Proceedings of the Desert Fishes Council Special Publication 2021:77-103

ISSN: 1068-0381

ARTICLE

Conservation Status of Native Fishes in the Chihuahuan Desert Region of the United States: a spatial perspective

Joshuah S. Perkin*
Department of Ecology and Conservation Biology, Texas A&M University, 2258 TAMU, College Station, Texas 77843, USA

Matthew J. Troia
Department of Environmental Science and Ecology, University of Texas at San Antonio, One UTSA Circle, San Antonio, Texas 78249, USA

Matthew R. Acre
Columbia Environmental Research Center, United States Geological Survey, 4200 New Haven Road, Columbia, Missouri 65201, USA

Abstract

Native fishes in the American Southwest are in need of conservation because of anthropogenic riverscape alterations involving habitat destruction, introduction of non-native species, and dewatering. Status assessments are useful conservation planning tools, but there is a need for transparent, repeatable, and empirically-driven assessment frameworks. We present a multi-criteria status assessment framework based on publicly available geospatial data and apply this framework to native fishes occupying the United States Chihuahuan Desert region. Criteria included (1) area occupied, (2) dependence on human protected areas, (3) genetic risk from non-native congeners, (4) vulnerability to expected climate change, (5) presence of anthropogenic threats, and (6) regional endemism. Of the 65 species reviewed, four are considered globally extinct, three are considered extirpated from the region, and 10 persist but are rarely encountered. Of the remaining 48 species with recent (i.e., post 1999) records, the current assessment ranked 6 (13%) as in danger of extinction (Endangered), 11 (23%) as on a trajectory towards extinction (Vulnerable), 5 (10%) as Near-Threatened, and 26 (54%) as Least Concern. These percentages broadly matched status ranks developed by multiple conservation entities based on a meta-status metric (i.e., status of statuses) that averaged ranks from multiple, existing assessments. Of the five species listed as Endangered under the federal Endangered Species Act (ESA), three were ranked as Endangered and two were ranked as Vulnerable in the current assessment. The two species listed as Threatened under the ESA were ranked as Vulnerable in the current assessment. Three species listed as Endangered and seven species listed as Vulnerable in the current assessment are not currently listed under the ESA. Range contraction scenarios based on recent region-wide studies of four species revealed that the status scores developed here are sensitive to potential species declines. The data-driven framework developed here supplements those used by agencies at state, federal, and international scales and can be repeated over short time intervals to develop responsive and timely status assessments.

*Corresponding author: jperkin@tamu.edu
Received December 1, 2020; accepted May 10, 2021

Key words: *endemic fishes, American Southwest, spatial ecology, conservation planning, status assessment*

The conservation status of desert fishes in the American Southwest has long been of concern because of human destruction of freshwater habitats and over-allocation of finite water resources (Pister 1974; Meffe and Vrijenhoek 1988; Budy et al. 2015). In fact, Minckley and Deacon (1991) characterized efforts to conserve desert fishes as a "battle against extinction", a battle that continues even decades later (Stewart et al. 2017; Propst et al. 2020). Key advancements in this battle have come from efforts to illuminate threats facing desert fishes (e.g., Fagan et al. 2002) and designation of areas where conservation preserves might be established (e.g., Pool et al. 2013). Given the evolving nature of threats and species persistence across increasingly human-dominated riverscapes, recurring status assessments have emerged as a valuable tool for conservation managers (e.g., Contreras-Balderas et al. 2008). However, conservation assessments for fishes lag behind other vertebrate groups on a global scale (Miqueleiz et al. 2020), including regions such as the Chihauhuan Desert (Edwards et al. 2002; Taylor et al. 2019).

A regional, spatially-based, multi-criteria status assessment will benefit conservation efforts for Chihuahuan Desert fishes. Moyle et al. (2011) suggested a benefit of regional freshwater fish status assessments over those conducted at broader spatial scales is that regional assessments can be conducted repeatedly using systematic and quantitative methods over relatively brief time periods. Though some rapid status assessments based on spatial data are built using unpublished and inaccessible data (e.g., Faucheux et al. 2019), there is a need for increased transparency and inclusion of publicly available data so that assessments can be temporally replicated to track changes in status (Bachman et al. 2011). Moreover, although extent of occurrence (EOO) and the area of occupancy (AOO) are commonly applied spatial criteria for assessing regional status of species (Gärdenfors et al. 2001), criteria beyond these are needed to understand causes of imperilment (Moyle et al. 2011). For example, understanding the extent to which species depend upon regional protected areas (PA) such as national parks for persistence can inform the resiliency of fishes to riverscape change as well as the capacity of PA to achieve conservation goals (Lawrence et al. 2011). Genetic risk caused by introduced species known to cause hybridization and introgression is another criterion that should be assessed given the prevalence of non-native fishes in contemporary riverscapes in the American Southwest (Pool et al. 2013). Finally, climate change threatens desert fishes and the extent of its effects will depend on the spatial distribution of fishes and local changes in precipitation and temperature regimes (Jaeger et al. 2014). Addressing these conservation challenges requires timely information on the current status and dynamic trajectories of multiple species, two needs that are met by regional conservation status assessments (Gauthier et al. 2010; Adams et al. 2019).

The purpose of this work was to develop a case study for the use of geospatial data in defining the conservation status of native fishes inhabiting the Chihuahuan Desert region in the United States. Previous conservation status assessments of the region were conducted by Edwards et al. (2002), Bell et al. (2004), Faucheux et al. (2019), Garrett et al. (2019), and McClung et al. (2019). These previous works focused on the occurrence of fishes in specific habitats (Edwards et al. 2002) or the delineation of conservation areas based on overlapping occurrences of (1) multiple taxa including fishes (Belle et al. 2004) or (2) fishes only (Garrett et al. 2019). McClung et al. (2019) assessed spatial heterogeneity in habitat alterations caused by oil and gas resource development but did not directly assess the status of biota. Faucheux et al. (2019) included a portion of the Chihauhaun Desert in their status assessment of fishes, but this assessment was based on non-public data describing EOO and AOO and did not consider a broader range of criteria related to causes of imperilment. Our objectives were to: (1) develop a multi-criteria status assessment ranking system based on publicly available occurrence data, (2) compare the ranking of species from this spatially-based status assessment with a review of current species rankings from multiple conservation entities, and (3) assess the responsiveness of the spatially-based status assessment to change in species occurrence by examining recent case studies focusing on the distribution of four native Chihuahuan Desert fishes. Our framework is based on Moyle et al. (2011) and provides status ranks that follow the general language of the International Union for the Conservation of Nature (IUCN 2012). The approach allows for species rankings that are independent of, but comparable to, agency methodologies (e.g., Cohen et al. 2018; Smith et al. 2018; Birdsong et al. 2020a, 2020b) and therefore allows for meta-status approaches to assessing species status using multiple lines of evidence.

Methods

Study Area

The Chihuahuan Desert is an arid region of North America spanning the international border of the United States and Mexico and covering approximately 350,000 km^2. The average annual air temperature is 18.6 °C and average annual precipitation is 235 mm (Schmidt 1979). The region experiences seasonal monsoonal weather patterns with high precipitation during the fall (September-November) and low precipitation during summer (June-August; Heard et al. 2012). We defined the U.S. Chihuahuan Desert region using the Level 3 Ecoregion for the Chihuahuan Desert from the United States Environmental Protection Agency (USEPA 2019). We restricted the analysis to the United States because of biases in data availability and standardization, particularly for protected areas and watershed boundaries. The final focal study area included 49 watersheds defined as 8-digit hydrologic unit codes (HUCs) from the National Hydrography Dataset (NHD; McKay et al. 2013). These 49 HUCs spanned portions of Arizona, New Mexico, and Texas in the United States and Chihuahua and Coahuila in Mexico (Figure 1).

Sources of Information

We relied on publicly available data sources for fish occurrences and existing status assessments. Of the 111 species known to occur in the Chihuahuan Desert region (Bell et al. 2004), 65 occurred in our study area (Miller 1978; Garrett et al. 2019) and 48 had occurrences during the past 20 years (i.e., 1999-2018) reported in the Global Biodiversity Information Facility (GBIF; www.gbif.org; see Appendix Table 1). The GBIF is an international data sharing network where historical, contemporary, professional, and amateur observations are catalogued in an open access format. Jelks et al. (2008) defined a possible extinction as a species that has not been documented for 20-50 years,

therefore in our assessment we used only occurrences that were in the GBIF with dates of observation during 1999-2018. We focused on the 48 species with contemporary occurrences for the spatially-based quantitative status assessment, but reviewed the status ranks by other conservation entities for all 65 species or subspecies. Sources of information for status listings by other entities included the American Fisheries Society (Jelks et al. 2008), the IUCN Red List (https://www.iucnredlist.org/), NatureServe

FIGURE 1. Map of 49 watersheds draining the United States Chihuahuan Desert used for the spatially-based status assessment. The inset map shows the full extent of the Chihuahuan Desert Ecoregion.

(https://www.natureserve.org/), and the United States Fish and Wildlife Service (https://ecos.fws.gov/ecp/).

We used publicly available datasets for spatial data pertaining to riverscape attributes. We defined protected areas using property boundaries included in the Protected Areas Database of the United States (USGS 2018); political boundaries in the Texas Natural Resources Information System (TNRIS 2015); lands owned, operated, or under easements with The Nature Conservancy (TNC 2019); and lands within the Texas Parks and Wildlife Department State Parks system boundaries (TPWD 2019). Hydrographic, geological, and soil characteristics for 1,156 stream reaches within our study area were downloaded from the NHD (McKay et al. 2013) and StreamCat (Hill et al. 2016). We acquired average monthly precipitation totals and monthly air temperature minima, means, and maxima for all reaches for present (1999-2017) and future (2080-2100) time periods from the ClimateNA program (Wang et al. 2016). We assessed the presence of anthropogenic causes of decline for each species using a list of anthropogenic threats tabulated from Jelks et al. (2008).

Criteria Used in Evaluation

We used six criteria to evaluate the conservation status of Chihuahuan Desert fishes. Our initial goal was to use the framework presented by Moyle et al. (2011), which included seven criteria: (1) area occupied, (2) estimated adult abundance, (3) human intervention dependence, (4) tolerance, (5) genetic risk, (6) climate change vulnerability, and (7) anthropogenic causes of decline. However, there were no clear spatial proxies for estimated adult abundance or tolerance for species. Consequently, we could not include these criteria in our evaluation. We added a criterion we call "regional endemism" because, unlike California fishes, many of the species in the Chihuahuan Desert occur outside of the region and for some fishes the Chihuahuan Desert is only on the fringe of their range. By accounting for regional endemism, our evaluation gives stronger weight to regional species compared to those that might be broadly distributed elsewhere. We used the same ranking system and scales as Moyle et al. (2011), including assigning values from 1 (species most strongly affected by a criterion) to 5 (species least affected by a criterion). Evaluation criteria included consideration of the area of the U.S. Chihuahuan Desert occupied by each species, dependence on humans measured as the fraction of occurrences within the boundaries of protected lands, genetic risk associated with occurrence of a non-native congener introduced across basin boundaries, vulnerability to climate change, presence of anthropogenic causes of decline, and level of regional endemism (Table 1).

Area Occupied. – We quantified the area of the Chihuahuan Desert occupied (AO) by each species using the number of 8-digit HUCs with records. This metric is most closely linked to the broadly used AOO metric, defined as the area in which a species occurs (Bachman et al. 2011). We scored occurrences on a scale of 1 to 5, with 1 representing the narrowest possible area occupied (i.e., 1 HUC), 5 representing regionally common species that occurred in over half of the 49 HUCs in the region (i.e., >25 HUCs), and 3 presenting the median value from that data distribution (i.e., 6 HUCs). This resulted in the following scoring system: 1 (1 HUC), 2 (2-5 HUCs), 3 (6-10 HUCs), 4 (11-25 HUCs), and 5 (>25 HUCs).

Dependence on Humans. – We quantified dependence on humans (DH) or human intervention by considering the spatial overlap between protected areas and occurrences of species. Although dependence on humans can be used to describe process such as supplemental stocking, habitat management and preservation within protected areas is included in this category (Moyle et al. 2011). We calculated the percent of total occurrences within 1 km of a protected area boundary to yield a value ranging from 0% (i.e., no records of a species in any protected areas) to 100% (i.e., species occurred only on protected areas). We then ranked species dependence on humans on a scale of 1 to 5, with 5 representing no dependence on humans and the remaining categories based on data quartiles. This resulted in the following scoring system: 1 (>75% of occurrences within protected areas), 2 (50-75%), 3 (25-50%), 4 (1-25%), and 5 (0%).

Genetic Risk. – Genetic risk (GR) caused by hybridization and introgression with introduced non-native congeners is documented among fishes

TABLE 1. Criteria and thresholds used for ranking conservation status of Chihuahuan Desert native fishes.

Code	Name	Description and thresholds
AO	Area Occupied	Number of 8-digit hydrologic unit codes (HUCs) occupied by the species. Rankings included: 1 (1 HUC); 2 (2-5 HUCs); 3 (6-7 HUCs); 4 (8-12 HUCs); 5 (>12 HUCs).
DH	Dependence on Humans	Percent of occurrences on or within 1 km of a protected area. Rankings included: 1 (100%); 2 (80-99%); 3 (50-79%); 4 (25-49%); 5 (<25%).
GR	Genetic Risk	Non-native congener known to cause hybridization and introgression is present within the region. Rankings included: 1 (present); 5 (absent).
CV	Vulnerability to Climate Change	Average present-to-future change in precipitation and temperature changes at stream segments with high probability of occurrence. Rankings included: 1 (0.80-1.0); 2 (0.60-0.79); 3 (0.40-0.59); 4 (0.20-0.39); 5 (<0.20).
AT	Anthropogenic Threats	Number of anthropogenic threats known to affect species present in the region. Rankings included: 1 (≥4 threats present); 2 (three threats present); 3 (two threats present); 4 (one threat present); 5 (none present).
RE	Regional Endemism	Percent of occurrences that occur within Chihuahua Desert. Rankings included: 1 (100%); 2 (80-99%); 3 (50-79%); 4 (25-49%); 5 (<25%)

include hybridization and introgression among fishes in the genera *Cyprinodon* (Wilde and Echelle 1992), *Gambusia* (Sanchez et al. 2014), *Hybognathus* (Moyer et al. 2005), and *Ictalurus* (McClure-Baker et al. 2010). Because the levels and extent of fish hybridization and introgression are still being uncovered in the region (e.g., Parker et al. 2021), we assigned a value of 1 to species with known genetic threats and 5 to species without demonstrated hybridization and introgression with an introduced congener. Given the propensity of Western Mosquitofish (Gambusia affinis) to be introduced widely and hybridize broadly (Pyke 2008), we assigned a genetic risk value of 1 to all regionally endemic Gambusia spp.

Vulnerability to Climate Change. – We used species distribution modelling (SDM) to assess vulnerability to climate change (CV) for each species. For the SDM, we used 1,156 perennial (FCode = 46006) confluence-to-confluence stream reaches in the study region and assigned fish presence in species-specific models based on GBIF data. We then used hydrographic, geological, and soil characteristics combined with present (1999-2017) precipitation and air temperature data to assign suitability. Climate data included mean temperature in the coldest month, mean temperature in the warmest month, precipitation in the driest month, precipitation in the wettest month, precipitation during the coldest month, and precipitation in the warmest month. We checked variable pairs for correlations (Pearson’s r) and retained only uncorrelated variables ($|r| \leq 0.7$) known to affect in-stream habitat suitability of stream fishes (Huang and Frimpong 2015). We fit SDMs with the Maximum Entropy algorithm using the MIAmaxent library in R (Vollering et al. 2019), and projected habitat suitability as the probability ratio output (PRO) to all 1,156 reaches. We evaluated model performance by computing the area under the curve (AUC) of the receiver operator characteristic.

For each species, we computed the present (1999-2017) to future (2080-2100) difference for all six climate variables as the mean across all reaches weighted by habitat suitability score (i.e., PRO). Calculation of a weighted mean among reaches ensured that climate change variables were representative of climate change vulnerability in the reaches where each species presently occurs. Future climate projections were based on an ensemble of 15 general circulation models assuming the Representative Concentration Pathway (RCP) 8.5 scenario of greenhouse gas emissions (Wang et al. 2016). Next, each climate change variable was rescaled from 0 to 1 for each species to standardize variable unites (i.e., temperature in degrees Celsius versus precipitation in mm) and an average of the six variables was calculated. We then ranked species vulnerability to climate change on a scale of 1 to 5, with 1 representing the highest vulnerability and 5 representing lowest vulnerability, and remaining classes assigned based on splitting the range into fifths. This resulted in the following scoring system: 1 (average change = 0.80-1.00), 2 (0.60-0.79), 3 (0.40-0.59), 4 (0.20-0.39), and 5 (<0.20).

Anthropogenic Causes of Decline. – We used data from Jelks et al. (2008) to quantify the number of anthropogenic threats (AT) facing each species. The five possible threats included present or threatened destruction of habitat, over-exploitation, disease or parasitism, effects of non-native species, or narrowly restricted range. Although a portion of these threats are redundant with other criteria used in the spatial assessment (e.g., genetic threat from non-native congeners, range size), this metric links the current assessment with broader information derived from a peer-reviewed framework that is itself updated on a recurrent basis. This metric is conceptually similar to published causes of decline employed by Moyle et al. (2011). We then ranked species by their known causes of decline on a scale of 1 to 5, with 5 representing species that were not listed and the remaining ranks increasing as the number of threats increased. This resulted in the following scoring system: 1 (>4 threats), 2 (3 threats), 3 (2 threats), 4 (1 threat), and 5 (species not listed by Jelks et al. 2008).

Regional Endemism. – The regional delimitation we used to define endemism included both biogeographical boundaries and political boundaries without biogeographic significance. Consequently, some species included in the assessment occurred outside of the region and in some cases were broadly distributed, while others were endemic to the study area. We included consideration of regional endemism (RE) by quantifying the percent of occurrences within the study area. This metric is most closely related to the broadly used EOO metric, defined as the geographic range size of a species (Bachman et al. 2011). We ranked species by their regional endemism on a scale of 1 to 5, with 1 representing species that occurred only within the study area, and the remaining ranks based on quartile distributions. This resulted in the following scoring system: 1 (100% of occurrences within 1 km of the study area boundary), 2 (75-99%), 3 (50-74%), 4 (25-49%), and 5 (<25%).

Quantitative Assessment

We developed a quantitative, multi-metric scoring system based on the above listed criteria. We first ordinated criteria scores from the five metrics for the 48 species using principal components analysis (PCA). We then created a status score for each species using a weighted-average approach. This included first extracting the score for each criterion along the first principal component (PC) axis, and then weighting values for each criterion by these scores when averaging across criteria. This was done to account for the fact that some criteria more strongly affected species status compared with others (Moyle et al. 2011). The first PC axis explained 57% of variation in metric scores and the criteria scores along PC 1 were AO (1.56), DH (0.66), GR (1.55), CV (0.81), AT (1.39), and RE (2.41). We used these PC 1 criteria scores as weights to calculate a weighted average across the six criteria by first multiplying criteria scores by weighting scores and then dividing the sum of these products by the sum of all weighting scores. We defined the status score (SS) as:

$$SS = \frac{AO_{score}\,(1.56) + DH_{score}\,(0.66) + GR_{score}\,(1.55) + CV_{score}\,(0.81) + AT_{score}\,(1.39) + RE_{score}\,(2.41)}{1.56 + 0.66 + 1.55 + 0.81 + 1.39 + 2.41}$$

We then ranked fishes using terminology consistent with the IUCN (2012). Fishes with status scores ranging 1-1.99 were considered Endangered, or in immediate threat of global extinction, while fishes with status scores ranging 2.0-2.99 were considered Vulnerable, or declining and likely to become endangered in the near future. Fishes with scores ranging 3.0-3.99 were considered Near Threatened, or in decline but not in immediate threat of extinction because of ongoing conservation efforts. Finally, fishes with scores ranging 4.0-5.0 were considered Least Concern, or species with a low enough threat of extinction that they are not of conservation concern. We compared the resulting status ranks from the spatially-based assessment with those conducted by other conservation entities. For this analysis, we ranked species status listings on a scale of 1-4. We assigned rank values based on species status listings, including 1 for species listed as Endangered (here, IUCN, AFS) or G1 (NatureServe), 2 for species listed as Vulnerable (here, IUCN, AFS) or G2 (NatureServe), 3 for species listed as Near-Threatened (here, IUCN) or Threatened (AFS) or G3 (NatureServe), and 4 for species listed as Least Concern (here, IUCN) or not listed (AFS) or G4 or G5 (NatureServe). We then calculated the average and standard deviation of ranks to quantify meta-status (i.e., status of statuses) and uncertainty among listing entities.

Sensitivity Scenarios

We used recent region-wide assessments for four fishes to assess the sensitivity of the ranking system to changes in species AO within the U.S. Chihuahuan Desert. Region-wide collection efforts were recently conducted for Rio Grande Shiner (*Notropis jemezanus*) and Speckled Chub (*Macrhybopsis aestivalis*) by Osborne et al. (2021), including a detailed comparison between historical and contemporary collection locations. These data allowed for assessing the differences in the occurrence of these species in the 1999-2018 GBIF data versus more recent sampling by Osborne et al (2021). We supplemented the occurrence data from Osborne et al. (2021) with sampling in the Big Bend region conducted by Edwards (2017). Edwards (2017) conducted intensive sampling for Rio Grande Silvery Minnow (*Hybognathus amarus*) within the Rio Grande reintroduction zone and concluded a self-sustaining population was not present. This finding allowed for assessing the change in Rio Grande Silvery Minnow status if the species is absent from HUCs where it was recently reintroduced and documented in GBIF. Finally, McClure-Baker et al. (2010) and Parker et al. (2021) sampled across the range of Headwater Catfish (*Ictalurus lupus*) in the Chihuahuan Desert region of the United States and documented presence and absence of the species. We used these recent studies to assess how the status of each species was affected if the AO metric was updated with new information. This is the intended use for the current conservation assessment as new information on species distributions is collected in the future.

Results

Of the 65 species included in the assessment, 17 did not have contemporary records in GBIF and 48 were assigned a quantitative status score. Among the 17 species listed as occurring in the region but not reported in GBIF since 1999, Maravillas Red Shiner (*Cyprinella lutrensis blairi*), Phantom Shiner (*Notropis orca*), Rio Grande Bluntnose Shiner (*Notropis simus simus*), and Amistad Gambusia (*Gambusia amistadensis*) are considered to be extinct based on literature (Hubbs et al. 2008; Craig and Bonner 2019). Shovelnose Sturgeon (*Scaphirhynchus platorynchus*), Rio Grande Cutthroat Trout (*Oncorhynchus clarkii virginalis*), and Blotched Gambusia (*Gambusia senilis*) are considered extirpated from the region based on literature (Koch and Quist 2010; Garrett and Mattlock 1991; Craig and Bonner 2019). The remaining undetected species persist in the U.S. Chihuahuan Desert according to the literature but are apparently infrequently encountered during standard sampling efforts. Among the 48 fishes included in the quantitative conservation assessment, 6 (13%) scored as Endangered, 11 (23%) scored as Vulnerable, 5 (10%) scored as Near-Threatened, and 26 (54%) scored as Least-Concern (Table 2). Species scores segregated in multivariate space, with those listed as most endangered negative along PCA 1 and species of least concern positive along PCA 1 (Figure 2).

Conservation status of the fishes included in the spatially-based quantitative assessment showed general agreement in the number of species in each ranking category compared with other listing entities, with the exception of a greater number of species ranked as vulnerable in the current assessment (Figure 3). The IUCN and NatureServe both also list 13% of assessed fishes as endangered (NatureServe term = “critically imperiled”), though the identities of the species differed among listing entities (Table 2). The AFS lists a larger percentage (21%) as endangered, and all but one species (Rio Grande Shiner) were considered endangered or vulnerable in the spatially-based assessment. The spatially-based ranking of 23% of species as vulnerable was larger than the IUCN (13%), the AFS (6%), and Natureserve (8%; termed “imperiled”); whereas, the ranking of 10% of species as near-threatened was greater than IUCN (2%) but less than the AFS (17%; termed “threatened”) and NatureServe (21%, termed “vulnerable”). The spatially-based ranking of 54% of species as least concern was less than the IUCN (65%) but comparable to the AFS (56% of species not listed by AFS) and NatureServe (54%; termed “secure”). Meta-status ranks highlighted species-specific agreement and disagreement among conservation status assessment entities and highlighted greater uncertainty among status listings for some species (Figure 4). The spatially-based conservation assessment was sensitive to changes in species OA across the four species recently reviewed in other studies. Documented range contraction by Rio Grande Shiner reduced the number of HUCs where the species occurred from 8 to 4 (Figure 5). This resulted in a change in status score from 3.4 (Near-Threatened) to 2.9 (Vulnerable). Similarly, potential range contraction of Speckled Chub from upstream-most HUCs in the Pecos River and Rio Grande reduced the number of HUCs occupied from 9 to 7, resulting in a score change from 3.1 (Near-Threatened) to 2.9 (Vulnerable). Additional sampling may reveal the presence of these species in the HUCs we classified as absent, but these scenarios illustrate the responsiveness of the assessment to species range contractions. Recent evidence that the reintroduced population of Rio Grande Silvery Minnow in the Big Bend area is not self-sustaining, if further supported by future research, would reduce the number of occupied HUCs from 8 to 4. The reduction in the

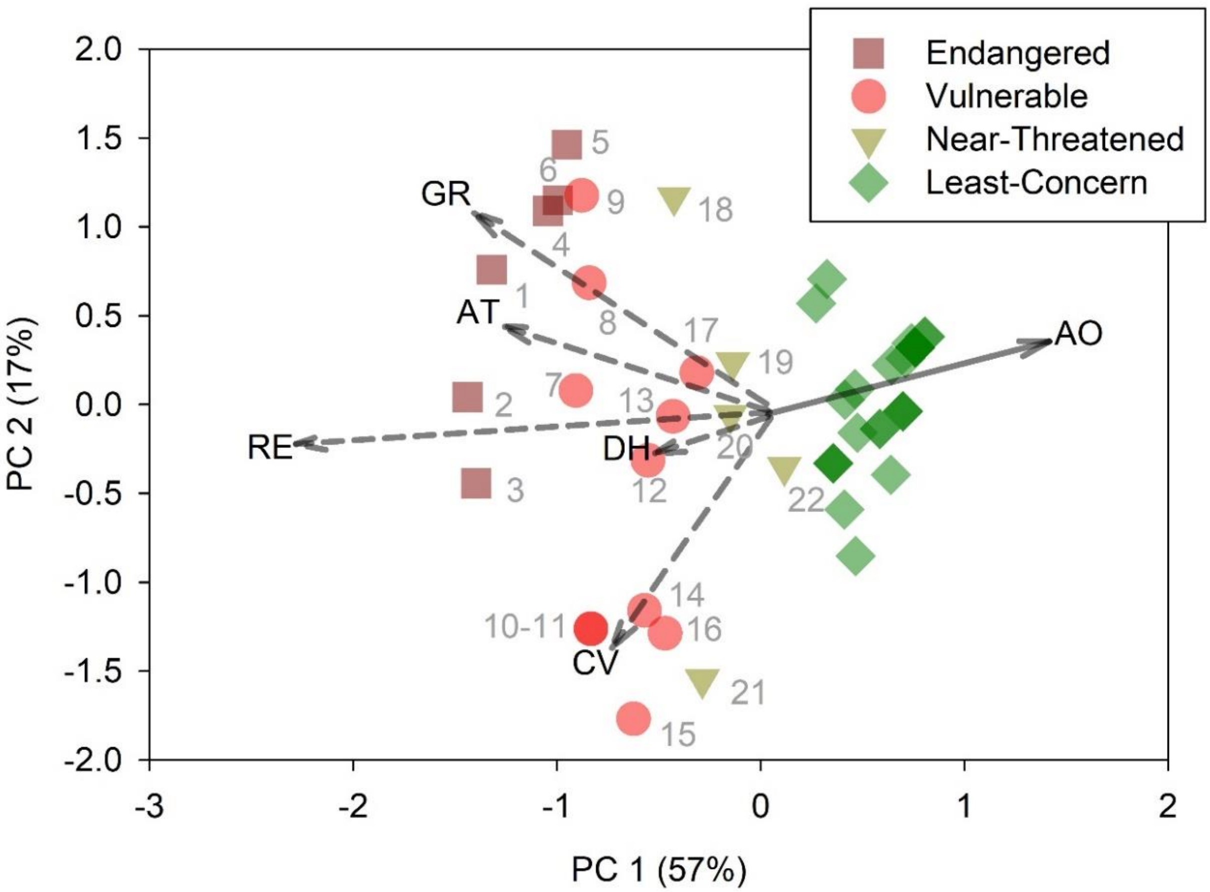

FIGURE 2. Principal components analysis (PCA) results illustrating ordination of 48 U.S. Chihuahuan Desert fishes based on criteria scores for area occupied (AO), dependence on humans (DH), genetic risk (GR), climate vulnerability (CV), anthropogenic threats (AT), and regional endemism (RE). Each point represents a species, points are colored according to status designations, and the species ranked 1-22 in descending status rank are labelled with a number (see Table 2). The percent of variation in criteria scores explained by each PC axis are given in parentheses and dashed arrows represent arrows reflected (i.e., axis scores multiplied by -1) to indicated the direction of species threated by criteria (i.e., because lower ranks equate to greater conservation concern, reflected arrows go in the direction of smaller magnitude score and greater threat).

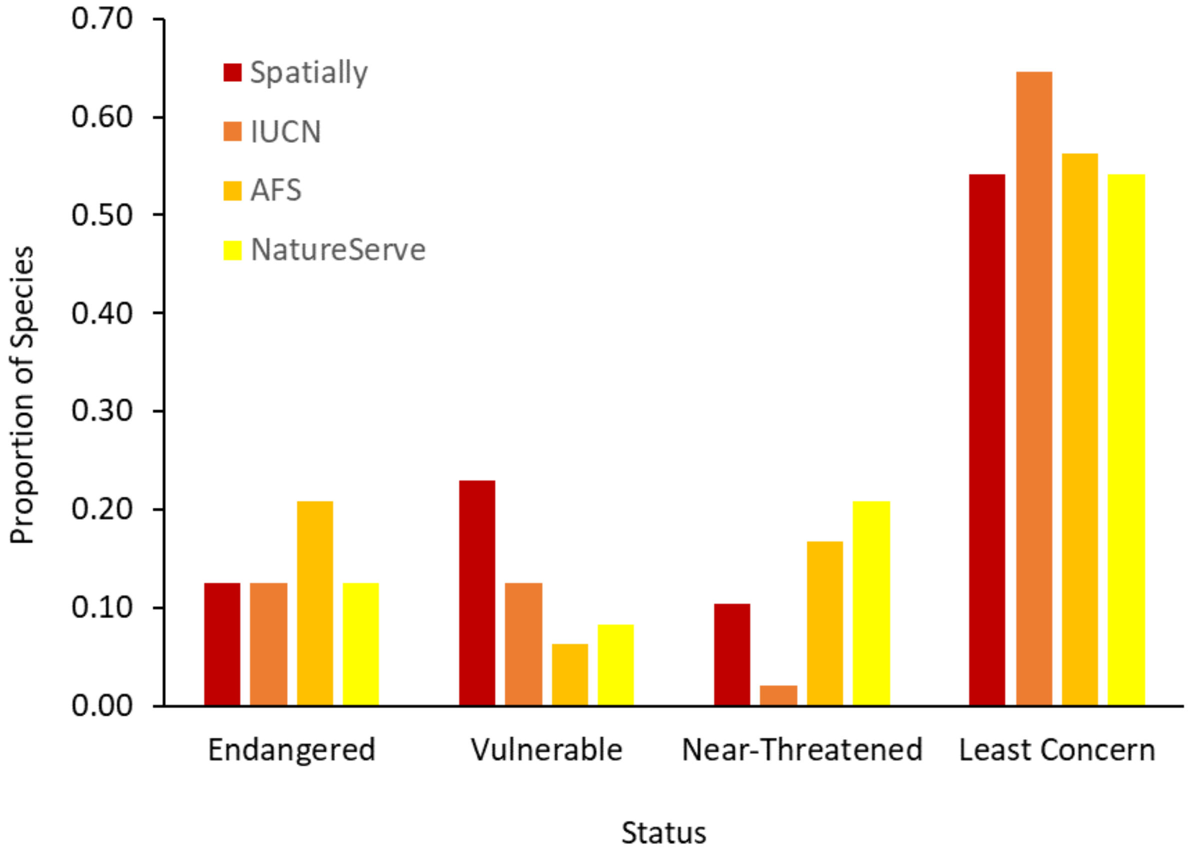

FIGURE 3. Conservation status of 48 U.S. Chihuahuan Desert native fishes based on multiple sources, including the spatially-based status assessment developed here (Spatially), the International Union for the Conservation of Nature (IUCN), American Fisheries Society (AFS), and NatureServe. Status titles shown from left to right are after NaturServe, but differ slightly for AFS (Endangered, Vulnerable, Threatened, Not Listed) and NatureServe (Critically Imperiled, Imperiled, Vulnerable, Secure).

TABLE 2. List of 65 freshwater fishes native to the U.S. Chihuahuan Desert, including 48 species with recent collections housed in the Global Biodiversity Information Facility and 17 with historical occurrences. For each species or subspecies, common and scientific names, scores for six criteria used to quantify conservation status (AO = area occupied; DH = dependence on humans; GR = genetic risk; CV = climate vulnerability; AT = anthropogenic threats; RE = regional endemism), spatially-based conservation status score, categorical status based on the continuous score, and status listed by the American Fisheries Society (Jelks et al. 2008), the International Union for the Conservation of Nature (IUCN), Natureserve (NS), and United States Fish and Wildlife Service (USFWS). Superscripts by species common names show status ranks 1 through 48 and correspond to points shown in Figure 2.

		Spatially-based Assessment								Existing Assessments			
Common	Scientific	AO	DH	GR	CV	AT	RE	Score	Status[a]	AFS[b]	IUCN[c]	NS[d]	USFWS[e]
[1]Big Bend Gambusia	*Gambusia gaigei*	1	1	1	-	2	1	1.1	E	E	V	G1	E
[2]Leon Springs Pupfish	*Cyprinodon bovinus*	1	1	1	2	2	1	1.3	E	E	V	G1	E
[3]Spotfin Gambusia	*Gambusia krumholzi*	1	1	1	1	3	1	1.3	E	V	V	G1	NL
[4]Conchos Pupfish	*Cyprinodon eximius*	1	3	1	-	4	2	1.8	E	T	NT	G3	NL
[5]Pecos Gambusia	*Gambusia nobilis*	2	1	1	5	3	1	1.9	E	E	E	G2	E
[6]Pecos Pupfish	*Cyprinodon pecosensis*	2	2	1	5	3	1	1.9	E	E	V	G2	NL
[7]Comanche Springs Pupfish	*Cyprinodon elegans*	2	5	1	5	2	1	2.0	V	E	E	G1	E
[8]Pecos Bluntnose Shiner	*Notropis simus pecosensis*	1	1	5	5	1	1	2.1	V	E	E	T2	T
[9]Rio Grande Silvery Minnow	*Hybognathus amarus*	4	3	1	4	2	1	2.2	V	E	E	G1	E
[10]Devils River Minnow	*Dionda diaboli*	2	3	5	1	2	1	2.2	V	E	E	G1	T
[11]Proserpine Shiner	*Cyprinella proserpina*	2	3	5	1	2	1	2.2	V	E	V	G3	NL
[12]Rio Grande Blue Sucker	*Cycleptus elongatus cf sp*	2	3	5	-	3	1	2.3	V	T	LC	G3	NL
[13]Chihuahua Shiner	*Notropis Chihuahua*	2	4	5	-	2	2	2.5	V	T	LC	G3	NL
[14]Longlip Jumprock	*Moxostoma albidum*	2	1	5	1	5	1	2.6	V	NL	DD	GNR	NL
[15]Rio Grande Darter	*Etheostoma grahami*	2	3	5	2	4	1	2.7	V	T	V	G2	NL
[16]West Texas Shiner	*Notropis megalops*	2	3	5	2	5	1	2.8	V	NL	NL	GNR	NL
[17]Headwater Catfish	*Ictalurus lupus*	4	3	1	4	3	3	2.9	V	T	DD	G3	NL
[18]Speckled Chub	*Macrhybopsis aestivalis*	4	2	5	5	3	1	3.1	NT	T	LC	G3	NL
[19]Manantial Roundnose Minnow	*Dionda argentosa*	3	2	5	1	5	2	3.2	NT	NL	E	G3	NL
[20]Tamaulipas Shiner	*Notropis braytoni*	4	3	5	4	3	2	3.4	NT	T	LC	G4	NL

[21]Rio Grande Shiner	*Notropis jemezanus*	4	2	5	5	3	2	3.4	NT	E	DD	G3	NL
[22]Largespring Gambusia	*Gambusia geiseri*	3	3	5	4	5	3	3.8	NT	NL	LC	G4	NL
[23]Rio Grande Chub	*Gila pandora*	3	4	5	5	2	5	4.0	LC	V	LC	G3	NL
[24]Mexican Stoneroller	*Campostoma ornatum*	5	4	5	5	2	4	4.1	LC	V	LC	G3	NL
[25]Spotted Gar	*Lepisosteus oculatus*	2	3	5	4	5	5	4.2	LC	NL	LC	G5	NL
[26]Freshwater Drum	*Aplodinotus grunniens*	2	3	5	4	5	5	4.2	LC	NL	LC	G5	NL
[27]Smallmouth Buffalo	*Ictiobus bubalus*	2	3	5	4	5	5	4.2	LC	NL	LC	G5	NL
[28]Black Bullhead	*Ameiurus melas*	2	3	5	5	5	5	4.3	LC	NL	LC	G5	NL
[29]Texas Shiner	*Notropis amabilis*	3	3	5	3	5	5	4.3	LC	NL	LC	G4	NL
[30]Yellow Bullhead	*Ameiurus natalis*	2	4	5	5	5	5	4.4	LC	NL	LC	G5	NL
[31]Roundnose Minnow	*Dionda episcopa*	5	2	5	4	5	4	4.4	LC	NL	LC	G4	NL
[32]Rio Grande Cichlid	*Herichthys cyanoguttatus*	4	3	5	2	5	5	4.4	LC	NL	LC	G5	NL
[33]Flathead Catfish	*Pylodictis olivaris*	5	3	5	-	5	5	4.4	LC	NL	LC	G5	NL
[34]Gray Redhorse	*Moxostoma congestum*	4	3	5	4	5	5	4.6	LC	T	LC	G4	NL
[35]Rainwater Killifish	*Lucania parva*	4	3	5	4	5	5	4.6	LC	NL	LC	G5	NL
[36]Blue Catfish	*Ictalurus furcatus*	4	3	5	5	5	5	4.7	LC	NL	LC	G5	NL
[37]Fathead Minnow	*Pimephales promelas*	5	3	5	3	5	5	4.7	LC	NL	LC	G5	NL
[38]Mexican Tetra	*Astyanax mexicanus*	5	3	5	4	5	5	4.8	LC	NL	LC	G5	NL
[39]River Carpsucker	*Carpiodes carpio*	5	3	5	4	5	5	4.8	LC	NL	LC	G5	NL
[40]Longnose Gar	*Lepisosteus osseus*	5	2	5	5	5	5	4.8	LC	NL	LC	G5	NL
[41]Longnose Dace	*Rhinichthys cataractae*	4	5	5	5	5	5	4.8	LC	NL	LC	G5	NL
[42]Longear Sunfish	*Lepomis megalotis*	5	3	5	5	5	5	4.8	LC	NL	LC	G5	NL
[43]Western Mosquitofish	*Gambusia affinis*	5	3	5	5	5	5	4.8	LC	NL	LC	G5	NL
[44]Red Shiner	*Cyprinella lutrensis*	5	3	5	5	5	5	4.8	LC	NL	LC	G5	NL
[45]Green Sunfish	*Lepomis cyanellus*	5	3	5	5	5	5	4.8	LC	NL	LC	G5	NL
[46]Gizzard Shad	*Dorosoma cepedianum*	5	3	5	5	5	5	4.8	LC	NL	LC	G5	NL
[47]Bullhead Minnow	*Pimephales vigilax*	5	4	5	5	5	5	4.9	LC	NL	LC	G5	NL
[48]Bluegill	*Lepomis macrochirus*	5	4	5	5	5	5	4.9	LC	NL	LC	G5	NL
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*	-	-	-	-	-	-	-	-	NL	V	G4	T-S
Alligator Gar	*Atractosteus spatula*	-	-	-	-	-	-	-	-	V	LC	G3	NL

American Eel	*Anguilla rostrata*	-	-	-	-	-	-	-	-	NL	E	G4	NL
Maravillas Red Shiner	*Cyprinella lutrensis blairi*	-	-	-	-	-	-	-	-	EX	NL	GNR	NL
Conchos Shiner	*Cyprinella panarcys*	-	-	-	-	-	-	-	-	E	NT	GNR	NL
Conchos Roundnose Minnow	*Dionda* sp 1	-	-	-	-	-	-	-	-	NL	NL	GNR	NL
Phantom Shiner	*Notropis orca*	-	-	-	-	-	-	-	-	PE	EX	GX	NL
Rio Grande Bluntnose Shiner	*Notropis simus simus*	-	-	-	-	-	-	-	-	PE	NL	TX	NL
Black Buffalo	*Ictiobus niger*	-	-	-	-	-	-	-	-	NL	LC	G5	NL
Mexican Redhorse	*Moxostoma austrinum*	-	-	-	-	-	-	-	-	V	DD	G3	NL
Chihuahua Catfish	*Ictalurus sp*	-	-	-	-	-	-	-	-	NL	NL	NL	NL
Rio Grande Blue Catfish	*Ictalurus sp*	-	-	-	-	-	-	-	-	NL	NL	NL	NL
Mexican Blindcat	*Prietella phreatophila*	-	-	-	-	-	-	-	-	E	V	GNR	E
Amistad Gambusia	*Gambusia amistadensis*	-	-	-	-	-	-	-	-	EX	EX	GX	NL
Blotched Gambusia	*Gambusia senilis*	-	-	-	-	-	-	-	-	T	NT	G3	NL
Rio Grande Largemouth Bass	*Micropterus salmoides nuecensis*	-	-	-	-	-	-	-	-	NL	NL	GNR	NL
Rio Grande Cutthroat Trout	*Oncorhynchus clarkii virginalis*	-	-	-	-	-	-	-	-	T	DD	T3	NL

[a]Status E = Endangered, V = Vulnerable, NT = Near-Threatened, LC = Least-Concern

[b]American Fisheries Society Status E = Endangered, V = Vulnerable, T = Threatened, NL = Not Listed, EX = Extinct, PE = Possibly Extinct

[c]International Union for the Conservation of Nature Status E = Endangered, V = Vulnerable, NT = Near-Threatened, LC = Least-Concern, DD = Data Deficient, EX = Extinct, NL = Not Listed

[d]NatureServe Status G1 = Critically Imperiled, G2 = Imperiled, G3 = Vulnerable, G4 = Apparently Secure; G5 = Secure, GX = Presumed Extinct, T2 = Imperiled Subspecies, T3 = Vulnerable Subspecies, TX = Presumed Extinct Subspecies, GNR = Unranked

[e]United States Fish and Wildlife Service Status E = Endangered, T = Threatened, T-S - Threatened Similarity of Appearance, NL = Not Listed

number of HUCs occupied equates to a change in status rank from 2.2 (Vulnerable) to 1.8 (Endangered). An alternative perspective is, if eventually successful, reintroduction efforts will have improved the status of Rio Grande Silvery Minnow according to the spatially-based assessment. Finally, the GBIF data for Headwater Catfish used in the spatially-based status assessment included occurrence in 11 HUCs and resulted in a status score of 2.9. Recent range-wide sampling for the species revealed occurrence in 9 HUCs and resulted in a status score of 2.7, thus supporting the Vulnerable status of Headwater Catfish.

Discussion

Native fishes in the U.S. Chihuahuan Desert region represent an imperiled fauna in which nearly half of the species are ranked as Endangered, Vulnerable, or Near-Threatened. This level of imperilment is consistent among assessments conducted on a continental scale by the American Fisheries Society Imperiled Species Committee (Jelks et al. 2008) as well as global assessments by the IUCN and NatureServe. Preservation of this highly imperiled desert fish fauna was historically described as a battle against extinction (Minckley and Deacon 1991) and conservation intervention efforts now stand between preservation and extinction of desert fishes (Propst et al. 2020). Despite four extinctions and three regional extirpations, there remains opportunity for conservation intervention to preserve the remaining regional fish fauna. Conservation assessments represent key decision-support tools for conservation managers, particularly when assessments can be repeated in relatively short time intervals that capture the sometimes rapid changes in species status (Hoagstrom et al. 2010). We present a spatially-based, quantitative conservation status assessment that can be used to supplement existing frameworks used by state, federal, and international conservation entities (Cohen et al. 2018; Smith et al. 2018), and can be applied at any relevant spatial extent. For example, the spatial distribution of future oil and gas resource development in the region can be planned to accommodate the distributions of highly imperiled species (McClung et al. 2019). This framework also complements recent development of native fish conservation areas for the Chihuahuan Desert (Garrett et al. 2019) because the collective status of multiple species within sub-regions can be used to weight decisions for conservation resource allocation (Birdsong et al. 2019).

Regional Status Assessment

Regional status assessments represent an intermediate spatial scale relative to single basin (fine scale) or global (broad scale) frameworks. Fausch et al. (2002) suggested that intermediate spatial scales represent the extent at which human alterations to riverscapes most strongly influence life history needs of fishes. An earlier status assessment for fishes in the Chihuahuan Desert conducted by Edwards et al. (2002) at the scale of a single basin identified a number of threats to fishes, including spring dewatering, water pollution, dam construction, overgrazing within catchments, bank stabilization and subsequent stream entrenchment, and introduction of non-native species. While these same threats operate to imperil aquatic biodiversity on a global scale (Dudgeon et al. 2006), global assessments of conservation status are generally too coarse to uncover direct causes of imperilment (Miqueleiz et al. 2020). Regional assessments offer the opportunity to assess many taxa simultaneously, though not nearly the magnitude of global-scale assessments, while also uncovering causes for decline, though not with the resolution as local-scale assessments (Moyle et al. 2011). Based on the criteria included, we found the largest contributing factors to Chihuahuan Desert fish conservation status were related to regionally endemic species with small areas of occupancy in

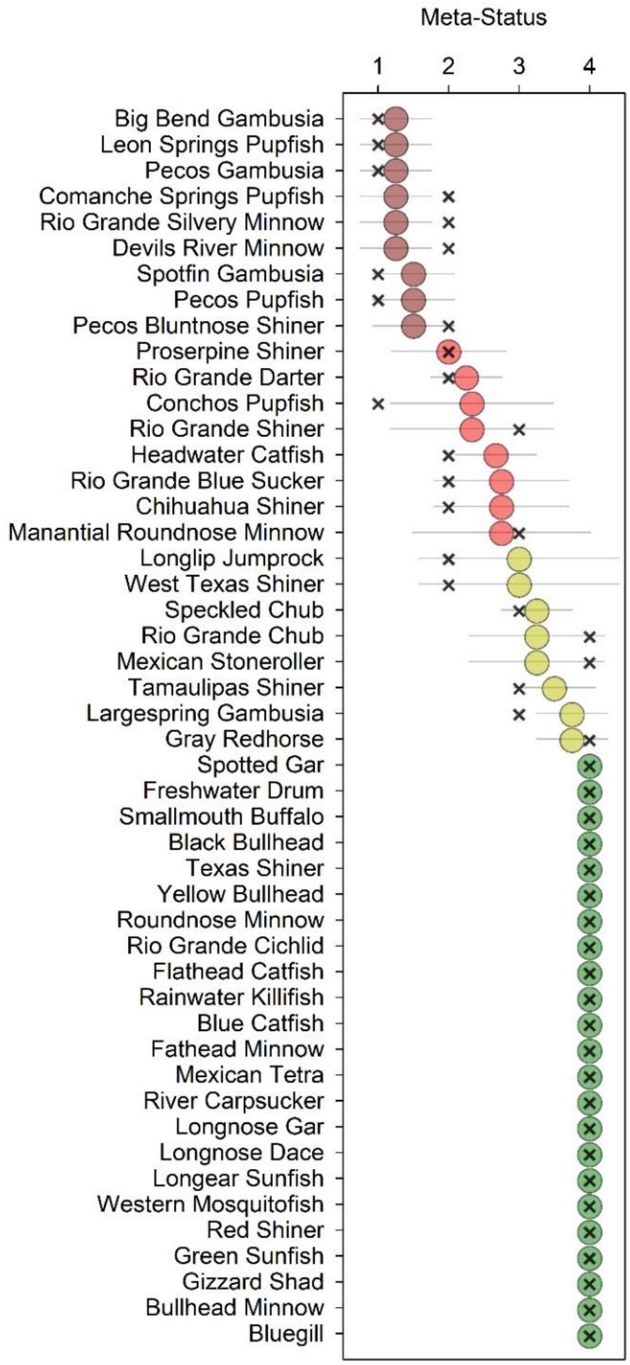

FIGURE 4. Conservation status ranking of U.S. Chihuahuan Desert fishes based on meta-status (i.e., status of statuses) derived from calculating the average (circles) and standard deviation (error bars) across ranked statuses listed by multiple conservation entities. Colors denote meta-status values 1-1.9 (dark red), 2-2.9 (light red), 3-3.9 (yellow), and 4 (green). Status ranking from the spatially-based conservation assessment is shown as an “x” for reference.

which multiple anthropogenic threats are documented, particularly non-native congeners known to cause hybridization and introgression. Although some species have naturally small areas of occupancy (i.e., regional or basin endemics), many fishes that currently occupy small areas have experienced long-term declines in distribution. Species with naturally narrow ranges are inherently at risk of extinction because even a single catastrophic perturbation could cause extinction. The status of these species is unlikely to change even under intensive conservation efforts because of the lack of redundancy, or the ability of the species to endure catastrophic events by spreading risk across broad space or multiple populations (Smith et al., 2018). Conservation assessments can be more informative for broadly-distributed species that have experienced range reductions. Although conservation assessments provide only a snapshot of the distribution of these species, the greatest benefit comes from replicated assessment over time as a means of monitoring range contractions (e.g., Osborne et al. 2021) or potential expansion following reintroduction efforts (e.g., Malone et al. 2018). This opens the opportunity to track species "conservation trajectories" or how conservation status has changed over time. Thus, regional spatial scales are likely the scales at which range contractions and expansions are most likely to be detected (Taylor et al. 2019).

A number of caveats should be considered with the spatially-based conservation assessment presented here. First, this assessment does not directly consider population resiliency nor representation, two concepts central to species listings under the ESA (Smith et al. 2018). Resiliency is the ability of a species to endure stochastic disturbance through fast population growth rates, large population sizes, or high connectivity among populations that allows for rescue effects. Representation is the ability of a species to adapt to environmental change because of high genetic diversity or the use of highly heterogeneous habitats. These concepts require considerable effort to populate data matrices and represent conservation needs that current research endeavors are directly addressing for Chihuahuan Desert native fishes such as Comanche Springs Pupfish (*Cyprinodon elegans*; Acre et al. 2021), Headwater Catfish (Parker et al. 2021), and Rio Grande Shiner and Speckled Chub (Osborne et al. 2021). In the meantime, some regional conservation assessments indirectly address resiliency and representation using coarse spatial surrogates (e.g., Haak and Williams 2012; Faucheux et al. 2019) or order of magnitude estimates of abundance that require considerable expert insight (e.g., Moyle et al. 2011). A second caveat is that we used unfiltered GBIF data in our assessment, though we recognize these data are spatially biased and require continuous refinement to address inaccuracies (Beck et al. 2014). For example, a single record of Rio Grande Silvery Minnow in the upper Pecos River collected during 2001 (Figure 5) might represent a questionable locality that could easily be addressed by examining the preserved specimen at the Museum of Southwestern Biology (Catalogue Number: MSB:Fish:48229). This illustrates an acceptable tradeoff whereby some degree of spatial bias and inaccuracy is foregone for the benefit of rapidly updating assessments over short time intervals. A third caveat is that spatial differences in sampling effort among repeated assessments could influence interpretation and reliability of results. In our four case studies, we relied on range-wide assessments of species occurrences but these data are not always available. Parker et al. (2021) tested for bias in sampling sites for Headwater Catfish based on GBIF data from 1980-1999 and 2000-2019 and found minimal differences. Similar tests could be used ahead of future reassessments to ensure that any detected changes in occurrence are not caused by shifts in sampling effort. Finally, this status assessment is intended to serve as a supplement rather than a replacement of agency-based conservation assessments. Official designations by agencies require considerable expert opinions and insights that cannot be replicated by spatial analyses alone, but quantitative assessments such as the one presented here can inform the best available science at the time of species reviews. Overviews of the methods used by state (e.g., Cohen et al. 2018; Birdsong et al. 2020a, 2020b), federal (e.g., Smith et al. 2018), and international (e.g., Bachman et al. 2011) listing entities highlight the need for input from biologists and ecologists serving on these multiple levels. The current status assessment is one additional tool these conservation managers can use when developing their view of species conservation need.

Comparison with Previous Assessments

Previous status assessments provide explanations for why some fishes were not present within the U.S. Chihuahuan Desert region according to GBIF records for the period 1999-2018. Among the 17 species not represented in contemporary sampling, four are considered globally extinct, three are considered extirpated from the region, six may still exist but are infrequently encountered by standard sampling methods, and four are not formally described and thus not yet incorporated into the GBIF. The four extinct species included Maravillas Red Shiner, Phantom Shiner, Rio Grande Bluntnose Shiner, and Amistad Gambusia. The three species presumed extirpated from the region included Shovelnose Sturgeon (Koch and Quist 2010), Rio Grande Cutthroat Trout (Garrett and Mattlock 1991), and Blotched Gambusia (Craig and Bonner 2019). The six species considered present in the region but not frequently encountered during standard sampling included Alligator Gar (*Atractosteus spatula*), American Eel (*Anguilla rostrata*), Black Buffalo (*Ictiobus niger*), and Mexican Redhorse (*Moxostoma austrinum*; Craig and Bonner 2019), as well as only recently encountered Mexican Blindcat (*Prietella phreato*; Hendrickson et al. 2017) and Conchos Shiner (*Cyprinella panarcys*; Pinion et al. 2018). The four putative species or subspecies not yet fully described but recognized in regional species keys included Conchos Roundnose Minnow (*Dionda sp. 1*), Chihuahua Catfish (*Ictalurus sp.*), Rio Grande Blue Catfish (*Ictalurus sp cf furcatus*), and Rio Grande Largemouth Bass (*Micropterus salmoides nuecensis*; Hubbs et al. 2008). While some of these fishes will undoubtedly be components of the future fish fauna, additional research and monitoring is needed to determine their ultimate status within the region. For example, recent genetic surveys conducted by the Texas Parks and Wildlife Department suggest Rio Grande Blue Catfish is not sufficiently different from Blue catfish (*Ictalurus furcatus*) to merit listing as a species of greatest conservation need (Megan Bean, Texas Parks and Wildlife Department, unpublished data). Similarly, a recent range-wide survey of Headwater Catfish in Texas did not reveal evidence of persistence of Chihuahua Catfish (Parker et al., 2021).

Despite general agreement among conservation entities regarding the percentages of fishes within each status ranking, there was obvious disagreement on the identities of species assigned to each rank. Our use of the meta-status metric provided a quantitative overview of species status designations across multiple listing entities. Based on meta-status, the nine most-imperiled fishes in the region are Big Bend Gambusia (*Gambusia gaigei*), Leon Springs Pupfish (*Cyprinodon bovinus*), Pecos Gambusia (*Gambusia nobilis*), Comanche Springs Pupfish, Rio Grande Silvery Minnow, Devils River Minnow (*Dionda diaboli*), Spotfin Gambusia (*Gambusia krumholzi*), Pecos Pupfish (*Cyprinodon pecosensis*), and Pecos Bluntnose Shiner (*Notropis simus pecosensis*). Of these nine species, all except Spotfin Gambusia and Pecos

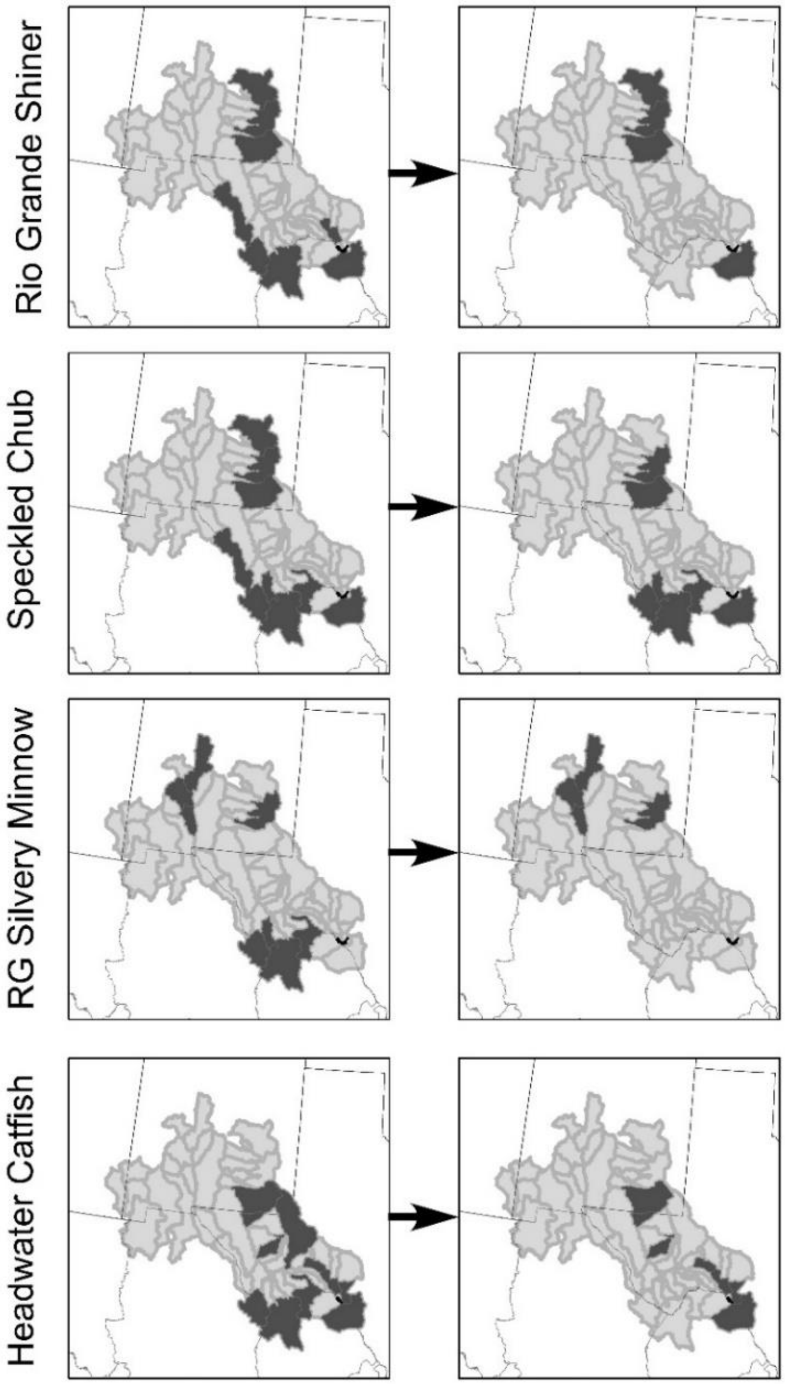

FIGURE 5. Maps illustrating the 8-digit hydrologic unit codes where fishes occurred (dark gray polygons) within the U.S. Chihuahuan Desert region (light gray polygons) according to Global Biodiversity Information Facility records for 1999-2018 (left column) and in recent studies (right column) of the distribution of Rio Grande Shiner (*Notropis jemezanus*; Osborne et al. 2021), Speckled Chub (*Macrhybopsis aestivalis*; Osborne et al. 2021 and Edwards 2017), Rio Grande Silvery Minnow (*Hybognathus amarus*; Edwards 2017), and Headwater Catfish (*Ictalurus lupus*; Parker et al. 2021).

Pupfish are listed as Endangered or Threatened by the USFWS. Across all species, the spatially-based status assessment ranked 15 species as in greater need, and 9 species in lesser need, of conservation than broader-scale assessments. The uncertainty around meta-status values could be used to prioritize species-based research endeavors aimed at filling gaps in current knowledge. The species with the greatest uncertainty around their meta-status were West Texas Shiner (*Notropis megalops*; SD = 1.4), Longlip Jumprock (*Moxostoma albidum*; SD = 1.4), Manantial Roundnose Minnow (*Dionda argentosa*; SD = 1.3), Rio Grande Shiner (SD = 1.2), and Conchos Pupfish (*Cyprinodon eximius*; SD = 1.2). West Texas Shiner is a recently resurrected species endemic to the region that is morphologically similar to Texas Shiner (Conway and Kim 2016), while Longlip Jumprock is morphologically similar to both Mexican Redhorse and Gray Redhorse and contemporary collections were only recently confirmed based on voucher specimens in museum collections (Cohen et al. 2020). The documented distributions of these species clearly requires additional research attention given uncertainties in identifications. Manantial Roundnose Minnow is a member of the Dionda spp. complex (Schönhuth et al. 2012), was recently documented in wider range than previously thought (Carson et al. 2010), and shares distributional and ecological similarities to Devils River Minnow (Robertson and Bonner 2016). Clarity on the conservation status and distribution of species within the genus *Dionda* will only come from straitening the regional "Dionda Dishevelment" and research in this area should be a high priority. Finally, clarity regarding the plight of Rio Grande Shiner is emerging and highlights a prevailing pattern of greater conservation concern for the species (Osborne et al. 2021), while additional research on the abundance and distribution of Conchos Pupfish is needed (Garrett et al. 2005).

Responsiveness of the Assessment

Our analysis of scenarios of change in species area of occupancy and resulting status scores based on recent comprehensive reviews of four species provided evidence that the spatially-based conservation assessment is responsive to species range expansion or contraction, thus providing validation of the framework as a rapid assessment tool. Each of the studies we reviewed (McClure-Baker et al. 2010; Edwards 2017; Osborne et al. 2021; Parker et al. 2021) documented some level of range contraction for each species during recent sampling compared to the 1999-2018 GBIF occurrences. This might not be surprising given that sampling over shorter time periods generally results in smaller areas of occupancy because of accumulation of rare occurrences with greater effort (Stolar and Nielsen 2015). However, the datasets for each species we reviewed spanned multiple years and were comprehensive from a spatial perspective. This means data from the studies are, at the very least, useful from a range-shift scenario perspective. Based on these scenarios, we found that status rankings for both Rio Grande Shiner and Speckled Chub elevated from Near-Threatened to Vulnerable. For Rio Grande Silvery Minnow, the scenario we analyzed essentially reflects potential for improved status if the reintroduced population in the Big Bend reach of the Rio Grande is eventually successful. Our analysis suggests that expansion of Rio Grande Silvery Minnow into a broader portion of its historical range coincided with a status change from Endangered to Vulnerable. This level of down-listing associated with conservation action is generally a goal defined during federal listings (Smith et al. 2018) and highlights the benefit of temporal iterations of conservation status assessments (Jelks et al. 2008; Moyle et al. 2011). Similar "what-if" scenarios can be analyzed using the conservation status assessment presented here to provide quantitative insight into conservation efforts prior to their initiation. By the same token, because the regional endemism scoring component carried so much weight, our assessment is also sensitive to detecting declines by species outside of the Chihuahuan Desert region if the proportion of collections within the region increases over time. As new information is collected and uploaded to GBIF (or other comprehensive biodiversity databases), the status of species included in this assessment should be reevaluated.

Conclusions

The status of the U.S. Chihuahuan Desert fish fauna broadly matches the status of desert fish faunas elsewhere and requires continued conservation and research efforts to preserve remaining species. This work benefits conservation efforts by synthesizing current assessments and providing an additional framework for measuring change in status through repeated assessments. Results also support previous conclusions that although national parks do provide habitat for imperiled fishes, these protected areas alone are not enough to preserve existing biodiversity (Lawrence et al. 2011). Consequently, spatially-based conservation efforts at broader spatial scales are necessary for meaningful protection (Garrett et al. 2019), especially given expected expansion of habitat alterations in the region (McClung et al. 2019). Conservation status assessments in which information on biodiversity and natural features is collected are a key step in the systematic conservation planning process that ultimately informs management actions (Adams et al. 2019). Unfortunately, status assessments of freshwater fishes lag behind other vertebrates, especially in remote desert regions (Miqueleiz et al. 2020). As habitats in desert regions continue to be altered by human activities such as water over-allocation, conservations assessments of desert fishes will become increasingly important for advancing the battle against extinction (Propst et al. 2020).

Acknowledgments

This study was conducted with support from the Texas Parks and Wildlife Department State Wildlife Grant Program (grant # TX-T-183-441 R-1) and the USDA National Institute of Food and Agriculture, HATCH Project 1017538. Manuscript drafts were improved by Chandler Creek chats with THP and befitted from the relentless spirit of Bob Wiley.

ORCID

Joshuah Perkin https://orcid.org/0000-0003-4928-9178
Matthew Troia https://orcid.org/0000-0001-9403-9931
Matthew Acre https://orcid.org/0000-0002-5417-9523

References

Acre, M. R., J. S. Perkin, and M. G. Bean. 2021. Multiple survey methods reveal greater abundance of endangered pupfish in restored habitats. Aquatic Conservation: Marine and Freshwater Ecosystems 31(1):198-209.

Adams, V. M., M. Mills, R. Weeks, D. B. Segan, R. L. Pressey, G. G. Gurney, C. Groves, F. W. Davis, and J. G. Álvarez-Romero. 2019. Implementation strategies for systematic conservation planning. Ambio 48:139-152.

Bachman, S., J. Moat, A. W. Hill, J. De La Torre, and B. Scott. 2011. Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. ZooKeys 150:117-126.

Beck, J., M. Böller, A. Erhardt, and W. Schwanghart. 2014. Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. Ecological Informatics 19:10-15.

Bell, G. P., S. Yanoff, J. Karges, J. A. Montoya, S. Najera, A. M. Arango, and A. G. Sada. 2004. Conservation blueprint for the Chihuahuan Desert ecoregion. Pages 1-36 in J. C. Barlow, A. M. Powell, and B. N. Timmermann, editors. Proceedings of the Sixth Symposium on the Natural Resources of the Chihuahuan Desert Region, Texas Tech University Press, Lubbock, Texas.

Birdsong, T. W., G. P. Garrett, M. G. Bean, P. T. Bean, S. Curtis, P. Fleming, A. Grubh, D. LutzCarrillo, K. B. Mayes, C. Robertson, S. Robertson, J. W. Schlechte, and N. G. Smith. 2020a. Conservation of Texas freshwater fish diversity: selection of Species of Greatest Conservation Need. Texas Parks and Wildlife

Department. PWD RP T3200-2780 (10/20). Austin, Texas. Available online: https://tpwd.texas.gov/publications/pwdpubs/media/PWD%20RP%20T3200-2780%20(Oct%202020).pdf

Birdsong, T. W., G. P. Garrett, M. G. Bean, S. G. Curtis, K. B. Mayes, S. M. Robertson. 2020b. Conservation status of Texas freshwater fishes: Informing state-based species protections. Journal of the Southwestern Association of Fish and Wildlife Agencies 8:40-52.

Birdsong, T. W., G. P. Garrett, B. J. Labay, M. G. Bean, P. T. Bean, J. Botros, M. J. Casarez, and D. A. Hendrickson 2019. Texas Native Fish Conservation Areas Network: strategic investments in restoration and preservation of freshwater fish diversity. Pages 183-229 in D. C. Dauwalter, T. W. Birdsong, and G. P. Garrett, editors. Multispecies and watershed approaches to freshwater fish conservation. American Fisheries Society Symposium Volume 91, Bethesda, Maryland.

Budy, P., M. M. Conner, N. L. Salant, and W. W. Macfarlane. 2015. An occupancy-based quantification of the highly imperiled status of desert fishes of the southwestern United States. Conservation Biology 29(4):1142-1152.

Carson, E. W., A. H. Hanna, G. P. Garrett, J. R. Gibson, and J. R. Gold. 2010. Conservation genetics of cyprinid fishes (genus Dionda) in southwestern North America. II. Expansion of the known range of the Manantial Roundnose Minnow, Dionda argentosa. The Southwestern Naturalist 55(4):576-581.

Cohen, A. E., G. P. Garrett, M. J. Casarez, D. A. Hendrickson, B. J. Labay, T. Urban, J. Gentle, D. Wiley, and D. Walling. 2018. Conserving Texas biodiversity: status, trends, and conservation planning for fishes of greatest conservation need. Texas Parks and Wildlife Department, Austin, Texas.

Cohen, A. E., D. A. Hendrickson, and G. P. Garrett. 2020. The Value of Specimen Collections for Conserving Biodiversity. Pages 199-206 in D. L Propst, J. E. Williams, K. R. Bestgen, and C. W. Hoagstrom, editors. Standing between Life and Extinction: Ethics and Ecology of Conserving Aquatic Species in North American Deserts. The University of Chicago Press, Chicago, Illinois.

Contreras-Balderas, S., G. Ruiz-Campos, J. J. Schmitter-Soto, E. Díaz-Pardo, T. Contreras McBeath, M. Medina-Soto, L. Zambrano-González , A. Varela-Romero , R. Mendoza-Alfaro , C. Ramírez-Martínez , M. A. Leija-Tristán , P. Almada-Villela , D. A. Hendrickson, and J. Lyons. 2008. Freshwater fishes and water status in México: A country-wide appraisal. Aquatic Ecosystem Health and Management 11(3):246-256.

Conway, K. W., and D. Kim. 2016. Redescription of the Texas Shiner Notropis amabilis from the southwestern United States and northern Mexico with the reinstatement of N. megalops (Teleostei: Cyprinidae). Ichthyological Exploration of Freshwaters 26(4):305-340.

Craig, C. A., and T. H. Bonner. 2019. Drainage basin checklists and dichotomous keys for inland fishes of Texas. ZooKeys 874:31-45.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z. I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A-H. Prieur-Richard, D. Soto, M. L. J. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81:163-182.

Edwards, R. J. 2017. Biological monitoring of the reintroduction efforts of the Rio Grande silvery minnow into the Big Bend region of Texas and Mexico. Final performance report to Texas Parks and Wildlife Department Endangered Species Program. Available online: https://tpwd.texas.gov/business/grants/wildlife/section-6/docs/fish/tx-e-169-r-final-performance-report.pdf

Edwards, R. J., G. P. Garrett, and E. Marsh-Matthews. 2002. Conservation and status of the fish communities inhabiting the Rio Conchos basin and middle Rio Grande, Mexico and USA. Reviews in Fish Biology and Fisheries 12:119-132.

Fagan, W. F., P. J. Unmack, C. Burgess, and W. L. Minckley. 2002. Rarity, fragmentation, and extinction risk in desert fishes. Ecology 83(12):3250-3256.

Faucheux, N. M., C. A. Craig, and T. H. Bonner. 2019. Rapid Assessment for Identifying Species of Greatest Conservation Need: Towards a Unified Approach. Fisheries 44(10):488-497.

Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52(6):483-498.

Gärdenfors, U., C. Hilton-Taylor, G. M. Mace, J. P. Rodríguez. 2001. The application of IUCN Red List criteria at regional levels. Conservation Biology 15(5):1206-1212.

Garrett, G. P., T. W. Birdsong, and M. G. Bean, and B. J. Labay. 2019. Chihuahuan Desert Native Fish Conservation Areas: A Multispecies and Watershed

Approach to Preservation of Freshwater Fish Diversity. Pages. 231-252 in D. C. Dauwalter, T. W. Birdsong, and G. P. Garrett, editors. Multispecies and watershed approaches to freshwater fish conservation. American Fisheries Society Symposium Volume 91, Bethesda, Maryland.

Garrett, G. P., C. Hubbs, and R. J. Edwards. 2005. Threatened fishes of the world: Cyprinodon eximius Girard 1859. Environmental Biology of Fishes 72:98.

Garrett, G. P., and G. C. Matlock. 1991. Rio Grande Cutthroat Trout in Texas. Texas Journal of Science 43(4):405-410.

Gauthier, P., M. Debussche, and J. D. Thompson. 2010. Regional priority setting for rare species based on a method combining three criteria. Biological Conservation 143(6):1501-1509.

Haak, A. L., and J. E. Williams. 2012. Spreading the risk: native trout management in an warmer and less-certain future. North American Journal of Fisheries Management 32(2):387-401.

Heard, T. C., J. S. Perkin, and T. H. Bonner. 2012. Intra-annual variation in fish communities and habitat associations in a Chihuahua Desert reach of the Rio Grande/Rio Bravo Del Norte. Western North American Naturalist 72(1):1-15.

Hendrickson, D. A., J. Johnson, P. Sprouse, S. Howard, G.P. Garrett, J.K. Krejca, A. Gluesenkamp, J. A. Dávila Paulín, L. Dugan, A. E. Cohen, A. Hernández Espriú, J. P. Sullivan, D. B. Fenolio, J. Karges, R. Smith, F. J. García De León, B. Wolaver?, J. Reddell. 2017. Discovery of the Mexican Blindcat, Prietella phreatophila, in the U.S., and an update on its rangewide conservation status. University of Texas Biodiversity Center, Austin, Texas.

Hill, R. A., M. H. Weber, S. G. Leibowitz, A. R. Olsen, and D. J. Thornbrugh. 2016. The Stream-Catchment (StreamCat) Dataset: A database of watershed metrics for the conterminous United States. JAWRA Journal of the American Water Resources Association 52(1):120-128.

Hoagstrom, C. W., N. D. Zymonas, S. R. Davenport, D. L. Propst, and J. E. Brooks. 2010. Rapid species replacements between fishes of the North American plains: a case history from the Pecos River. Aquatic Invasions 5(2):141-153.

Huang, J., and E. A. Frimpong. 2015. Using historical atlas data to develop high-resolution distribution models of freshwater fishes. PloS one, 10(6), e0129995.

Hubbs, C., R. J. Edwards, and G. P. Garrett. 2008. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Academy of Science 60:2-87.

IUCN (International Union for Conservation of Nature). 2012. IUCN red list categories and criteria: version 3.1. IUCN Species Survival Commission.

Jaeger, K. L., J. D. Olden, and N. A. Pelland. 2014. Climate change poised to threaten hydrologic connectivity and endemic fishes in dryland streams. Proceedings of the National Academy of Sciences 111(38):13894-13899.

Jelks, H.L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson and S. P. Platania. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries, 33(8):372-407.

Koch, J. D. and M. C. Quist. 2010. Current status and trends in shovelnose sturgeon (Scaphirhynchus platorynchus) management and conservation. Journal of Applied Ichthyology 26(4):491-498.

Lawrence, D. J., E. R. Larson, C. A. R. Liermann, M. C. Mims, T. K. Pool, and J. D. Olden. 2011. National parks as protected areas for US freshwater fish diversity. Conservation Letters 4(5):364-371.

Malone, E. W., J. S. Perkin, B. M. Leckie, M. A. Kulp, C. R. Hurt, and D. M. Walker. 2018. Which species, how many, and from where: Integrating habitat suitability, population genomics, and abundance estimates into species reintroduction planning. Global Change Biology 24(8):3729-3748.

McClung, M. R., N. T. Taylor, B. K. Zamzow, E. T. Stone, H. Abad, and M. D. Moran. 2019. The threat of energy diversification to a bioregion: a landscape-level analysis of current and future impacts on the US Chihuahuan Desert. Regional Environmental Change 19(7):1949-1962.

McClure-Baker, S. A., A. A. Echelle, R. A. Van den Bussche, A. F. Echelle, D. A. Hendrickson, and G. P. Garrett. 2010. Genetic status of headwater catfish in Texas and New Mexico: a perspective from mtDNA and morphology. Transactions of the American Fisheries Society 139(6):1780-1791.

McKay, L., T. Bondelid, and T. Dewald. 2013. National Hydrography Dataset Plus Version Two. Available online: https://www.usgs.gov/core-science-systems/ngp/national-hydrography [Accessed 1 August 2019].

Meffe, G. K., and R. C. Vrijenhoek. 1988. Conservation genetics in the management of desert fishes. Conservation Biology 2(2):157-169.

Miller, R. R. 1978. Composition and derivation of the native fish fauna of the Chihuahuan Desert region. Pages 365-381 in R. H. Wauer and D. H. Riskind, editors. Transactions of the Symposium of the Biological Resources of the Chihuahuan Desert Region, United States and Mexico. United States National Park Service Transactions Proceedings Series 3. Sul Ross State University, Alpine, Texas.

Minckley W. L., and J. E. Deacon. 1991. Battle against extinction: native fish management in the American West. University of Arizona Press, Tuscon, AZ.

Miqueleiz, I., M. Bohm, A. H. Ariño, and R. Miranda, R. 2020. Assessment gaps and biases in knowledge of conservation status of fishes. Aquatic Conservation: Marine and Freshwater Ecosystems 30(2):225-236.

Moyer, G. R., M. Osborne, and T. F. Turner. 2005. Genetic and ecological dynamics of species replacement in an arid-land river system. Molecular Ecology 14(4):1263-1273.

Moyle, P. B., J. V. Katz, and R. M. Quiñones. 2011. Rapid decline of California's native inland fishes: a status assessment. Biological Conservation 144(10):2414-2423.

Osborne, M., D. Portnoy, A. Fields, Conway, K., M. Bean, and C. W. Hoagstrom. 2021. Under the radar: genetic assessment of Rio Grande Shiner (Notropis jemezanus) and Speckled Chub (Macrhybopsis aestivalis), two Rio Grande basin endemic cyprinids that have experienced recent range contractions. Conservation Genetics 22:187–204.

Parker, S. D., J. S. Perkin, M. G. Bean, D. Lutz-Carrillo, and M. R. Acre. 2021. Temporal distribution modelling reveals upstream habitat drying and downstream non-native introgression are squeezing out an imperiled headwater fish. Diversity and Distributions 27(3):533-551.

Pinion, A. K., S. D. George, J. S. Perkin, and K. W. Conway. 2018. First record of the Conchos Shiner Cyprinella panarcys (Hubbs & Miller, 1978) from the mainstem of the Rio Grande along the USA–Mexico border. Check List 14(6)1123–1129.

Pister, E. P. 1974. Desert fishes and their habitats. Transactions of the American Fisheries Society 103(3):531-540.

Pool, T. K., A. L. Strecker, and J. D. Olden. 2013. Identifying preservation and restoration priority areas for desert fishes in an increasingly invaded world. Environmental Management 51(3):631-641.

Propst, D. L., J. E. Williams, K. R. Bestgen, and C. W. Hoagstrom. 2020. Standing between Life and Extinction: Ethics and Ecology of Conserving Aquatic Species in North American Deserts. The University of Chicago Press, Chicago, Illinois.

Pyke, G. H. 2008. Plague minnow or mosquito fish? A review of the biology and impacts of introduced Gambusia species. Annual Review of Ecology, Evolution, and Systematics 39:171-191.

Robertson, S. M., and T. H. Bonner. 2016. Effects of habitat utilization on the life histories of two imperiled, sympatric Dionda (Cyprinidae) in the Rio Grande basin, Texas. The American Midland Naturalist 175(2):222-232.

Sanchez, J. L., B. B. Boutwell, S. T. Hamontree, G. P. Garrett, R. H. Lewis, A. N. Ragan, M. Tobler, and R. D. Haynes, R. D. 2014. Reproductive characteristics of two Gambusia congeners in west Texas. The Southwestern Naturalist 59(3):438-441.

Schmidt Jr, R. H. 1979. A climatic delineation of the 'real'Chihuahuan Desert. Journal of Arid Environments 2(3):243-250.

Schönhuth, S., D. M. Hillis, D. A. Neely, L. Lozano-Vilano, A. Perdices, and R. L. Mayden. 2012. Phylogeny, diversity, and species delimitation of the North American round-nosed minnows (Teleostei: Dionda), as inferred from mitochondrial and nuclear DNA sequences. Molecular Phylogenetics and Evolution 62(1):427-446.

Smith, D. R., N. L. Allan, C. P. McGowan, J. A. Szymanski, S. R. Oetker, and H. M. Bell. 2018. Development of a species status assessment process for decisions under the US Endangered Species Act. Journal of Fish and Wildlife Management 9(1):302-320.

Stewart, D. R., M. J. Butler, G. Harris, and W. R. Radke. 2017. Mark-recapture models identify imminent extinction of Yaqui catfish Ictalurus pricei in the United States. Biological Conservation 209:45-53.

Stolar, J., and S. E. Nielsen. 2015. Accounting for spatially biased sampling effort in presence-only species distribution modelling. Diversity and Distributions 21(5):595-608.

Taylor, C. M., S. Miyazono, C. A. Cheek, R. J. Edwards, and R. Patiño. 2019. The spatial scale of homogenisation and differentiation in Chihuahuan Desert fish assemblages. Freshwater Biology 64(1):222-232.

TNRIS (Texas Natural Resources Information System). 2015. Political Boundaries, 2015-12-16. Available online: https://data.tnris.org/ [Accessed 25 September 2019].

TPWD (Texas Parks and Wildlife Department). 2019. State Park Boundaries geographic information system data. Available online at: https://tpwd.texas.gov/gis/ [accessed 25 September 2019].

TNC (The Nature Conservancy). 2019. TNC Lands and Water online database. Available online: http://www.tnclands.tnc.org/ [Accessed 25 September 2019].

USEPA (United States Environmental Protection Agency). 2019. Level III Ecoregions of North America Shapefile. Available online: https://www.epa.gov/eco-research/ecoregions-north-america [Accessed 25 August 2019].

U.S. Geological Survey (USGS) Gap Analysis Project (GAP), 2018, Protected Areas Database of the United States (PAD-US): U.S. Geological Survey data release, Available online: https://doi.org/10.5066/P955KPLE.

Vollering, J., R. Halvorsen and S. Mazzoni. 2019. The MIAmaxent R package: Variable transformation and model selection for species distribution models. Ecology and evolution 9(21):12051-12068.

Wang, T., A. Hamann, D. Spittlehouse, and C. Carroll. 2016. Locally downscaled and spatially customizable climate data for historical and future periods for North America. PloS one, 11(6), e0156720.

Wilde, G. R., and A. A. Echelle. 1992. Genetic status of Pecos pupfish populations after establishment of a hybrid swarm involving an introduced congener. Transactions of the American Fisheries Society 121(3):277-286.

Manuscripts in this Desert Fishes Council Special Publication 2021 were submitted to the Chihuahuan Desert Symposium held during the 2019 Desert Fishes Council Meeting.

Appendix Table 1. References for fish occurrence data obtained from the Global Biodiversity Information Facility (GBIF) including species names and authorities as well as GBIF references for obtaining the occurrence data used in the spatially-based conservation status assessment. Species are given in the order of conservation status with most imperiled first (see Table 2 in the main text) and species for which authorities are given in parentheses represent species previously described as a member of a different genus.

GBIF Name and Authority	GBIF Reference
Gambusia gaigei Hubbs, 1929	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.ysxiee
Cyprinodon bovinus Baird & Girard, 1853	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.wxu3gq
Gambusia krumholzi Minckley, 1963	GBIF.org (19 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.n19sxf
Cyprinodon eximius Girard, 1859	GBIF.org (25 September 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.uk2iok
Gambusia nobilis (Baird & Girard, 1853)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.tvardu
Cyprinodon pecosensis Echelle & Echelle, 1978	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.tsekce
Cyprinodon elegans Baird & Girard, 1853	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.1yn4ft
Notropis simus pecosensis Gilbert & Chernoff, 1982	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.ffnngq
Hybognathus amarus (Girard, 1856)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.9ovqeq
Dionda diaboli Hubbs & Brown, 1957	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.dbozrz
Cyprinella proserpina (Girard, 1856)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.6hprtv
Cycleptus elongatus (Lesueur, 1817)	GBIF.org (19 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.axes7e
Notropis chihuahua Woolman, 1892	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.5m8fwj
Moxostoma albidum (Girard, 1856)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.kp4zhu
Etheostoma grahami (Girard, 1859)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.g6n8a1
Notropis megalops (Rafinesque, 1817)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.pzjz51
Ictalurus lupus (Girard, 1858)	GBIF.org (11 September 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.c9bg8a
Macrhybopsis aestivalis (Girard, 1856)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.nabz8c
Dionda argentosa Girard, 1856	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.puiiuh
Notropis braytoni Jordan & Evermann, 1896	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.il5tbk
Notropis jemezanus (Cope, 1875)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.wplvdn
Gambusia geiseri Hubbs & Hubbs, 1957	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.ib0qxa
Gila pandora (Cope, 1872)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.fvxjs5
Campostoma ornatum Girard, 1856	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.u1ufmj

Lepisosteus oculatus Winchell, 1864	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.lph677
Aplodinotus grunniens Rafinesque, 1819	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.xfmdxm
Ictiobus bubalus (Rafinesque, 1818)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.axzt0o
Ameiurus melas (Rafinesque, 1820)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.92zi3a
Notropis amabilis (Girard, 1856)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.uumksy
Ameiurus natalis (Lesueur, 1819)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.hvvg8k
Dionda episcopa Girard, 1856	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.8mbdzw
Herichthys cyanoguttatus Baird & Girard, 1854	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.jp49x9
Pylodictis olivaris (Rafinesque, 1818)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.0gaxlo
Moxostoma congestum (Baird & Girard, 1854)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.1gdrx2
Lucania parva (Baird & Girard, 1855)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.jqmmes
Ictalurus furcatus (Valenciennes, 1840)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.rzwnur
Pimephales promelas Rafinesque, 1820	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.aei1eh
Astyanax mexicanus (De Filippi, 1853)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.kxaj2n
Carpiodes carpio (Rafinesque, 1820)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.xpefpx
Lepisosteus osseus (Linnaeus, 1758)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.rpx9qy
Rhinichthys cataractae (Valenciennes, 1842)	GBIF.org (11 September 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.63awtc
Lepomis megalotis (Rafinesque, 1820)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.s32yrh
Gambusia affinis (Baird & Girard, 1853)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.9jlysg
Cyprinella lutrensis (Baird & Girard, 1853)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.uund6r
Lepomis cyanellus Rafinesque, 1819	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.ozxj1w
Dorosoma cepedianum (Lesueur, 1818)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.rod3cl
Pimephales vigilax (Baird & Girard, 1853)	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.7xt0e2
Lepomis macrochirus Rafinesque, 1819	GBIF.org (16 November 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.yptrfc