Received: 26 March 2022 | Revised: 5 August 2022 | Accepted: 7 November 2022
DOI: 10.1111/csp2.12856

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access
WILEY

Small-bodied fish species from the western United States will be under severe water stress by 2040

Sebastian Theis[1] | **Dante Castellanos-Acuña**[2] | **Andreas Hamann**[2] | **Mark S. Poesch**[1]

[1]Faculty of Agricultural, Life and Environmental Sciences, University of Alberta, Fisheries, and Aquatic Conservation Lab, Edmonton, Canada

[2]Faculty of Agricultural, Life and Environmental Sciences, University of Alberta, Spatial Information Systems Lab, Edmonton, Canada

Correspondence
Sebastian Theis, Faculty of Agricultural, Life and Environmental Sciences, University of Alberta, Fisheries, and Aquatic Conservation Lab, 433 South Academic Building, Edmonton AB, T6G 2J7, Canada,
Email: theis@ualberta.ca

Funding information
Mitacs, Grant/Award Numbers: RES0021639, RES0027784

Abstract

Human need to appropriate freshwater in combination with climate change has intensified the rapid decline in freshwater biodiversity. Based on 216 currently imperiled freshwater species in the United States, the Southwest, and the Rocky Mountains, were predicted to experience the highest increase in future water stress for 2040 in 41 minor watersheds. Resident-small species in the Southwest, found in single locations (21.6%) or on local level (62.2%), were listed as endangered ($n = 37$) and are predicted to experience severe water stress increases by 2040. Endangered species in the Rocky Mountains ($n = 9$), were found on a basin or local level (33.3%), exhibiting predominantly potamodromous behavior (66.7%). Furthermore, many endangered species in key regions lack life-history data (41%). Our results highlight that determining priority of species for conservation using biodiversity as an indicator may not be useful for identifying future impacts to imperiled species, since many regions undergoing high water stress did not coincide with biodiversity hotspots.

KEYWORDS

at-risk, biodiversity, climate, ecosystem, freshwater, stressors

1 | INTRODUCTION

Freshwater fishes are among the most threatened vertebrate groups based on recent assessments covering so far more than 5000 individual species (International Union for Conservation of Nature and Natural Resources [IUCN], 2021; Magurran, 2009; Reid et al., 2019). Main threats are commonly attributed to overexploitation, habitat loss and degradation; pollution, and invasive species (e.g., Dudgeon et al., 2006; Magurran, 2009). Environmental stressors can interact with each other forming cumulative stressors through their coincidental nature (e.g., invasive species stocking in combination with overexploitation) or by acting through multiple pathways (Dudgeon et al., 2006; Reid et al., 2019). Background processes like climate change (e.g., increasing demand for freshwater) or policy changes (e.g., reduction in conservation spending and policy development; ineffective conservation practices) can further accelerate threats, or (Reid et al., 2019; Waldron et al., 2017).

While many of these threats can be detrimental for different fish species, species-specific sensitivity can play a vital role in determining the likelihood and severity of each threat/s (e.g., Lintermans et al., 2020; Olden et al., 2007; Van Treeck et al., 2020). Life history and physiology (e.g., body size, temperature tolerance, or migratory behavior) play an important role in determining species-specific sensitivities (Clavero et al., 2010; Warren et al., 1999), and these sensitivities can exist in a feedback loop with background accelerators, such as water stress, measured as percent change in human water withdrawal from the current baseline, consequently affecting freshwater ecosystems (Pfister & Hellweg, 2009; Richter et al., 2020).

Assessing climate change impacts on freshwater ecosystems is complex (i.e., extreme events, high uncertainty), while the metric of water stress integrates different anthropogenic and environmental aspects into a useful threat determinant (Pfister & Hellweg, 2009; Richter et al., 2020). Water stress can impact freshwater fish species through increases in water withdrawal with the past decades being characterized by clear signs of human water use exceeding sustainable levels (e.g., Postel, 2000; Xenopoulos et al., 2005). Identifying regions at risk or likely to become at risk of increased water stress has become an urgent conservation objective to secure both essential ecosystem services and freshwater biodiversity (e.g., McCartney, 2002; Wolf et al., 2003).

While large-scale conservation efforts are underway to preserve freshwater biodiversity hotspots and address underestimated risks like the effect of conservation-oriented stocking or potentially unintended effects of habitat restoration and enhancement (e.g., Arthington et al., 2016; Schirmer et al., 2014), concerns exist about biodiversity as the commonly applied main target conservation planning target (e.g., Hrdina & Romportl, 2017; Jézéquel et al., 2020). Endangered species (e.g., listed under the Endangered Species Act; ESA), often tend to be obscure and insufficiently studied both in terms of their distribution or roles within ecosystems and ecosystem components (Cooke et al., 2012). Many of these species get listed in a reactionary approach on a regional level after often irreversible impacts have been done or cascading ecosystem effects have been set in motion (Bush et al., 2014; Mamo et al., 2019). Consequently, an overuse of biodiversity as a conservation priority indicator could potentially inadequately cover low diversity but high-risk and high-pressure regions, as biodiversity does not necessarily coincide with at-risk species, or species with unique life history or distribution patterns (Bush et al., 2014; Mamo et al., 2019). Furthermore, listed species are often not adequately protected or conservation with reactionary protections often being too little too late for many imperiled species (e.g., Mamo et al., 2019; Whelan et al., 2004).

To investigate imperiled freshwater species in the United States, in a holistic way, we use region-specific differences of future water stress and imperilment ratios to address the following questions:

1. What regions in the United States will be likely to experience extreme increases in anticipated water stress in the future?
2. What regions in the United States are linked to a high rate of imperiled species in terms of listing status as well as related to overall biodiversity?
3. Do basic life-history traits like size, migratory behavior and distribution relate to imperilment status and regions of high anticipated water stress?

2 | METHODS

2.1 | Species threats and sensitivity traits

Freshwater biodiversity data was acquired through NatureServe in the form of GIS layers containing species numbers for the continental United States (exclusion of Hawaii; Alaska; Washington, DC due to lack of sufficient data) and its 48 states, on a minor basin level (layers available through NatureServe; Version 3.0). All species present in the GIS layers were extracted by name and filtered by their status according to the United States Fish and Wildlife Service (Endangered Species Act status; U.S. Fish and Wildlife Service [USFWS], 2021). Based on current literature we identified threats (*Overharvest*; *Pollution*; *Habitat*; *Invasion*) in the United States for each species in the three imperilment categories *Endangered* ($n = 77$), *Threatened* ($n = 46$), or *Of Concern* ($n = 93$), (Dudgeon et al., 2006; Fishbase, 2021; IUCN, 2021; Reid et al., 2019; USFWS, 2021). Imperiled species were categorized by three sensitivity indicators: distribution, basic life history, and size. Distribution was divided into *National*, *Basin*, *Local* and *Single Location* (USGS, 2021), with full definitions in Table S1. Basic life history traits were *Diadromous*; *Potamodromous*; *Resident-Large* (>100 mm) and *Resident-Small* (<100 mm) based on maximum length in mm (Center for Biological Diversity, 2021; Fishbase, 2021; USFWS, 2021; Van Treeck et al., 2020). Distribution and basic life history traits were included as a sensitivity indicator since fish imperilment is often linked to species range, movement, and size (e.g., Clavero et al., 2010; Lintermans et al., 2020; Olden et al., 2007; Warren et al., 1999). Furthermore, we collected data according to literature whether species in key regions were lacking population status, ecosystem health monitoring and life-history data or were associated with stakeholder conflicts, leading to increased detrimental effects on the species or delaying conservation measures.

2.2 | Anticipated water stress

For future water stress, we used anticipated water stress, change from baseline, for the year 2040, available through the World Resources Institute (WRI, Version 3.0; FAO minor basin; $n = 921$; WRI, 2021). Water stress changes from the current baseline are estimated through ratios of total annual water withdrawal to total available renewable surface and groundwater supply, with withdrawals covering domestic, industrial, agricultural, irrigation and non-consumptive uses (WRI, 2021; Table S2). Water stress was chosen as the main stress metric since it covers many of the anthropogenic influences exerted on freshwater species compared to other metrics like urbanization or carbon footprint (e.g., Pfister & Hellweg, 2009; Richter et al., 2020). Water stress scenarios for the year 2040 were run under a "business as usual" scenario (Table S2). Total water stress on a state level was divided into three categories (*Low-stress* = <1.2× state-level increase; *Medium-stress* 1.2–1.4×state-level increase; *High-stress* = >1.4× state-level increase; Jenks natural breaks; North, 2009).

2.3 | Risk ratio

Risk ratio was a measure for total imperiled species in each state in relation to overall freshwater biodiversity. This measurement was included since studies caution for a generalized overuse of biodiversity as a conservation priority indicator, potentially missing low diversity but high-risk regions (e.g., Mamo et al., 2019; Whelan et al., 2004). Risk ratio categories were formed; *Low-risk* (<10% imperiled to state biodiversity); *Medium-risk* (10%–25% imperiled); *High-risk* (>25% imperiled).

2.4 | Regions

We chose 8 geographic regions for the 48 states: New England, Mid-Atlantic, South, Midwest, Great Plains, Rocky Mountains, Southwest, West-Coast (state list in Table S3).

2.5 | Statistical analyses

2.5.1 | Regions to imperilment status, water stress, and risk ratio relation

Regions were analyzed through chi-squared tests of independence. Positive residuals indicate a positive correlation and negative residuals a negative correlation between imperilment category and species data. Post-hoc analysis for chi-squared tests was based on standardized residuals (Bonferroni corrected), indicating the significance of positive or negative correlations (accepted $\alpha < .05$; Ebbert, 2019). Regions were related to species frequency across threat categories (*Of Concern*; *Threatened*; *Endangered*), water stress categories (*Low-stress* = <1.2× state-level increase; *Medium-stress* 1.2–1.4× state-level increase; *High-stress* = >1.4× state-level increase on a state level) and risk ratio categories (*Low-risk* (<10% imperiled); *Medium-risk* (10%–25% imperiled); *High-risk* (>25% imperiled); Jenks natural breaks; North, 2009). All statistical analysis was done in R, version 4.1.0, and GitHub extensions (R Core Team, 2021).

3 | RESULTS

3.1 | Anticipated water stress by 2040 across the United States

For the business-as-usual scenario, by 2040 49% of all watershed area is predicted to be within baseline stress values (3.77×10^6 km^2) while 36% (2.79×10^6 km^2) are predicted to experience a 1.4× increase in water stress and 11% (8.84×10^5 km^2) a 2× increase and 2% (1.59×10^5 km^2) a 2.8× or greater increase (Figure 1a). Only a cumulative 2% (1.4× decrease = 9.73×10^4 km^2; 2× decrease = 7.17×10^4 km^2; 2.8× or greater decrease = 1.90×10^3 km^2) of km^2 are predicted to decrease in water stress (Figure 1a). Our results point toward 41 minor watersheds with a high/extreme water stress increase of more than 2.8× (Figure S1) from current baselines by 2040. They were the Southwest and Rocky Mountains, with 36 and 9 freshwater fish species listed as *Endangered* respectively. These minor watersheds correspond on a larger scale to regions such as the Texas-Gulf, Rio Grande, Colorado, and Arkansas Red White watersheds (Figure 1a).

3.2 | Key regions for freshwater threats in the United States

Our results identified two key areas with overall high risk for freshwater fish species, the Southwest (positive relation to *Endangered* species residuals: 2.39; $p < .05$; *High-stress*—water; residuals: 4.08; $p < .001$) and *High-risk* (risk ratio; residuals: 3.54; $p = .001$), and the Rocky Mountains (positive relation to *Endangered* species residuals: 1.31; $p = 1.00$; *High-stress*—water; residuals: 2.37; $p < .052$) risk and *Medium-risk* (risk ratio; residuals: 4.00; $p < .001$; Figure 2 and Table S4). The West Coast should also be included as it had a high degree of species *Of Concern* residuals: 2.99; $p < .05$, and *High-risk* ratios (residuals: 0.71; $p = 1.00$). Although, with lower water stress, the South was strongly associated with *Threatened* species (residuals: 3.47; $p < .001$). Noteworthy is that both

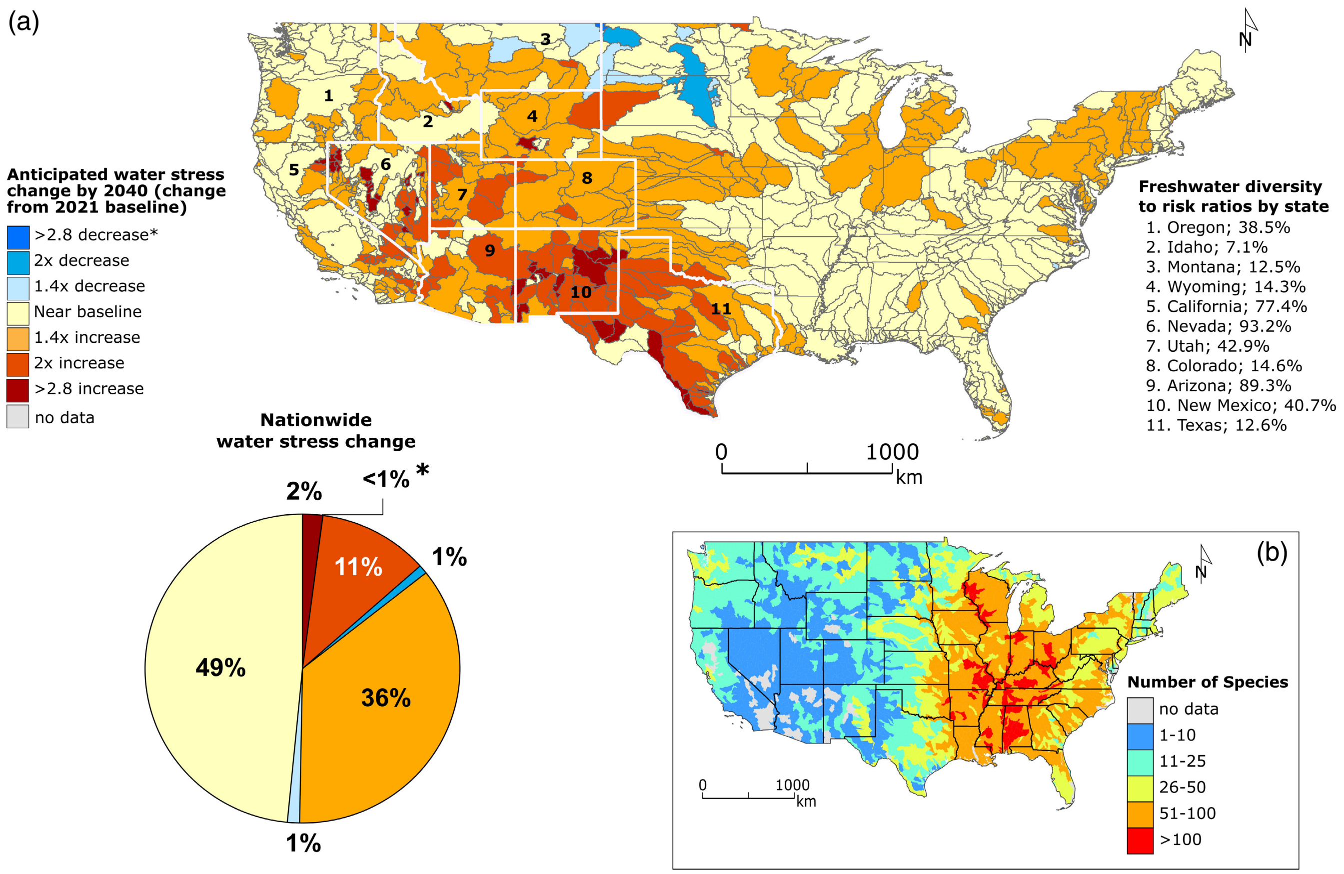

FIGURE 1 Visualization of anticipated water stress by 2040 divided into increase and decrease categories (2.8×; 2×; 1.4×; near baseline; no data) based on WRI data and pie chart for nationwide predicted changes in water stress based on the affected area in km^2 (a; * refers to anticipated water stress decrease exceeding 2.8×; main high threat regions, Rocky Mountains and Southwest highlighted through white bold outlines). Freshwater diversity to risk ratios (%) listed for main high threat regions as well as Oregon and California as additional high risk ratio states outside of the main high threat regions (1–11). Freshwater biodiversity as reference (b). List of minor watersheds with severe anticipated water stress and endangered freshwater species provided in the Supplemental Material (Figure S1)

the Southwest and Rocky Mountains fall into regions with low overall freshwater biodiversity (Figure 1b).

3.3 | Key characteristics for endangered species in key regions of high-water stress and high-risk ratios

Our results showed that *Endangered* species in the Southwest ($n = 37$; *Leuciscidae* = 37.8%) are generally associated with *Resident-small* fish (62.2%) threatened by *Habitat* loss and degradation and found in *Single Locations* (21.6%) and on a *Local* level (62.2%; Table 1). Two-third of the *Endangered* species, mainly from the *Leuciscidae* family (55.5%) in the Rocky Mountains ($n = 9$) were found on a *Basin* (33.3%) or *Local* level (33.3%), exhibiting predominantly *Potamodromous* behavior (66.7%) being at risk for *Habitat* loss and degradation (66.7%; Table 1). The West Coast, as a region of lower anticipated water stress but *High*-risk ratios (>25%), was associated with Habitat loss and degradation (76.9%) for *Endangered* species of *Local* distribution (61.5%), mainly *Potamodromous* (46.2%) or *Resident Small* (30.7%) and belonging to the *Catostomidae* (30.8%) or *Leuciscidae* family (38.5%; Table 1). Overall, 41% ($n = 24$) out of 59 Endangered species in these key regions stated a lack of monitoring and life-history data and 35 species (59%) were associated with stakeholder conflicts, leading to increased detrimental effects on the species or delaying conservation measures.

4 | DISCUSSION

Severe water stress due to an increase in human water use is often associated with a decrease in freshwater fish richness due to unfavorable habitat conditions like increasing water temperatures, reduced flow, increased sedimentation, or a general reduction in ecosystem functionality (primary production, respiration, organic matter

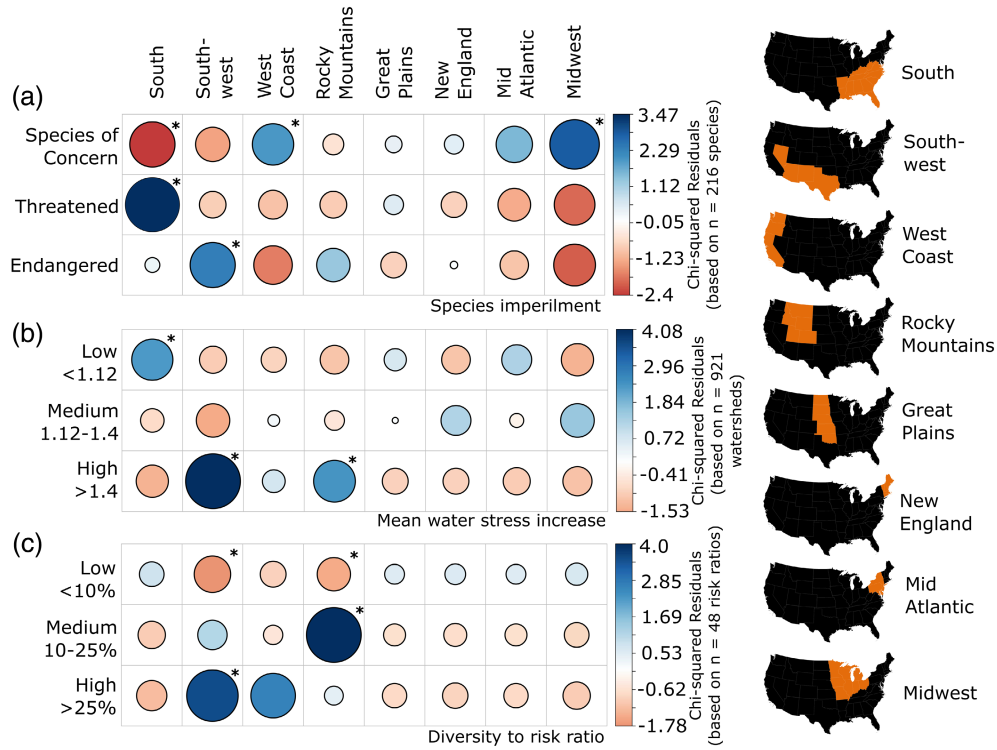

FIGURE 2 Chi-squared test of independence for imperilment status (species of concern; threatened; endangered) (a); total weighted water stress increase by 2040 on a state level (low <1.12; medium 1.12–1.4; high >1.4) (b); risk ratio as defined by imperiled species in relation total freshwater biodiversity per state (low <10%; medium 10 to 25%; high >25%) (c) in relation to main geographic regions (South; Southwest; West-Coast; Rocky Mountains; Great Plains; New England; Mid-Atlantic; Midwest). Positive residuals indicate a positive correlation blue) and a negative in red between two categories and circle size indicates residual magnitude. Post-hoc analysis for chi-squared test based on standardized residuals with Bonferroni correction indicating significance of positive or negative correlations by *

breakdown and accumulation; Kalogianni et al., 2017; Sabater et al., 2018). Aside from a reduction in ecosystem function, water stress can also lead to direct habitat loss through flow diversion, channelization, loss of shaded riparian area or damming and prevent migratory species from accessing life-stage specific habitat (Kalogianni et al., 2017; Sabater et al., 2018). Common management interventions are often on a watershed scale (e.g., through Watershed Restoration Plans) like restoration of connectivity or reduction of stressor intensity and frequency (Hatch et al., 2022; McEvoy et al., 2018). Local on the ground efforts for affected species often focus on protection of remaining existing habitat and genetic diversity (Finger et al., 2013) or protection and removal of invasive species and provision of essential habitat like spawning or rearing areas (Brown et al., 2001).

The Southwest and Rocky Mountains had a high threat likelihood for freshwater populations based on anticipated water stress and risk ratio. Our assessment points toward 41 minor watersheds with a water stress increase of more than 2.8× of the current baselines by 2040 in the Southwest and Rocky Mountains, with 36 and 9 freshwater fish species listed as Endangered respectively. Our study shows that on a larger scale, the Texas-Gulf, Rio Grande, Colorado, and Arkansas Red White watersheds will need to be protected from the anticipated severe water stress. Anthropogenic impacts and associated mitigation efforts are generally low in these low population states, with large federal land ownership and management (Congressional Research Service, 2020). This combination has proven itself to be potentially detrimental for species conservation in the past with issues of jurisdictional overlap, as well as, the often-limited agency capacities in combination with often underestimated conservation costs (e.g., Roper et al., 2019; Scarlett & Boyd, 2015). Consequently, these regions should be more strongly incorporated into alternative conservation and preservation frameworks and networks ranging from stewardship among landowners and anglers to larger scale protected areas under fee-programs, conservation easements or third-party organizations (e.g., Berlin & Malone, 2019; Theis & Poesch, 2022; Xenopoulos et al., 2005).

Biodiversity alone may not be useful for prioritizing impending conservation efforts. For example, we show that the Rocky Mountains, Southwest, and parts of the

TABLE 1 Characteristics (distribution; life-history; Main threat; family) of endangered species in key regions with anticipated extreme water stress by 2040 and high imperilment to overall biodiversity ratios (risk ratio)

	***Endangered* species in key regions of extreme future water stress and *high*-risk ratios**		
	Southwest (n = 37)	**Rocky Mountains (n = 9)**	**West Coast (n = 13)**
Distribution			
National	-	22.2%	-
Basin	16.2%	33.3%	23.1
Local	62.2%	33.3%	61.5%
Single location	21.6%	11.1%	15.4%
Life-history			
Diadromous	-	11.1%	-
Potamodromous	24.3%	66.7%	46.2%
Resident large	13.5%	-	23.1%
Resident small	62.2%	22.2%	30.7%
Main threat			
Habitat	64.9%	66.7%	76.9%
Invasion	24.3%	22.2%	15.4%
Pollution	10.8%	11.1%	7.7%
Overharvest	-	-	-
Family			
Acipenseridae	-	22.2%	-
Catostomidae	8.1%	11.1%	30.8%
Cyprinidae	10.8%	11.1%	-
Cyprinodontidae	16.2%	-	15.4%
Gasterosteidae	-	-	7.7%
Goodeidae	8.1%	-	-
Ictaluridae	2.7%	-	-
Leuciscidae	37.8%	55.5%	38.5%
Oxudercidae	-	-	7.7%
Percidae	2.7%	-	-
Poeciliidae	13.5%	-	-
Associated issues			
Species lacking data and life history data		41% (n = 24)	
Stakeholder conflicts associated with the species		59% (n = 35)	

Note: Based on NatureServe data (version 3.0) for 216 imperiled fish species for the conterminous United States.

West Coast generally had overall low freshwater biodiversity compared to other regions, while showing high anticipated water stress (Figure 1a,b). This can lead to potential oversight/s for impending threats and conservation issues when using biodiversity as the key indicator, and creating reactive versus proactive conservation (e.g., Mamo et al., 2019; Whelan et al., 2004). Many conservation frameworks focus on biodiversity hotspots in proactive approaches while lower biodiversity areas with individual species are mostly managed reactively (Mamo et al., 2019; USFWS, 2021; Whelan et al., 2004). These threats are further exacerbated by interactions of threats, species sensitivity, and other accelerators (e.g., climate change; Xenopoulos et al., 2005).

Species with limited range and cryptic life-history often suffer from lack of monitoring data and knowledge deficiencies (e.g., Lintermans et al., 2020; Mamo et al., 2019; Olden et al., 2007). Our results provide evidence about the gaps for many *Endangered* species in our areas anticipated to undergo severe water stress (Table 1).

Specific life-history traits like low fecundity or migratory behavior can increase extinction risks in regions exposed to water stress and large-scale anthropogenic impacts (e.g., Bennett, 2005; Richter et al., 2020). Examples include the Delta smelt (*Hypomesus transpacificus*), a small-bodied fish species, inhabiting low-salinity freshwater habitats in the San Francisco estuary, listed as threatened due to rapid population decreases, struggling with stakeholder conflicts over water withdrawal and lack of knowledge on life-history and effective stock assessments (e.g., Bennett, 2005; Brown & Kimmerer, 2002; USFWS, 2021). Also, the Gila Trout (*Oncorhynchus gilae*), suffering from competition with invasive species and extreme environmental events like fires. Owens's pupfish (*Cyprinodon radiosus*) who is population decline due to water withdrawal was expedited through isolated remnant populations struggling with preserving genetic diversity (e.g., Brown et al., 2001; Finger et al., 2013). These knowledge gaps for often cryptic species remain a prominent bottleneck for future conservation efforts.

Based on our analysis, the Rocky Mountains and Southwest will be under severe water stress by 2040, yielding a high number of *Endangered* species while not being in known biodiversity hotspots. Considering that many of the Endangered species in these areas are small-bodied and limited in range, mostly *Leuciscidae*, or larger species relying on migratory behavior like *Catostomidae* and *Acipenseridae*, creates an urgent need to protect these species under a more proactive approach focusing on managing future water stress (Magurran, 2009; Xenopoulos et al., 2005). Imperiled species are listed under the Endangered Species Act (ESA) because they often have severely declining populations. To help achieve recovery, strategic action and incorporation of high threat areas and sensitivity of species traits need to be included into land use planning and evaluations of anticipated water stress, environmental extreme events, and climate change to ensure conserve goals of freshwater fishes are being met (e.g., Bush et al., 2014; Mamo et al., 2019; McCartney, 2002; Wolf et al., 2003; Xenopoulos et al., 2005). Reactive approaches and collection of species data once a species is listed can often be too late or prevent recovery with species existing as remnant populations often struggling with invasion, pollution, and inadequate genetic diversity (Bush et al., 2014; Mamo et al., 2019). Managing water resources in the western United States will be essential to preserve currently *Endangered* species, as well as, to prevent endangerment of more species in the future.

ACKNOWLEDGMENTS

Funding for this project was provided by Mitacs Cluster Accelerate (RES0027784) and Converge (RES0021639) grants to M.P. Industry support was provided by Canadian Natural Resources Limited (CNRL).

FUNDING INFORMATION

Funding for this project was provided by Mitacs Cluster Accelerate (RES0027784) and Converge (RES0021639) grants to M.P.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

Data is available through contacting the authors, in the supplemental material or through fighshare: https://doi.org/10.6084/m9.figshare.19224528.

ORCID

Sebastian Theis https://orcid.org/0000-0002-9840-3806
Dante Castellanos-Acuña https://orcid.org/0000-0001-9016-4049
Andreas Hamann https://orcid.org/0000-0003-2046-4550
Mark S. Poesch https://orcid.org/0000-0001-7452-8180

REFERENCES

Arthington, A. H., Dulvy, N. K., Gladstone, W., & Winfield, I. J. (2016). Fish conservation in freshwater and marine realms: Status, threats and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(5), 838–857. https://doi.org/10.1002/aqc.2712

Bennett, W. A. (2005). Critical assessment of the delta smelt population in the San Francisco Estuary, California. *San Francisco Estuary and Watershed Science*, *3*(2), 1. https://doi.org/10.15447/sfews.2005v3iss2art1

Berlin, D., & Malone, J. (2019). Benefits and challenges of port-sponsored mitigation banks. *Ports, 2019: Port Planning and Development*, 22–32. https://doi.org/10.1061/9780784482629.003

Brown, R., & Kimmerer, W. (2002). *Delta smelt and CALFED's environmental water account: A summary of the 2002 delta smelt workshop*. http://science.calwater.ca.gov/pdf/ewa/EWA_workshop_smelt_summary_100102.pdf

Brown, D. K., Echelle, A. A., Propst, D. L., Brooks, J. E., & Fisher, W. L. (2001). Catastrophic wildfire and number of populations as factors influencing risk of extinction for gila trout (*Oncorhynchus gilae*). *Western North American Naturalist*, *61*(2), 139–148 https://www.jstor.org/stable/41717118

Bush, A., Hermoso, V., Linke, S., Nipperess, D., Turak, E., & Hughes, L. (2014). Freshwater conservation planning under climate change: Demonstrating proactive approaches for Australian odonata. *Journal of Applied Ecology*, *51*(5), 1273–1281. https://doi.org/10.1111/1365-2664.12295

Center for Biological Diversity. (2021). Center for Biological Diversity-Fish. https://www.biologicaldiversity.org/

Clavero, M., Hermoso, V., Levin, N., & Kark, S. (2010). Biodiversity research: Geographical linkages between threats and imperilment in freshwater fish in the Mediterranean basin. *Diversity* *and Distributions*, *16*(5), 744–754. https://doi.org/10.1111/j.1472-4642.2010.00680.x

Cooke, S., Paukert, C., & Hogan, Z. (2012). Endangered river fish: Factors hindering conservation and restoration. *Endangered Species Research*, *17*(2), 179–191. https://doi.org/10.3354/esr00426

Congressional Research Service. (2020). *Federal land ownership: Overview and data*. https://sgp.fas.org/crs/misc/R42346.pdf

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z., Howler, D. J., Leveque, C., Naiman, R. J., Prieur-Richard, A., Soto, D., Stiassny, M. L., & Sullivan, C. A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews*, *81*, 163–182. https://doi.org/10.1017/S1464793105006950

Ebbert, D. (2019). *Package 'chisq.posthoc.test'*. https://cran.r-project.org/web/packages/chisq.posthoc.test/chisq.posthoc.test.pdf

Finger, A. J., Parmenter, S., & May, B. P. (2013). Conservation of the Owens pupfish: Genetic effects of multiple translocations and extirpations. *Transactions of the American Fisheries Society*, *142*(5), 1430–1443. https://doi.org/10.1080/00028487.2013.811097

Fishbase. (2021). *FishBase*. https://www.fishbase.org

Hatch, M. D., Abadi, F., Porter, M. D., & Cowley, D. E. (2022). Mitigation of recurrent perturbation mortality is an important goal for river restoration and conservation of freshwater fish species. *Restoration Ecology*, *30*(8), e13649. https://doi.org/10.1111/rec.13649

Hrdina, A., & Romportl, D. (2017). Evaluating global biodiversity hotspots—Very rich and even more endangered. *Journal of Landscape Ecology*, *10*(1), 108–115. https://doi.org/10.1515/jlecol-2017-0013

International Union for Conservation of Nature and Natural Resources. (2021). *About the freshwater biodiversity unit*. IUCN http://www.iucn.org/about/work/progra

Jézéquel, C., Tedesco, P. A., Darwall, W., Dias, M. S., Frederico, R. G., Hidalgo, M., Hugueny, B., Maldonado-Ocampo, J., Martens, K., Ortega, H., Torrente-Vilara, G., Zuanon, J., & Oberdorff, T. (2020). Freshwater fish diversity hotspots for conservation priorities in the Amazon basin. *Conservation Biology*, *34*(4), 956–965. https://doi.org/10.1111/cobi.13466

Kalogianni, E., Vourka, A., Karaouzas, I., Vardakas, L., Laschou, S., & Skoulikidis, N. T. (2017). Combined effects of water stress and pollution on macroinvertebrate and fish assemblages in a Mediterranean intermittent river. *Science of the Total Environment*, *603-604*, 639–650. https://doi.org/10.1016/j.scitotenv.2017.06.078

Lintermans, M., Geyle, H. M., Beatty, S., Brown, C., Ebner, B. C., Freeman, R., Hammer, M. P., Humphreys, W. F., Kennard, M. J., Kern, P., Martin, K., Morgan, D. L., Raadik, T. A., Unmack, P. J., Wager, R., Woinarski, J. C., & Garnett, S. T. (2020). Big trouble for little fish: Identifying Australian freshwater fishes in imminent risk of extinction. *Pacific Conservation Biology*, *26*(4), 365. https://doi.org/10.1071/pc19053

Magurran, A. E. (2009). Threats to freshwater fish. *Science*, *325*(5945), 1215–1216. https://doi.org/10.1126/science.1177215

Mamo, L. T., Coleman, M. A., Dwyer, P. G., & Kelaher, B. P. (2019). Listing may not achieve conservation: A call for proactive approaches to threatened species management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *30*(3), 611–616. https://doi.org/10.1002/aqc.3256

McCartney, M. P. (2002). Freshwater ecosystem management: From theory to application. *International Journal of Water*, *2*(1), 1. https://doi.org/10.1504/ijw.2002.002074

McEvoy, J., Bathke, D. J., Burkardt, N., Cravens, A. E., Haigh, T., Hall, K. R., Hayes, M. J., Jedd, T., Poděbradská, M., & Wickham, E. (2018). Ecological drought: Accounting for the non-human impacts of water shortage in the upper Missouri headwaters basin, Montana, USA. *Resources*, *7*(1), 14. https://doi.org/10.3390/resources7010014

North, M. A. (2009). A method for implementing a statistically significant number of data classes in the Jenks algorithm. *2009 Sixth International Conference on Fuzzy Systems and Knowledge Discovery*. https://doi.org/10.1109/fskd.2009.319

Olden, J. D., Hogan, Z. S., & Zanden, M. J. (2007). Small fish, big fish, red fish, blue fish: Size-biased extinction risk of the world's freshwater and marine fishes. *Global Ecology and Biogeography*, *16*(6), 694–701. https://doi.org/10.1111/j.1466-8238.2007.00337.x

Pfister, S., & Hellweg, S. (2009). The water "shoesize" vs. footprint of bioenergy. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(35), E93–E94. https://doi.org/10.1073/pnas.0908069106

Postel, S. L. (2000). Entering an era of water scarcity: The challenges ahead. *Ecological Applications*, *10*(4), 941–948. https://doi.org/10.1890/1051-0761(2000)010[0941:eaeows]2.0.co;2

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing https://www.R-project.org/

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K., Vermaire, J. C., Dudgeon, D., & Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, *94*(3), 849–873. https://doi.org/10.1111/brv.12480

Richter, B. D., Bartak, D., Caldwell, P., Davis, K. F., Debaere, P., Hoekstra, A. Y., Li, T., Marston, L., McManamay, R., Mekonnen, M. M., Ruddell, B. L., Rushforth, R. R., & Troy, T. J. (2020). Water scarcity and fish imperilment driven by beef production. *Nature Sustainability*, *3*(4), 319–328. https://doi.org/10.1038/s41893-020-0483-z

Roper, B. B., Saunders, W. C., & Ojala, J. V. (2019). Did changes in western federal land management policies improve salmonid habitat in streams on public lands within the interior Columbia River basin? *Environmental Monitoring and Assessment*, *191*(9), 574. https://doi.org/10.1007/s10661-019-7716-5

Sabater, S., Bregoli, F., Acuña, V., Barceló, D., Elosegi, A., Ginebreda, A., Marcé, R., Muñoz, I., Sabater-Liesa, L., & Ferreira, V. (2018). Effects of human-driven water stress on river ecosystems: A meta-analysis. *Scientific Reports*, *8*, 11462. https://doi.org/10.1038/s41598-018-29807-7

Scarlett, L., & Boyd, J. (2015). Ecosystem services and resource management: Institutional issues, challenges, and opportunities in the public sector. *Ecological Economics*, *115*, 3–10. https://doi.org/10.1016/j.ecolecon.2013.09.013

Schirmer, M., Luster, J., Linde, N., Perona, P., Mitchell, E. A., Barry, D. A., Hollender, J., Cirpka, O. A., Schneider, P., Vogt, T., Radny, D., & Durisch-Kaiser, E. (2014). Morphological, hydrological, biogeochemical and ecological changes and challenges in river restoration—The Thur river case study. *Hydrology and Earth System Sciences*, *18*(6), 2449–2462. https://doi.org/10.5194/hess-18-2449-2014

Theis, S., & Poesch, M. S. (2022). Current capacity, bottlenecks, and future projections for offsetting habitat loss using mitigation and conservation banking in the United States assessed through the Regulatory In lieu fee and Bank Information Tracking System. *Journal for Nature Conservation*, *67*, 126159.

U.S. Fish and Wildlife Service. (2021). *Endangered species*. USFWS https://www.fws.gov/endangered/

United States Geological Survey. (2021). *USGS.gov | Science for a changing world*. https://www.usgs.gov/

Van Treeck, R., Van Wichelen, J., & Wolter, C. (2020). Fish species sensitivity classification for environmental impact assessment, conservation and restoration planning. *Science of the Total Environment*, *708*, 135173. https://doi.org/10.1016/j.scitotenv.2019.135173

Waldron, A., Miller, D. C., Redding, D., Mooers, A., Kuhn, T. S., Nibbelink, N., Roberts, J. T., Tobias, J. A., & Gittleman, J. L. (2017). Reductions in global biodiversity loss predicted from conservation spending. *Nature*, *551*(7680), 364–367. https://doi.org/10.1038/nature24295

Warren, M. L., Jr., Angermeier, P. L., Burr, B. M., & Haag, W. R. (1999). Decline of a diverse fish Fauna: Patterns of imperilment and protection in the southeastern United States. In G. W. Benz & D. E. Collins (Eds.), *Aquatic fauna in peril: The southeastern Prespective* (1st ed.). Aquatic Research Institute.

Whelan, R. J., Brown, C. L., & Farrier, D. (2004). The precautionary principle: What is it and how might it be applied in threatened species conservation? In P. A. Hutchings, D. Lunney, & C. R. Dickman (Eds.), *Threatened species legislation: Is it just an act?* (pp. 49–58). Royal Zoological Society of New South Wales. https://doi.org/10.7882/fs.2004.056

Wolf, A. T., Yoffe, S. B., & Giordano, M. (2003). International waters: Identifying basins at risk. *Water Policy*, *5*(1), 29–60. https://doi.org/10.2166/wp.2003.0002

World Resources Institute. (2021). *World Resources Institute | Making big ideas happen*. https://www.wri.org/

Xenopoulos, M. A., Lodge, D. M., Alcamo, J., Marker, M., Schulze, K., & Van Vuuren, D. P. (2005). Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Global Change Biology*, *11*(10), 1557–1564. https://doi.org/10.1111/j.1365-2486.2005.001008.x

SUPPORTING INFORMATION

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

How to cite this article: Theis, S., Castellanos-Acuña, D., Hamann, A., & Poesch, M. S. (2023). Small-bodied fish species from the western United States will be under severe water stress by 2040. *Conservation Science and Practice*, *5*(1), e12856. https://doi.org/10.1111/csp2.12856