approximately equivalent to IUCN threat level of *Least Concern*.



Tables

Metric	Score	Justification
Area occupied	2	Two distinct populations in different parts of San Francisco Estuary, using different rivers for spawning.
Estimated adult abundance	4	Large in Delta, likely small in San Pablo Bay
Intervention dependence	3	Floodplain areas need special management for spawning during droughts.
Tolerance	5	One of the most physiologically tolerant native fishes
Genetic risk	3	Two populations, genetically fairly diverse
Climate change	1	Extremely vulnerable to droughts and sea level rise.
Anthropogenic threats	2	Multiple threats, see threats table.
Average	2.9	20/7
Certainty (1-4)	3	Only Delta population well studied

Table 1. Metrics for determining the status of California fishes, with Sacramento splittail as example. Each metric is scored on a 1-5 scale where 1 is a major negative factor contributing to status, 5 is a factor with no or positive effects on status, and 2-4 are intermediate values. Scoring is described in Table 2. A more detailed basis of scores for splittail is found in Table 3 and Moyle et al. (2010).

1A. Area occupied: resident fish

1. One watershed/stream system in California only, based on watershed designations in Moyle and Marchetti (2006)
2. 2-3 watersheds/stream systems without fluvial connections to each other
3. 3-5 watersheds/stream systems with or without fluvial connections
4. 6-10 watersheds/stream systems
5. More than 10 watersheds/stream systems

1B. Area occupied: anadromous fish

1. 0-1 apparent self-sustaining populations today
2. 2-4 apparent self-sustaining populations today
3. 5-7 apparent self-sustaining populations today
4. 8-10 apparent self-sustaining populations today
5. More than 10 apparent self-sustaining populations today

2. Estimated adult abundance

1. ≤500
2. 501-5000
3. 5001-50,000
4. 50,001-500,000
5. 500,000 +

3. Dependence on human intervention for persistence

1. Captive broodstock program or similar extreme measures required to prevent extinction
2. Continuous active management of habitats (e.g., water addition to streams, establishment of refuge populations, or similar measures) required.
3. Frequent (usually annual) management actions needed (e.g., management of barriers, special flows, removal of alien species).
4. Long-term habitat protection or improvements (e.g., habitat restoration) needed but no immediate threats need to be dealt with.
5. Species has self-sustaining populations that require minimal intervention

4. Environmental tolerance under natural conditions

1. Extremely narrow physiological tolerance in all habitats
2. Narrow physiological tolerance to conditions in all existing habitats or broad physiological limits but species may exist at extreme edge of tolerances
3. Moderate physiological tolerance in all existing habitats
4. Broad physiological tolerance under most conditions likely to be encountered
5. Physiological tolerance rarely an issue for persistence

5. Genetic risks/problems

1. Fragmentation, genetic drift, and isolation by distance, owing to very low levels of migration, and/or frequent hybridization with related fish are the major forces reducing genetic viability.
2. As above, but limited gene flow among populations, although hybridization can be a threat.
3. Moderately diverse genetically, some gene flow among populations; hybridization risks low but present.
4. Genetically diverse but limited gene flow to other populations, often due to recent reductions in connectivity.
5. Genetically diverse with gene flow to other populations (good metapopulation structure)

6. Vulnerability to climate change

1. Vulnerable to extinction in all watersheds inhabited.
2. Vulnerable in most watersheds inhabited (possible refuges present).
3. Vulnerable in portions of watersheds inhabited (e.g., headwaters, lowermost reaches of coastal streams.)
4. Low vulnerability due to location, cold water sources and/or active management.
5. Not vulnerable, most habitats will remain within tolerance ranges.

7. Anthropogenic threats analysis

1. One or more threats rated *critical* or 3 or more threats rated *high*– indicating species could be pushed to extinction by one or more threats in the immediate future (within 10-25 years)
2. 1 or 2 threats rated *high*;, species could be pushed to extinction in the foreseeable future (within 50 years)
3. No *high* threats but 5 or more threats rated *medium*; no single threat likely to cause extinction but all threats in aggregate could push species to extinction in the next century
4. 1-4 threats rated *medium*; no immediate extinction risk but taken in aggregate threats reduce population viability
5. 1 *medium* all others *low*; known threats do not imperil the species.

Table 2. Scoring rubric for seven metrics used to evaluate status of native freshwater fishes of California. Final status score is the average score of all seven metrics.

Status metric	Rating	Explanation
Major dams	Medium	All waters have flows regulated by dams and diversions
Agriculture	Medium	Pollution, channel modification, entrainment in major diversions
Grazing	Low	Little known impact
Rural residential	Low	Residences on the edges of Petaluma, Napa, and Suisun marshes
Urbanization	Medium	Most habitat is on urban fringes; sewage; water diversion and entrainment
Instream mining	Low	Some gravel mining in floodplain areas
Mining	Low	Legacy effects of gold mining, e.g. mercury
Transportation	Medium	Migratory corridors lined with roads and railroads, which also cross Suisun Marsh
Logging	No	No known impact
Fire	Low	Little known impact
Estuarine alteration	High	San Francisco Estuary is highly modified, especially Delta (major habitat area)
Recreation	Low	Recreational boating etc. may affect habitat
Harvest	Medium	Some harvest for bait and of migrating adults for food
Hatcheries	No	No known impact
Alien species	Medium	Effects of new invaders unpredictable; predation and competition possible

Table 3. Major anthropogenic factors limiting, or potentially limiting, viability of freshwater fishes of California, using Sacramento splittail as an example. A factor rated "critical" could push the species to extinction in 3 generations or 10 years which ever is less, a factor rated "high" could push the species to extinction in 10 generations or 11-50 years which ever is less, a factor rated "medium" is unlikely to drive a species to extinction by itself but contributes to increased extinction risk over the next century, a factor rated "low" may reduce populations but extinction unlikely as a result, and a factor rated "no" has no known impact to the taxon under consideration.