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## PERSPECTIVE

# Keeping up with the status of freshwater fishes: A California (USA) perspective

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## Abstract

Freshwater biodiversity loss exceeds that in terrestrial systems; fishes are a predominant indicator of this catastrophe. Current worldwide estimates of freshwater fish species threatened with extinction are about 30%. We discuss why standard monitoring of the status of most fishes is inadequate to keep up with declines. Rapid population declines and shrinking freshwater fish distributions result in shifting baselines that make it challenging to evaluate conservation status reliably and promptly and effectively address further decreases. We present the California Method for Status Evaluation of Fishes as an alternative to existing methods for assessing the regional status of freshwater fishes. This method uses local expertise to score metrics and generates a fish status rating to inform short-term management decisions. This approach applies to Distinct Population Segments, subspecies, species, and entire regional fish faunas and is adaptable to local, changing environmental conditions. Using this method, we update the freshwater status scores for 131 native California fish species, a fauna in rapid decline.

## KEYWORDS

assessment, California, conservation, extinction, fishes, freshwater, global, IUCN, status, threatened

## 1 | INTRODUCTION

Freshwater biodiversity loss exceeds that of terrestrial systems. Freshwater fishes are a leading indicator of this calamity (Harrison et al., 2018; Reid, Carlson, Creed, Eliason, et al., 2018; World Wildlife Fund, 2021). Therefore, documenting the changing status of freshwater fishes is critical for prioritizing actions and garnering public support for aquatic conservation strategies. However, we do not have clear accounts of most freshwater fishes' conservation status or global distribution. The International Union for the Conservation of Nature's (IUCN) Red List of

Threatened Species provides the most comprehensive global threat assessment of fishes (IUCN, 2021). Still, only 56% of known fishes have been evaluated in the IUCN Red List, and even fewer have recent (<10 years) evaluations. Current global estimates of threatened freshwater fishes hover around 30% of those species for which sufficient information exists to evaluate status (Darwall & Freyhof, 2016; Tickner et al., 2020). That one-third of freshwater fishes are extinct or threatened with extinction in the near future is alarming. This fraction is likely an under-estimate and is predicted to increase considerably by 2050 (Moyle & Leidy, in press).

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All indications are that the breakneck decline of fishes will continue absent Herculean conservation efforts (Darwall et al., 2018). Thus, between 1970 and 2016, the Global Living Planet Index (GLPI) found that freshwater vertebrate populations declined by an average of 84%, or about 4% per year (World Wildlife Fund, 2020). The number of threatened freshwater fishes globally has increased by an average of 10% per year over the last 5 years (IUCN, 2021). In addition, the Intergovernmental Panel on Biodiversity and Ecosystem Services (2018) estimates that within 30 years, only 10% of the Earth's land surface will be free from human impact, mostly in mountain, desert, tundra, and polar regions where freshwater fish diversity is low.

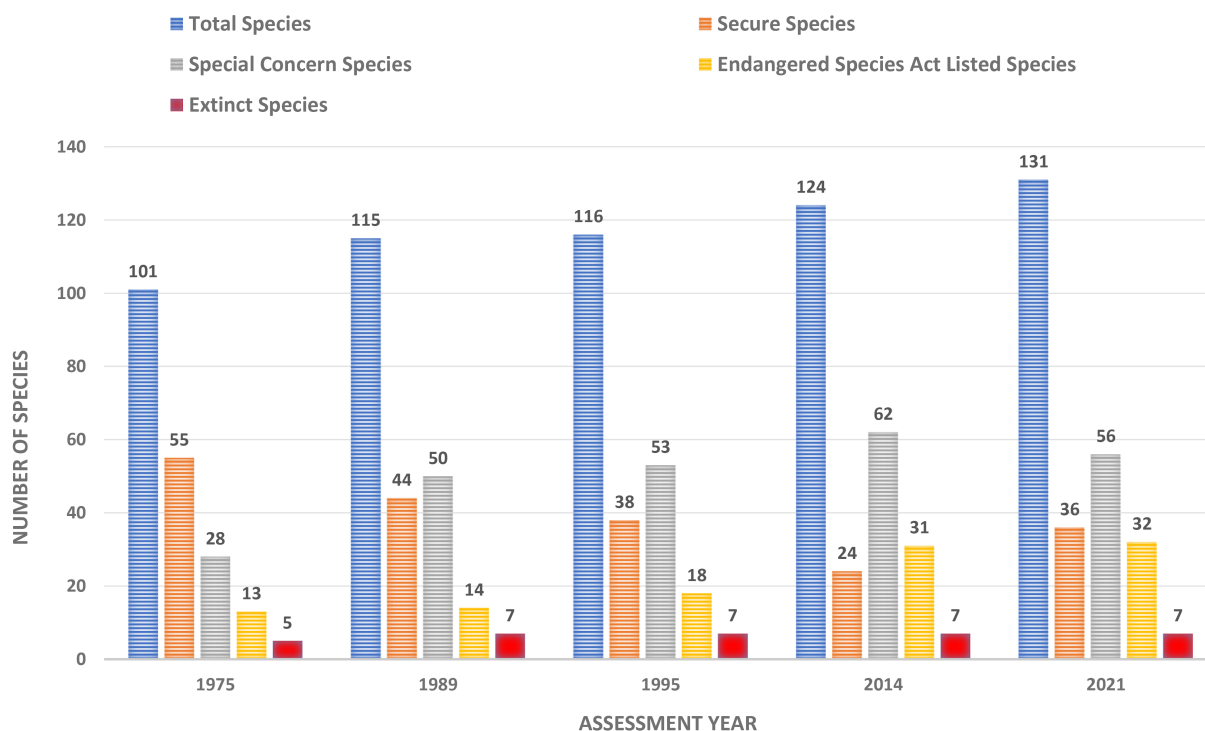
## 2 | KEEPING TRACK OF FRESHWATER FISHES

Unfortunately, even keeping track of the status of most fishes remains elusive for several reasons.

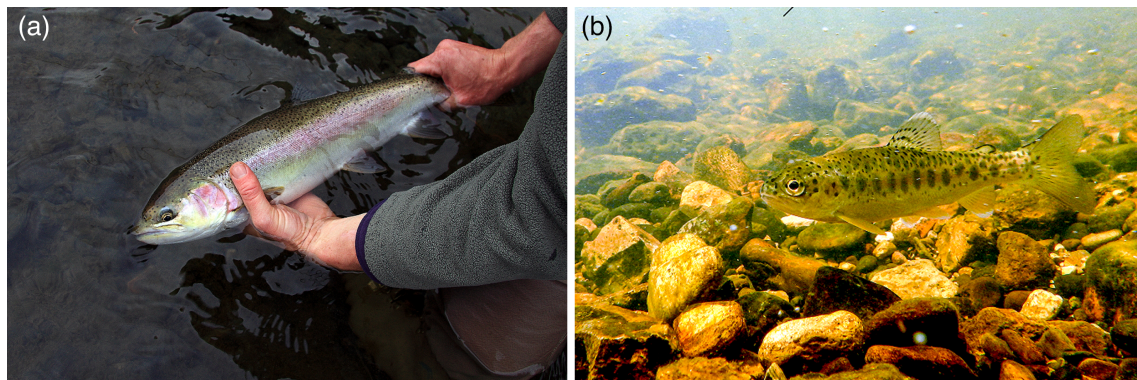
1. Human transformation of natural ecosystems is so rapid and pervasive that freshwater fishes are declining faster than scientists can document, continuously shifting the baseline of evidence on which to base

conservation actions. The rapid population declines and shrinking distributions of freshwater fishes seem to make it impractical to evaluate their conservation status reliably and to act to stem further declines promptly and effectively, using existing methods. For example, California's freshwater fish species have declined swiftly over the last 50 years to the point that by 2021, only 36% of species could be considered "secure" and not threatened with extinction (Figure 1).

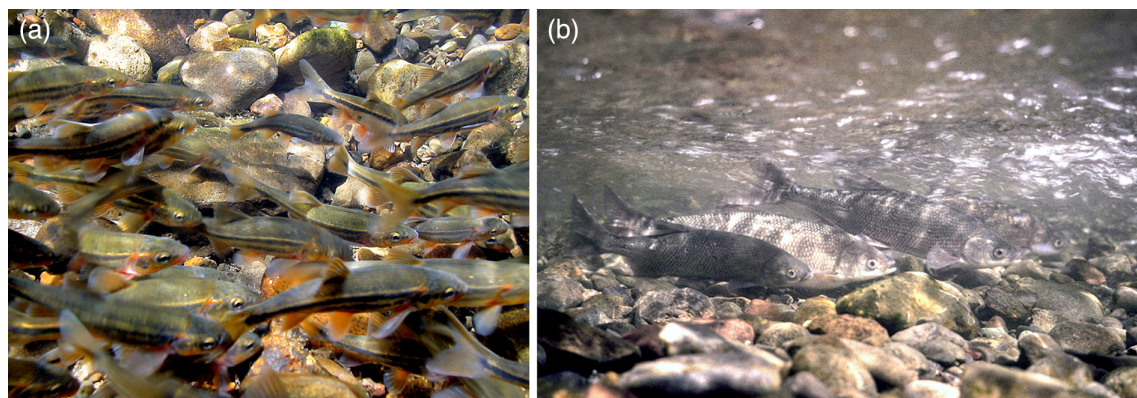
2. Taxonomic units below the species level, such as subspecies and Distinct Population Segments (DPSs), are underrepresented in status evaluations, even though they often behave as species in natural environments. For example, not included on the IUCN Red List are Chinook salmon (*Oncorhynchus kisutch*) and rainbow trout (*O. mykiss*). As species, these fish are not threatened due to their broad distributions and large populations worldwide. However, in California Chinook salmon and rainbow trout combined consist of 16 endemic DPSs, many threatened with extinction (Moyle, Lusardi, Samuel, & Katz, 2017) (Figure 2). Worldwide, the IUCN Red List contains only 55 subspecies of freshwater fish while California, alone, is known to support 50 subspecies (Moyle, Quiñones, Katz, & Weaver, 2015).



**FIGURE 1** Status of California Freshwater Fishes, 1974–2021 (based on Moyle et al., 2015 with updates from P. B. Moyle, unpublished data, November 2020). The fish status numbers for 2020 reflect updates on the 2014 numbers by Moyle (unpublished) based on new information, including genetic studies revealing cryptic species and the most recent status information



**FIGURE 2** (a) Summer steelhead (*Oncorhynchus mykiss* DPS, photo courtesy Jeff Weaver) and (b) Goose Lake redband trout (*O. mykiss stonei*, photo courtesy Thomas Taylor) are two examples of trout below the species level threatened with extinction in California



**FIGURE 3** (a) This school of southern coastal roach (*Hesperoleucis venustus subditus*, photo courtesy Jonathan Koehler) from California is part of a complex that includes six species, four subspecies, and several distinct population segments. (b) California's critically endangered Clear Lake hitch (*Lavinia exilicauda chi*, photo courtesy Thomas Taylor) has no federal recovery plan and is threatened by limited tributary spawning habitat, non-native fishes, loss of lacustrine wetlands, and poor water quality

3. Each year, about 400 new fish species are described, many from fresh waters (Fricke, Eschmeyer, & Fong, 2020; Reis et al., 2016). A growing portion of the increase in freshwater fish species is of genetically distinguishable but otherwise morphologically cryptic species within widely distributed species (Adams, Raadik, Burrige, & Georges, 2014). Thus, genomic analysis revealed that a widespread cyprinid, the California roach (*Hesperoleucis symmetricus*) is a complex that includes six species, four subspecies, and several distinct population segments (Baumsteiger & Moyle, 2019) (Figure 3a). In assessments of freshwater fish diversity, documentation of cryptic diversity is accelerating (Bartáková et al., 2019; Jirsová, Štefka, et al., 2019; Li, Jiang, et al., 2020; Ramirez, Birindelli, Carvalho, et al., 2017; Shelley et al., 2018).
4. Assessments of freshwater fishes often have no alternative but to rely on incomplete or old data,

restricting our ability to accurately assess their status. Of the 10,200 species of freshwater fishes evaluated in the IUCN Red List by 2021, 31% need updating because their status information is not current (IUCN, 2021).

5. Twenty-one percent of freshwater fishes lack adequate information (i.e., are data deficient) to determine their extinction risk. Worse, most threatened freshwater fishes have no conservation action plan (IUCN, 2021). Threatened or near-threatened species with declining populations and no recovery measures are especially likely to decline rapidly to extinction. Most threatened fishes in California lack recovery plans even though the fish fauna overall is well studied (Figure 3b).

Over the last decade, freshwater fish status assessments have documented an acceleration in number of threatened species (Moyle & Leidy, in press). The rapid pace of



global change to freshwater environments means that protecting threatened fishes within reasonable and actionable timeframes remains difficult. It is conceivable that all but the hardiest freshwater fishes, plus a few fully protected species, will become globally threatened or extinct within this century.

While the IUCN Red List and the GLPI provide the best syntheses of worldwide trends in fish populations, these efforts have limited utility for conservation actions at the local or regional scale (e.g., Faucheux, Craig, & Bonner, 2019). This problem stems from the nature of the two approaches that need constant updating with large amounts of sampling data to be reliable. The IUCN Red List (2021) relies on five, stand alone, quantitative criteria (i.e., population size reduction, geographic range/area of occupancy, small population size and decline, number of mature individuals, and the probability of extinction) to assess the threatened status of a taxon. This approach uses a standard template for all species, terrestrial and aquatic, which we (authors) have found cumbersome to apply to fishes. The IUCN Red List requires a full understanding of several voluminous guidance documents (e.g., IUCN, 2019) and quantitative data that is not available for most fishes.

Using the same standard assessment metrics for terrestrial and aquatic species is also problematic. For example, one of the five assessment criteria used by the IUCN Red List includes the geographic extent of occurrence and area of occupancy as measured in square kilometers. This metric is problematic for freshwater fishes in linear riverine environments where more useful measures might include river kilometers, the number of watersheds occupied, or the number of self-sustaining populations. The GLPI conducts trend analyses on fishes for which there is sufficient data; typically, these are species subject to managed fisheries or endangered or declining species. While many fishes in the GLPI database have data from multiple populations, others use only single sources (e.g., Delta smelt, *Hypomesus transpacificus*, and splittail, *Pogonichthys macrolepidotus*, in California).

NatureServe is another successfully tested tool with broad applications for assessing the conservation status of species and ecosystems (Master et al., 2012). It is conceptually similar to the IUCN Red List and the California Method (presented below). A critical difference from the IUCN Red List approach is in addition to its global application, NatureServe can be used at national and sub-national (e.g., regional, state) scales. NatureServe does not attempt to include all taxa such as subspecies and DPSs, although they often are included when information is available. As a result, for California freshwater fishes, we have found that about 10% of California fishes have not been evaluated by NatureServe, and many more

require status updating. Their evaluations seem to depend on older versions of information used in the California Method (e.g., Moyle, Yoshiyama, Williams, & Wikramanayake, 1995).

Other approaches include expert consensus and shared trait analysis. Expert consensus involves an agency or NGO assembling perceived experts and soliciting a consensus on how well declining species fit into loosely defined threat categories (e.g., Jelks et al., 2008). This top-down approach has problems with repeatability and the criteria for selecting the experts. Shared trait analysis assumes similar species will share similar threats (Miles, 2020; Urban et al., 2016). We have not evaluated this approach closely because we work in part with “complexes” of similar, closely related fishes that include both abundant species and rare ones (Baumsteiger & Moyle, 2019). Shared trait analysis would likely work best in regions characterized by poorly understood fish faunas with most species qualifying as “Data Deficient” by the IUCN.

### 3 | THE CALIFORNIA METHOD FOR STATUS EVALUATION OF FISHES

Here we briefly present an established method that has been used for over a decade to successfully evaluate the regional status of the highly threatened freshwater fishes of California. The California Method for Status Evaluation of Fishes (California Method) is not intended to replace other global (i.e., IUCN Red List) or regional (i.e., NatureServe) assessment approaches. The California Method uses local expertise to score metrics and to generate a fish status rating that can inform short-term management decisions until more quantitative information is available (Moyle et al., 2015, 2017). It can be applied to DPSs, subspecies, and species, and can be used to evaluate all species in regional fish faunas simultaneously. Its metrics are adaptable to local environmental conditions. Various iterations of the California Method have successfully been tested in California for over more than a decade, where the fish fauna is well known. It has also been used successfully for retrospective status determinations. An important feature of the method is that it has a metric for rating confidence in the evaluations, so managers know how much to trust the evaluation scores.

The California Method involves four steps:

**Step 1.** Convene qualified biologists who have some knowledge of the freshwater fishes, or other taxa, of interest. Ideally, the evaluation of each species would be part of a regional evaluation of the status of all native fish taxa, to develop a data base for comparisons across years and taxa and for multi-species management efforts.

**TABLE 1** Rubric used to assign scores to seven metrics to assess the status of native freshwater fishes in California using the California Method**1A. Area occupied: resident fish**

1. 1 watershed/catchment(s) in California only, based on 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
2. 2–4 apparent self-sustaining populations
3. 5–7 apparent self-sustaining populations
4. 8–10 apparent self-sustaining populations
5. More than 10 apparent self-sustaining populations

**2. Estimated adult abundance of individual fish**

1.  $\leq 500$
2. 501–5,000
3. 5,001–50,000
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, the establishment of refuge populations, hatchery propagation, 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 addressed.
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 the extreme edge of tolerances
3. Moderate physiological tolerance in all current habitats
4. Broad physiological tolerance under most conditions likely to be encountered
5. Physiological tolerance rarely an issue for persistence.

**5. Genetic risks**

1. Fragmentation, genetic drift, and isolation by distance, owing to very low levels of migration and/or frequent hybridization with related fish, reduce 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 habitat connectivity
5. Genetically diverse with gene flow to other populations (good metapopulation structure).

**6. Vulnerability to climate change** (based, if possible, on score using Moyle et al., 2013)

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

(Continues)

TABLE 1 (Continued)

5. Not vulnerable, most habitats will remain within tolerance ranges.

**7. Anthropogenic threats analysis** (see Moyle et al., 2015, 2017 for definitions of threats)

1. Critical threat: 1 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 years or 3 generations).
2. High threat: 1 or 2 threats rated high—species could be pushed to extinction in the foreseeable future (within 50 years or 10 generations).
3. Medium threat: 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 foreseeable future (within the next century).
4. Low threat: 2–4 threats rated medium—no immediate extinction risk but, taken in aggregate, threats reduce population viability.
5. No threat: 1 medium all others low—known threats do not imperil species.

*Note:* The final status score is the average of all seven metric scores. 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; 2–4 are intermediate values. While each factor is weighted the same in this example, it would be possible to weight metrics thought to be more important than others (e.g., vulnerability to climate change). From Moyle et al. (2015, 2017).

**Step 2.** Develop or update existing species accounts from the published and unpublished literature, and interview additional fish experts.

**Step 3.** For each species, assign a score on a 1–5 scale for each of seven metrics. Metrics include the area occupied (i.e., number of watersheds, or for anadromous fishes, number of self-sustaining populations), estimated adult abundance, dependence on human intervention to persist, environmental tolerance under natural environmental conditions, genetic risks, vulnerability to climate change, and analysis of anthropogenic threats (Table 1). A score of “1” denotes a strongly negative effect on status, while “5” denotes no negative effect. Values of “2” to “4” are intermediate. Scoring metric rationales are found in Moyle, Kiernan, Crain, and Quiñones (2013), Moyle et al. (2015, 2017).

**Step 4.** Assign a score of 1–4 for confidence in the evaluation and the information on which it is based (Table 2).

**Step 5.** Average all seven metric scores to derive final species' status scores ranging from 0.0 to 5.0 (Table 3).

The California Method assesses two critical elements evaluating extinction risk that are not directly incorporated into IUCN extinction criteria, although NatureServe uses somewhat similar elements (Master et al., 2012). The California Method rates the effects of climate change and combines 15 other potential anthropogenic threats to aquatic systems (i.e., major dams, agriculture, grazing, rural residential development, urbanization, instream mining, hardrock mining, transportation, timber harvest, fire, estuary alteration, recreational activities, fish harvesting, hatcheries, non-native species) and combines them into one evaluation metric (Table S1; Moyle et al., 2013). Threats are subjectively assessed using a five-tier ordinal scale; all reviewers must agree with each rating (Table 4).

TABLE 2 Rating and criteria for certainty of status evaluations, using the California Method (from Moyle et al., 2015, 2017)

1. Status is based on professional judgment, with little or no published information.
2. Status is based on professional judgment augmented by moderate amounts of published or unpublished literature.
3. Status is based on reports found mainly in the unpublished literature with some information in peer-reviewed sources, but where gaps exist in some important areas (e.g., genetics).
4. Status is based on highly reliable information from accounts in the peer reviewed and agency literature.

Using the California Method, we updated status scores for 130 native fish species from the most recent assessment (California Department of Fish and Wildlife, 2015) (Table S2). California Trout, an NGO, commissioned a similar report for the state's 32 salmonid taxa (Moyle et al., 2017) and has found it to be a useful tool when making conservation recommendations to state and federal fisheries agencies. This method is relatively easy to update and understand because its use does not require quantitative population studies. California's regional methodology produces results broadly comparable to evaluations of the IUCN Red List and NatureServe (Table S2).

California has several advantages for testing and comparing this method. The freshwater fishes are well documented (Moyle, 2002; Moyle et al., 2015). The state is large (411,000 km<sup>2</sup>), covering 10° of latitude, and supports a wide variety of aquatic habitats from small desert springs to large cold-water rivers. The state is also geographically complex, divided into distinct zoogeographic regions and numerous watersheds that are largely isolated from one another. These characteristics have promoted high endemism in the fishes (83% are

**TABLE 3** Status categories, score ranges, and definitions of status categories for California native fishes using the California Method (from Moyle et al., 2015, 2017)

Status	Scores	Definition
Extinct	0	Globally extinct or extirpated from inland waters of California.
Critical concern	1.0–1.9	High risk of extinction in the wild; range seriously reduced or greatly restricted in California; population abundance critically low or declining; threats projected to reduce remaining California habitat and populations in the short-term (<10 generations).
High concern	2.0–2.9	High risk of becoming a critical concern species; range and abundance significantly reduced; existing habitat and populations continue to be vulnerable in the short-term (<10 generations).
Moderate concern	3.0–3.9	Declining; fragmented and/or small populations possibly subject to rapid status change; management actions needed to prevent increased conservation concern.
Low concern	4.0–5.0	California populations do not appear to be in overall decline; abundant and widespread.

native only to California or watersheds shared with a neighboring state). California also has a highly developed economy that places a great demand on the state's limited water supply, so most of the native fishes are in decline or extinct. Thirty-two (24%) are listed as threatened or endangered under state and federal endangered species acts (Figure 1).

This evaluation system makes possible a retrospective look at the status of the California fish fauna, using the information from five reports using previous versions of the CA Method (Moyle, 1976; Moyle et al., 1995, 2015; Moyle, Williams, & Wikramanayake, 1989), plus a few additional historical reports (Figure 1). The analysis shows that the decline of native freshwater fish species in California has accelerated over the last 50 years. For example, the delta smelt (*Hypomesus transpacificus*), regarded as having a healthy population in the 1970s, is now on the verge of extinction in the wild, if it is not already extinct (Börk, Moyle, Durand, Hung, & Rypel, 2020). A similar problem exists for the Long Valley speckled dace (*Rhinichthys osculus* subsp.), which disappeared from their sole remaining stream habitat in 2019

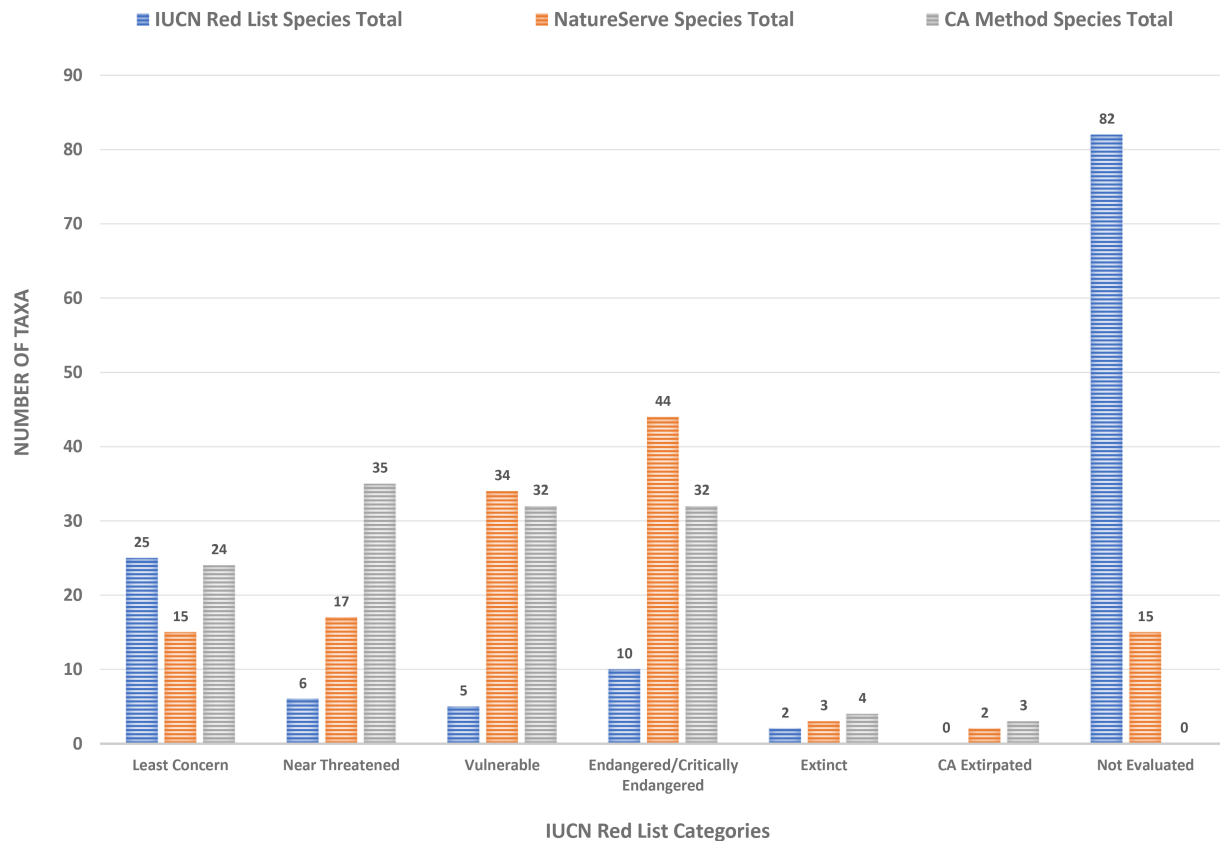
**TABLE 4** Ratings criteria for anthropogenic threat factors with correlated timelines (adapted from Moyle et al., 2013)

Factor threat rating	Criteria	Timeline
Critical	Could push species to extinction	3 generations or 10 years, whichever is less
High	Could push species to extinction	10 generations or 11–50 years, whichever is less
Medium	Unlikely to drive a species to extinction by itself but contributes to increased extinction risk	Within next 100 years
Low	May reduce populations but extinction is unlikely as a result	Within next 100 years
Not applicable (n/a)	Metric is not applicable to species	n/a

and live now only as captive populations (pers. comm., S. Parmenter, California Department of Fish and Wildlife).

Sixty-three percent ( $n = 83$ ) of California freshwater fishes have yet to be assessed by the IUCN Red List in large part because the Red List does not generally include DPSs and subspecies that account for most of the state's fish diversity (Table S2). Although the California Method, IUCN Red List, and NatureServe approaches have several similar scoring metrics, they differ from each other as well (Table S3). Notwithstanding the problems with equating different methods, we compared status ranks for California fish species ( $n = 130$ ) for the three approaches using IUCN status categories (Table S4). The results show that NatureServe and the IUCN Red List agree only about 50% of the time with the California Method scores (Figure 4; Table S2). The IUCN Red List focuses on the status of species globally. Therefore, we would expect that its species status designations might significantly differ from the CA Method, a regional assessment tool. NatureServe also assesses species regionally, so it is somewhat surprising its status scores vary considerably from the California Method. For example, NatureServe found many more endangered and critically endangered and far fewer near-threatened fishes than the California Method (Figure 4). Dissimilarities in NatureServe and the California Method ranking outcomes may be due to reliance by NatureServe on somewhat different conservation status





**FIGURE 4** Comparison of status ratings for California fishes ( $n = 130$ ) assessed by both IUCN Red List (v. 2020–3), NatureServe, and the California Method

rank definitions, distinct factor ratings, metrics, and weights, and the use of outdated taxonomic, distributional, and population abundance data. Differences between these three assessment methods illustrate a significant challenge to maintaining up-to-date and consistently accurate species assessment for conservation actions.

As discussed, the California Method is a bottom-up approach capable of assessing DPSs, subspecies, and species. It can be used to evaluate all species in regional fish faunas simultaneously. An additional advantage is that trained biologists who might not be experts on the assessed fishes can implement the method. It has the added benefits of being well-tested, repeatable, and once adopted, relatively easy to update every few years.

## 4 | CONCLUSIONS

Successful strategies for protecting freshwater fishes require development of tools that assess their rapidly changing population status. The California Method thus serves as a model for regional assessments, thereby freeing scientists and managers from the tyranny of the shifting baseline of fish status, especially given the

tendency of formal status assignments to be static. Such reviews could focus on clusters of freshwater fishes and other co-occurring aquatic species (e.g., mollusks, amphibians). Governments and NGOs can also develop regional assessments using similar procedures and local expertise to review native fishes' status at the watershed scale (Moyle, Katz, & Quiñones, 2011; Moyle et al., 2013, 2015; Van Rees, Waylen, Schmidt-Kloiber, et al., 2020). At a minimum, such approaches could be developed with an eye toward the distinctive characteristics of aquatic ecosystems and include metrics for genetic risks, vulnerability to climate change, anthropogenic threats, and the number of sustainable populations. Such techniques could link regional assessments to the more demanding global IUCN Red List by being the source of regularly updated information on the status of species. The goal would be to keep managers informed of both short and long-term declines of fishes that will protect species threatened with extinction and begin “bending the curve” of biodiversity loss worldwide (Tickner et al., 2020).

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Both authors led the study, defined its focus, and participated with writing and revising the manuscript.

## ETHICS STATEMENT

No ethics approval was required for this research.

## DATA AVAILABILITY STATEMENT

All data are freely available either within the supporting information documents, from the referenced sources, or from the authors upon request.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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