Native Fish Conservation Areas of the Southwestern USA

Facilitating Landscape-Scale Conservation of Aquatic Habitats and Freshwater Fishes

Llano River, Texas located within the Central Edwards Plateau Rivers Native Fish Conservation Area

Trout Unlimited
Desert Fish Habitat Partnership
Siglo Group
Great Plains Landscape Conservation Cooperative
The University of Texas at Austin
Western Native Trout Initiative
Texas Parks & Wildlife
Southeast Aquatic Resources Partnership SARP
Southern Rockies Landscape Conservation Cooperative

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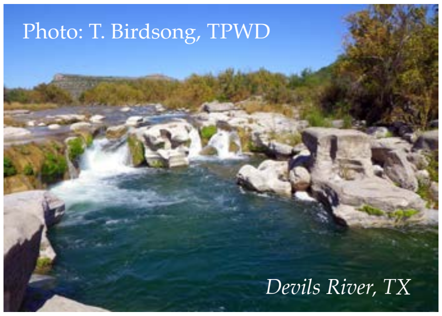

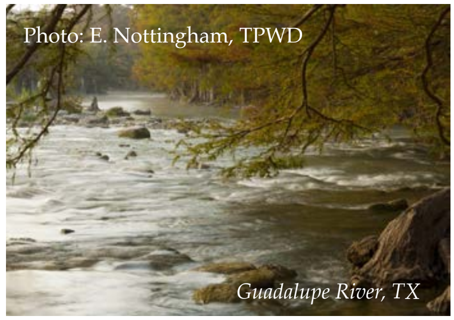

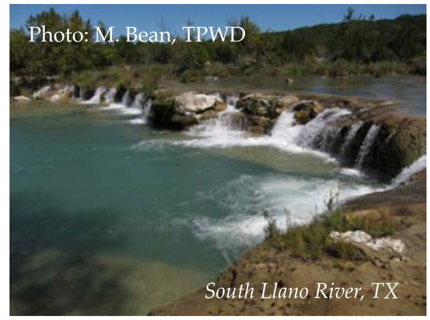

Executive Summary

Native Fish Conservation Areas of the southwestern USA consist of springs, ciénegas, creeks, rivers, and associated watersheds uniquely valued in preservation of freshwater fish diversity. These freshwater systems were identified through a spatial prioritization approach that identifies areas critically important to the long-term persistence of focal fish species. Through a shared mission of collaborative stewardship, conservation partnerships have formed among non-governmental organizations, universities, and state and federal agencies to plan and deliver actions to restore and preserve native freshwater fishes and aquatic habitats within the Native Fish Conservation Areas. Furthermore, the Native Fish Conservation Areas have increased awareness of the ecological, recreational, and economic values of freshwater systems in the region, and helped increase interest and capacity of local landowners, communities, and recreational users (e.g., paddlers, anglers) to act as advocates and local stewards of these systems. By facilitating partnership development, coordinating multi-species, watershed-based conservation planning, and leveraging technical and financial resources toward strategic conservation investments, Native Fish Conservation Areas have served as a catalyst for collaborative, science-based stewardship of native freshwater fishes and aquatic habitats in the southwestern USA. Efforts described herein to prioritize and deliver a network of Native Fish Conservation Areas in the southwestern USA offer a successful case study in multi-species and watershed approaches to freshwater fish conservation transferrable to other states and regions of the USA. This report offers a synthesis of recent (2011-2018) multi-species aquatic assessments, Native Fish Conservation Area prioritizations, conservation planning, and conservation delivery within the southwestern USA explicitly focused on implementation of the Native Fish Conservation Areas approach.

Photo: T. Birdsong, TPWD

Lower Colorado River Native Fish Conservation Area located downstream of Austin, Texas

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Conservation Needs of Native Freshwater Fishes in the Southwestern USA

The primary cause of fish species imperilment in the southwestern USA (delineated for the purposes of this report as the area contained within the U.S. states of Arizona, New Mexico, Oklahoma, and Texas) is anthropogenic alteration of freshwater systems, which continues to occur at rates and scales that threaten the long-term resiliency of freshwater habitats, species, and ecosystems (Dodds et al. 2013). Extraction of groundwater for agricultural irrigation, energy development, and municipal water supply has substantially altered groundwater levels and resulted in concomitant reductions in spring discharge and instream flows (Costigan and Daniel 2012; Steward et al. 2013; Garrett et al., in press). The erection of dams has fragmented rivers, altered natural flow patterns, and reduced the availability of suitable habitats for native fishes (Wilde and Urbanczyk 2013; Perkin et al. 2014; Worthington et al. 2014; Perkin et al. 2015; Mayes et al., in press). The cumulative impacts of urbanization and other land use changes have substantially altered natural watershed processes. These and a myriad of other interrelated challenges – degradation of water quality, instream habitat degradation, and the negative effects of non-indigenous species (e.g., predation on, competition with, and hybridization with native forms) – threaten freshwater fish diversity (Gido et al. 2010; Hoagstrom et al. 2011). If unchecked, these issues will likely continue to contribute to the imperilment and loss of native fishes and other freshwater species (Gido et al. 2010; Hoagstrom et al. 2011). Coordinated conservation intervention is urgently needed to ensure the preservation of native freshwater fish diversity (Hoagstrom et al. 2011; Perkin et al. 2015).

Declining freshwater fish diversity is a conservation issue not unique to the southwestern USA (Jelks et al. 2008). Freshwater fishes are threatened globally. Only 46% of 7,301 freshwater fish species have been mapped and have had threats identified, and of those, 31% are threatened with extinction (Darwall and Freyhof 2016). North America alone has over 700 species of freshwater fishes (Page and Burr 1991). Fishes, along with mollusks, snails, and crayfishes, are highly imperiled, and many species are listed as endangered and some are known to have gone extinct (Taylor et al. 2007; Jelks et al. 2008; Haag and Williams 2014). The imperilment status of fishes and other aquatic species also exceeds that of their terrestrial counterparts (Master et al. 2000). Innovative and systematic conservation approaches are needed that can be effective at restoration and maintenance of the functional watershed processes necessary to sustain freshwater systems and native fishes (Margules and

Pressey 2000; Groves et al. 2002; Balmford and Whitten 2003; Abell et al. 2007; Martinuzzi et al. 2014; Donlan 2015).

Partnership-Based Efforts to Conserve Native Fishes in the Southwestern USA

The National Fish Habitat Action Plan (NFHAP; AFWA 2012; http://fishhabitat.org) provides strategies for cooperative, inter-jurisdictional, and landscape-scale conservation of fishes and other aquatic resources in the USA, and serves as the strategic plan for a network of regionally-focused conservation partnerships. Within the southwestern USA, three conservation partnerships are actively engaged in regional implementation of the NFHAP.

The Desert Fish Habitat Partnership (DFHP) was formed in 2005 to conserve native desert fishes by protecting, restoring, and enhancing their habitats in cooperation with state and tribal fish and wildlife agencies, federal resource agencies, research and private organizations, and engaged individuals (www.desertfhp.org; DFHP 2015). DFHP supports on-the-ground projects that protect the most under-served, imperiled desert fish species by addressing critical fish and aquatic habitat conservation needs in the Great Basin and Mohave, Sonoran, and Chihuahuan deserts in the southwestern USA. These lands support 179 non-salmonid native fish taxa prioritized for conservation by DFHP under the guidance of State Wildlife Action Plans and DFHP (DFHP 2015). By identifying priority species and habitats, working across geo-political boundaries, integrating and applying the best available science and promoting community involvement, DFHP identifies and prioritizes necessary conservation actions to protect and restore desert fish habitats. Through 2018, DFHP has directed over $2.6 million in federal NFHAP funds to support 28 habitat protection and restoration projects to benefit desert fishes.

The Western Native Trout Initiative (WNTI) works collaboratively across 12 western U.S. states to conserve, protect, restore, and recover 21 native trout and char species throughout their historical ranges (www.westernnativetrout.org). Operating under the guidance of the Western Association of Fish and Wildlife Agencies since 2006 and as a recognized NFHAP Fish Habitat Partnership since 2007, WNTI is governed by a Steering Committee that represents 12 western U.S. state fish and wildlife agencies, 5 federal natural resource management agencies, tribes, and nonprofit conservation organizations. WNTI and its partners invest private and public resources toward completing the highest-impact, on-the-ground projects led by local communities and resource agencies across the western USA.

To achieve its mission, WNTI works together with its partners to establish joint priorities for conservation by combining science-based assessments with expert and local knowledge to establish joint priorities for native trout conservation at a landscape scale. Through its Campaign for Western Native Trout, WNTI catalyzes education, outreach, and stewardship by raising awareness for the importance of healthy watersheds and facilitating greater public support for native trout conservation within local communities. Between 2006 and 2017, WNTI directed almost $5.5 million in federal NFHAP funds leveraged with just over $25 million in public and private matching dollars to implement 141 priority conservation projects. WNTI and its partners have removed 87 barriers to fish passage, reconnected or improved 1,817 km (1,129 mi) of native trout habitat, assessed 671 watersheds or populations, and placed 30 protective fish barriers to conserve important native trout conservation populations (WNTI 2008; WNTI 2016).

The Southeast Aquatic Resources Partnership (SARP; http://www.southeastaquatics.net/) is a collaborative, multi-agency conservation partnership geographically aligned with the 14 member states of the Southeastern Association of Fish and Wildlife Agencies, including the southwestern U.S. states of Oklahoma and Texas. Formed in 2001, the mission of SARP is to protect, conserve and restore aquatic resources, including habitats throughout the region, for the continuing benefit, use and enjoyment of the American people. Since the partnership's inception, SARP has served as a regional catalyst and network builder for fish habitat conservation, spearheading regional assessments of flow alteration, riparian condition, and fish passage barriers, and supporting on-the-ground delivery of 180 aquatic habitat restoration projects. The partnership was formally-recognized as a NFHAP Fish Habitat Partnership in 2007, and in 2008, SARP and partners published the Southeast Aquatic Habitat Plan (SARP 2008), which established regional conservation objectives (Table 1) and targets (i.e., 5, 10, and 15-year outcomes) used by the partnership to monitor progress and to continually adapt and refine regional fish habitat conservation strategies (SARP 2014). The Southeast Aquatic Habitat Plan has also provided the fundamental underpinnings for multi-species, watershed-scale conservation projects conducted or supported by SARP through its Native Black Bass Initiative (http://southeastaquatics.net/sarps-programs/native-black-bass-initiative) and Southeast Aquatic Connectivity Project (http://southeastaquatics.net/sarps-programs/southeast-aquatic-connectivity-assessment-program-seacap).

Table 1 - Objectives of the Southeast Aquatic Habitat Plan, the strategic plan of the Southeast Aquatic Resources Partnership (SARP 2008, 2014).

Objectives of the Southeast Aquatic Habitat Plan
(1) Establish, improve and maintain riparian zones
(2) Improve or maintain water quality
(3) Improve or maintain watershed connectivity
(4) Improve or maintain appropriate hydrologic conditions for the support of biota
(5) Establish, improve and maintain sediment flows
(6) Maintain and restore physical habitat in freshwater systems
(7) Restore or improve the ecological balance in habitats negatively affected by invasive species
(8) Conserve, restore or create coastal, estuarine and marine habitats

Maximizing Efficiency and Effectiveness of Investments in Conservation of Native Fishes

Restoration of aquatic systems is now a multi-billion dollar per year industry (Bernhardt et al. 2005). Restoration programs exist in every corner of North America, as well as in many parts of the world (Cowx and Welcomme 1998; Palmer et al. 2007). Early restoration efforts (i.e., following passage of the Clean Water Act and similar environmental laws) focused on restoring water quality degraded from point source pollutants. Current restoration efforts have transitioned toward integrated restoration of ecosystem processes and ecological integrity (Beechie et al. 2013; Jones et al. 2018). The majority of restoration projects are small-scale, short-term, and implemented on a reach-by-reach basis, whereas some are focused in entire watersheds over decades (Bernhardt et al. 2007; Pierce and Podner 2019).

Efficient allocation of scarce resources to maximize conservation benefits is challenging but can be guided by effective goal development, resource assessment, planning, and prioritization (Knight et al. 2006; Ferrier and Wintle 2009). There are many different sites or watersheds in which to implement conservation actions, and prioritizing conservation actions or restoration treatments in a watershed can be difficult (Williams et al. 2007; Roni et al. 2013). However, advances in spatial data and assessment methods over the last 40 years help to facilitate a better understanding of resources and prioritization of conservation actions across broad landscapes (Ferrier and Wintle 2009). This has allowed spatial conservation assessment and prioritization to become more available as a formal part of conservation planning and decision making (Knight et al. 2006).

Assessment of aquatic systems and species can take many forms. It can range from assessment of water quality and single-species in individual waterbodies (Zale et al. 2012), to broad-scale surveys designed to draw regional inferences on the status and trend of ecological integrity (Karr 1993). More recently, assessment of aquatic systems has included spatially explicit, desktop assessments of habitat condition, ecological threats, and species diversity (Kuehne et al. 2017). This has been facilitated by recognition of the need to go beyond single-species approaches to focus on ecosystems and entire communities (Franklin 1993), as well as continued advancement of spatially explicit datasets representing various aquatic ecosystem components and improved prediction of species distributions (Olden 2003; Mainali et al. 2015; Dauwalter et al. 2017). Some contemporary multi-species aquatic conservation assessments now integrate conservation biology principles underpinning protected area or reserve selection to conserve biodiversity (Table 2) with ecological integrity and threat assessment in a spatially explicit framework. The assessment output is a conservation rank or value for each spatial planning unit (e.g., catchment, watershed, hydrologic unit) across entire river basins.

Table 2 - Definitions of terms and concepts used in spatial conservation planning and prioritization (Kukkala and Moilanen 2013).

Definitions
Systematic conservation planning - A structured approach to identify priority areas based on their complementarity
Complementarity - The contribution of a spatial planning unit toward a measure of biodiversity (i.e., functional, community, species) that complements other units
Comprehensiveness - The representation of many biodiversity features across all planning units in a set
Efficiency - Representation of the highest amount of biodiversity features in the fewest number of planning units
Irreplaceability - A measure of uniqueness associated with a spatial planning unit based on the biodiversity features represented
Representation - The occurrence of a biodiversity feature in a selected set of spatial planning units
Representativeness - The total number biodiversity features represented in a selected set of spatial planning units
Redundancy - The replication of the measure of biodiversity across spatial planning units

Methods for assigning conservation value to spatial planning units can generally be categorized as scoring-based or complementarity-based approaches (Ferrier and Wintle 2009). Scoring-based approaches are relatively straight-forward as they assign an independent score for each planning unit based on specified factors of interest (e.g., habitat quality, presence/absence of focal species, species richness, threats). Multiple factors are often scored and summed (or multiplied) into a final composite score intended to reflect conservation value. For example, if each planning unit in Figure 1A receives one point for each species present, planning unit 1 will have the highest score (and thus highest conservation value) and planning units 2 and 3 will have the same score (tied conservation value) despite different species composition and not accounting for the species represented in planning unit A. While scoring approaches have utility for some applications, they fail to account for species membership and complementarity, that is, how different planning units complement each other when considered as a set (McKinney 1997), which is one of the conceptual underpinnings of contemporary systematic conservation planning (Margules and Pressey 2000; Sarkar and Illoldi-Rangel 2010; Linke et al. 2011). Some conservation planning problems require that the maximum number of species be represented in a minimum number (or a set number) of planning units. For example, in Figure 1A planning unit 1 has the highest conservation value because it represents five species. However, the next highest conservation value would be assigned to planning unit 5 because it is the only planning unit that contains a new species not represented in planning unit 1; that is, planning unit 5 complements planning unit 1 and together they represent the greatest number of species across a set of two planning units. Thus, their value depends on what is represented in the other planning units in the set and how they complement one another. A set of planning units with high complementarity will have the most species represented in the fewest number of planning units, or in other words, they will have the highest benefit:cost (number of species:number of units) ratio for conservation purposes (Nel et al. 2009). Complementarity is often the fundamental basis for the complex algorithms implemented in popular spatial conservation prioritization software programs (e.g., Marxan, Zonation, ConsNet, C-Plan; Moilanen et al. 2005).

Quantitative approaches to conservation assessment for terrestrial and marine systems were developed far ahead of approaches for freshwater systems (Linke et al. 2011). However, assessment methods now exist to address the unique lateral and longitudinal characteristics of dendritic riverine systems (Linke et al. 2008). Unlike terrestrial systems, riverine systems can be impacted by threats occurring far upstream in the watershed. Freshwater assessment

A)

Species	Planning Unit 1	2	3	4	5	Range
A	1	1	1	1	0	**4**
B	1	0	1	1	0	**3**
C	1	1	0	0	1	**3**
D	1	0	1	1	0	**3**
E	1	1	1	0	0	**3**
F	0	1	0	0	1	**2**
G	0	0	0	0	1	**1**
Richness	**5**	**4**	**4**	**3**	**3**	

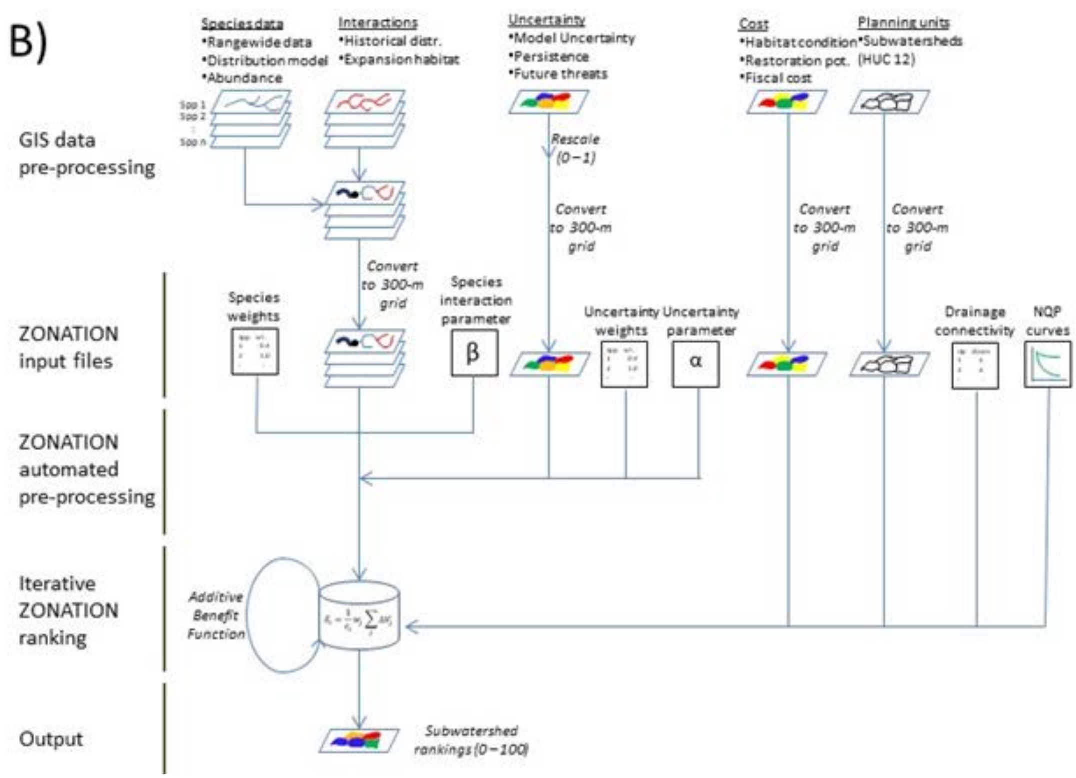

Figure 1 - Simple set of planning units and species presence data showing complementarity and species representation (A), versus one example of a more complex analysis workflow that incorporates different types of species data, connectivity among planning units, habitat condition, species interactions, and other ecological factors in a complementary-based algorithm (B).

methods can now account for dendritic connectivity in riverine systems and integrate them with complementarity principles (Abell et al. 2007; Linke et al. 2008). Zonation and Marxan are two commonly-used software programs that now have this capability. At the same time, conservation assessments can also incorporate more than just species representation by including factors that contribute to species persistence such as habitat types, stream connectivity, dispersal capabilities, or minimum home range size (Margules and Pressey 2000; Nel et al. 2011). Figure 1B depicts the complexity and ecological reality that can now be incorporated into aquatic conservation assessments, which includes: species representation and persistence, interactions between species, minimum habitat requirements based on home range size, and the effect of current habitat conditions or future threats on the landscape. Each of these factors can now be integrated into a comprehensive assessment of entire river basins where each catchment or stream segment can be assigned a conservation value between 0 (low value) to 1 (high value). High conservation values reflect important planning units for the representation of native fish species balanced by the habitat condition or threat level, watershed connectivity, and in some cases proximity to protected areas (e.g., National Parks). The availability of these approaches has led to their increased use in freshwater conservation planning applications (Wenger et al. 2009; Dauwalter et al. 2011; Howard et al. 2018; Birdsong et al., in press).

Multispecies Aquatic Assessments Conducted within the Southwestern USA

Conservation organizations and partnerships representing large geographies often have the difficult task of deciding where to focus conservation efforts with limited resources. Numerous approaches to aquatic conservation assessment have been developed to help with this task (Kuehne et al. 2017). Assessment frameworks range from simple overlays of spatial data on environment and human stressors, to very quantitative optimization algorithms focused on the conservation principles of comprehensiveness, representation, and others while accounting for species biology (home ranges), landscape connectivity, threats, climate change, and other factors as described herein and elsewhere (Pressey and Cowling 2001; Moilanen et al. 2005). Algorithms, and the assessment outputs they produce (rankings and priority areas), are not a panacea but rather serve to guide and inform rather than prescribe planning decisions. They are part of the planning process and not the process itself. The assessments simply highlight important areas and become part of a decision support system, in which humans are integral, for conservation decision making (Pressey and Cowling 2001). When good data are available, quantitative assessment and prioritization can enhance the explicitness, repeatability, and scientific credibility of conservation decision making (Ferrier and Wintle 2009).

As partnerships representing large geographies, DFHP and WNTI have had to be creative in completing aquatic assessments in focal basins (and WNTI focal species and subspecies) that represent both the scale at which the partnerships operate and a scale appropriate to the conservation priorities and historical ranges of native fishes. The partnerships have had to work together to identify diverse funding sources and diverse partners to pursue development of basin-specific assessments. Likewise, basin-specific aquatic assessments naturally align with the regional biogeography of fishes. For example, the historical distribution of native trouts largely align with the individual basins for which assessment were completed: Colorado River Cutthroat Trout *O. c. pleuriticus* in the Upper Colorado River basin; Apache Trout *O. apache* and Gila Trout *O. gilae* in the Lower Colorado River basin; Rio Grande Cutthroat Trout *O. c. virginalis* in the Rio Grande Basin. Non-game fish distributions are also, mostly, unique to individual basins at the same scale (Smith 1981). Early, trout-based rangewide assessments funded by WNTI have produced spatial data on trout populations across the species (or subspecies) ranges that been used directly in some assessments.

The aquatic assessments completed to date have largely been used to provide a landscape or basin-wide perspective to projects proposed to these Fish Habitat Partnerships for funding. Both Fish Habitat Partnerships use a scoring rubric to rank proposed projects. As mentioned earlier, projects proposed to DFHP for funding include projects on streams and rivers – habitats for which the assessments discussed herein focus – but they also include projects on springs and ciénegas where assessments have not been completed. The lack of consistent information across habitat types and geographies prohibits the assessments from being formally integrated into project scoring rubrics. However, completed assessments: 1) do give important basin-wide context to proposed projects, 2) highlight hydrologic units with high value for conserving native fish diversity at a landscape scale because of high species richness or representation of rare species; 3) identify habitat and protection needs by overlaying high value hydrologic units with human stressor indices or land protection status (Howard et al. 2018; Williams et al., in press); and 4) can be used to identify focal watersheds for collaboration, efficient use of resources, and targeted long-term conservation efforts (Dauwalter et al. 2011; Birdsong et al. 2015; Labay et al. 2018). Social, economic, and political considerations all influence where conservation is implemented on the ground. However, landscape-scale aquatic assessments such as those presented here can be used in conjunction with socioeconomic and political factors to ensure that opportunities for conservation action are balanced with biological priorities as a form of informed opportunism (Noss et al. 2002; Pressey and Bottrill 2008).

Efficient conservation delivery is a balance between pragmatism, socioeconomic and political forces, and maximizing the representation persistence of focal biodiversity. There are simply not enough conservation resources available to be wasteful, and many freshwater fishes are imperiled (Darwall and Freyhof 2016). Luckily, spatial conservation assessment methods are more accessible than ever and are being applied to aquatic systems with watersheds as a focal unit. Completed assessments facilitate conservation planning at landscape scale through integration with the local knowledge and pragmatism of field biologists that have expertise on native fishes and in habitat restoration, land protection, and threat abatement. This naturally lends itself to a dual-pronged approach that is both top down (assessment driven) and bottom up (local knowledge) to deliver informed and efficient conservation across broad landscapes and large river basins.

Because of the large landscapes they cover, DFHP and WNTI have together pursued development and use of multi-species aquatic assessments that highlight hydrologic units important for native fish diversity to inform partnership decision making within river basins (WNTI has also supported development of species-specific range-wide status assessments, e.g., Gresswell 2011; Muhlfeld et al. 2015). These assessments produce a rank for all catchments (land area draining a ~1-km stream segment) or subwatersheds (Hydrologic Unit Code 12, ~30,000 ha) that represent conservation value of that unit based on fish species richness and representation of rare species (representation, complementarity, and comprehensiveness), aquatic connectivity relative to species biology, and threats to aquatic systems (Figure 2). The values are scaled to range from low to high conservation value. The initial assessment effort (Table 3) focused on the Lower Colorado River basin, Arizona, whereby the U.S. Geological Survey initiated an aquatic gap analysis to identify riverine fishes that were inadequately represented (gaps) within the existing network of protected lands (e.g., National Parks; Whittier et al. 2011). The analytical framework used known and modeled species distributions, riverine connectivity, species-specific home range sizes, and an ecological threat index. The utility of the Lower Colorado River basin assessment resulted in interest in an equivalent assessment in the Upper Colorado River, which was funded through the U.S. Fish and Wildlife Service Multistate Conservation Grant program to the National Fish Habitat Partnership, administered by the Western Association of Fish and Wildlife Agencies and WNTI, and completed by the University of Missouri (Whittier and Sievert 2014). The Rio Grande basin assessment was funded by the Southern Rockies

Landscape Conservation Cooperative and WNTI, and it was completed by Siglo Group (Figures 2 and 3; Table 3; Labay et al. 2018). The diverse partners represented in each assessment effort represents a synergy towards combining resources to accomplish a common goal, that is, developing the assessment and shepherding it towards meaningful and targeted delivery of aquatic conservation on the landscape.

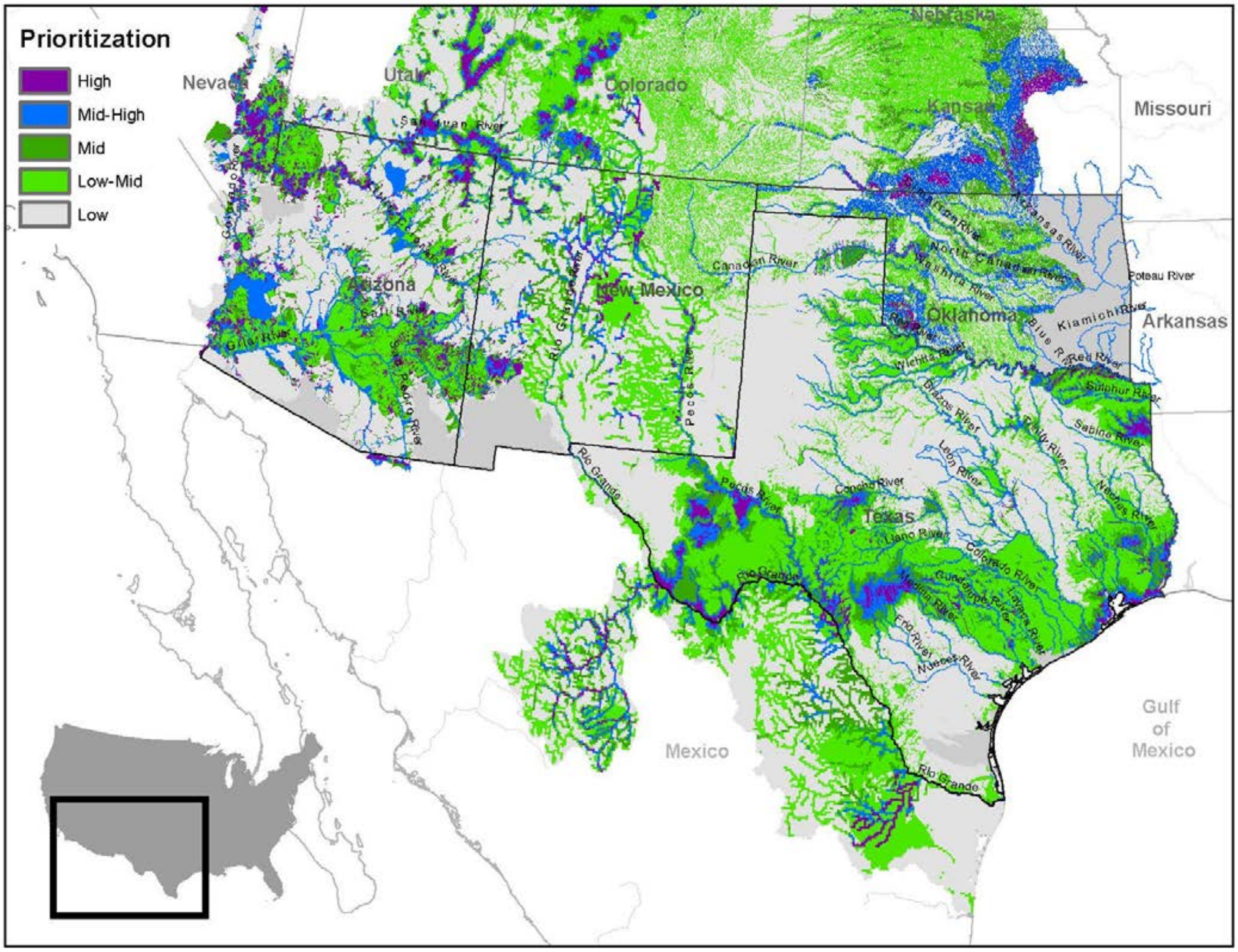

Figure 2 - Conservation value of freshwater systems of the southwestern USA based on fish species richness and representation of rare species (representation, complementarity, and comprehensiveness), aquatic connectivity relative to species biology, and threats to aquatic systems.

Table 3 - Funding sources and lead entities of multispecies aquatic assessments completed for use in State Fish and Wildlife Agency and Fish Habitat Partnership decision-making in the southwestern USA.

Region/Basin	Funding	Assessment Lead	Year Completed
Lower Colorado River Basin	U.S. Geological Survey National Gap Program	U.S. Geological Survey / Kansas State University	2011
High Plains, Southwestern Tablelands, Central Great Plains, Arizona/New Mexico Mountains, Chihuahuan Desert, and Edwards Plateau ecoregions of Texas	Texas Parks and Wildlife Department / Great Plains Landscape Conservation Cooperative	University of Texas at Austin / Texas Parks and Wildlife Department	2013
Upper Colorado River Basin	U.S. Fish and Wildlife Service Multistate Conservation Grant Program / Western Native Trout Initiative	University of Missouri	2014
Portions of the Arkansas, Canadian, and Red River Basins within the U.S. Great Plains	Great Plains Landscape Conservation Cooperative	University of Texas at Austin	2014
State of Texas	U.S. Fish and Wildlife Service State Wildlife Grants Program / Texas Parks and Wildlife Department	University of Texas at Austin / Texas Parks and Wildlife Department	2015
Rio Grande Basin	Southern Rockies Landscape Conservation Cooperative / Western Native Trout Initiative	Siglo Group	2018

Consistent with the conservation prioritization needs of DFHP and WNTI, SARP has collaborated with State Fish and Wildlife Agencies to select priority watersheds throughout the partnership's 14-state geography. Termed "Conservation Opportunity Areas," those watersheds have been targeted for investments in conservation planning, restoration of instream connectivity, instream flow restoration, riparian habitat restoration, and other conservation actions. Conservation Opportunity Areas have been selected based on priorities identified in existing conservation plans, such as State Wildlife Action Plans, with each member state requested by SARP to select their five highest priority watersheds (Hydrologic Unit Code 8). As a potential supplemental approach to consider in selection of Conservation Opportunity Areas, SARP partnered with the U.S. Fish and Wildlife Service Science Applications Program (i.e., Great Plains Landscape Conservation Cooperative), Great Plains

Fish Habitat Partnership, Texas Parks and Wildlife Department (TPWD), University of Texas at Austin, and Siglo Group to conduct a series of multi-species aquatic assessments (Table 3) that utilized consistent methods as those completed for DFHP and WNTI. The assessments combined known and modeled fish species distributions and spatial prioritization analysis to identify high priority freshwater systems within a portion of the State of Oklahoma contained within the U.S. Great Plains (funded by the Great Plains Landscape Conservation Cooperative; Labay et al., in press) and for the entirety of the State of Texas (funded in part by the Great Plains Landscape Conservation Cooperative and the U.S. Fish and Wildlife Service State Wildlife Grants Program; Birdsong et al., in press).

Freshwater systems of Texas and western Oklahoma were prioritized based on their ability to meet the four critical elements of a Native Fish Conservation Area (NFCA), as defined by Williams et al. (2011): (1) natural physical processes remain intact (or have the potential to be restored) within the watershed that support the maintenance of freshwater habitat complexity, diversity and connectivity; (2) habitats are contained within the watershed that support all life history stages of the fish species being preserved; (3) the watershed or fragmented river segment is large enough to provide for long-term persistence of native fish populations (e.g., effective population size); and (4) management plans and other agreements can be developed that will allow the watershed or river segment to be managed in a manner that sustains aquatic and riparian habitat integrity over time and across management jurisdictions and land ownerships. This resulted in development of conservation planning products including species distribution models for focal freshwater fishes, a landscape ranking and prioritization that identifies focal areas for conservation of focal species, and a spatial framework for conservation planning and delivery via identification of high-priority freshwater systems considered NFCAs (Birdsong et al., in press; Labay et al., in press). Detailed descriptions of the concepts and methods used in prioritization of NFCAs are discussed by Labay et al. (2018) and Labay et al. (in press). Thus, methods will be only briefly discussed here.

For the multispecies aquatic assessment focused on the State of Texas, fish species chosen for distribution modeling and subsequent analyses were selected on the basis of their inclusion in a recommended list of Texas freshwater fish species of greatest conservation need (SGCN) assembled by Cohen et al. (2018). The list identifies 90 species of freshwater fishes, each with a conservation status that warrants listing as SGCN (Appendix A). It is anticipated that those 90 species will be listed as SGCN in the forthcoming update of the Texas State Wildlife Action Plan (i.e., Texas Conservation Action Plan; TPWD 2012) in 2023. Species distribution models (SDMs) were assembled for 85 of the 90 species; SDMs were not assembled for four species that are likely extinct (Maravillas Red Shiner *Cyprinella lutrensis blairi*, San Marcos Gambusia *Gambusia georgei*, Phantom Shiner *Notropis orca*, Rio Grande Bluntnose Shiner *Inotropic simus simus*) or for one additional species considered a unique, disjunct population (Spotted Sucker *Minytrema melanops*). This list of focal species encompassed the freshwater fish SGCN contained in the interjurisdictional watersheds shared by the states of Oklahoma and Texas (i.e., Canadian and Red rivers).

The SDMs converted point occurrence data into range-wide probabilities of occurrence (Guisan et al. 2013). Fish occurrence data used in development of SDMs consisted of museum-vouchered specimens available from the University of Texas at Austin Fishes of Texas database and data available from the Global Biodiversity Information Facility that were compiled, reviewed, and partially normalized (Hendrickson et al. 2010; Cohen et al. 2013). Specific hydrologic, climatic, and topographic variables included in SDM development are described by Labay et al. (in press). Individual SDMs in GIS-ready formats and detailed information on the model production methodology can be accessed through the University of Texas at Austin Fishes of Texas Project model download portal (http://www.fishesoftexas.org/models/).

The SDMs were used within Zonation (conservation planning software; Moilanen et al. 2005) to spatially rank and prioritize freshwater systems based on their value in conservation of the diversity of freshwater fish SGCN. Conservation value was assessed based on spatially explicit levels of species, habitat, or ecosystem occurrence, as defined by SDM estimation of the relative probability of occurrence. The prioritization emphasized species rarity as opposed to species richness (Moilanen et al. 2005). This approach resulted in prioritization of freshwater systems important in preservation of the diversity of freshwater fish SGCN (Figure 2). Zonation was then used to identify species-based geographic management units, here referred to as NFCAs, based on distance and compositional similarity among the priority freshwater systems. This analysis resulted in identification of 20 NFCAs for inclusion in the target geography (Figure 3), which represents a selection of springs, ciénegas, creeks, rivers, and associated watersheds that serve as “native fish strongholds” and that are now considered priority landscapes for conservation investments by SARP, DFHP, TPWD, and local conservation partners (Birdsong et al., in press). The diversity of native and non-native fishes that occur (or occurred historically) in each of the 20 NFCAs are outlined in Appendix A. Consistent methods were used by Labay et al. (2018) to expand the multi-species aquatic assessment and NFCA prioritization of the Rio Grande basin within Texas to incorporate the

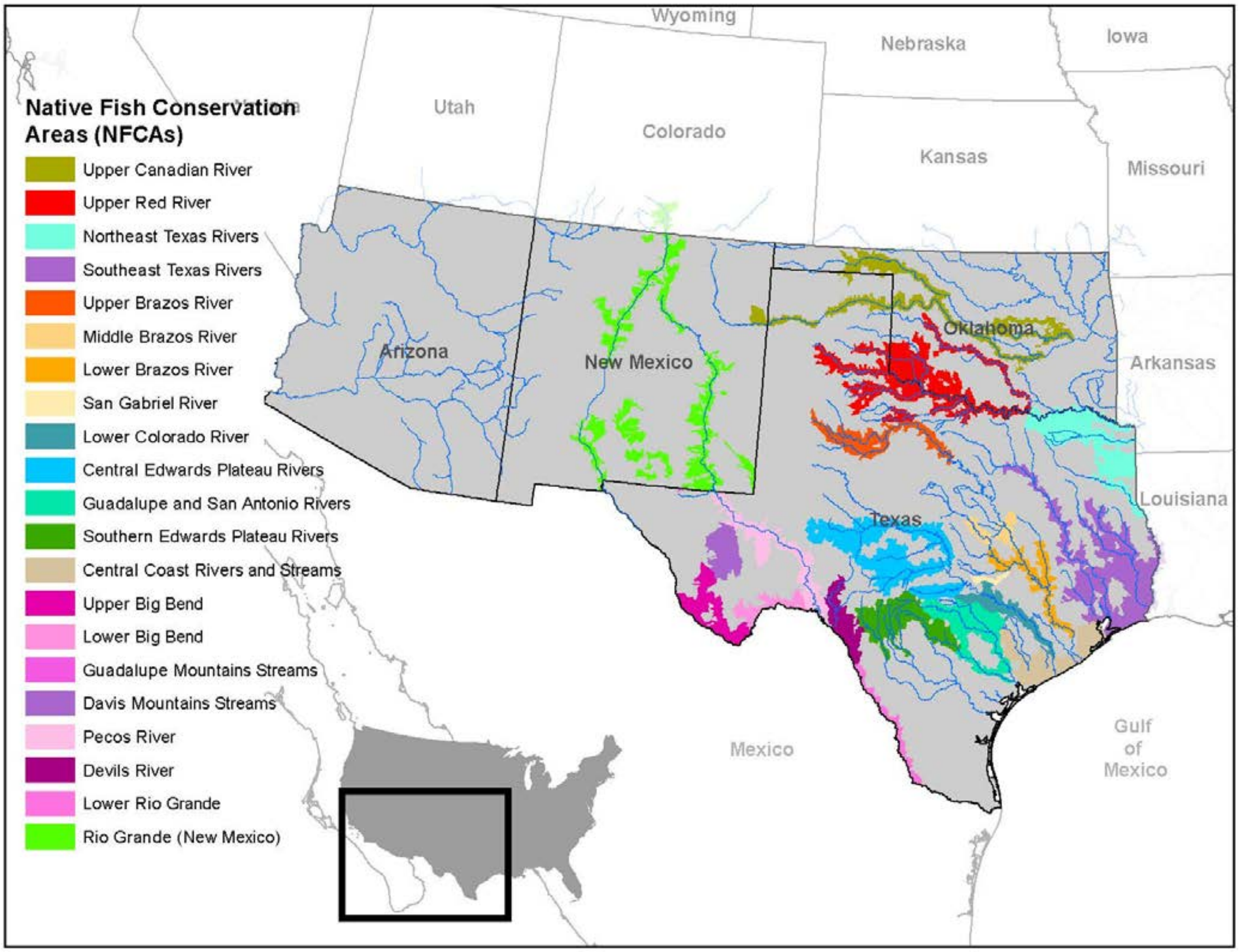

Figure 3 - Freshwater systems of the southwestern USA prioritized for investments in conservation of native freshwater fishes and aquatic habitats, and recommended as Native Fish Conservation Areas.

remainder of the basin in Colorado, New Mexico, and Mexico. Labay et al. (2018) recommended establishment of additional NFCAs within the upper Rio Grande, upper Pecos River, and their tributaries throughout the upper Rio Grande basin (i.e., area of Figure 3 shaded in lime green). Those recommended NFCAs are now being considered as potential priority areas for conservation investments by WNTI, DFHP, and partners.

Initial efforts to prioritize NFCAs in Texas were conducted in 2013 (Table 3), through funding provided by the Great Plains Landscape Conservation Cooperative (Birdsong et al., in press). That pilot phase focused on prioritization of freshwater systems for conservation of 71 fish SGCN that occur within six ecoregions located in the northwestern portion of the state (i.e., High Plains, Southwestern Tablelands, Central Great Plains, Arizona/New Mexico Mountains, Chihuahuan Desert, and Edwards Plateau ecoregions). Prioritization of freshwater systems in that geography identified the following 11 conservation priority areas: Upper Canadian River NFCA, Upper Red River NFCA, Upper Brazos River NFCA, Central Edwards Plateau Rivers NFCA, Southern Edwards Plateau Rivers NFCA, Devils River NFCA, Pecos River NFCA, Guadalupe Mountains Streams NFCA, Davis Mountains Streams NFCA, Upper Big Bend NFCA, and Lower Big Bend NFCA (Figure 3). Through additional funding provided by the Great Plains Landscape Conservation Cooperative, Labay et al. (in press) completed a prioritization of NFCAs throughout the entire geography of the Great Plains Landscape Conservation Cooperative. That prioritization recommended additional NFCAs within the states of Oklahoma, Kansas, Nebraska, and South Dakota, including expansion of the Upper Red River and Upper Canadian River NFCAs of Texas into western Oklahoma (Figure 3). Prioritization of NFCAs in the eastern and southern portions of Texas was subsequently completed in 2015 (Birdsong et al., in press), identifying nine additional conservation priority areas: Northeast Texas Rivers NFCA, Southeast Texas Rivers NFCA, San Gabriel River NFCA, Middle Brazos River NFCA, Lower Brazos River NFCA, Lower Colorado River NFCA, Guadalupe and San Antonio Rivers NFCA, Central Coast Rivers and Streams NFCA, and Lower Rio Grande NFCA (Figure 3). The collective value of these multispecies aquatic assessments is that the groundwork has now been laid for strategic conservation planning and delivery to be focused within a set of watersheds recognized as critically important in the preservation of regional freshwater fish diversity.

Conservation Planning within Native Fish Conservation Areas of the Southwestern USA

Critically important to the success of Fish Habitat Partnerships has been the ability to facilitate communication and cooperative planning among local, state, and federal natural resources management agencies, non-governmental organizations, and other stakeholders. Collaborative planning allows for identification of shared geographic (e.g., ecoregions, watersheds) and thematic (e.g., dam removal, flow restoration, riparian restoration) priorities and supports strategic investments and leveraging of available technical and financial resources, often allowing for significant expansion of the scope and scale of local conservation projects (e.g., extent of watershed restored, inclusion of project-based monitoring or applied research necessary to evaluate and improve restoration designs). The Fish Habitat Partnerships have supported implementation of numerous successful case studies in multi-jurisdictional, watershed-scale conservation planning and delivery that have demonstrated holistic, integrated, and multi-species approaches to conservation of aquatic resources (e.g., Birdsong et al. 2015). Those case studies highlight the value of a watershed-based approach in assembling and integrating interdisciplinary perspectives and expertise (e.g., aquatic biology, terrestrial ecology, fluvial geomorphology, public policy, fundraising, and advocacy) and in integrating formerly disjunct planning efforts such as state-based conservation planning activities that may only consider the portion of a multi-jurisdictional watershed or species range contained within that state. As Fish Habitat Partnerships expand this landscape-scale approach to other watersheds, assessments and decision support tools, such as those referenced above, are needed that help prioritize watersheds based on value in preservation of regional fish diversity and that help facilitate cooperation, foster collaboration, and guide strategic investments of available resources toward science-based conservation delivery.

Since prioritization of the initial 11 Texas NFCAs in 2013 (i.e., northwestern portion of Texas), TPWD, SARP, DFHP, and the U.S. Fish and Wildlife Service Science Applications Program have invested significant technical and financial resources toward conservation planning and delivery within those watersheds. This has included investments in habitat restoration (e.g., focal watersheds of the TPWD Landowner Incentive Program and SARP Aquatic Habitat Restoration Program), habitat preservation (e.g., targeted watersheds for conservation easements supported through the TPWD Farm and Ranch Lands Conservation Program), research (e.g., funding priorities of the State Wildlife Grants Program and Great Plains Landscape Conservation Cooperative), and biological assessments (supported through the joint TPWD and University of Texas at Austin gap sampling program). Those investments have contributed toward achieving the NFCA vision of restoring and preserving freshwater systems to the level that native fishes thrive as stable components of diverse ecological communities, simultaneously providing clean water, outstanding outdoor recreation, and a stable economic base for present and future citizens. This vision was adapted from the vision established for the Little Tennessee River NFCA (Harris et al., in press), which is considered the first NFCA officially designated in the USA.

Conservation planning and delivery within NFCAs of Texas has involved a diverse group of conservation partners from non-governmental organizations, state and federal agencies, and universities with a shared vision of collaborative stewardship and a shared mission to restore and preserve wild and native fishes and the habitats they need to thrive. Partners have focused on guiding strategic investments and leveraging available technical and financial resources to achieve scale-appropriate and transformative actions for conservation of native fishes, their habitats, and other freshwater resources. The critical elements of NFCAs described by Williams et al. (2011), outlined previously in this report, have been adopted as the core principles of the Texas NFCAs. To facilitate conservation planning and align specific conservation actions undertaken within Texas NFCAs with those core principles, eight goals and related implementation strategies were established (Table 4).

Table 4 - Goals and implementation strategies established for Native Fish Conservation Areas of Texas.

Goal 1 - Protect and maintain intact, healthy habitats
- Determine locations and extent of healthy habitats
- Assess degree of threats and limiting factors present in healthy habitats
- Develop a priority list of stream segments for protective actions
- Organize Technical Advisory Teams for individual stream segments to analyze current data, define challenges, determine conservation methods and engage public support
- Develop action plans for addressing the objectives, select the best watershed management alternatives, list strategies for implementing alternatives, and determine appropriate milestones for measuring progress
- Maintain floodplain functions such as aquifer recharge, natural flow regime, base flows, spring flows, water quality, soil moistening, habitat diversity and, sediment transport
- Maintain appropriate sediment transport and avoid channel narrowing
- Maintain native vegetation throughout stream segments, including riparian corridors, floodplains, and upland areas
- Develop voluntary, non-regulatory tools such as financial incentives, conservation easements, landowner agreements, and targeted acquisition
- Seek appropriate easements, water rights acquisitions, and flow agreements to maintain appropriate hydrologic conditions
- Adopt conservation approaches that are cost-effective and sustainable over time
- Convene stakeholder groups to foster support of action plans
- Monitor conservation efforts and assess benefits to focal species populations
Goal 2 - Restore impacted habitats
- Determine locations, extent, and type of impacted habitats
- Assess degree of threats and limiting factors present in impacted habitats
- Develop a priority list of stream segments for restoration actions
- Organize Technical Advisory Teams for individual stream segments to analyze data, define challenges, determine restoration methods, and engage public support

- Develop action plans for addressing the objectives, select the best watershed management alternatives, list strategies for implementing alternatives, and determine appropriate milestones for measuring progress
- Where feasible, restore floodplain functions such as aquifer recharge, natural flow regime, base flows, spring flows, water quality, soil moistening, habitat diversity, and sediment transport
    - Restore appropriate sediment transport and reduce channel narrowing
    - Restore native vegetation throughout stream segments, including riparian corridors, floodplains, and upland areas
- Develop voluntary, non-regulatory tools such as financial incentives, conservation easements, landowner agreements, and targeted acquisition
- Seek appropriate easements, water rights acquisitions, and flow agreements to improve appropriate hydrologic conditions
- Adopt conservation approaches that are cost-effective and sustainable over time
- Convene stakeholder groups to foster support of action plans
- Monitor restoration efforts and assess benefits to focal species populations

Goal 3 - Restore stream and habitat connectivity

Inventory fish passage barriers and delineate impacts on ecology of focal species

Where feasible, diminish or remove fish passage barriers and restore aquatic connectivity

Goal 4 - Mitigate effects of invasive species

- Assess current status of focal species affected by invasive species
- Develop methods for reducing non-native species in targeted areas
- Develop methods to prevent introductions of invasive species and minimize impacts of existing invasive species
- Restore or improve the ecological balance in habitats negatively affected by non-native, invasive or problem species
- Reestablish genetic integrity of hybridized populations in targeted areas

Goal 5 - Organize and facilitate conservation partnership networks

- Provide technical guidance workshops, newsletters, social media, etc. to facilitate development and expansion of local citizen-based partnerships
- Landowner networks should be committed to the cooperative conservation of land and water resources within the watershed
- Landowner networks should promote values of functional upland, riparian, and stream systems and emphasize the conservation of native fish communities and supporting habitats

	- Landowner networks should work to reduce or eliminate activities on the landscape that degrade water quality, reduce water quantity, degrade riparian systems, favor non-native species or fragment stream systems
	- Landowner networks should encourage an array of sustainable land-use activities that are compatible with aquatic resource conservation
	- Landowner networks should promote collaboration across jurisdictional and land ownership boundaries
Goal 6 - Establish conservation demonstration areas	
	- Provide fishing, paddling, and hiking opportunities
	- Promote sustainable public use of rivers
	- Describe benefits to other native species
	- Demonstrate best management practices
	- Highlight restoration actions through educational kiosks
Goal 7 - Conduct research to fill critical science needs	
	- Identify knowledge gaps critical to restoration and conservation of the focal species
	- Design and conduct research as needed to enhance conservation efforts outlined in Goals 1-4
	- Initial sampling at representative locations within each NFCA should be quarterly and include:
	- Biological characteristics of focal species: population size, population structure (genetics & demographics), fecundity, food habits, habitat selectivity, flow-ecology relationships, associated species
	- Habitat structure: flow and discharge rates, channel width, channel morphology, substrate types, depth, cover, trends in surrounding land use
	- Water quality: temperature, pH, dissolved oxygen, conductivity, total dissolved solids, alkalinity, hardness, chemical and biological oxygen demand
	- Threats and limiting factors for the focal species will determine the scale at which the monitoring is designed. As baseline data are developed, monitoring parameters can be modified and streamlined to address critical issues and needs for the focal species
Goal 8: Monitor Conservation Outcomes and Perform Adaptive Management	
	- Develop annual and long-term reporting requirements to document acquired data, departures from plan, and evaluations necessary for adaptive management
	- Determine research needs for refining restoration and management actions
	- Periodically modify strategies based on monitoring, evaluation, and research results
	- Share information with the public in an easy to use and understandable format

Adoption of the eight goals outlined in Table 4 was intended to promote the restoration of watershed functions, emphasizing actions that curtail or eliminate activities on the landscape that degrade water quality, reduce water quantity, degrade riparian systems, favor non-native species, or fragment river systems, while encouraging a wide array of sustainable land-use and water-based recreational activities that are compatible with freshwater fish conservation. Furthermore, those goals have served as thematic topics used to facilitate cooperative planning and identification of NFCA-specific conservation needs, related conservation strategies, project-level conservation actions, and research and monitoring needs.

To plan and coordinate conservation delivery within NFCAs of Texas, watershed-based conservation partnerships were formed. To initiate the partnerships, local, state, and federal natural resources management agencies, universities, non-governmental organizations, and other local conservation partners were invited to participate in conservation planning webinars, workshops, and field days. Webinars were used to present an overview of the conceptual underpinnings of NFCAs, review the eight NFCA goals and related implementation strategies (Table 4), and to review the geographic extent of the freshwater systems recommended as NFCAs (Figure 3). The subsequent workshops and field days were used to engage partners in identification of desired outcomes for populations of freshwater fish SGCN and their habitats, with an emphasis on potential strategies to support maintenance of watershed processes, restoration of degraded habitats, preservation of intact habitats, and local capacity-building to ensure that conservation actions are sustainable long-term. During 2015-2018, workshops and field days were organized and conducted for the Upper Canadian River, Upper Red River, Upper Brazos River, Lower Colorado River, Central Edwards Plateau Rivers, Upper Big Bend, Lower Big Bend, Guadalupe Mountains Streams, Davis Mountains Streams, Pecos River, and Devils River NFCAs (Figure 4), for the purpose of facilitating development of NFCA-specific conservation action plans. In partnership with the Great Plains Fish Habitat Partnership, conservation planning workshops were also conducted in the U.S. Great Plains for four additional NFCAs proposed by Labay et al. (in press; i.e., Arkansas, Kansas, Platte, and White rivers; Figure 4).

Conservation planning workshops were attended by 132 fish and wildlife conservation professionals representing state and federal resource management agencies, universities, and conservation non-profits. Participants were tasked with identification and prioritization of specific conservation projects that could be implemented to conserve native fishes and their habitats within the NFCAs (e.g., improved land management practices within associated watersheds, barrier removal, water rights acquisition, flow agreements, research). Workshop participants identified and prioritized 176 individual conservation actions, which are outlined in Tables 5-9 and identified in Figure 5 by location and by the corresponding NFCA goal addressed. Priority conservation actions are summarized below for each of the 11 NFCAs for which conservation planning workshops were conducted, along with a characterization of each of the 11 NFCAs.

Additional webinars and conservation planning workshops are scheduled to occur during 2019-2020 within the Northeast Texas Rivers, Southeast Texas Rivers, Guadalupe and San Antonio Rivers, Central Coast Rivers and Streams, San Gabriel River, Middle Brazos River, Lower Brazos River, Southern Edwards Plateau Rivers, and Lower Rio Grande NFCAs (supported through the State Wildlife Grants Program). Workshop outcomes, including lists of priority conservation actions identified by stakeholders, will be made accessible at: http://nativefishconservation.org/

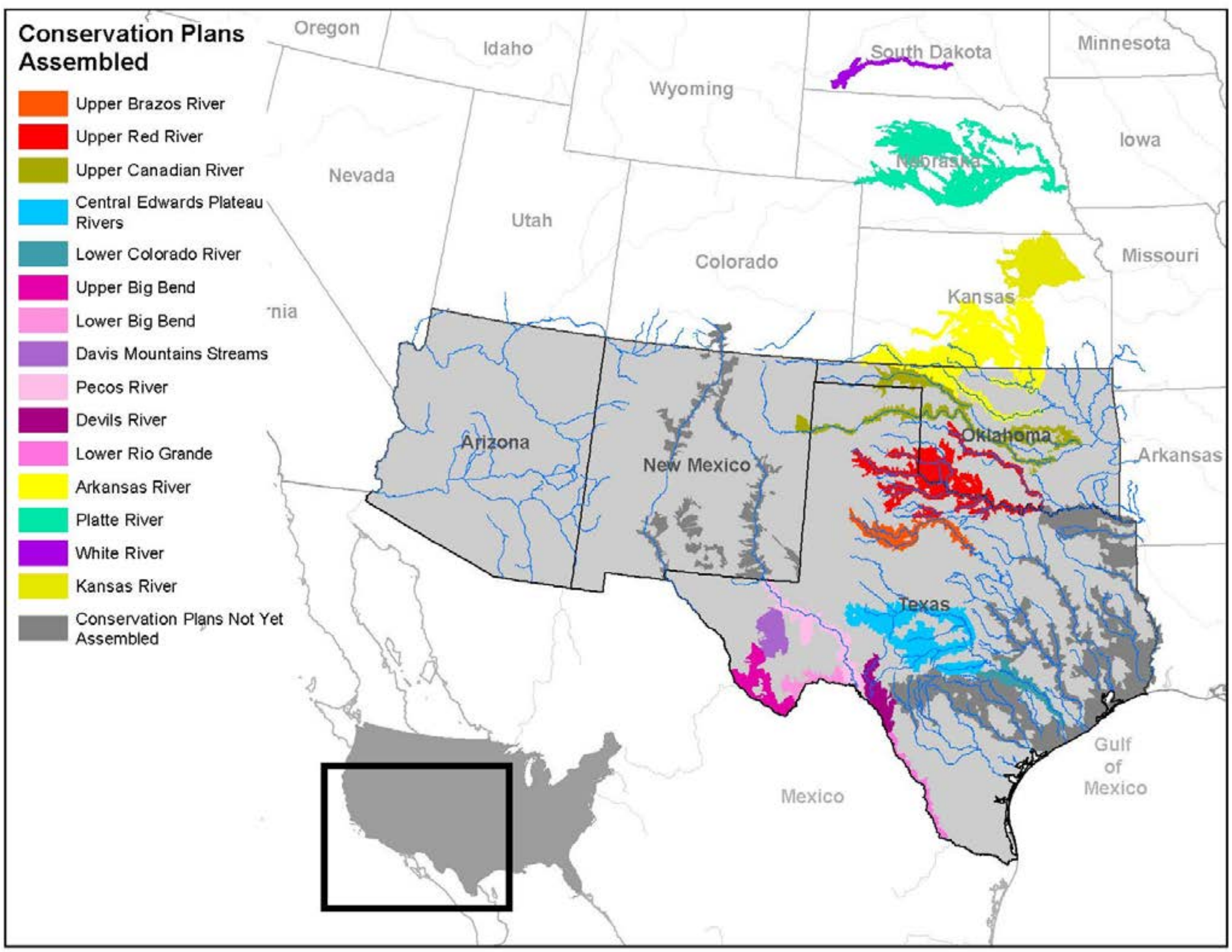

Figure 4 - Native Fish Conservation Areas of the U.S. Southwest and U.S. Great Plains for which conservation planning workshops have been conducted and conservation action plans assembled.

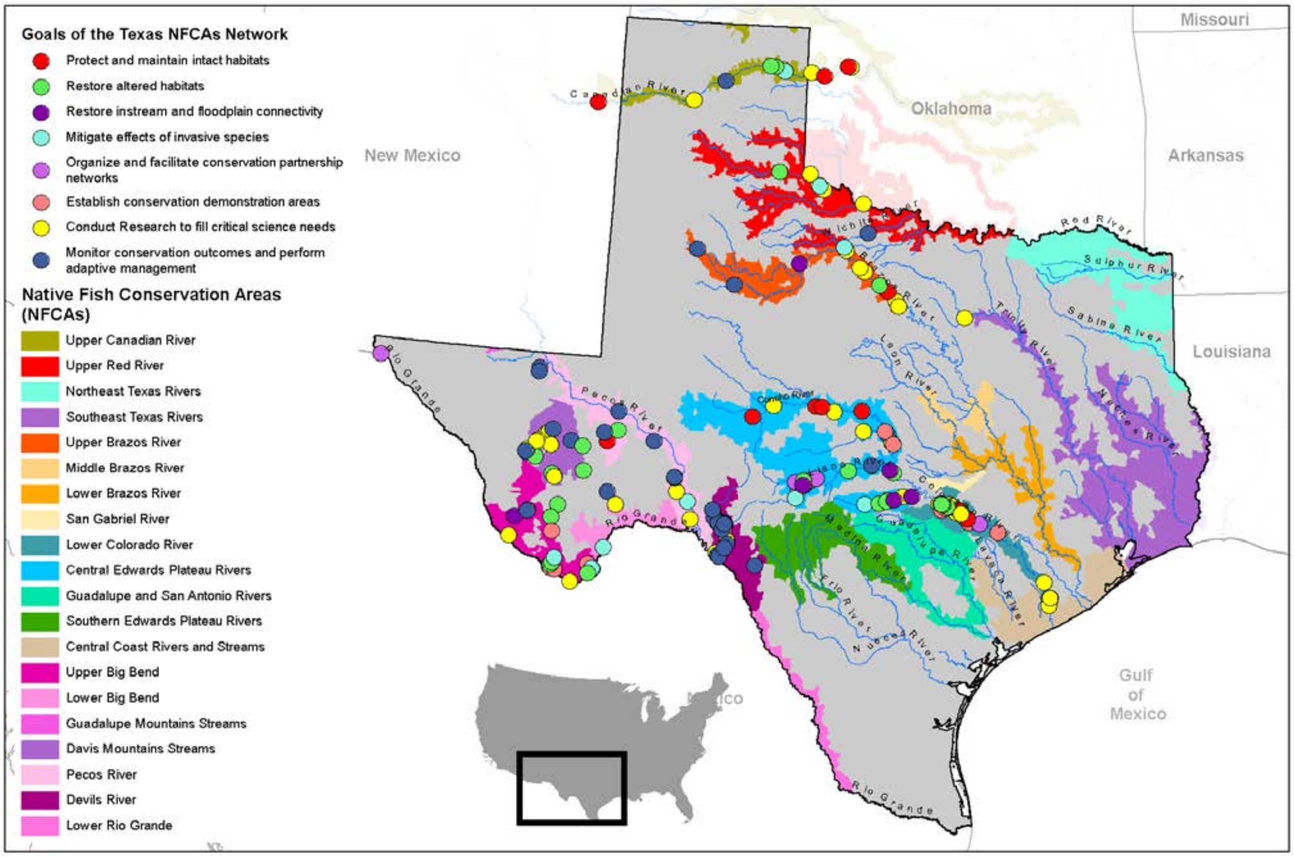

Figure 5 - Conservation actions, identified by location and NFCA goal, recommended by conservation practitioners at conservation planning workshops.

Conservation Action Plan for Native Fish Conservation Areas of the Chihuahuan Desert Ecoregion of Texas

In the Chihuahuan Desert ecoregion of Texas, 40 of the 93 native freshwater fishes documented to have occurred in the ecoregion were selected as focal species for the multispecies aquatic assessment and NFCA prioritization (Appendix A; Garrett et al., in press). The NFCA prioritization resulted in selection of six NFCAs (i.e., Guadalupe Mountains Streams, Davis Mountains Streams, Pecos River, Upper Big Bend, Lower Big Bend, and Devils River NFCAs), which have since been adopted by DFHP, TPWD, and local partners as priorities for conservation investments. The Chihuahuan Desert NFCAs contain a diversity of habitats with many uniquely adapted plants and animals. In addition to flows from the Rio Grande, Río Conchos, Pecos River, and Devils River, three major (Hueco-Mesilla Bolsons, Pecos Valley, and Edwards-Trinity Plateau) and six or more minor aquifers provide water to the region.

Freshwater systems of the Chihuahuan Desert ecoregion (and desert ecosystems in general) are fragile and slow to recover from perturbations. Some disruptions may not be recoverable. Deep downcutting of streams by erosion from overgrazing and deforestation (Ohmart and Anderson 1982), reduced instream flow, introductions of non-native species, and extinction of native species may cause irreversible damage to these ecosystems. Under such conditions, droughts are even more devastating and amplify anthropogenic impacts. Droughts not only reduce rainfall magnitude and frequency, but also cause an increase in groundwater pumping for agricultural and municipal uses as surface waters abate. Such extreme conditions put stress on fish community equilibrium with more tolerant species gaining a competitive and numerical advantage. Tributary creeks tend to be impacted more severely yet are critical to the breeding and rearing of young of many of the endemic species (e.g., Mexican Stoneroller *Campostoma ornatum*, Chihuahua Shiner *Notropis chihuahua*, Big Bend Gambusia *Gambusia gaigei*, Conchos Pupfish *Cyprinodon eximius*; Hubbs 1990). These changes have been gradual and long-term, taking place since the mid-1800s (Miller 1961), but their effects have been compounded over time and are now becoming dramatic. While perturbations such as pollution, reduced groundwater, and dam construction are theoretically fixable, recovery to a pristine state is unlikely.

Although many data gaps exist, what is known about Chihuahuan Desert fish and other aquatic organisms is distressing. Approximately half of the native fishes of the Chihuahuan Desert ecoregion are threatened with extinction or are already extinct (Hubbs 1990). Likely extinctions from this area include: Maravillas Red Shiner *Cyprinella lutrensis blairi*, Phantom Shiner *Notropis orca*, Rio Grande Bluntnose Shiner *Notropis simus simus* and Amistad Gambusia *Gambusia amistadensis* (Miller et al. 1989). Extirpations include Rio Grande Shiner *Notropis jemezanus* in the New Mexico portion of the Rio Grande (Propst et al. 1987) and Shovelnose Sturgeon *Scaphirhynchus platorynchus*, Rio Grande Silvery Minnow *Hybognathus amarus*, Rio Grande Cutthroat Trout *Oncorhynchus clarkii virginalis*, and Blotched Gambusia *Gambusia senilis* in Texas (Hubbs et al. 2008). Endemic species, such as mussels, are being lost as well (Rio Grande Monkeyface *Quadrula couchiana*, False Spike *Quincuncina mitchelli*, and Mexican Fawnsfoot *Truncilla cognata*; Howells and Garrett 1995). Left unchecked, this trend of species extirpation and extinction is likely to continue.

Another significant threat to a substantial portion of the Chihuahuan Desert NFCAs is the establishment of invasive Giant Reed *Arundo donax* and Saltcedar *Tamarix spp.* These non-native plants have effectively channelized stream segments and the resulting constricted flow has reduced shallow, backwater habitat and changed bottom sediments from a mixture of sand and gravels to one of primarily larger gravels and cobble. The dense stands have also armored and stabilized the riverbanks thus preventing natural sediments and sand from being available within the river itself, impacting important habitat for many species (Garrett and Edwards 2014).

The streams of the Chihuahuan Desert NFCAs hardly resemble their natural state where many of the original water courses were once lined with gallery forests and diverse riparian zones. Of the more than 100 moderate (2.8 - 28 L/s) and major (>28 L/s) historical springs, 50% are no longer extant (Brune 1981; Garrett et al., in press). Early records, some as far back as 1583, mention expansive ciénegas and abundant fishes (Brune 1981). Exploitation of limited resources, particularly groundwater pumping, has degraded that environment, caused extirpation and extinction of species, and ultimately perpetuated the loss of habitats and ecosystems (Smith and Miller 1985). The few relatively natural faunas and reasonably intact ecosystems that remain need careful management if they are to be preserved.

Upper Big Bend and Lower Big Bend Native Fish Conservation Areas

The Upper Big Bend NFCA (Figure 6) and Lower Big Bend NFCA are located along the international border in Presidio, Brewster, and Terrell counties. They represent two contiguous, but very different stream segments (upstream and downstream of Mariscal Canyon) with distinct differences in base flow, sediment movement, and water quality. These differences are primarily due to reduced base flow and water quality in the Upper Big Bend NFCA and considerable spring flow inputs and improved water quality in the Lower Big Bend NFCA (Bennett et al. 2014). As a result, the Lower Big Bend NFCA remains somewhat ecologically intact and still supports a high diversity of native aquatic species (Bennett and Urbanczyk 2014). However, more than half of the 42 native fish species in the two Big Bend NFCAs are imperiled and of those, almost 50% are already extirpated or extinct (Garrett et al., in press). In addition, 29% of the fish species that currently occur in these two NFCAs are non-native (Appendix A).

Bennett et al. (2014) noted that numerous threats to aquatic resources have been documented within the two Big Bend NFCAs, including channel narrowing and sediment accumulation (Dean and Schmidt 2011; Dean et al. 2011), deteriorating aquatic habitat (Heard et al. 2012), invasive and non-native species (Everitt 1998), water-quality deterioration (Sandoval-Solis et al. 2010; Bennett et al. 2012), elevated concentrations of mercury, arsenic, and selenium in fishes (Schmitt et al. 2005), groundwater extraction (Donnelly 2007), and climate change (Ingol-Blanco 2011). The combination of regional water management and invasive, non-native riparian species has changed stream flow, sediment dynamics, and riparian vegetation cover (Everitt 1998; Schmidt et al. 2003; Dean and Schmidt 2011). The

Figure 6 - Upper Big Bend Native Fish Conservation Area at the confluence of Terlingua Creek and the Rio Grande.

once wide and shallow channel of the Rio Grande has become narrow and deep. Non-native riparian plants (primarily Giant Reed and Saltcedar) affect channel sediment dynamics, aquatic habitat, and riparian communities by covering up and eliminating backwaters and side channels, diminishing channel conveyance capacity, and increasing flooding frequency (Dean and Schmidt 2011; Garrett and Edwards 2014). Feral pigs *Sus scrofa*, burros *Equus africanus asinus*, horses *Equus ferus caballus*, and cattle *Bos spp.* occur in the area and have negatively impacted natural resources within the river corridor by further degrading riparian habitats.

The focal fishes of the two Big Bend NFCAs include four undescribed taxa, Conchos Roundnose Minnow *Dionda sp. 1*, Rio Grande Blue Sucker *Cycleptus sp.*, Chihuahua Catfish *Ictalurus sp. 1*, and Rio Grande Blue Catfish *Ictalurus sp. 2*. In addition to the focal fish species, other aquatic species of concern include Salina Mucket *Potamilus metnecktayi*, Tampico Pearlymussel *Cyrtonaias tampicoensis*, Texas Hornshell *Popenaias popeii*, Big Bend Rough-

footed Mud Turtle *Kinosternon hirtipes murrayi*, Big Bend Slider *Trachemys gaigeae*, American Beaver *Castor canadensis*, and Pecos River Muskrat *Ondatra zibethicus ripensis*.
Areas being actively managed for conservation of species and habitats include Big Bend National Park, Rio Grande Wild and Scenic River, Big Bend Ranch State Park, Black Gap Wildlife Management Area, Chinati Mountains State Natural Area, and the Terlingua and Alamito Creek watersheds (through significant investments by resource management agencies, private landowners, and conservation non-profit organizations).

Pecos River Native Fish Conservation Area

The Pecos River NFCA encompasses a wide variety of habitat quality. Agricultural and municipal water diversions have greatly diminished water quantity in the upper reaches and increased salinity (as high as 12,000 mg/L). High salinity has resulted in the loss of many fish species and the repeated occurrence of toxic golden alga *Prymnesium parvum* blooms. Freshwater inputs from Independence Creek (Figure 7) and other springs greatly improve water quality and quantity in the lower Pecos River. Other threats include groundwater extraction, oil and gas development, and invasive species. In addition to the focal fish species (Appendix A), other aquatic species of concern include the Rio Grande Cooter *Pseudemys gorzugi*, American Beaver, and Pecos River Muskrat. An 8,000-ha preserve along Independence Creek is owned by The Nature Conservancy with an adjacent 280 ha under conservation easement (Karges 2014a).

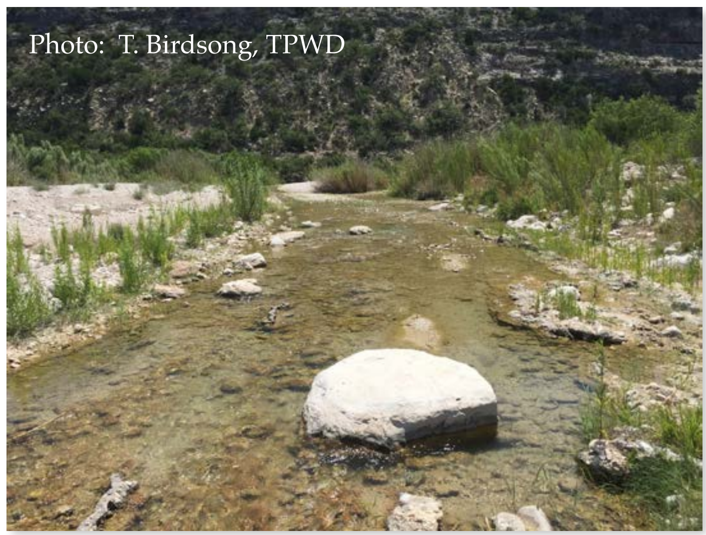

Figure 7 - Independence Creek immediately upstream of the confluence with the lower Pecos River within the Pecos River Native Fish Conservation Area.

Davis Mountains Streams Native Fish Conservation Area

The Davis Mountains Streams NFCA includes desert habitats such as the Balmorhea Springs Complex, as well as streams in the Davis Mountains. The mountain streams harbor at least two species of conservation concern: Rio Grande chub *Gila pandora* and Chihuahua catfish. The Balmorhea Springs Complex is considered one of the largest and most important of the remaining desert spring systems in West Texas (Karges 2014b). The main springs include Phantom Lake, San Solomon, Giffin, Saragosa, Toyah Creek, East Sandia, and West Sandia springs. This was once a massive, interconnected network of ciénegas fed by cumulative spring discharges of approximately 130,000,000 L/day (White et al. 1941). Groundwater pumping and draining of ciénegas for agriculture has reduced flow by more than one-third and disconnected the ciénega network (Garrett et al., in press). All that remains for aquatic habitat are three small springs (East Sandia, West Sandia, and Giffin), artificial refuge ciénegas (Figure 8), and irrigation canals (Garrett 2003). These remaining habitats are essential for the survival of the two federally endangered fishes, Pecos Gambusia *Gambusia nobilis* and the endemic Comanche Springs Pupfish *Cyprinodon elegans*. In addition to the focal fishes (Appendix A), other aquatic species of concern in this NFCA include the Diminutive Amphipod *Gammarus hyalleloides*, Phantom Cave Snail *Pyrgulopsis texana*, Phantom Springsnail *Tryonia cheatumi*, Rio Grande Cooter, and Pecos sunflower *Helianthus paradoxus*. Areas being actively managed for species and habitat conservation include Davis Mountains State Park, Balmorhea State Park, Phantom Lake, and The Nature Conservancy's Sandia Springs and Davis Mountains preserves.

Figure 8 - Artificial ciénega, located within the Davis Mountains Streams Native Fish Conservation Area at the TPWD Balmorhea State Park.

The Davis Mountains Streams NFCA also includes Comanche, Leon, and Diamond-Y springs in Pecos County near Fort Stockton. Comanche Springs no longer flow and as Gunnar Brune (1981) noted, "failure of Comanche Springs was probably the most spectacular example in Texas of man's abuse of nature." Flowing at 1,200 - 1,900 L/s, this spring was one of the largest in Texas, but flow completely ceased in 1962 due to aquifer pumping for irrigation from a well field up-gradient of the springs during the drought of the 1950s (Mace 2001). The outflow from the springs, Comanche Creek, supported a vast ciénega of approximately 25 km in length. The drying of the springs extirpated the Pecos Gambusia and Comanche Springs Pupfish and was not only an ecological disaster, but also had severe impacts on the more than 100 farmers who had, since the 1860s, depended on waters flowing from Comanche Springs and the ciénega for irrigation of approximately 2,500 ha of cropland (Brune 1981).

Leon Springs, up-gradient and in the same aquifer as Comanche Springs, were also modified to provide irrigation for farming. Originally the springs were deep and up to 30 m in diameter and supported a large ciénega that extended for many kilometers downstream (Brune 1981). During the 1920s, a stone and earth dam created Lake Leon (Scudday 2003) that backed water up to, or over, Leon Springs. Unfortunately, this modification likely led to the extirpation of both Pecos Gambusia and Leon Springs Pupfish *Cyprinodon bovinus* as none were collected by Carl Hubbs in his 1938 survey of this type locality for the Leon Springs Pupfish (Hubbs 1980, Minckley et al. 1991). The same groundwater pumping that led to the demise of Comanche Springs also dried Leon Springs in 1958 (Brune 1981). Although Diamond-Y Springs were not as large as Comanche and Leon springs, they continue to flow, so far, and provide habitat for the federally endangered Pecos Gambusia and Leon Springs Pupfish as well as several other species; however, the flow is greatly reduced from historical levels (Scudday 2003). Fortunately, the Diamond-Y Springs ecosystem does not derive all of its flow from the same aquifer as Comanche and Leon springs (Sharp et al. 2003). Other rare species in this system include federally endangered invertebrates: Diamond Tryonia *Pseudotryonia adamantina*, Gonzales Tryonia *Tryonia circumstriata*, Pecos Amphipod *Gammarus pecos*, and Pecos Assiminea *Assiminea pecos*, and the federally threatened Pecos Sunflower. Some degree of protection is afforded the inhabitants of the ciénega at Diamond-Y Springs in that The Nature Conservancy owns 1,600 ha that encompass it and is committed to its maintenance and perpetuation. Although state water law recognizes that The Nature Conservancy "owns" the water beneath their land, it does not allow them to protect this "owned" water from pumping. Additionally, the Diamond-Y Springs is adjacent to an active oil and gas extraction field (with some of the active pumps located on the preserve). Working wells are within 100 m of surface water, a natural gas refinery is 30 m upslope from the spring, and old brine pits are just a few meters away (Garrett et al., in press).

Guadalupe Mountains Streams Native Fish Conservation Area

The Guadalupe Mountains Streams NFCA (Figure 9) is unique in that it supports a population of introduced Rainbow Trout *Oncorhynchus mykiss* and might have had a native population of Rio Grande Cutthroat Trout *O. clarkii virginalis* (Garrett and Matlock 1991; Petersen 2002). The creek is fully protected within the Guadalupe Mountains National Park and by conservation easements held by The Nature Conservancy, and could provide a viable option for establishment of refuge populations of Rio Grande Cutthroat Trout and Rio Grande Chub.

Figure 9 - McKittrick Creek in the Guadalupe Mountains Streams Native Fish Conservation Area.

Devils River Native Fish Conservation Area

The Devils River NFCA includes the Devils River (Figure 10), which extends 100 km from its headwaters at Pecan Springs to Amistad International Reservoir, and San Felipe Creek located in the City of Del Rio. The springs of the Devils River and surrounding area are fed by the Edwards-Trinity Plateau Aquifer, which produces the largest number of springs in Texas, with 46 occurring in Val Verde County alone, as well as the third (Goodenough Springs) and fourth (San Felipe Springs) largest springs in the state (Brune 1981). Goodenough Springs, now covered by Amistad Reservoir, still maintain a significant discharge under the lake surface (Ashworth and Stein 2005). Amistad Gambusia was endemic to the headsprings and the 1.3-km spring run downstream to its confluence with the Rio Grande (Peden 1973) but inundation by the reservoir resulted in its extinction.

Figure 10 - Devils River Native Fish Conservation Area at the Dan Allen Hughes Unit of the TPWD Devils River State Natural Area.

The Devils River occurs at the juncture of the Chihuahuan Desert, Southern Texas Plains, and Edwards Plateau ecoregions (TCEQ 2014). This unique intersection of arid desert, brushland, and karst topography provides a diversity of habitat types, which support numerous aquatic and terrestrial species, including several regionally endemic species classified as threatened or endangered by TPWD and the U.S. Fish and Wildlife Service. The Devils River, and its major tributary Dolan Creek (Figure 11), are home to four state threatened fish species: Proserpine Shiner *Cyprinella proserpina*, Conchos Pupfish *Cyprinodon eximius*, Rio Grande Darter *Etheostoma grahami*, and Devils River Minnow *Dionda diaboli* (El-Hage and Moulton 2001). The Devils River Minnow was also listed as federally threatened in 1999 based on documented population declines attributed to a loss of habitat within the species range due to the construction of Amistad Reservoir, spring dewatering, and stream modifications (USFWS 1999). Other focal fishes that occur in the Devils River NFCA include the Mexican Blindcat *Prietella phreatophila*, Spotfin Gambusia *Gambusia krumholzi*, Blotched Gambusia, Manantial Roundnose Minnow *Dionda argentosa*, Tamaulipas Shiner *Notropis braytoni*, Rio Grande Shiner, West Texas Shiner *Notropis megalops*, Longlip Jumprock *Moxostoma albidum*, Headwater Catfish *Ictalurus lupus*, and Rio Grande Largemouth Bass *Micropterus salmoides nuecensis*.

Figure 11 - Devils River Native Fish Conservation Area at the confluence of Dolan Creek and the Devils River at the interface of The Nature Conservancy's Dolan Falls Preserve and the Del Norte Unit of the TPWD Devils River State Natural Area.

In addition to the focal fish species (Appendix A), other species of concern include the Texas Hornshell *Popenaias popeii*, Rio Grande Cooter, Spring Salamander *Eurycea spp.*, and endemic spring invertebrates. The Texas Hornshell, the only native mussel species known to occur in the NFCA (Howells 2014; Randklev et al. 2018), was listed as federally endangered in 2018 due to the threat imposed by habitat degradation in the form of hydrologic alteration, sedimentation, predation, instream fish passage barriers, and water quality impairment (USFWS 2018). American Beaver also inhabit the river, but suffer from habitat loss, changes to the natural hydrological regime, competition with non-native Nutria *Myocastor coypus*, decreased food supply, and the presence of the invasive Giant Reed and Saltcedar (Garrett et al. 2014). The river and riparian corridor are utilized by several state and federally listed bird species including black-capped vireo *Vireo atricaplla*, tropical parula *parula pitiayumi*, interior least tern *Sterna antillarum athalassos*, and zone-tailed hawk *Buteo albonotatus* (El-Hage and

Moulton 2001). The Devils River corridor is also home to rare plants including the Texas snowbell *Styrax platanifolius texanus*, a riparian shrub (USFWS 2008), and the Tobusch fishhook cactus, a cacti known to occur in flood-prone riparian areas (TPWD 1995). Additionally, the Devils River watershed is located along a major migratory path for monarch butterfly *Danaus plexippus* (Reppert et al. 2010), which is under review for federal listing. The watershed is also home to Fern Cave, which serves as a maternity roost for approximately 10 million Mexican free-tailed bats *Tadarida brasiliensis* from May through October each year (TNC 2008).

Arguably the largest threat currently facing the river and the many species that depend on it is the potential for declining groundwater supplies, which in turn impact spring discharge and river flows (TPWD 2012a). Water quality in the Devils River has historically ranked as excellent when compared to water quality standards established by the Texas Commission on Environmental Quality (TCEQ 2004). This high-quality surface water can be partially attributed to the many mapped and unmapped springs along the river's length (Brune 1981) and the rural, undeveloped nature of the watershed (Anderson et al. 2014). These springs supply the river with up to 75% of the baseflow and, via Amistad Reservoir, provide approximately 15% of the water needed for municipal and agricultural water supplies in the Lower Rio Grande Valley (Green et al. 2014). While these spring discharges provide an oasis of pristine water in an otherwise arid environment for numerous rare and endemic taxa, they also make the Devils River vulnerable to reductions in baseflows from reduced groundwater availability. In addition to a predicted 73% increase in human populations between 2020 and 2070, Texas is projected to suffer a 24% decrease in groundwater availability over the same time period (TWDB 2017).

In addition to the potential for reduced river flows from declining groundwater availability, other current threats to the Devils River include watershed alteration, introduction and expansion of invasive species, and increased recreational use. Land use within the watershed has historically been comprised of large-acreage cattle, sheep, and goat ranches. Continued overgrazing in portions of the watershed has led to changes in terrestrial ecosystems, with a shift from native grassland prairie habitats to bare soil and shrubland (Brune 1981; TPWD 2010). With an increase in the surface area of bare ground, there has been an increase in surface runoff and a decrease in infiltration for groundwater recharge (Brune 1981). This, coupled with increasing groundwater withdrawals, has contributed to declines in the discharge of springs that support river baseflows.

In recent decades, some of the historically large ranches in the Devils River watershed have been subdivided and sold for home sites. Those housing developments have limited regulation and pose potential threats to the river, such as point source pollution from faulty septic systems (McQuillan 2004). Other ranches have shifted from domestic livestock production to exotic game ranches. Escapement of non-native ungulates from these ranches has led to the establishment of feral populations of, most notably, axis deer *Cervus axix* and aoudod or Barbary sheep *Ammotragus lervia*. The addition of non-native ungulates to the Devils River landscape has increased the abundance of foraging species in an already sensitive and overgrazed system. The proliferation of these non-native grazing species can lead to further habitat reduction through reduced forage diversity for native species and increased runoff (TPWD 2010), contributing to further reductions in groundwater infiltration rates and increased potential for sedimentation in the river. In addition to non-native terrestrial species, several non-native aquatic species have been introduced to and become established in the river including Blue Tilapia *Oreochromis aureus*, Common Carp *Cyprinus carpio*, Asian Clam *Corbicula fluminea*, and Red-rimmed melania *Melanoides tuberculata*. Red-rimmed melania serve as an intermediate host for an nonindigenous digenetic trematode gill parasite *Centrocestus formosanus*, which is known to cause mortality in fish with high infestation rates (McDonald et al. 2006) and has been documented in Devils River fish populations, including Devils River Minnow (McDermott, et al. 2014).

Although most of the Devils River flows adjacent to private property, several conservation areas and initiatives exist within the watershed. TPWD currently protects 15,000 ha in the Devils River State Natural Area (Figures 10 and 11). In addition, The Nature Conservancy owns and manages the 1,900-ha Dolan Falls Preserve (Figure 11) and a total of 63,000 ha of private and public lands are currently under conservation easements (Garrett et al. 2014). The Devils River is considered one of the last true wilderness paddling experiences in Texas and is revered for its biological, aesthetic, cultural, and recreational values (El-Hage and Moulton 2001; NPS 2018). It has been nominated as a National Wild and Scenic River and is recognized as an Ecologically Significant Stream Segment (El-Hage and Moulton 2001).

Conservation Planning within Chihuahuan Desert NFCAs

In order to restore and protect the six NFCAs described above, conservation partners intend to employ a multispecies, habitat-based approach to species conservation that provides an improved method for addressing the common nature and magnitude of threats facing these ecosystems and their component species. It also improves efficiency, cost effectiveness, and is more likely to be implemented (Knight et al. 2006). This approach is designed to coordinate projects to improve water quality, increase water quantity, restore natural habitats, reduce impacts of non-native species, diminish stream system fragmentation, and restore proper function of springs, ciénegas, creeks, rivers, and riparian areas. It will only be effective if it is able to inform and influence water management, land-use planning and zoning, and land-management decisions that will determine current and future conditions of rivers and streams and the associated habitat quality for native fishes. Additionally, to provide long-term benefits to focal species populations, conservation actions must be coordinated at sufficient scales to meet all life history stages of these species and must adopt conservation approaches that are cost-effective and sustainable over time.

To accomplish this goal, it is necessary to develop a holistic, habitat-oriented approach to conservation of focal species, restore and protect habitat, restore habitat connectivity, and reduce deleterious effects of non-native species. Threat factors need to be delineated and prioritized based on threat level and what can be managed. Currently known threats in the Chihuahuan Desert NFCAs include:

a. habitat fragmentation
b. barriers to migration
c. loss of natural flow regime
d. reduced stream flow
e. spring flow declines and aquifer depletion
f. channel narrowing and sediment accumulation
g. groundwater pollution
h. habitat loss
i. non-native species – habitat modification, hybridization, competition and predation

In order to develop and refine conservation actions plans for the six NFCAs in the Chihuahuan Desert ecoregion of Texas, an interdisciplinary team of 55 individuals, representing TPWD Inland Fisheries Division, TPWD Wildlife Division, TPWD State Parks Division, U.S. Fish and Wildlife Service Partners for Fish and Wildlife Program and Texas Fish and Wildlife Conservation Office, National Park Service, University of Texas at Austin, Texas Tech University, Fort Worth Zoo, The Nature Conservancy of Texas, World Wildlife Fund, Desert Fish Habitat Partnership, Big Bend Conservation Alliance, and Devils River Conservancy formed the Chihuahuan Desert Native Fish Conservation Network (NFCN). The Chihuahuan Desert NFCN met by webinar in fall 2016 and then through workshops in spring 2017 and spring 2018. Cooperators were tasked with: 1) identifying priority research, monitoring, and restoration actions for preservation of native fishes, their habitats and other aquatic resources in the Chihuahuan Desert of Texas; 2) catalyzing cooperation, collaboration, and leveraging of technical and financial resources among local, state and federal natural resource management agencies, universities, non-governmental organizations, and other local partners that contribute to the conservation of native fishes and other aquatic resources in the watersheds of the Chihuahuan Desert; and 3) facilitating local implementation of the NFHAP and Texas Conservation Action Plan in the Chihuahuan Desert NFCAs.

Priorities for research, monitoring, and restoration were identified by the Chihuahuan Desert NFCN. Those actions focused on addressing the eight NFCA goals outlined previously (Table 4). The Chihuahuan Desert NFCN met initially by webinar to familiarize cooperators with the rationale and approach used in identification of the NFCAs, and to review the proposed process for development of a joint conservation action plan. The NFCN then held in-person workshops to identify and prioritize research, monitoring and restoration projects that need to be initiated. These discussions resulted in the identification of 77 priority actions that serve as the basis for a multi-year conservation action plan now being used to guide cooperative conservation by the Chihuahuan Desert NFCN (Table 5). Funding and other means of support for delivery of these actions are now being assembled by cooperators.

Table 5 - Conservation Action Plan for the six Native Fish Conservation Areas of the Chihuahuan Desert ecoregion of Texas (i.e., Guadalupe Mountains, Davis Mountains, Pecos River, Upper Big Bend, Lower Big Bend, and Devils River Native Fish Conservation Areas).

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	BMPs for stream corridor restoration	Conduct research and monitoring to evaluate restoration strategies and techniques being used throughout the region and determine what works well, what does not work and why	Improved efficiency and success of restoration and conservation projects
Research	Data/information clearinghouse for research, monitoring, and restoration actions that have occurred within the Chihuahuan Desert	Conduct data/information mining/sharing project and collate/summarize relevant research, monitoring, and restoration actions that have occurred within the Chihuahuan Desert over the past 10 years; assemble a historical summary of regional conservation efforts (as far back as possible)	Provide access to recent and historical information relevant to fish and wildlife conservation in the Chihuahuan Desert ecoregion

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Groundwater-surface water interactions and environmental flows targets	Develop science to increase understanding of groundwater-surface water interactions; assemble environmental flows targets	Increased understanding of groundwater-surface water interactions and establishment of environmental flows targets
Research	Effective groundwater management in Chihuahuan NFCAs	Develop strategies to effectively manage groundwater to achieve specific targets for spring discharge and instream flows	Development and implementation of strategies to effectively manage groundwater to achieve specific targets for spring discharge and instream flows
Research	Biological monitoring and riparian restoration	Meet with Sul Ross State University to explore programmatic partnership to increase involvement in biological monitoring and riparian restoration in the region	Increased and enhanced biological monitoring and riparian restoration in the region
Partnerships	Rio Grande/ Bravo Water Forum	Bring together teams of folks who are working on water and natural resource conservation to learn from one another and enhance collaboration for greater impact	Enhanced collaboration on regional conservation issues
Habitat Protection / Habitat Restoration	Ciénega Research and Management	Develop research recommendations and BMPs for ciénegas	Increase understanding of flow alteration, marsh encroachment, and other changes to the system; establish benchmarks based on historical conditions; develop strategies to inform effective management
Habitat Restoration	Assessment of of stream restoration potential	Determine, on a regional-scale, where conditions are appropriate and conducive for restoration of riparian plant communities	Effective restoration of riparian zones
Habitat Restoration / Connectivity	Regional assessment of water table in ephemeral streams	Conduct a GIS-based regional assessment (w/ the possibility of a field-based component) of water table in ephemeral streams of the region to determine restoration potential (use of ground-penetrating LIDAR or other remote sensing data/techniques); model/project likelihood of restoration success given environmental conditions identified that influence restoration	Determine likelihood of restoration success and prioritize efforts to restore ephemeral streams

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	Fish monitoring in the Devils River and Dolan Creek	Continue regular fish monitoring in the Devils River and Dolan Creek	Effective conservation of fish SGCN
Monitoring and Adaptive Management	Streamflow gauge operation on Dolan Creek	Continue the streamflow gauge operation on Dolan Creek for at least 5 years	Ensures effective conservation and understanding of spring and streamflow effects on native fauna and flora
Monitoring and Adaptive Management	Streamflow gauge operation on Devils River at Bakers Crossing	Explore transfer of Devils River Bakers Crossing gauge from IBWC to USGS	Ensures effective conservation and understanding of spring and streamflow effects on native fauna and flora
Monitoring and Adaptive Management	Additional groundwater well recorder	Add at least one more groundwater well recorder on the Devils River and ensure location in best areas	Ensures effective conservation and understanding of aquifer / streamflow interactions
Monitoring and Adaptive Management	Water quality monitoring in the Devils River	Add water quality monitoring sites throughout the river	Ensures effective conservation and monitoring of water quality
Monitoring and Adaptive Management	Reestablish / repatriate native fish communities in Pinto Creek	Develop a plan to reestablish / repatriate native fish communities in Pinto Creek utilizing hatchery stock of Devils River Minnow (after genetic assessment) and wild source for other native fishes	Reestablish / repatriate native fish communities in Pinto Creek including Devils River Minnow
Monitoring and Adaptive Management / Research	Water budget in the Devils River basin	Science to understand water budget in the Devils River basin including the full area of groundwater contributions in the basin	Improved ability to evaluate effects of pumping on Devils River flow and springs in the Devils River basin
Monitoring and Adaptive Management / Research	Modeling of aquifer flow paths in the upper Devils River	Develop models of aquifer flow paths in the upper Devils River	Improved ability to evaluate effects of pumping on Devils River flow and springs in the Devils River basin
Monitoring and Adaptive Management / Research	Flow reduction effects on Devils River Minnow and other biota and water quality	Develop predictive models of flow reduction effects on Devils River Minnow and other biota and water quality	Improved ability to evaluate effects of pumping on Devils River flow and springs in the Devils River basin
Monitoring and Adaptive Management / Research	Devils River contributions to salinity budget of Lake Amistad	Science to increase understanding of Devils River contributions to salinity budget of Lake Amistad	Improved understanding of effects and value of Devils River flows

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management / Research	Importance of Devils Riveron downstream agricultural and municipal water supply	Examine water availability and importance of Devils River in meeting downstream agricultural and municipal water supply needs in the lower Rio Grande	Improved understanding of effects and value of Devils River flows
Monitoring and Adaptive Management / Research	Habitat and flow-ecology needs of Texas Hornshell	Assess specific habitat and flow-ecology needs of Texas Hornshell (soon to be federally listed) in the Devils River; biology / habitat requirements may make this the best indicator species for environmental health; incorporate biology / habitat requirements into water management framework (e.g., groundwater-flows management plan currently being examined jointly by TWDB, TCEQ and TPWD through a Legislative directive)	Enhanced conservation of Texas Hornshell
Monitoring and Adaptive Management / Research	Spring- and aquifer-associated communities in the Devils River basin	Assess spring- and aquifer-associated communities throughout the basin, especially Pecan Springs	Enhanced conservation of SGCN
Monitoring and Adaptive Management / Research	Groundwater levels, spring discharge, instream flows, and habitat availability effects	Examine relationships among groundwater levels, spring discharge, instream flows, and habitat availability for focal fishes and Texas Hornshell in the Devils River	Enhanced conservation of SGCN

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management / Research	Devils River monitoring	Spring ecosystem, salamander monitoring; Continue the streamflow gage operation on Dolan Creek for at least 10 years; Add at least one more groundwater well recorder and ensure location in best areas; Re-establish TCEQ water quality recorder; Improved ability to evaluate effects of pumping on Devils River flow and springs in the Devils River basin; Water budget in the Devils River basin, including the full area of groundwater contribution to the basin; Understanding and modeling of aquifer flow paths in the upper Devils River; Better understanding of flow reduction effects on Devils River minnow and other biota and water quality	Effective conservation of aquatic and riparian habitats
Monitoring and Adaptive Management / Habitat Protection	Spring ecosystem / salamander monitoring	Continue and expand monitoring of spring ecosystems and salamander populations	Conservation of spring habitats and SGCN
Research	Data/information clearinghouse for research, monitoring, and restoration actions that have occurred within the Devils River watershed	Conduct pilot project in the Devils River watershed to serve as a proof of concept and lessons learned to guide a work plan for the entire Chihuahuan Desert	Provide access to recent and historical information relevant to conservation in the Devils River watershed
Research / Habitat Protection	Assessment of subterranean fauna in Devils River NFCA	Determine locations and range extent of subterranean fauna, including blindcatfish and salamanders, in the Devils River NFCA	Effective conservation of subterranean fauna and protection of cave and aquifer habitats

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Conservation Demonstration / Habitat Restoration	Riparian restoration project downstream of Dolan Falls	Conduct a riparian restoration project downstream of Dolan Falls (25 mi downstream; 100-m reach has been cleared); initial outreach/ education to landowner by Devils River Conservancy, and explore possible riparian restoration workshop and planting project	Increased landowner awareness of benefits and importance of riparian habitats
Conservation Demonstration / Habitat Restoration	Riparian restoration project downstream of Bakers Crossing	Conduct a riparian restoration project on west bank, six miles downstream of Bakers Crossing – address 2 miles of riparian degradation and road construction that brought gravel from Nueces (possible introduction of Arundo?)	Increased landowner awareness of benefits and importance of riparian habitats
Conservation Demonstration / Habitat Restoration	Riparian restoration projects at Blue Sage and Rock Canyon subdivisions	Conduct riparian education and explore opportunities for septic system replacement/redesign Blue Sage and Rock Canyon subdivisions	Increased landowner awareness of benefits and importance of riparian habitats
Monitoring and Adaptive Management	Leon Springs Pupfish monitoring and response guidelines.	Monitor status and trends of refuge population (continue Dr. Itzkowitz's research/monitoring), establish additional refuge populations (possibly at Dexter or San Marcos National Fish Hatcheries), and assemble plans for water quality monitoring and disaster response in the event that oil and gas activity impacts the springs and pupfish population	Security and conservation of Leon Springs Pupfish
Monitoring and Adaptive Management	Genetic management/ restoration plan for Pecos Pupfish	Develop a genetic management and restoration plan for Pecos Pupfish including the potential and criteria for using the refuge population at the Ft Worth Zoo	Conservation of Pecos Pupfish
Monitoring and Adaptive Management	Pecos Pupfish refuge populations	Assess potential for establishing refuge populations of Pecos Pupfish on shrimp farms and other similar off-channel sites	Conservation of Pecos Pupfish

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	Pecos Pupfish in Salt Creek	Continue monitoring genetic integrity of Pecos Pupfish in Salt Creek and assure that the upper 2-3 miles of Salt Creek does not have Sheepshead Minnow hybrids. Also, document that the existing barrier continues to prevent upstream movement; determine what would serve as an effective barriers if the need existed to construct them to protect Pecos Pupfish from hybridization	Conservation of Pecos Pupfish
Monitoring and Adaptive Management	Balmorhea State Park Monitoring	In response to increased oil/gas activity near Balmorhea, a USGS gauge has been installed, water quality monitoring is being conducted, and fish/invertebrate communities are being monitored	Assure survival of native organisms and environmental compliance by oil and gas industry
Monitoring and Adaptive Management	Phantom Lake Springs Monitoring and Management	Develop a plan for long-term management of organisms and infrastructure as the ownership changes from the Bureau of Reclamation to another entity	Assure survival of native organisms
Monitoring and Adaptive Management	Restoration of native beavers, muskrats and otters	Develop a restoration plan for Rio Grande beavers, Pecos River muskrats, and otters	Restore native mammals to aquatic ecosystems
Monitoring and Adaptive Management / Research	Independence Creek monitoring	Determine if monitoring Caroline Springs (T5) flow is feasible; Ensure adequate well monitoring on the preserve and throughout the watershed; Determine approach to monitoring stream cross-sections, determine if riparian monitoring is needed; Determine local and regional groundwater flow paths, what areas contribute flow to the creek and springs and identify any threats to the aquifer system	Effective conservation of aquatic and riparian habitats

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management / Research	Diamond Y monitoring	Establish baseline and regular monitoring of rare fishes, invertebrates and Pecos sunflower; Re-establish USGS springflow gage; Establish additional flow monitoring of the downstream reach; Ensure adequate aquifer level monitoring; Determine if riparian/ marsh monitoring is needed and, if so, develop method; Contribute to understanding of the groundwater system feeding Diamond Y Spring; Assess small scale connectivity within each reach	Effective conservation of aquatic and riparian habitats
Monitoring and Adaptive Management / Research	Sandia Springs monitoring	Pecos sunflower assessment and monitoring; Ensure adequate aquifer level monitoring; Determine if riparian/wetland monitoring is needed, develop method; Contribute to overall understanding of the groundwater system that feeds the Balmorhea Springs complex; Mapping of watercourse, dams and habitats; Ongoing stewardship needs, primarily saltcedar removal	Effective conservation of aquatic and riparian habitats

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management / Research	Davis Mountains monitoring	Establish baseline and regular monitoring of Rio Grande chub and evaluate need to monitor Little Aguja pondweed, Davis Mountains snail and other aquatic species; Establish approach to map Little Aguja pools and monitor both flow and water quality; Ensure adequate aquifer level monitoring to track aquifer health; Evaluate need for regular water quality sampling in springs; Determine if riparian monitoring is needed and, if so, develop method; Evaluate effects of historical land use change, drought and wildfires on Madera Creek watershed conditions, flow and biota, includes baseline aquatic biological inventory and flow monitoring	Effective conservation of aquatic and riparian habitats
Monitoring and Adaptive Management / Habitat Protection	Davis Mountains wildfire fuel reduction	Establlish a wildfire fuel reduction program similar to the one underway in the Davis Mountains Preserve	Reduce the amount and intensity of habitat loss from fires
Research	Life history of Pecos Pupfish	Use refuge population at Ft Worth Zoo for lab-based, captive studies of life history attributes of Pecos Pupfish	Conservation of Pecos Pupfish
Research	Status of Rio Grande Chub and Chihuahua Catfish	Determine status of Rio Grande Chub and Chihuahua Catfish	Improve understanding of current status and conservation needs
Research	Hydrology and water quality in Davis Mountains streams	Assess hydrology and water quality in Davis Mountains streams	Improve understanding of current status and conservation needs
Research	Invertebrates, plants, etc. in Davis Mountains streams	Assess diversity and status of invertebrates, plants, etc. in Davis Mountains streams	Improve understanding of current diversity, status and conservation needs

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Researh	Access in Davis Mountains streams	Improve access through roadway improvements on private lands	Enable access for assessments, monitoring, and restoration
Research / Invasive Species Management	Riparian plant communities assesment	Conduct large-scale assessment of riparian plant communities to inform control of riparian invasive plants	Planning for conservation of native riparian plants and removal of invasive species
Research / Habitat Restoration	Habitat enhancement / restoration to address immediate needs for Leon Springs Pupfish	Research to understand changes in vegetative communities (potentially associated with hydrologic changes) and actions that can be taken to better manage these wetlands systems through fire or other actions. Includes monitoring / evaluation to generate guidelines for vegetation management in ciénegas (e.g., hydrology / water management, use of fire, grazing, etc.)	Improved management of ciénega complexes
Research / Habitat Restoration	Effects of wildfire on condition of stream habitats in Davis Mountains streams	Research to understand changes in faunal and floral communities (potentially associated with hydrologic changes) and actions that can be taken to better manage these streams before and after wildfires	Improve understanding and develop guidelines for post-fire restoration
Conservation Demonstration	Alpine Creek conservation demonstration area	Develop a conservation demonstration area on Alpine Creek, incorporating the existing birding trail, and implement riparian restoration and flow improvements	Raise awareness of value of riparian and stream habitats in desert environments; possible native fish refuge
Conservation Demonstration / Partnerships	River conservation workshops for landowners	Conduct river conservation workshops for landowners, including creation of landowner partnerships to support possible reintroduction of RGSM to the lower Pecos River	Develop landowner support for riparian conservation as well as assure understanding of benefits of RGSM establishment
Invasive Species Management / Partnerships	Riparian restoration through control of Arundo and other riparian invasive plants	Engage landowners in large-scale riparian restoration through control of Arundo and other riparian invasive plants	Large-scale riparian restoration through control of Arundo and other riparian invasive plants

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Habitat Restoration	Saltcedar control at Diamond Y Refuge	Remove, control and monitor saltcedar infestation	Enhance restoration of cienega habitats
Habitat Restoration	Riparian fencing of Limpia Creek	Work with landowners on Limpia Creek to protect sensitive riparian areas	Reduce landowner cost-share to increase participation in protecting sensitive riparian zones
Habitat Restoration	Calamity Creek bank stabilization and riparian restoration	Initiate bank stabilization and riparian restoration on Calamity Creek at Elephant Mountain WMA	Restore inpacted riparian areas to promote habitat integrity and reduce erosion
Habitat Restoration	Riparian restoration in Pecos County	Develop opportunities with willing landowner in Pecos County to conduct riparian restoration and artificial wetlands projects	Restore impacted habitats and develop new locations for refuge populations
Habitat Restoration	Riparian plant sources	Develop sources for plant materials (particularly cottonwood trees) to be used in riparian restoration projects	Enable more effective restoration of riparian zones
Conservation Demonstration / Habitat Restoration	Tornillo Creek riparian/spring restoration	Conduct riparian/spring restoration in Tornillo Creek watershed and use as a case study in planning/ conservation of ephemeral streams in the region	Restore inpacted riparian areas to promote habitat integrity and reduce erosion and use as conservation demonstration areas for grazing practices and other management actions
Monitoring and Adaptive Management	Rio Grande Silvery Minnow repatriation	Explore a programmatic relationship with Sul Ross (or another university) to support/ involve faculty, post-docs, graduate students, etc. in research/ monitoring efforts for Rio Grande Silvery Minnow	Restore native faunal element to the Rio Grande and Pecos Rvier
Monitoring and Adaptive Management / Research	Monitoring subsurface water levels/flows in Alamito Creek watershed.	Establish long-term monitoring sites to evaluate effects of management actions in Alamito Creek watershed on subsurface water levels/flows	Improved understanding of effects and value of riparian restoration in Chihuahuan Desert
Research	Conchos Pupfish assessement	Range-wide genetics, habitat, and flow-ecology assessment for Conchos Pupfish	Effective conservation of Conchos Pupfish

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Ecology of Mexican Fawnsfoot and Salina Mucket	Determine temperature tolerances, distribution, and fish-hosts for Mexican Fawnsfoot and Salina Mucket	Enhance conservation efforts for Mexican Fawnsfoot and Salina Mucket
Conservation Demonstration / Invasive Species Management	River trails to promote river conservation	Conduct river trails assessment for the Big Bend Reach of the Rio Grande (to identify a network of single-day paddling opportunities); examine opportunities to enhance outreach and education efforts associated with Arundo control, RGSM reintroduction, and other conservation projects; use the river trails to promote river conservation	Engage public in conservation efforts
Conservation Demonstration / Partnerships	Conservation-oriented recreation on the Big Bend Reach of the Rio Grande.	Conduct an assessment of the recreational and economic value of paddling, wildlife viewing, and other conservation-oriented recreation on the Big Bend Reach of the Rio Grande	Engage public in conservation efforts
Conservation Demonstration / Partnerships / Habitat Restoration	Riparian restoration in Big Bend tribs	Build capacity for riparian restoration in Big Bend tribs through partnerships with non-profits to administer a large-scale riparian restoration program including riparian restoration workshops, volunteer coordination, planning/ delivery of service projects (explore opportunities to hire a full-time biologist to provide support)	Long-term, large-scale riparian restoration in the Big Bend region
Conservation Demonstration / Habitat Restoration	Riparian restoration at the Alamito Creek	Continue riparian restoration at the Alamito Creek Preserve and other areas of Alamito Creek including Big Bend Ranch SP and use as conservation demonstration areas for grazing practices and other management actions	Restore inpacted riparian areas to promote habitat integrity and reduce erosion and use as conservation demonstration areas for grazing practices and other management actions

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Habitat Restoration / Connectivity	Revegetation of riparian habitats on Terlingua Creek	Determine to what extent revegetation is benefiting groundwater systems, channel morphology, and habitat conditions for focal species; also need to identify additional landowners to expand riparian restoration efforts on Terlingua Creek	Improved sediment management and overall habitat conditions
Invasive Species Management /	Arundo control in the Big Bend Reach of the Rio Grande	Add a component that evaluates biotic response to ongoing Arundo control efforts to restore riparian plant communities along the Big Bend Reach of the Rio Grande; monitoring of riparian plant communities and channel morphology is ongoing	Improved sediment management and overall habitat conditions; provide the conditions to restore channel morphology upon ideal flow conditions
Invasive Species Management / Habitat Restoration / Partnerships	Arundo biocontrols in the Big Bend Reach of the Rio Grande	Explore opportunities for use of Arundo biocontrols and the potential to expand the ongoing USDA Arundo biocontrol program that is active in the lower Rio Grande. Education/outreach to landowners is needed in advance of a biocontrol program	Improved sediment management and overall habitat conditions; provide the conditions to restore channel morphology upon ideal flow conditions
Invasive Species Management / Habitat Restoration / Partnerships	Arundo control in the Black Gap reach of the Rio Grande	Explore opportunities to expand partnerships and expand Arundo control downstream into the Black Gap reach	Improved sediment management and overall habitat conditions; provide the conditions to restore channel morphology upon ideal flow conditions
Habitat Restoration	Grasslands restoration and riparian restoration at O2 Ranch	Conduct grasslands and riparian restoration on hundreds of thousands of acres at the O2 Ranch and adjacent ranches and include monitoring/evaluation; evaluation of effects/appropriateness of fire for specific soil types in the region should be included as a component of a research/monitoring plan	Restore inpacted grasslands and riparian areas to promote habitat integrity and reduce erosion
Habitat Restoration	Riparian fencing for tributaries	Explore potential for fencing riparian areas in Rio Grande tributaries	Restore inpacted riparian areas to promote habitat integrity and reduce erosion

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Habitat Restoration	Riparian restoration in Terlingua Creek	Continue to deliver/expand large-scale riparian restoration in Terlingua Creek and explore opportunities in other tributaries in the Big Bend Reach of the Rio Grande	Restore inpacted riparian areas to promote habitat integrity and reduce erosion
Habitat Restoration / Connectivity	Flow restoration targets to improve sediment management and habitat conditions	Examine flow regimes and develop a sediment budget in order to identify flow restoration targets to improve sediment management and overall habitat conditions	Improved sediment management and overall habitat conditions
Connectivity	Ciénega Creek dam removal	Conduct a small dam removal project at Ciénega Creek in Big Bend Ranch State Park	Restore stream and habitat connectivity

The partnerships and collaborations forged during the Chihuahuan Desert NFCN conservation planning process are expected to enable leveraging of funding and other resources to initiate and complete priority projects. The Chihuahuan Desert NFCN intends to hold annual meetings to review progress in implementation of the Conservation Action Plan. Furthermore, the Conservation Action Plan is expected to guide partner investments over the next 5-10 years in cooperative, watershed-scale conservation of native fishes and other aquatic resources in the six NFCAs. Additional information on the Chihuahuan Desert NFCN and Conservation Action Plan for NFCAs of the Chihuahuan Desert ecoregion can be found at http://nativefishconservation.org/.

Conservation Action Plan for Native Fish Conservation Areas of the Colorado River Watershed (TX)

Edwards Plateau Rivers Native Fish Conservation Area and Lower Colorado River Native Fish Conservation Area

The Colorado River (Figure 12) originates in northwest Texas and flows in a southeasterly direction for approximately 965 km, eventually flowing into Matagorda Bay and the Gulf of Mexico. The watershed drains 103,341 square kilometers and flows through six ecoregions (Clay and Kleiner 2010), including the Edwards Plateau ecoregion, a karst landscape home to 14 endemic freshwater fishes (Bowles and Arsuffi 1993; Hubbs 2008). The portion of the mainstem Colorado River and tributaries located in the 4.4 million-ha Edwards

Plateau ecoregion, including the Concho, San Saba, Llano, and Pedernales rivers (Figure 13), are contained within the Central Edwards Plateau Rivers NFCA.

In the middle portion of the Colorado River watershed, immediately upstream of the City of Austin, a chain of six mainstem impoundments (referred to as the Highland Lakes) fragment and inundate approximately 322 km of the mainstem Colorado River. Management of the Highland Lakes to meet downstream water demands has substantially altered the natural flow regime and water quality throughout the middle and lower portions of the watershed (Mosier and Ray 1992). The Lower Colorado River NFCA encompasses the 470-km reach of the mainstem Colorado River and its tributaries from Austin to the Gulf of Mexico. The Lower Colorado River NFCA is home to two focal flow-dependent fishes, Guadalupe Bass *Micropterus treculii* (Figure 14) and Blue Sucker *Cycleptus elongatus*. Guadalupe Bass are a highly sought after sport fish for river anglers (Thomas et al. 2015), and are a species of conservation concern due to habitat degradation (Hurst et al. 1975; Edwards 1978) and hybridization with non-native Smallmouth Bass *Micropterus dolomieu* (Edwards 1980). Habitat degradation, resulting from urbanization in central Texas, is a chronic threat to the conservation of Guadalupe Bass populations (Bean et al. 2013; Curtis et al. 2015; Pease et al. 2017). Blue Sucker is listed as State Threatened in Texas and of Special Concern in North America (Jelks et al. 2008), with early life history stages hypothesized as vulnerable to flow alteration (Adams et al. 2006).

Threats to these focal fishes and other flow-dependent aquatic species in the Central Edwards Plateau Rivers and Lower Colorado River NFCAs are largely associated with increasing human populations and associated demands for surface and groundwater. Human populations are expected to more than double in portions of the watershed by 2050 (Hoque et al. 2014; Colby and Ortman 2015). The population of the City of Austin's five-county metropolitan area has increased 37.7 % over the decade preceding 2016, and now exceeds two million people; Austin is the fastest growing metropolitan area in the state and is ranked ninth in the USA. The Edwards Plateau ecoregion, located west of the City of Austin, is undergoing unprecedented population growth, increasing from approximately 800,000 in 1950 to 2.6 million in 2000, and is projected to grow to 4.3 million by 2030 (HCA 2008). Future demands on surface and groundwater for municipal and industrial uses are expected to continue to increase (TWDB 2016). Land use in the Central Edwards Plateau Rivers NFCA, which historically consisted of farming and ranching, has shifted to developments of single-family homes, as residents from Austin and San Antonio relocate to affordable housing in what are increasingly considered suburban areas (HCA 2008).

Groundwater withdrawals and stream habitat alteration are of particular concern for Guadalupe Bass populations in the Central Edwards Plateau Rivers NFCA given recent and projected human population growth, concomitant changes in watershed land uses, and increased demands on water resources (Birdsong et al. 2010). Changes to population dynamics (i.e., reproduction, recruitment, and growth) resulting from changing hydrology have been hypothesized (Grabowski 2014), but are largely unstudied with a few exceptions (e.g., Edwards 1978; Groeschel 2013, Pease 2017). The clear and fast-flowing headwater streams of the Central Edwards Plateau Rivers NFCA meet the habitat requirements of Guadalupe Bass, while river base flows are largely dependent on spring discharge from groundwater that is under increased threat of pumping due to human development pressures. Numerous springs and streams throughout Texas have experienced general declines in annual flows, or ceased to flow permanently as a result of groundwater pumping (Bowles and Arsuffi 1993). Long-term reductions in base flow could decrease growth of Guadalupe Bass (Groeschel 2013), and change their population structure (Pease et al. 2017). Reduction of spring flow would also likely negatively impact the thirteen endemic species of fish in the Edwards Plateau ecoregion that are considered spring-associated obligates (Craig et al. 2016).

River flows in the Lower Colorado River NFCA downstream of the City of Austin are largely dependent on controlled releases from the upstream Highland Lakes. Unlike the fast flowing, narrow and clear headwater streams located in the Central Edwards Plateau Rivers NFCA, this portion of the river is relatively wide and slow moving with intermittent pools, riffles, occasional rapids, and intermittent boulder fields (Magnelia 2018). Chute and rapid habitats with bedrock substrate strewn with boulders provide quality habitats for Blue Sucker (Mosier and Ray 1992). The reach also supports a unique Guadalupe Bass population, which is much higher density than typical populations found on the Central Edwards Plateau Rivers NFCA (Pease et al. 2017). Individuals also exhibit faster growth rates (Pease et al. 2017), which provides opportunity for growth to a large size. A new world record Guadalupe Bass (1.68 kg, 43 cm) was caught in the Lower Colorado River NFCA in 2014, and the reach of river from Austin to Columbus, TX is considered the premier fishery for trophy size (> 381 mm; Cummings and DeJesus 2018) Guadalupe Bass (Bean 2017).

Blue Sucker are associated with big river ecosystems (Mettee 2000) like that found in the Colorado River downstream of Austin, and are considered vulnerable throughout their range (Jelks et al. 2008) as many of these systems have been highly altered. Their spawning requirements and factors affecting juvenile survival are poorly understood (Mosier and Ray

Figure 12 - TPWD biologists conduct fish population surveys in the Lower Colorado River Native Fish Conservation Area.

1992). Early life history stages are hypothesized as vulnerable to flow alteration (Adams et al. 2006) and, as with Guadalupe Bass, changes in hydrology may affect population dynamics (Grabowski 2014). Instream flows for providing adequate Blue Sucker spawning habitat were recommended (Mosier and Ray 1992) and incorporated into the Lower Colorado River Water Management Plan, which provides guidance for releases from the Highland Lakes system to, in part, maintain a healthy aquatic community in the lower Colorado River, and healthy ecological environment in Matagorda Bay (Mosier and Ray 1992). Long-term changes to the timing, magnitude, and duration of releases in the Lower Colorado River NFCA resulting from increasing demand for water from the Highland Lakes and/or increased frequency of drought, would likely change the structure of Guadalupe Bass (Pease et al. 2017) and Blue Sucker (Grabowski 2014) populations.

In fall 2015, a series of conservation planning workshops were held involving 32 fish and wildlife conservation professionals representing conservation non-profits, universities, and state and federal agencies from throughout the Colorado River watershed for the purpose of assembling a Conservation Action Plan (Table 6) for the Central Edwards Plateau Rivers and Lower Colorado River NFCAs. The initial workshop was held in Austin, TX in September 2015. Participants identified 113 project-level research, monitoring, and restoration

Figure 13 - Pedernales River within the Central Edwards Plateau Rivers Native Fish Conservation Area.

actions needed to preserve native fishes of the Colorado River watershed. At a second workshop held in Junction, TX in October 2015, those same partners began to integrate and formulate these actions into a multi-year work plan. Actions were prioritized and specific project cooperators and potential funding sources were identified to support delivery. Priority actions compiled in Table 5 represent a Conservation Action Plan that will guide partner investments over the next 5-10 years in cooperative, watershed-scale conservation of native fishes and other aquatic resources in the Colorado River watershed.

Priority science needs identified within the Central Edwards Plateau Rivers NFCA and Lower Colorado River NFCA primarily centered on the need for development of river reach-specific data and decision support tools that can be used to inform the conservation of environmental flows (through mechanisms such as inclusion of prescribed releases in water rights permits and dam operations plans or leases of existing water rights for instream uses). Another area of interest focused on the need for data and decision support tools to guide and prioritize restoration and preservation of riparian and floodplain habitats (through mechanisms such as conservation easements or other landowner incentives). Three highest-priority projects emerged during the Colorado River conservation planning process. Those three projects are listed below, all three of which are currently underway or recently completed through support from TPWD and the U.S. Fish and Wildlife Service State Wildlife Grants Program.

Figure 14 - Guadalupe Bass collected from the Pedernales River, located within the Central Edwards Plateau Rivers Native Fish Conservation Area.

1) Examine flow-ecology relationships to inform instream flow prescriptions in the Lower Colorado River Water Management Plan to conserve Guadalupe Bass and Blue Sucker
2) Application of the Texas Ecological Indices Project to prioritize riparian buffers for protection through landowner incentives and conservation easements supported by the Texas Farm and Ranch Lands Conservation Program and TPWD Landowner Incentive Program
3) Examine opportunities for water leases, water rights acquisition, and voluntary incentive-based programs to achieve flow restoration targets for conservation of Guadalupe Bass in the Central Edwards Plateau Rivers NFCA

Table 6 - Conservation Action Plan for Native Fish Conservation Areas of the Colorado River watershed, TX (i.e., Central Edwards Plateau Rivers and Lower Colorado River Native Fish Conservation Areas).

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	Conservation outcomes of South Llano River Conservation Demonstration Areas	Develop and implement a monitoring program to evaluate the ecological outcomes of conservation actions implemented through the South Llano River Conservation Demonstration Area Master Plan	Documentation of ecological outcomes of conservation actions

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	Genetic integrity of Guadalupe Bass populations	Monitor genetic introgression of Guadalupe Bass populations and identify conservation strategies to preserve intact populations and ameliorate genetic introgression in hybridized populations	Guadalupe Bass conservation
Monitoring and Adaptive Management	Population assessment of Hill Country focal species	Conduct baseline assessments of population size and structure of focal species of the Hill Country Rivers NFCA and establish routine monitoring programs	Information on focal species status
Research	Alligator Gar assessment	Assess Alligator Gar populations	Information on assemblages
Research	American Eel assessment and barrier impacts	Assessment American Eel populations and barrier impacts	Determine distribution, abundance, genetics, and movement patterns
Research	Annual economic impact of paddling, angling, and other water-based recreation	Complete a study of the annual economic impact of paddling, angling, and other water-based recreation in the lower Colorado River and specifically the Guadalupe Bass Fishery and the Texas Paddling Trails network	Understanding use patterns and use for justification for protecting the resource
Research	Blue Sucker habitat use	Identify habitat use patterns by Blue Sucker	Additional informaiton on habitat associations
Research	Dam influence on fish passage	Determine influence of dams on fish passage, accessibility? (considering the Altair dam and the one in Bay City)	Assess connectivity and influence on focal species
Research	Effects of Water Supply Enhancement projects on groundwater, surface water and aquatic ecosystems	Conduct applied research to examine the effects of projects supported through the Texas State Soil and Water Board's Water Supply Enhancement Program on groundwater, surface water and aquatic ecosystems	Improved understanding of project impacts on groundwater, surface water and aquatic ecosystems

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Effects of riparian invasive plants on fluvial processes and habitat conditions	Characterize the effects of riparian invasive plants (e.g., giant reed, elephant ear, salt cedar) on fluvial processes (e.g., channel morphology, flow velocity, sediment transport) and habitat conditions for Species of Greatest Conservation Need	Documentation of effects of riparian invasive plants on fluvial processes and habitat conditions for Species of Greatest Conservation Need
Research	Fish population dynamics at the fresh and estuarine interface	Assess dynamics of fish populations at the fresh and estuarine interface	Information on assemblages
Research	Flow ecology of Guadalupe Bass	Assess Guadalupe Bass pouplations and flow-ecology relationships	Additional informaiton on habitat associations
Research	Focal species presence and habitat use	Determine focal species presence and habitat use - Altair to Bay City	Information on assemblages
Research	Linkages among land use, upland vegetation, watershed processes, and focal species	Examine linkages among land use cover, upland vegetative communities, physical watershed processes, and status of focal species and their habitats	Better understanding of linkages among land use cover, upland vegetative communities, physical watershed processes, and status of focal species and their habitats
Research	Linkages among riparian buffer, instream habitat, and use by focal species	Examine linkages among riparian buffer intactness, instream habitat quality, and use by focal species	Better understanding of linkages among riparian buffer intactness, instream habitat quality, and use by focal species
Research	Macrobrachium assessment	Assess Macrobrachium populations	Information on assemblages
Research	Restoration of natural bank/riparian conditions	Develop strategies, guidelines, and restoration designs to stabilize erosional cut-banks and restore natural bank/riparian conditions	Stabilization of erosional cut-banks and restoration natural bank/riparian conditions
Research	Restoration of the North Llano River sand and gravel mining area	Conduct a geomorphic assessment to inform the development of restoration design options for the North Llano River sand and gravel mining area (including potential stormwater management wetland for surface runoff from I-10)	Restoration of the North Llano River sand and gravel mining area

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Use of tributary streams by focal species	Examine use of tributary streams by focal species (this can apply throughout Lower Colorado)	Determine contribution of tributaries to populations
Research / Habitat Restoration	Water leases and rights acquisition	Complete an analysis of existing water rights and patterns of water use to identify available water and explore opportunities for water leases, water rights acquisition, and voluntary incentive-based programs to achieve flow restoration targets	Influence environmental flows, decision support tool
Conservation Demonstration	Enhance management of river access at the Colorado River Sanctuary	Collaborative with the Pines and Prairies Land Trust to enhance management of the river access area at the Colorado River Sanctuary (immediately upstream of Tahitian Village) for use as a riparian conservation demonstration area	Increased access and public awareness
Conservation Demonstration	Incorporate river access into new bridge design	Coordinate with Travis County to incorporate river access into the design of the new bridge crossing at FM 973	Increase access, public engagement
Conservation Demonstration	Leased access at the County Road 150 bridge	Explore leased fishing access opportunities at the County Road 150 bridge crossing on the South Llano River (including opportunities for use of the access area to support upstream expansion of the South Llano River Paddling Trail)	Increase access, public engagement
Conservation Demonstration	Leased access, riparian restoration, and sustainable use	Establish leased fishing access agreements, implement riparian restoration, and develop sustainable use management plans on private riverside properties in strategic locations throughout the Central Edwards Plateau Rivers NFCA	Increase access, public engagement
Conservation Demonstration	Prioritize conservation actions in the South Llano River Conservation Demonstration Area Master Plan	Prioritize conservation actions identified in the South Llano River Conservation Demonstration Area Master Plan, and develop a phased approach for implementation	Increased public awareness, improved watershed function

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Conservation Demonstration	Provide additional public access	Coordinate with public entities etc. to provide additional public access	Increase access, public engagement
Conservation Demonstration	River access for new bridge from FM 969 to XS Ranch	Collaborate with XS Ranch (planned subdivision located on the Colorado River between the Wilbarger Creek and Sandy Creek confluences), TxDOT and Bastrop County to ensure that river access is incorporated into the design of the new bridge that will provide access from FM 969 to XS Ranch	Increase access, public engagement
Conservation Demonstration	Secure leased river access to expand the paddling trail network	Explore opportunities to secure leased river access for anglers/ paddlers across private lands to create additional launch areas that will allow expansion of the current Colorado River paddling trail network from Tahitian Village to the City of Smithville	Increase access, public engagement
Conservation Demonstration	South Llano River Paddling Trail link to South Llano River Conservation Demonstration Area Master Plan	Ensure that the South Llano River Paddling Trail is considered and linked to nature trails and other recreational enhancements identified in the South Llano River Conservation Demonstration Area Master Plan, including trails at the South Llano River State Park and Texas Tech University Llano River Field Station	Access and opportunity for public recreation in the South Llano River
Conservation Demonstration	Special harvest regulations for Guadalupe Bass	Examine potential use of special harvest regulations for Guadalupe Bass in the lower Colorado River	Information to make harvest recommendations
Conservation Demonstration	Special harvest regulations for overexploited fishes	Explore special harvest regulations for potentially overexploited sportfishes, especially regionally endemic sport fishes such as Guadalupe Bass	Information to make harvest recommendations

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Conservation Demonstration	Sustainable access and use of park lands along the Onion Creek corridor	Coordinate with TPWD McKinney Falls State Park, City of Austin Parks and Recreation, and Travis County Parks and Recreation to develop strategies for sustainable access and use of the network of park lands and creekside trails being established along the Onion Creek corridor from the state park to the Colorado River confluence	Increase access, public engagement
Conservation Demonstration	Sustainable use plan for riverside parks along Onion Creek and the Colorado River	Coordinate with City of Austin and Travis County Parks and Recreation to develop a sustainable use management plan for riverside parks along Onion Creek and the Colorado River in Travis County	Increase access, public engagement
Invasive Species Management	Aquatic and riparian invasive species on the Llano and Pedernales rivers	Continue aquatic and riparian invasive species monitoring program on the Llano and Pedernales rivers to support adaptive management of ongoing invasive species control efforts (with a particular focus on control/management of elephant ear and giant reed)	Improved management of invasive species
Invasive Species Management	Elephant ear eradication in the Llano River watershed	Continue implementation of elephant ear management efforts throughout the Llano River watershed, w/ emphasis on headwaters region	Control of elephant ear infestation
Invasive Species Management	Giant reed management in the Pedernales River watershed	Continue implementation of giant reed management efforts throughout the Pedernales River watershed	Control of giant reed infestation in the Pedernales River watershed
Partnerships	Fishing guide services for conservation messaging and outreach	Establish and strengthen partnerships with fishing guide services (e.g., All Water Guides) to assist in conservation messaging and angler/public outreach campaigns	Increased public awareness, improved management of guadelupe bass fisheries

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Partnerships	Landowner conservation network to support collaborative conservation	Explore opportunities to form a landowner conservation network to support collaborative conservation of the Colorado River downstream of Smithville	Engage public, increase awareness
Partnerships	Promote trophy Guadalupe Bass fishery	Promote trophy Guadalupe Bass fishery to garner public support for conservation of the lower Colorado River, with a particular emphasis on the value of prescriptive releases of flows into the lower Colorado River from the Highland Lakes (consistent with the Lower Colorado River Authority's Water Management Plan)	Increased public awareness, improved management of guadelupe bass fisheries
Partnerships	Support for Llano River Watershed Alliance and Hill Country Alliance	Continue to support local stewardship and advocacy efforts of the Llano River Watershed Alliance and Hill Country Alliance	Increased public awareness, improved participation in stewardship
Partnerships	Upper Llano River Watershed Protection Plan	Facilitate implementation of the Upper Llano River Watershed Protection Plan	Increased public awareness, improved watershed function
Habitat Protection	TPWD permitting decisions	Expand efforts by Inland Fisheries to consider focal species, particularly endemic fishes and sensitive aquatic plant species (e.g., springrun whitehead), in permitting decisions (e.g., introduction of Grass Carp, stocking of sport fishes or forage fishes)	Conservation and restoration
Habitat Protection	Beneficial instream barriers	Identify beneficial instream barriers (i.e., that prevent introduction/expansion of non-native species and/or that serve as refugia for native species) and develop proactive messaging that delineates the differences between beneficial and harmful instream barriers	Improved understanding of effects of instream barriers
Habitat Protection	Blue Sucker spawning habitats	Develop conservation strategies for protection of Blue Sucker spawning habitats	Influence water management plan & enhance blue sucker populations

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Habitat Protection	Conservation easement opportunities	Conduct a riparian assessment to determine conservation easement opportunities	Identification of riparian areas for preservation and restoration
Habitat Protection	Conservation strategies for species and habitats threatened by land use changes	Develop conservation strategies for protection of unique and sensitive aquatic species and habitats threatened by land use changes, including recommended measures to consider in land use planning and zoning (e.g., recommended minimum width of riparian buffers, stormwater management techniques/measures, use of pervious paving materials and other low impact development strategies)	Increased public awareness, improved watershed function
Habitat Protection	Riparian buffer assessment	Assess condition of riparian buffers along Hill Country rivers and tributaries, and prioritize areas for restoration and protection (through acquisition, conservation easements or other landowner incentives)	Improved watershed function
Habitat Restoration	Degraded water quality in the North Llano River	Develop strategies and best management practices to address urban runoff and degraded water quality in the North Llano River associated with land use practices along the I-10 highway corridor	Reduced effects of urban runoff and degraded water quality in the North Llano River
Habitat Restoration	Herbivory and habitat degradation by native and non-native species	Develop conservation strategies to address herbivory by native and non-native ungulates and degradation of sensitive habitats by feral hogs	Reduced harmful impacts of herbivory and degradation of sensitive habitats
Habitat Restoration	Natural flow patterns for native aquatic communities	Examine flow-ecology relationships of Guadalupe Bass, Blue Sucker, and other focal species, and explore opportunities to adapt/refine current flow prescriptions in the Lower Colorado River Authority's Water Management Plan to support natural flow patterns that meet the needs of native aquatic communities	Inform water management plan and enhance blue sucker populations

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Habitat Restoration	Restoration and preservation of riparian plant diversity	Restore and preserve riparian plant diversity through planting of native species and use of exclusion fencing (to prevent overgrazing by ungulates and cattle)	Restoration and preservation of riparian plant diversity
Habitat Restoration	Restoration of sand and gravel pits	Characterize sand and gravel pits, assess jurisdictional authorities, and examine opportunities to restore habitation condition and river channel integrity, and/or enhance the value of the pits as adjacent wetland habitats	Characterization of function and status and how they influence riverine conditions, determine if remediation is necessary
Habitat Restoration	Status of off-channel sand and gravel pits	Coordinate with the General Land Office to evaluate the ownership and jurisdictional status of off-channel sand and gravel pits (i.e., considered public streambed vs private ownership?), particularly those with a continuous hydrologic connection to the lower Colorado River	Clarify status of properties
Habitat Restoration	Support water use efficiencies on private lands	Develop landowner incentives with the potential to provide water use efficiencies including replacement of outdated irrigation equipment and livestock watering facilities	Improved water use efficiencies
Habitat Restoration	Technical guidance on best management practices	Provide science-based technical guidance (to public and private landowners) on best management practices for conservation of natural landscapes, with a particular emphasis on preservation of instream habitats, riparian buffers, springs, aquifer recharge features, and upland landscapes (to maintain ground filtration and water quality)	Improved watershed function and aquatic resource conservation
Connectivity	Bridge at South Llano River State Park	Redesign and construct a new fish- and river-friendly bridge crossing at the South Llano River State Park that restores fluvial processes, restores fish passage, and enhances river recreation by allowing passage for paddlers	Improved stream function, improved biological connectivity, improved public access

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Connectivity	Conservation guidelines for low-water crossings	Develop conservation strategies, guidelines and designs for low-water crossings and low-head dams that restore fluvial processes, restore fish passage, and enhance river recreation by allowing passage for paddlers	Improved stream function, improved biological connectivity, improved public access
Connectivity	Design considerations for bridges	Develop design considerations and best management practices for use by the Texas Department of Transportation and county/local transportation authorities in bridge designs that preserve natural fluvial processes, allow for fish passage, and that maintain recreational access and use for paddlers	Improved stream function, improved biological connectivity, improved public access
Connectivity	Inventory and characterization of low-head dams	Conduct an inventory and characterization of low-head dams (not included in the current national inventory of dams)	Improved stream function, improved biological connectivity

Conservation Action Plan for the Upper Canadian River Native Fish Conservation Area

The Canadian River arises in Colorado, just north of the New Mexico border, and flows 1,220 km through New Mexico, Texas, and Oklahoma before joining the Arkansas River in eastern Oklahoma. The river is characterized by a shallow, sandy, braided channel. The Canadian River watershed totals 312,221 square km and contains four major impoundments: Conchas Lake and Ute Reservoir (NM), Lake Meredith (TX), and Eufaula Lake (OK). Portions of the Canadian River upstream of Conchas Lake in New Mexico have been recognized by the Nationwide Rivers Inventory for having remarkable scenic, recreational, geologic, wildlife, and historic value (NPS 2010). In Texas, the Canadian River flows through the Southwestern Tablelands ecoregion of the panhandle, with parts of the basin occurring in the High Plains ecoregion. Canadian River segments upstream and downstream of Lake Meredith were nominated by TPWD (2016a) as Ecologically Significant Stream Segments based upon riparian conservation areas and the presence of imperiled species and unique biological communities.

The Upper Canadian River NFCA is home to several imperiled fishes that, when coupled with close proximity to universities conducting aquatic research, have made it the location of numerous fish community studies. Research in the Texas portion of the NFCA includes studies on historical trends in relative abundance, life history of imperiled species, and the larval fish assemblage (Lewis and Dalquest 1955; Larson et al. 1991; L.W. Reed Consultants, Inc. 1995; TPWD unpublished data 1995; Bonner and Wilde 2000; Wilde et al. 2001; Durham and Wilde 2005; Durham and Wilde 2006; Durham and Wilde 2008). Historical fish collections from the Canadian River in Texas included three fishes currently identified by TPWD (2012) as SGCN: Red River Pupfish *Cyprinodon rubrofluviatilis*, Peppered Chub *Macrhybopsis tetranema*, and Arkansas River Shiner *Notropis girardi* (Hendrickson and Cohen 2015). Arkansas River Shiner is concurrently listed as federally and state threatened, although no critical habitat is defined in Texas (USDOI 2005). The current listing status of the Peppered Chub is under review and information indicates that listing as threatened or endangered may be warranted (USDOI 2009). It appears that the only remaining population of Peppered Chub is in the 220-km reach of the Canadian River upstream of Lake Meredith in New Mexico and Texas as it now appears to be extirpated from Colorado, Oklahoma, and Kansas (Pennock et al. 2017). No freshwater mussel SGCN have been collected from the Canadian River in Texas (TPWD 2008).

The Texas Commission on Environmental Quality has reported a number of water quality concerns for the Canadian River (TCEQ 2014a). Concerns downstream of Lake Meredith (Segment 0101), specifically within the section from the confluence with White Deer Creek upstream to the confluence with Dixon Creek (Segment 0101_03), include elevated levels of bacteria. Elevated chloride levels upstream of Lake Meredith (Segment 0103) have resulted in that segment being placed on the state list of impaired waters. There are no fish consumption advisories currently in place for the Canadian River in Texas; however, mercury is listed as a concern for fish from Lake Meredith and it is recommended that people limit consumption of Walleye (TPWD 2016e).

Historical accounts of the Canadian River riparian corridor indicate the river valley was broad and comprised of vegetation that was "more verdant" than that of the plains above. On a visit to the region in 1601, Don Juan Onate recorded the Indians offered them tasty plums that were found in the valley groves. He also recorded there were "springs of good water and groves of trees" that occurred fairly frequently. Other accounts through the 1800s spoke of good spring flow, cottonwood trees, wild fruits, and tall grasses along the Canadian River corridor. In 1839, Josiah Gregg investigated the Canadian corridor as a possible trade route and stated that the Canadian Valley was "one of the most magnificent sights I have ever beheld" (TSSWCB 2000). Over time, land management practices such as harvesting of trees for timber, overgrazing, flow alteration, and other disturbances have changed the composition and structure of the riparian habitat and allowed the establishment of non-native invasive species such as Saltcedar and Russian Olive *Elaeagnus angustifolia*, which can out-compete and displace native vegetation.

River fragmentation, hydrologic alteration, drought, habitat degradation, and an increasing abundance of native and non-native invaders all continue to pose threats to Upper Canadian River NFCA and other rivers of the U.S. Great Plains. Increasing salinity in the Canadian River due to Saltcedar and decreased water availability has already contributed to fish kills attributed to golden alga blooms in Lake Meredith. Declines of fluvial specialist fishes (e.g., Arkansas River Shiner, Flathead Chub, Plains Minnow, and Peppered Chub) have been documented in the Upper Canadian River NFCA, particularly downstream of Lake Meredith where none were collected during recent surveys (Robertson et al. 2017).

Conservation planning to assemble a Conservation Action Plan for the Upper Canadian River NFCA was conducted in winter 2016 via a webinar and an in-person workshop involving participants from Oklahoma and Texas. Because of similarities in the life history of focal species, conservation challenges, and conservation partners across the Upper Brazos River, Upper Canadian River, and Upper Red River NFCAs, the decision was made to integrate the planning processes for those three watersheds. An initial joint conservation planning webinar was conducted for these three watersheds in December 2015. Webinar participants were provided with an introduction to the watershed-based NFCAs approach; the NFCA prioritization; the watershed-based conservation planning process and NFCA goals and implementation strategies; and selected regulatory, policy and voluntary conservation programs, resources, and tools available to support implementation of the NFCAs approach. Finally, webinar participants were provided with a brief tutorial on completion of a survey (Google Form) developed to elicit input from subject matter experts on project-level research, monitoring, and conservation actions to be undertaken by conservation partners to conserve focal fishes and their habitats in the NFCAs.

A follow-up conservation planning workshop was held in February 2016 in Oklahoma City (in conjunction with the Oklahoma Natural Resources Conference). The workshop was attended by an interdisciplinary team of 45 conservation professionals representing conservation non-profits, universities, and federal and state agencies including the Great Plains Fish Habitat Partnership, Southeast Aquatic Resources Partnership, Great Great Plains

Landscape Conservation Cooperative, Oklahoma Department of Wildlife Conservation, Oklahoma Water Resources Board, Oklahoma State University, The Nature Conservancy, Texas Parks and Wildlife Department, Texas Tech University, University of Oklahoma, University of Texas at Austin, and U.S. Fish and Wildlife Service Science Applications, Ecological Services, and Fish and Aquatic Conservation programs. Workshop participants presented overviews of their organizations' recent and ongoing research, monitoring and conservation actions in the NFCAs. Participants then reviewed and refined the draft list of project-level research, monitoring and conservation actions (submitted through the Google Form referenced above), which are outlined in Tables 7-9. Those tables represent Conservation Action Plans that are expected to guide partner investments over the next 5-10 years in cooperative, watershed-scale conservation of native fishes and other aquatic resources in the NFCAs.

Table 7 - Conservation Action Plan for the Upper Canadian River Native Fish Conservation Area.

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	LIDAR imagery of the Canadian River	Acquire LIDAR natural color and infrared imagery of the Canadian River	Will allow for more accurate surveys to detect barriers for fish that hinder upstream migrations. It will also allow for more accurate vegetation surveys for finding saltcedar and other problematic plant species
Monitoring and Adaptive Management	Off-road vehicle impacts on fishes	Assess impacts of off-road vehicles on fishes of Canadian River	Understand affects of off-road vehicles on fish and other aquatic species, especially during periods of no flow, and riparian vegetation
Research	Migration of Arkansas River Shiner and Peppered Chub in the Canadian River	Document migration of Arkansas River Shiner and Peppered Chub in the Canadian River using stable isotopes; this also will allow determination of the spawning sites and nursery areas	This is critical in understanding the potential effects of instream barriers, low flows, and fragmentation on these species

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Movement by pelagic broadcast-spawning fishes over multiple spatial scales	Stream connectivity during low-flow conditions over an appropriate stream length that allows for successful egg and larvae development appear to be the most pressing flow need (Mills and Mann 1985; Nunn et al. 2003; Durham and Wilde 2006, 2008, 2009; Perkin and Gido 2011); however, it is unclear the role higher flows play in facilitating spawning migrations; this study would assess movement by pelagic broadcast-spawning fishes over multiple spatial scales (mesohabitat, segment) before, during, and following the spawning period	Understanding the movement of these fishes is necessary to prescribe appropriate conservation and management actions; for example, if some flow conditions facilitate upstream movements at certain times of the year, water releases during that period may be enough to prevent isolating populations that can no longer reproduce successfully
Research	Propagation and grow-out methods for broadcast-spawning minnows	Develop propagation and grow-out methods for broadcast-spawning minnows, including hatchery and field propagation techniques	This will provide a source of individuals for repatriation and mitigation of proposed projects; also, fish can be used for experimental and other purposes
Research	Propagation for Arkansas River Shiner and Peppered Chub	Improve propagation techniques for the federally-listed Arkansas River Shiner and imperiled Peppered Chub; these two fish reside in the South Canadian River where drought is affecting population numbers and threatens extirpation in certain stretches of the river; future supplementation in stretches of the river may be necessary; additionally, propagated fishes will be used for research purposes, including experimental populations and in-situ fish movement studies	Refined propagation techniques will allow for larger production of Arkansas River shiner and peppered chub, which will aid in possible supplementation efforts, experimental populations, and research studies such as fish movements

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Reearch	Relationship between pelagophilic fishes and flow elements	Pelagic broadcast-spawning fishes (pelagophils) are considered susceptible to flow alteration because eggs and larvae drift passively in suspension for several days until they become free swimming (Battle and Sprules 1960; Balon 1975; Platania and Altenbach 1998); this project would develop statistical models that describe the relationship between pelagophils (e.g., Arkansas River Shiner) and flow elements; the data were previously compiled by a SARP project; in conjunction, status surveys will be reviewed and follow up surveys would be completed in areas where data were lacking	Flow-ecology models across the region could be used to develop possible flow standards for Great Plains rivers; at a minimum, these efforts would benefit a recovery plan; these data would also be useful to better understand the likely implications of reduced flows on pelagic broadcast spawning fishes
Research	Slackwater habitats and reproductive success of pelagic broadcast-spawning fishes	Lateral connectivity to floodplains is fragmented when structures prevent water and aquatic organisms from accessing the floodplain, such that floodplain habitats are lost (Schlosser 1991); in this context, flow alterations that reduce discharge magnitudes and compromise floodplain inundation create a special case of habitat fragmentation and loss for pelagophils (Costigan and Daniels 2012; Hoagstrom and Turner 2015); this project would determine the relative importance of slackwater habitats (available at both low and high flows) to the reproductive success of pelagic broadcast-spawning fishes (e.g., Arkansas River Shiner)	Understanding survival related to spawning habitat and flow conditions would seem important prerequisites to being able to successfully model population responses to flow alteration; stream connectivity during low-flow conditions over an appropriate stream length that allows for successful egg and larvae development have been suggested (Mills and Mann 1985; Nunn et al. 2003; Durham and Wilde 2006, 2008a, 2009a; Perkin and Gido 2011) but the role of floodplains and other habitats that increase egg retention (Worthington et al. 2014) remain largely unexplored and have important implications for flow management
Research	Tolerances of larval and juvenile pelagic-spawning fishes	Develop information on physical and chemical tolerances of larval and juvenile pelagic-spawning fishes to assess adequacy of nursery habitat, which may be independently affected by dewatering and climate change	Understand affects of habitat modifications (dewatering) and climate change on young-of-year fishes; also, will help assess affects of invasive species.

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Invasive Species Management	Saltcedar management within Canadian River drainages	Conduct an inventory and characterization of saltcedar (SC) coverage, potential refugia, and fish passage barriers; develop plan for prioritized, stepwise, sustainable SC management within Canadian River drainages including SOPs for SC surveying and monitoring; implement prioritized, large-scale SC management that is adaptive to periodic reevaluation based on monitoring results	Plan for prioritized, stepwise, sustainable saltcedar management within basin; Maps of saltcedar coverage, potential refugia, and fish passage barriers; SOPs for surveying saltcedar coverage consistently over time and across basins; framework for evaluation and prioritization of treatment efforts (with periodic reevaluation/ reprioritization); SOPs for monitoring effects of treatment; mitigation of impacts of an invasive species likely to be synergistically increased by climate change; improvements in geomorphic processes, habitat, and connectivity at a scale relevant for long-term persistence of native fish populations
Habitat Protection	Fish refuge areas along the Canadian River	Assess fish refuge areas with aerial photography along the Canadian River during drought periods	Refugia areas for fishes in the Canadian River will be identified to better inform management decisions and conservation actions
Habitat Protection	Phragmites encroachment	Document the extent of Phragmites encroachment on the Canadian River, which has entrenched some 60 miles of river and initiate removal; Phragmites has restricted the wetted channel to one-third of its 2000 width and threatens populations of Arkansas River Shiner and Peppered Chub	Remove Phragmites and restore river to its original broad channel, which supports Arkansas River Shiner and Peppered Chub; reduce water loss due to transpiration by dense Phragmites stands
Habitat Protection	Species status assessment	Develop a species status assessment for imperiled fishes in the Canadian River; assessment will include species needs, current and future condition, and viability; information from assessment will be utilized for future management decisions and conservation actions in the Canadian River watershed	Development of species status assessment to inform on the ground conservation actions

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Habitat Restoration	Flow-ecology relationships of pelagic broadcast-spawning fishes	Examine flow-ecology relationships of pelagic broadcast-spawning fishes and explore opportunities to identify flow prescriptions in the South Canadian River to support natural flow patterns that meet the needs of native aquatic communities	Influence water management in the Canadian River and protect imperiled fish populations
Habitat Restoration	Identify available water to achieve flow restoration targets	Complete an analysis of existing water rights and patterns of water use to identify available water and explore opportunities for water leases, water rights acquisition, and voluntary incentive-based programs to achieve flow restoration targets	Influence water management and provide a decision support tool

Conservation Action Plan for the Upper Red River River Native Fish Conservation Area

The Red River flows 2,188 km through the states of Texas, Oklahoma, Arkansas, and Louisiana before reaching its confluence with the Mississippi River (Huser 2000). The mainstem Red River begins in Texas where the Prairie Dog Town Fork gives way to the Red River at the eastern edge of the Texas panhandle. The south bank of the river then goes on to form the Texas-Oklahoma border (Huser 2000), followed by the Texas-Arkansas border, before entering Louisiana (Huser 2000). The watershed drains an area of 169,900 square km and spans several Texas ecoregions: Western High Plains, Southwestern Tablelands, Texas Blackland Prairies, Central Oklahoma/Texas Plains, and South Central Plains (Griffith et al. 2004). Major tributaries to the Red River in Texas include several forks (Prairie Dog Town Fork, Salt Fork, and North Fork), the Wichita River, the Pease River, Big Cypress Bayou, and the Sulphur River. Only one major reservoir impounds the Red River within Texas, Lake Texoma (Huser 2000), which serves as the downstream extent of the Upper Red River NFCA.

Within the Upper Red River NFCA, the Prairie Dog Town Fork (Figure 15) has been recognized by the Nationwide Rivers Inventory for having remarkable cultural, geologic, historic, recreational, and scenic value (NPS 2010). Two segments of the Prairie Dog Town Fork have been nominated by TPWD as Ecologically Significant Stream Segments: Upper Prairie Dog Town Fork Red River (Texas Commission on Environmental Quality Segment 0229) and Lower Prairie Dog Town Fork Red River (0207; TPWD 2018a). The upper segment was recognized as having a riparian conservation area (i.e., Palo Duro Canyon State Park) and for high water quality, high aesthetic value, and exceptional aquatic life (TPWD 2018a). Both segments of the Prairie Dog Town Fork and two segments of the mainstem Red River (0205 and 0206) have been recognized for providing habitat for the federally threatened interior least tern *Sterna antillarum* (TPWD 2018a). Several additional tributaries of the Red River have been nominated, including the Pease (0220) and Middle Pease (0221) rivers as having riparian conservation areas (i.e., Copper Breaks State Park and Matador Wildlife Management Area, respectively; TPWD 2018a).

The University of Texas Biodiversity Collections has historic records for 66 species of freshwater fishes from the Upper Red River NFCA (Hendrickson and Cohen 2015); however, many reaches have not been surveyed. Ongoing fish data collection efforts in the Upper Red River NFCA at the TPWD Matador Wildlife Management Area beginning in 2004 by West Texas A&M University (WTAMU) have documented 20 fish species (personal communication, Richard Kazmaier, WTAMU). Historical fish collections from the Upper Red River NFCA included 11 SGCN: Goldeye *Hiodon alosoides*, American Eel *Anguilla rostrata*, Blue Sucker *Cycleptus elongatus*, Prairie Chub *Machrybopsis australis*, Silver Chub *Macrhybopsis*

Figure 15 - Headwaters of the Prairie Dog Town Fork of the Red River located within the Upper Red River Native Fish Conservation Area.

storeiana, Red River Shiner *Notropis bairdi*, Sharpnose Shiner *Notropis oxyrhynchus*, Chub Shiner *Notropis potteri*, Silverband Shiner *Notropis shumardi*, Red River Pupfish *Cyprinodon rubrofluviatilis*, and Orangebelly Darter *Etheostoma radiosum* (Hendrickson and Cohen 2015). Additionally, the Plains Minnow *Hybognathus placitus*, Shoal Chub *Macrhybopsis hyostoma*, and Suckermouth Minnow *Phenacobius mirabilis* are proposed for inclusion on the Texas Conservation Action Plan SGCN list (Cohen et al. 2018) and have been reported from the Upper Red River NFCA.

The same conservation planning process (and stakeholders) described above for the Upper Canadian River NFCA was also used for the Upper Red River NFCA conservation planning process. Conservation planning resulted in development of the Upper Red River Conservation Action Plan (Table 8), which is expected to guide partner investments over the next 5-10 years in conservation of native fishes.

Table 8 - Conservation Action Plan for the Upper Red River NFCA.

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	Wichita River mussel survey	Survey the Wichita River for mussels, including imperiled species	This study will locate extant populations of freshwater mussels in the Wichita River and determine if imperiled species occur and how they might be conserved
Research	Life history of the Prairie Chub	Conduct basic life history study on the Prairie Chub	This information is necessary to management of the species, determination of its status, and how to mitigate ongoing habitat change
Research	Migration of Prairie Chub, Plains Minnow, and Red River Shiner in the Red River and tributaries	Document migration of Prairie Chub, Plains Minnow, and Red River Shiner in the Red River and tributaries using stable isotopes; this also will allow determination of the relative importance of the Red River and its tributaries as spawning sites and nursery areas	This is critical in understanding the potential effects of instream barriers, low flows, and fragmentation on these species

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Physical and chemical tolerances of larval and juvenile pelagic-spawning fishes	Develop information on physical and chemical tolerances of larval and juvenile pelagic-spawning fishes to assess adequacy of nursery habitat, which may be independently affected by dewatering and climate change	Understand affects of habitat modifications (dewatering) and climate change on young-of-year fishes; also, will help assess affects of invasive species
Research	Propagation and grow-out methods for broadcast-spawning minnows	Develop propagation and grow-out methods for broadcast-spawning minnows, including hatchery and field propagation techniques	This will provide a source of individuals for repatriation and mitigation of proposed projects; also, fish can be used for experimental and other purposes
Invasive Species Management	Saltcedar management in the Red River	Conduct an inventory and characterization of saltcedar (SC) coverage, potential refugia, and fish passage barriers; develop plan for prioritized, stepwise, sustainable SC management within Red River drainages including SOPs for SC surveying and monitoring. Implement prioritized, large-scale SC management that is adaptive to periodic reevaluation based on monitoring results	Plan for prioritized, stepwise, sustainable saltcedar management within basin; Maps of saltcedar coverage, potential refugia, and fish passage barriers; SOPs for surveying saltcedar coverage consistently over time and across basins; framework for evaluation and prioritization of treatment efforts (with periodic reevaluation/reprioritization); SOPs for monitoring effects of treatment; mitigation of impacts of an invasive species likely to be synergistically increased by climate change; improvements in geomorphic processes, habitat, and connectivity at a scale relevant for long-term persistence of native fish populations
Habitat Restoration / Habitat Protection	Restoration and protection of riparian buffers along Red and Canadian rivers	Assess condition of riparian buffers along Red and Canadian rivers and tributaries, and prioritize areas for restoration and protection (through acquisition, conservation easements or other landowner incentives)	Identified Priority Areas for riparian restoration, increased efficiency and benefit for restoration activities

Conservation Action Plan for the Upper Brazos River Native Fish Conservation Area

The Upper Brazos River NFCA comprises the Brazos River and its tributaries (Salt Fork Brazos River and Double Mountain Fork Brazos River) upstream of Lake Possum Kingdom. This watershed is largely free-flowing and characterized by shallow, sandy, and braided stream channels. The Salt Fork Brazos River is fed by numerous Permian brine springs and at times leads to salinities greater than the Gulf of Mexico (Baker et al. 1964; Brune 2002) and very clear waters. The Salt Fork Brazos River contributes over 85% of the chloride load (850 tons daily average) to the Brazos River (Baker et al. 1964) and the volume of these brine springs created a great saline lake evident on 19th century maps of Texas. The White River, a tributary of the Salt Fork, was once fed by the fresher Ogallala Aquifer at the rate of 49,210 m3/day and was impounded in 1963 with the construction of White River Reservoir. Leakage from the dam forms a small trickle and groundwater pumping for irrigation has dried up nearly all springs fed by the Ogallala in the Salt Fork watershed. Lake Alan Henry, constructed by the City of Lubbock, impounds the Double Mountain Fork Brazos River before its confluence with the North Fork Double Mountain Fork Brazos River. Portions of the Double Mountain Fork are also underlain by the Ogallala. A long-standing invasion by Saltcedar has contributed to channel-narrowing with potential consequences on hydraulic habitat and use by native fishes.

River fragmentation and hydrologic alteration associated with reservoir development has led to substantial changes in fish communities including extirpations and assemblage shifts across the Upper Brazos River NFCA and other rivers of the U.S. Great Plains (Perkin et al. 2015). Water extractions reduce base flows, altering instream habitat and water quality and contributing to increased duration, severity, and frequency of drying/intermittency; during drought the effects of reduced base flows are intensified. While some fishes are more tolerant of the harsh environmental conditions in intermittent pools others perish as temperatures and salinities increase and dissolved oxygen levels decline (Ostrand and Wilde 2004).

Since its introduction to the Brazos River watershed in the first half of the 1900s, Saltcedar has expanded and is typically found in high density stands along the river's edge; new growth is often found in the river channel and in lines along high water marks. Saltcedar colonizes stream floodplains and terraces, armoring river terraces and reducing the ability of a stream to meander. As the channel narrows, stream depth increases and temperature decreases (Nagler et al. 2010; Dean et al. 2011). Saltcedar may be more drought tolerant than native species (Glenn and Nagler 2005) and is becoming the dominant woody species in riparian areas throughout the western USA. In the Brazos River between Lake Possum Kingdom and the confluence of the Double Mountain Fork, phreatophytic, woody vegetation in the floodplain increased from 39% in 1969 to 57% by 1979 (Blackburn et al. 1982). Saltcedar dominated areas where the floodplain was narrow and the stream channel was straight, providing optimum water table conditions for their growth and regeneration (Busby and Schuster 1973). Saltcedar invasion caused 3 m of sediment accumulation, reduced Brazos River width by approximately 90 m, reduced sediment input to Lake Possum Kingdom, and resulted in higher flood stages.

All riparian vegetation transpires large volumes of water and Saltcedar is no exception. However, the supposition, based on limited research, that Saltcedar uses considerably more water than other riparian vegetation has led to management efforts in west Texas and other areas of the southwestern USA. Some studies, including efforts on the Pecos River, have found that Saltcedar management produced negligible water gains due to old stand age and high flows following abatement (McDonald et al. 2015). Saltcedar transpiration on a reach of one Texas river was estimated to use 44,000 acre-feet per year (Busby and Schuster 1973), but substantial water yields have not yet been observed at watershed scales (Wilcox 2002; Wilcox et al. 2006; Doody et al. 2011). Furthermore, the impacts of salinity pulses on fish communities following Saltcedar treatments is largely unknown (Hart et al. 2005) and the geomorphic impacts to native fishes and instream habitat and evaluation of the change in geomorphology remain a key challenge for management of invasive plants in riparian areas.

The native fishes of the Upper Brazos River NFCA are structured by spatial and temporal variations in environmental conditions such as salinity and hydraulic habitat (Echelle et al. 1972; Ostrand and Wilde 2002) as well as isolating constraints from downstream dams. In the saline reaches, such as most of the Salt Fork Brazos River, salt-tolerant Red River Pupfish *Cyprinodon rubrofluviatilis* and Plains Killifish *Fundulus zebrinus* dominate assemblages, while in fresher reaches fish richness is greater due to the presence of numerous cyprinids (Moss and Mayes 1994; Ostrand and Wilde 2002). Using data from Moss and Mayes (1994) and more recent fish collections (Wilde 2015) from the upper Brazos River basin, Mayes et al. (In Press) assessed temporal changes in fish populations. Cyprinids in the pelagic-broadcast spawning reproductive guild showed declines in relative abundance (Smalleye Shiner *Notropis buccula*, Sharpnose Shiner *N. oxyrhynchus*, Chub Shiner *N. potteri* and Plains Minnow *Hybognathus placitus*) while Red Shiner *Cyprinella lutrensis* a crevicespawning minnow, Red River Pupfish a nest-builder, and the live-bearer Western Mosquitofish *Gambusia affinis* increased. Silver Chub *Macrhybopsis storeriana* (a broadcast spawner) has not been collected in the upper Brazos River since the early 1990s. Fishes that showed the greatest declines were pelagic, broadcast-spawning cyprinids. These cyprinids are characteristic of prairie streams such as the Brazos River and subject to great vulnerability due to their complex reproductive strategies and life history requirements (Durham and Wilde 2014; Worthington et al. 2017). Flowing water is essential to their successful reproduction and the survival of eggs and larval fish. Relatively long unobstructed river reaches are required to allow their semi-buoyant eggs enough distance to drift with the river's current. Once hatched, larval fish must stay suspended in the current (to prevent larval settlement) until they become strong enough to swim against currents. During times of sufficient flow, their populations expand while populations decline when flows are insufficient or rivers dry. This boom and bust cycle reflects the harsh yet cyclical nature of Great Plains prairie ecosystems (Dodds et al. 2004) and the opportunistic life history strategy of these cyprinids (Worthington et al. 2017). Further, when storm-driven high flow events occur during the reproductive season (~April–September), pelagic, broadcast-spawning minnows spawn simultaneously (i.e., synchronized spawning of more than one species; Durham and Wilde 2009a). Because these fishes only live for one to two years (rarely three), successful reproduction and survival of eggs and larval fish must occur on a frequent basis in order to maintain viable, resilient populations.

Two endemic pelagic-broadcast spawning cyprinids, Smalleye Shiner and Sharpnose Shiner, were historically found throughout the Brazos River basin, but are now found only in the Upper Brazos River NFCA (USFWS 2014b). Given this reduced distribution, which is constrained from downstream emigration and upstream colonization due to the presence of Lake Possum Kingdom, one adverse event such as a persistent drought of two consecutive years

Figure 16 - Double Mountain Fork Brazos River within the Upper Brazos River Native Fish Conservation Area.

could lead to extinction. This concern was amplified in 2011 when a record-setting drought and heatwave resulted in the driest 12 months (October 2010–September 2011) in Texas history (Hoerling et al. 2013). The long duration of intermittency in the upper Brazos River watershed resulted in complete reproductive failure by Smalleye Shiner, Sharpnose Shiner, and other broadcast-spawning minnows. The flow intermittency, high air and water temperatures, and reproductive failure led to a coordinated rescue effort. TPWD and Texas Tech University personnel collected several thousand Sharpnose Shiner and Smalleye Shiner from drying pools in mid-September 2011 and transported them to the Possum Kingdom State Fish Hatchery for over-wintering. Plans to collect additional shiners were halted when rains returned in late September 2011. In 2012, the pond was harvested; fifty of each species were taken to the Texas Tech University campus for captive spawning research and the remaining fishes (~370 of each) were repatriated to the lower Brazos River near Hearne, Texas. Although fish sampling has been conducted in the area, no occurrences of either species have been reported from the lower Brazos River.

To facilitate continued cooperation among universities and agencies actively engaged in conservation of native fishes in the Upper Brazos River NFCA, conservation planning was conducted in winter 2016 in conjunction with the planning processes for the Upper Canadian River and Upper Red River NFCAs. The planning process culminated in the development of a Conservation Action Plan (Table 9), which is expected to guide partner investments over the next 5-10 years in multispecies, watershed-based conservation of native freshwater fishes.

Table 9 - Conservation Action Plan for the Upper Brazos River Native Fish Conservation Area.

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	Middle Brazos River mussel survey	Survey mussels in the middle Brazos River, downstream from Possum Kingdom Reservoir; recent collection of a freshly dead Texas fawnsfoot suggest this river may support an important population of that, and other, species of imperiled freshwater mussel	Document the size and status of the imperiled Texas fawnsfoot and other freshwater mussels in the middle Brazos River
Monitoring and Adaptive Management	LIDAR imagery of the Upper Brazos River	Acquire LIDAR natural color and infrared imagery of the Upper Brazos River	Will allow for more accurate surveys to detect barriers for fish that hinder upstream migrations; it will also allow for more accurate vegetation surveys for finding saltcedar and other problematic plant species

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Monitoring and Adaptive Management	Long-term monitoring across Great Plains basins	Develop protocols and implement long-term monitoring sites across Great Plains basins	Multidisciplinary framework for monitoring hydrology, water quality, geomorphology, biology, and connectivity to support long-term science needs in Great Plains basins; benefits of standardized and comprehensive sampling would accrue across scales (e.g. regional flow-ecology; e-flow standards); across protection/restoration efforts (large scale invasive control; flow manipulation/restoration) and adaptive management strategies (where do you get most return); data needed for science gaps, listing and delisting processes, etc.
Monitoring and Adaptive Management	Upper Brazos River mussel survey	Survey the upper Brazos River for mussels, including imperiled species; populations of at least two species are known to occur based on finds of freshly dead material; these populations are 500 km upstream from the closest neighboring populations	This study will locate extant populations of freshwater mussels in the Upper Brazos River- 500 km upstream from other populations- and determine whether imperiled species occur and how they might be conserved
Research	Upper Brazos River basin of Texas	To understand how water resource development in the Upper Brazos River basin of Texas quantitatively affects spawning flows needed for Sharpnose Shiner (Notropis oxyrhynchus) and Smalleye Shiner (N. buccula) reproductive success by: (1) evaluating groundwater-surface water interactions with trends in baseflow and groundwater level, streamflow measurements during spawning, and hydrograph separation with conductivity, and (2) assessing changes in natural flow regime from reservoir operation using minimum-flow, high flow pulse, and bank storage metrics	This study will increase our understanding of how groundwater and surface water use—exacerbated by droughts and climate change—threaten current and future shiner habitat in the Upper Brazos River basin of Texas; this can inform Recovery Plan development, particularly research and management actions leading to restoration of spawning flows. Results can also be used to understand threats to other species of greatest conservation need in the Upper Brazos basin (TPWD, 2012, 2014)

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Environmental flow releases to support natural flow regimes and habitat conditions	Characterize and prioritize Great Plains reservoirs for environmental flow releases (physically, financially, ecologically) to support more natural flow regimes and habitat conditions in prairie rivers; implement experimental releases to support science needs of prairie streams/validate hypotheses; modify reservoir operating rules where appropriate	A screening and characterization (pros/cons) of Great Plains reservoirs for making e-flow releases (see Grantham et al. 2014); improved flow regimes through changes in reservoir operating rules where feasible; long-term implementation strategy; pre- and post-release data to inform/validate/refine hypotheses; restore biotic integrity, geomorphic processes, water quality conditions, connectivity.
Research	Migration of Sharpnose Shiner and Smalleye Shiner in the upper Brazos RIver	Document migration of Sharpnose Shiner and Smalleye Shiner in the upper Brazos River using stable isotopes; this also will allow determination of the relative importance of the Salt Fork, Double Mountain Fork, and Brazos River mainstem as spawning sites and nursery areas	This is critical in understanding the potential effects of instream barriers, low flows, and fragmentation on these species
Research	Physical and chemical tolerances of larval and juvenile pelagic-spawning fishes	Develop information on physical and chemical tolerances of larval and juvenile pelagic-spawning fishes to assess adequacy of nursery habitat, which may be independently affected by dewatering and climate change	Understand affects of habitat modifications (dewatering) and climate change on young-of-year fishes; also, will help assess affects of invasive species
Research	Propagation and grow-out for broadcast-spawning minnows	Develop propagation and grow-out methods for broadcast-spawning minnows, including hatchery and field propagation techniques	This will provide a source of individuals for repatriation and mitigation of proposed projects; also, fish can be used for experimental and other purposes.

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Research	Spawning flows for Sharpnose Shiner and Smalleye Shiner	To understand how water resource development in the Upper Brazos River basin of Texas quantitatively affects spawning flows needed for Sharpnose Shiner (Notropis oxyrhynchus) and Smalleye Shiner (N. buccula) reproductive success by: (1) evaluating groundwater-surface water interactions with trends in baseflow and groundwater level, streamflow measurements during spawning, and hydrograph separation with conductivity, and (2) assessing changes in natural flow regime from reservoir operation using minimum-flow, high flow pulse, and bank storage metrics	This study will increase our understanding of how groundwater and surface water use—exacerbated by droughts and climate change—threaten current and future shiner habitat in the Upper Brazos River basin of Texas; this can inform Recovery Plan development, particularly research and management actions leading to restoration of spawning flows; results can also be used to understand threats to other species of greatest conservation need in the Upper Brazos basin (TPWD, 2012, 2014)
Invasive Species Management	Inventory, characterization and management of saltcedar	Conduct an inventory and characterization of saltcedar (SC) coverage, potential refugia, and fish passage barriers; develop plan for prioritized, stepwise, sustainable SC management within upper Brazos River drainages including SOPs for SC surveying and monitoring. Implement prioritized, large-scale SC management that is adaptive to periodic reevaluation based on monitoring results	Plan for prioritized, stepwise, sustainable saltcedar management across the Southern Great Plains NFCA; Maps of saltcedar coverage, potential refugia, and fish passage barriers; SOPs for surveying saltcedar coverage consistently over time and across basins; framework for evaluation and prioritization of treatment efforts (with periodic reevaluation/reprioritization); SOPs for monitoring effects of treatment; mitigation of impacts of an invasive species likely to be synergistically increased by climate change; improvements in geomorphic processes, habitat, and connectivity at a scale relevant for long-term persistence of native fish populations
Habitat Protection	Inventory of point and non-point source discharges impacting water quality	Conduct an inventory of point and non-point source discharges impacting water quality in the upper Brazos River (above PK); prioritize discharges of highest concern to listed shiners and develop recommended management actions to address or otherwise ameliorate those impacts	Improved water quality to maintain healthy ecosystem in support of shiners

NFCA Goal Addressed	Project Title	Project Description	Expected Outcomes
Habitat Restoration	Suitability of Brazos River segments for repatriation of extirpated species	Assess Brazos River segments for suitability of repatriation of locally extirpated species; this will use a combination of GIS, existing data sets, and expert knowledge; this project also will provide a general model for similar studies in other river basins	Local populations of a growing number of fishes are disappearing to prevent these from becoming imperiled, there is a need to repatriate fish to suitable habitat reaches, thus maintaining continuity in their historic range; this also will aid recovery efforts for listed species
Connectivity	Fish barriers for Sharpnose Shiner and Smalleye Shiner	Identify partial fish barriers in occupied habitat for the Sharpnose Shiner and Smalleye Shiner and work with private landowners to design and replace water crossing structures; funding from USFWS through the Partners for Fish and Wildlife Program and National Fish Passage Program could support this effort	restore connectivity of habitat; facilitate larval recruitment to adulthood and enhance reproductive success

Case Study in Conservation Delivery within Native Fish Conservation Areas of Texas

During 2013-2018, TPWD, SARP, DFHP, U.S. Fish and Wildlife Service, and numerous local conservation partners cooperated to deliver strategic conservation projects throughout NFCAs of Texas. A case study in conservation delivery within NFCAs of Texas is provided below. This case study is adapted from Birdsong et al. (in press), and describes conservation investments toward achieving each of the eight NFCA goals previously outlined in Table 4.

NFCA Goal 1 – Protect and Maintain Intact Habitats

Effective January 2016, the Texas Legislature authorized and provided funding for TPWD to administer the Texas Farm and Ranch Lands Conservation Program (TFRLCP), a grant program designed to provide cost-share funding to land trusts for the purchase of conservation easements on private lands in support of the following objectives: (1) conserve water or protect water quality, (2) conserve native wildlife species through protection of their habitat, (3) conserve rare or sensitive species, (4) demonstrably contribute to preservation of a landscape of conservation lands, or (5) protect productive open-space land threatened by fragmentation or development. Specific project scoring, ranking, and selection criteria were assembled by TPWD and approved by the Governor-appointed Texas Farm and Ranch Lands Council, which provides leadership and oversight of the TFRLCP.

The 100 possible points awarded to grant applications submitted to the TFRLCP consider the following scoring criteria: (1) threat of development (20 points), (2) value and cost-effectiveness (20 points), (3) value in protection of watershed processes and aquatic habitats (20 points), (4) value in protection of habitats for SGCN (20 points), (5) contributions to protection of a conservation landscape such as a wildlife migration route or riparian corridor (10 points), and (6) terms of the conservation easement (10 points). Application scoring criteria 3-5 for the TFRLCP directly relate to variables considered in selection of freshwater systems designated as NFCAs in Texas. Grant applications to the TFRLCP that proposed conservation easements on private lands located within the Texas NFCAs scored considerably higher than those located elsewhere in the state. As such, the Texas NFCAs prioritization substantially influenced scoring of individual applications, and 13 of the 14 grants awarded by the TFRLCP in 2016-2018 supported preservation of private lands within the Texas NFCAs (Table 10).

Those 13 conservation easements funded by the TFRLCP protected 10,563 ha of springs and instream, riparian, and upland habitats within the Central Coast Rivers and Streams, Central Edwards Plateau Rivers, Guadalupe Mountains Streams, Guadalupe and San Antonio Rivers (Figure 17), Lower Colorado River (Figure 18), San Gabriel River, Southeast Texas Rivers, Southern Edwards Plateau Rivers, and Upper Red River NFCAs. Conservation biologists from the TPWD Inland Fisheries Division conducted site visits to the private properties selected for funding and consulted with landowners and partnering land trusts on the terms and conditions of the conservation easements to maximize their benefit and value in long-term protection of native fishes, their habitats, and other freshwater resources within those nine NFCAs.

The Western Association of Fish and Wildlife Agencies Crucial Habitat Assessment Tool (CHAT; www.wafwachat.org) identifies important fish and wildlife habitats and corridors across the 17 western states of the USA, including Texas. The purpose is to incorporate and inform consideration of fish and wildlife habitats in land use planning, zoning, and development decisions, such as planning of new energy or transportation corridors. Habitats identified as priorities within the CHAT were selected by cooperating state fish and wildlife agencies. Each state agency utilized a standard set of definitions, guidelines, and criteria to achieve a consistent regional approach. In 2018, TPWD finalized the CHAT input layers for Texas, including the Aquatic CHAT layer (Figure 19), which incorporated priority freshwater systems of the Texas NFCAs Network as a top tier priority for conservation of native fishes and other freshwater SGCN. As is the intent of the CHAT, this is expected to encourage land developers toward increased consideration, avoidance, and protection of freshwater systems contained within the Texas NFCAs Network.

Table 10 - Conservation easements secured within Native Fish Conservation Areas of Texas through the Texas Farm and Ranch Lands Conservation Program (2016-2018).

Native Fish Conservation Area	Number of Conservation Easements	Area Protected (Hectares)	Habitat Types Protected
Central Coast Rivers and Streams	2	2,276	Wetlands
Central Edwards Plateau Rivers	1	554	Riparian Habitats of the Mainstem Colorado River
Guadalupe Mountains Streams	1	2,925	Tributary Streams and Riparian Buffers of McKittrick Creek
Guadalupe and San Antonio Rivers	1	85	Tributary Streams and Riparian Buffers in the Blanco River Watershed
Lower Colorado River	3	635	Tributary Streams and Riparian Buffers in the Barton Creek and Onion Creek Watersheds
San Gabriel River	1	248	Tributary Streams and Riparian Buffers in the San Gabriel River Watershed
Southeast Texas Rivers	1	2,230	Tributary Streams and Riparian Buffers in the Neches River Watershed
Southern Edwards Plateau Rivers	2	953	Tributary Streams and Riparian Buffers in the Nueces River Watershed
Upper Red River	1	656	Riparian Habitats of the Mainstem Red River

Figure 17 - Riparian corridor of Wanslow Creek, preserved through a conservation easement, within the Guadalupe and San Antonio Rivers Native Fish Conservation Area.

NFCA Goal 2 – Restore Altered Habitats

Actions to restore altered habitats within Texas NFCAs have primarily centered on restoration of habitats for Guadalupe Bass *Micropterus treculii*, a SGCN and the official state fish of Texas (Birdsong et al. 2015; Garrett et al. 2015; Bean et al. In Press; Magnelia et al., in press). Supported through grants provided by SARP, National Fish and Wildlife Foundation, and U.S. Fish and Wildlife Service Texas Partners for Fish and Wildlife Program, TPWD and partners have restored 3,199 ha of springs, creeks, and riparian buffers within the Central Edwards Plateau Rivers NFCA, improving habitat conditions for native fishes in approximately 89 km of the James, Llano, and Pedernales rivers and their tributaries. Additionally, TPWD has provided technical guidance to approximately 850 landowners and other local stakeholders on recommended stewardship practices for management of instream and riparian habitats. Stewardship practices to maintain or restore physical watershed processes have been implemented on approximately 42,389 ha of ranchlands. Habitat

Figure 18 - Riparian corridor of Onion Creek, preserved through a conservation easement, within the Lower Colorado River Native Fish Conservation Area.

restoration was conducted in conjunction with Guadalupe Bass genetic restoration efforts, which involved the production and stocking of more than 793,629 genetically-pure Guadalupe Bass fingerlings to ameliorate hybridization between Guadalupe Bass and non-native, introduced Smallmouth Bass *Micropterus dolomieu* (Garrett et al. 2015; Fleming et al. 2015; Lutz-Carrillo et al. 2015).

Within the Southern Edwards Plateau Rivers NFCA, TPWD collaborated with private landowners and nongovernmental organizations to restore 209 ha of grasslands, riparian buffers, and instream habitats (Table 11). Biologists from TPWD cooperated with landowners to implement conservation best management practices on 9,930 ha of the Frio, Medina, Nueces, and upper Guadalupe rivers watersheds. Additionally, a partnership was formed among TPWD, The Nature Conservancy, U.S. Fish and Wildlife Service Partners for Fish and Wildlife Program, and the Texas Master Naturalists Program to provide landowners and citizen scientists with technical guidance on watershed stewardship practices, aquatic species identification, and aquatic resources monitoring strategies.

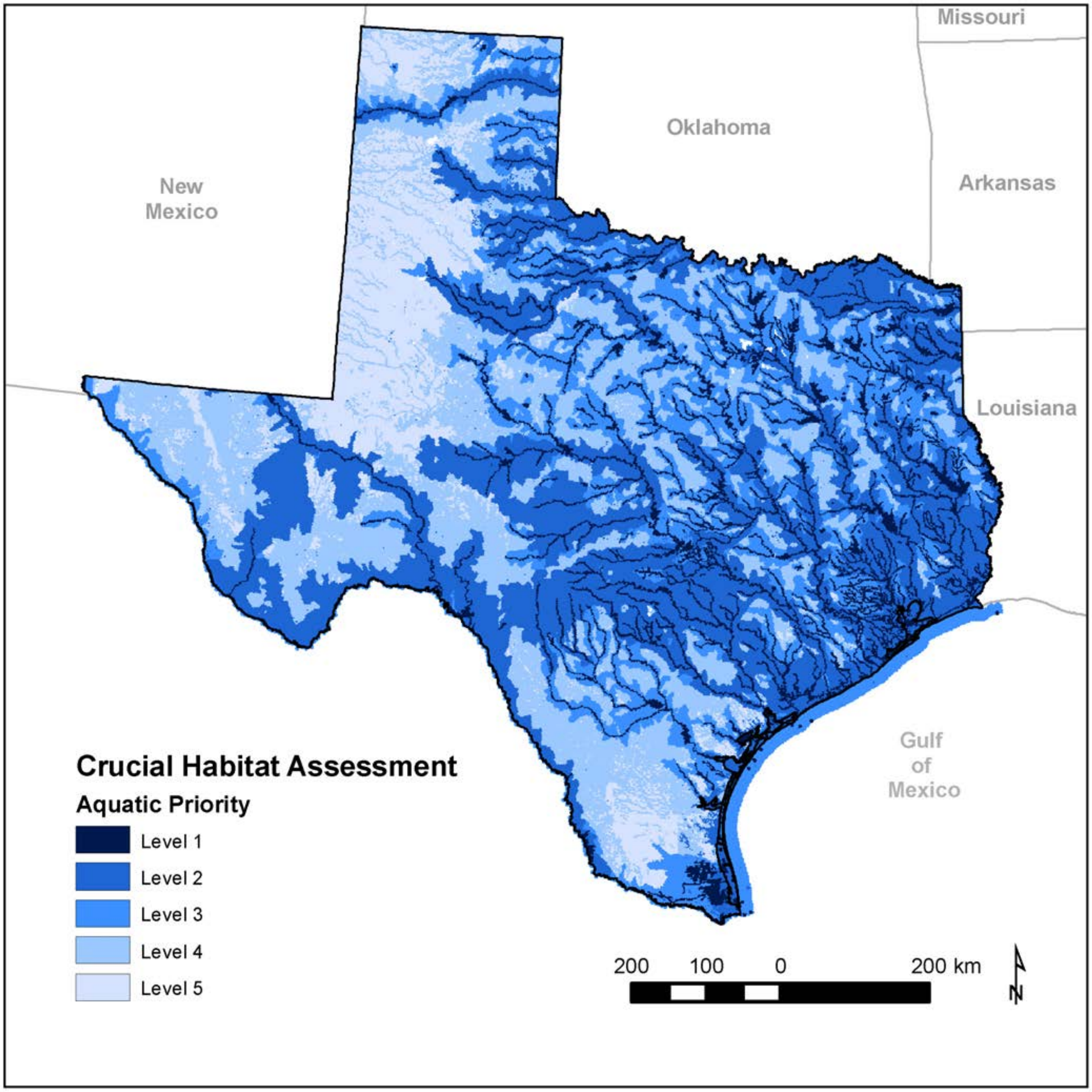

Figure 19 - Aquatic Crucial Habitat Rank for Texas freshwater systems identified in the Western Association of Fish and Wildlife Agencies Crucial Habitat Assessment Tool (Level 1 = Perennial streams and estuarine/coastal habitats with known occurrences of fish SGCN; Level 2 = Texas Native Fish Conservation Areas, Texas springs, and estuarine/coastal habitats known to support fish SGCN; Level 3 = Perennial streams within the modeled ranges of fish SGCN; Level 4 = All other perennial and intermittent streams; Level 5 = All other areas of the state).

In the Guadalupe and San Antonio Rivers NFCA, TPWD and partners organized eight riparian habitat restoration workshops attended by 525 riparian landowners and other local stakeholders. A landowner restoration manual was assembled that identifies strategies for accommodating recreational access to rivers while maintaining riparian functions (Asher et al. 2017). Similar to conservation efforts in the Central Edwards Plateau Rivers NFCA, the Southeast Aquatic Resources Partnership provided funding to TPWD and partners to deliver restoration of 142 ha of riparian buffer along the Blanco River (Table 11). Restoration included planting of 3,300 native riparian saplings and 15,000 riparian sedges to support revegetation of erosional river banks denuded of vegetation following catastrophic flooding. Habitat restoration was completed in conjunction with a non-native Smallmouth Bass removal and Guadalupe Bass stocking program, which successfully repatriated Guadalupe Bass to a fragmented reach of the Blanco River (Magnelia et al., in press).

Table 11 - Landowner technical guidance and habitat restoration completed within Texas Native Fish Conservation Areas (2013-2018).

Native Fish Conservation Area	Area of Ranchlands that Received Prescriptive Guidance on Best Practices for Watershed Management (Hectares)	Quantity of Habitats Restored (Hectares)	Habitat Types Restored
Central Edwards Plateau Rivers	42,389	3,199	Grasslands, Springs, Riparian and Instream Habitats
Guadalupe and San Antonio Rivers	472	142	Riparian and Instream Habitats
Pecos River	5,036	0.4	Springs, Instream Habitats
Southern Edwards Plateau Rivers	9,930	209	Grasslands, Riparian and Instream Habitats
Upper Big Bend	120,343	16,596	Grasslands, Springs, Riparian and Instream Habitats
Upper Brazos River	2,711	2,711	Riparian and Instream Habitats

Texas NFCAs have also been adopted as geographic priorities for investments by multiple conservation funding programs administered by federal agencies and foundations. The most recent 5-year strategic plan of the U.S. Fish and Wildlife Service Texas Partners for Fish and Wildlife Program (2017-2021) adopted the Davis Mountains Streams, Pecos River, Upper Big Bend, Lower Big Bend, Devils River, Central Edwards Plateau Rivers, Southern Edwards Plateau Rivers, Guadalupe and San Antonio Rivers, and Lower Colorado River NFCAs as “Geographic Focus Areas” for investments in habitat restoration and species conservation (Figure 20). The USFWS Texas Partners for Fish and Wildlife Program has an active partnership with the TPWD Landowner Incentive Program focused on restoration of grasslands, riparian buffers, and instream habitats. From 2013-2018, the two organizations cooperated on restoration of 1,793 ha of grasslands and 11 km of instream habitats and riparian buffers within the Upper Big Bend NFCA (Figures 3 and 6). Comparable investments are expected to continue across the Texas NFCAs.

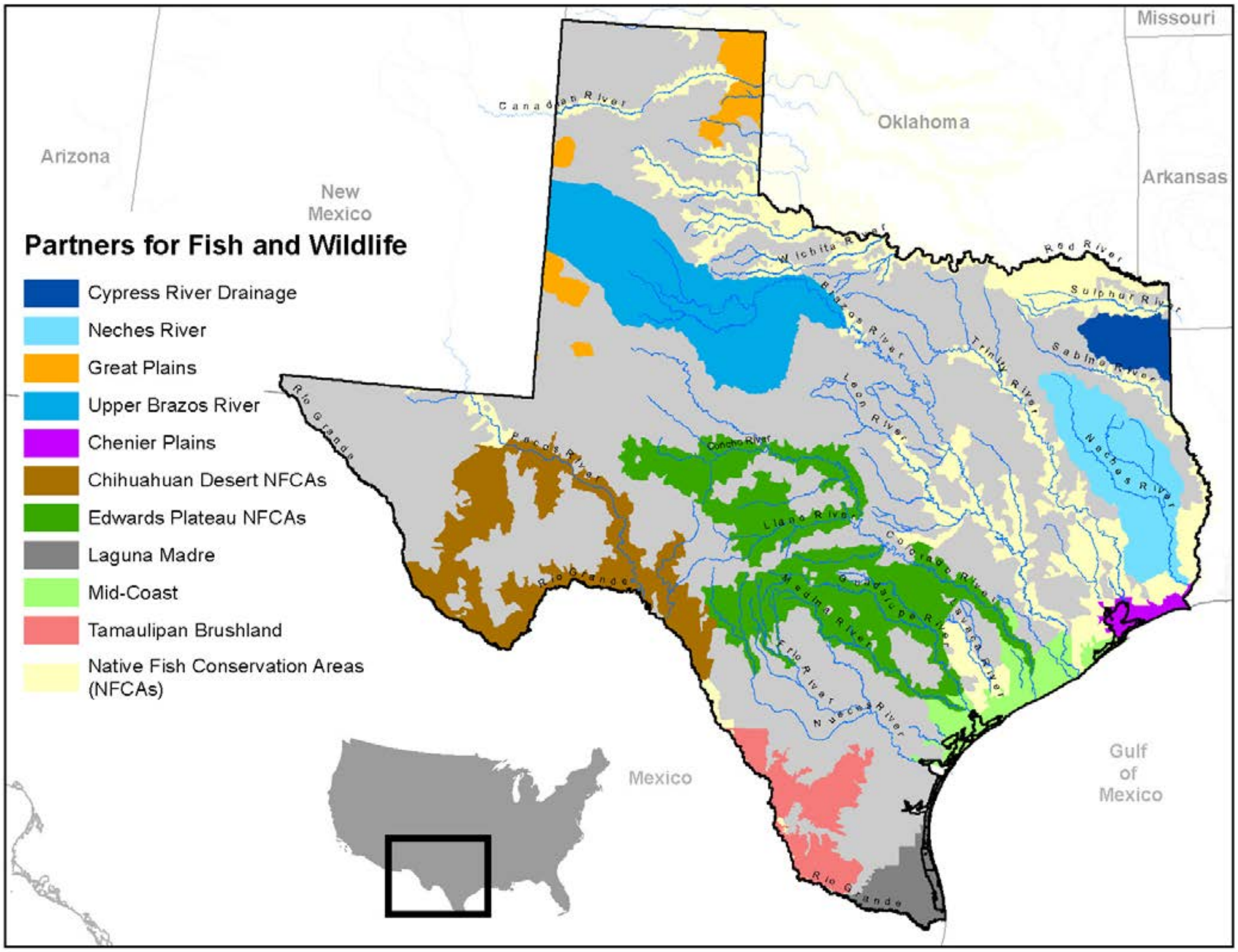

Figure 20 - Areas identified as priorities for conservation investments in the U.S. Fish and Wildlife Service Texas Partners for Fish and Wildlife Program 2017-2021 Strategic Plan.

The Texas Parks and Wildlife Foundation (TPWF) is the official non-profit partner of TPWD, and in 2013, TPWD and TPWF partnered to establish the Conserving Texas Rivers Initiative (CTRI), a fundraising program that has supported habitat restoration, native fish conservation, river access, and conservation demonstration within Texas NFCAs. The CTRI represents a public-private partnership, in which private donations have been leveraged with public funding available to TPWD (e.g., state fishing license revenues, federal grants through the Wildlife and Sport Fish Restoration Program, federal grants through the National Fish Habitat Partnership). During 2013-2018, private donors contributed $190,000, which was leveraged against approximately $1.2 million in state and federal funding to implement conservation projects in the Central Edwards Plateau Rivers, Guadalupe and San Antonio Rivers, and Devils River NFCAs. In 2017, TPWD designed a new vehicle license plate with artwork that features a Texas river (Figure 21). An annual fee of $30 is paid by Texas drivers to display the plate, with $22 allocated to the CTRI. Nearly 1,000 plates were sold in the initial 12 months that the plate was available for purchase, and efforts to market and raise public awareness of the plate are ongoing. The CTRI continues to address a critical need of providing non-federal funds to meet the cost-share requirements of grants that support conservation projects within Texas NFCAs.

Figure 21 - Vehicle license plate sold to raise funding for investments in Native Fish Conservation Areas.

The National Fish and Wildlife Foundation Southwest Rivers Program was established in 2017 to "fund effective conservation projects that achieve measurable outcomes and fill knowledge gaps where they exist, reinvigorating habitats throughout this unique American landscape" (www.nfwf.org/swrivers). The NFCAs located in the Chihuahuan Desert ecoregion of Texas (i.e., Davis Mountains Streams, Guadalupe Mountains Streams, Pecos River, Devils River, Upper Big Bend, and Lower Big Bend NFCAs) were adopted as "Focal

Watersheds" in the initial request for proposals of the Southwest Rivers Program. Grants totaling $1,535,755 were subsequently awarded by the National Fish and Wildlife Foundation in 2018 to TPWD, TPWF, and Sul Ross State University for restoration of streams, riparian buffers, and grasslands in those six NFCAs. A 10-year business plan is currently being assembled for the Southwest Rivers Program. The NFCAs of the Chihuahuan Desert ecoregion of Texas, and the associated freshwater fish SGCN, are being considered by the National Fish and Wildlife Foundation as strategic priorities are formalized within the plan.

State Technical Advisory Committees (STACs) serve in an advisory capacity to the Natural Resources Conservation Service (NRCS) and other agencies within the U.S. Department of Agriculture on the implementation of the natural resources conservation provisions of the U.S. Farm Bill legislation. The Texas STAC includes an active Wildlife Sub-Committee that informs consideration of fish and wildlife conservation needs, and that recommends geographic (e.g., focal watersheds, species ranges) and thematic priorities (e.g., riparian restoration, instream habitat improvements) for conservation initiatives supported through the U.S. Farm Bill in Texas. Since the statewide Texas NFCAs Network prioritization was completed in 2015, TPWD has recommended that the Texas STAC adopt the Texas NFCAs Network as geographic priorities for a variety of programs including the Conservation Stewardship Program, Environmental Quality Incentives Program, and Agricultural Conservation Easement Program. Additionally, the Texas STAC Wildlife Sub-Committee initiated establishment of an ad-hoc working group in 2018 to identify riparian habitat conservation priorities in Texas, and TPWD has encouraged the working group to consider inclusion of Texas NFCAs within that prioritization.

Also occurring in 2018, the NRCS awarded $5,150,000 through the Regional Conservation Partnership Program for habitat restoration and protection (i.e., conservation easements) in portions of the Central Edwards Plateau Rivers, Lower Colorado River, and Guadalupe and San Antonio Rivers NFCAs. The NRCS also selected the Lower Colorado River NFCA as a 2018 strategic priority for aquatic species conservation through the Working Lands for Wildlife Program. These NRCS-funded initiatives are expected to support restoration and preservation of instream and riparian habitats, benefiting the 54 species of native freshwater fishes historically known to occur in those three NFCAs (Appendix A).

NFCA Goal 3 – Restore Instream and Floodplain Connectivity

Efforts to restore instream connectivity (i.e., longitudinal connectivity) within Texas NFCAs has primarily centered on the removal of low-head dams and the redesign or removal of culverted bridge crossings. In 2014, TPWD and the Texas Commission on Environmental Quality cooperated on removal of a 1.2-m tall low-head dam spanning a 55-m wide reach of the North Fork Guadalupe River (Figure 22), which is located within the Southern Edwards Plateau Rivers NFCA. In 2016, the U.S. Fish and Wildlife Service, TPWD, and local partners cooperated on the removal of Ottine Dam, a 4-m tall and 30-m wide low-head dam on the San Marcos River, located within the Guadalupe and San Antonio Rivers NFCA. Removal of Ottine Dam restored instream connectivity in 63 km of the San Marcos River. Also occurring in 2016, TPWD cooperated with the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and Texas Commission on Environmental Quality on removal of a 2.4-m tall and 30-m wide culverted bridge crossing in the Upper Brazos River NFCA on the Double Mountain Fork of the Brazos River (Figure 23). Removal of the crossing restored instream connectivity for the last remaining populations of Sharpnose Shiner and Smalleye Shiner, two highly migratory prairie minnows currently listed as federally endangered. Additionally, TPWD has consulted on the redesign of several culverted bridge crossings planned for renovation in the Central Edwards Plateau Rivers and Southern Edwards Plateau Rivers NFCAs.

Figure 22 - Dam being removed from the North Fork Guadalupe River located in the Southern Edwards Plateau Rivers Native Fish Conservation Area.

Figure 23 - Culverted crossing removed from the Double Mountain Fork Brazos River located in the Upper Brazos River Native Fish Conservation Area.

To undertake a more proactive, strategic approach to restoration of instream connectivity, TPWD is currently partnering with SARP to complete a barrier inventory and prioritization for a portion of the Southern Edwards Plateau Rivers NFCA. Initiated in 2017, this project is expected to serve as a pilot program for possible expansion of the Southeast Aquatic Connectivity Project into Texas (Graham et al., in press). The goal of the Southeast Aquatic Connectivity Project is to restore connectivity, habitat, and ecological functions to streams by identifying and removing dams and other barriers to aquatic species passage.

Restoration of floodplain connectivity (i.e., lateral connectivity) in rivers and streams contained with Texas NFCAs has been primarily limited to the Northeast Texas Rivers NFCA, where The Nature Conservancy, U.S. Army Corps of Engineers, Northeast Texas Municipal Water District, TPWD, Caddo Lake Institute, and numerous other local conservation partners cooperated on a flow agreement to restore a more natural flow regime in Big Cypress Bayou downstream of Lake O' the Pines. The flow regime included prescriptions for high flow pulses and overbank flows intended to reconnect the river to its natural floodplain and benefit floodplain spawning fish SGCN, including Ironcolor Shiner *Notropis chalybaeus* and Taillight Shiner *Notropis maculatus*. Instream flow recommendations for high flow pulses and overbank flows to support longitudinal and lateral connectivity within the Texas NFCAs are also expected to result from research described within the summary for Goal 7.

NFCA Goal 4 – Mitigate Effects of Invasive Species

Efforts to address the negative effects of invasive species within Texas NFCAs have focused on identification and implementation of regulatory and permitting measures to mitigate impacts of invasive Tilapia *Oreochromis spp.* (McGarrity, in press) and control of invasive riparian plants that form dense, monotypic stands and degrade riparian habitat quality (Bell 1997; Di Tomaso et al. 1998). Efforts to control invasive riparian plants have primarily focused on management of Saltcedar and Giant Reed. These species have been shown to accumulate sediment, narrow stream channels, isolate floodplains, reduce instream flow, degrade water quality, increase erosion, and alter instream habitats (Birken and Cooper 2006; Blackburn et. al. 1986; Dean and Schmidt 2011; Dean et. al. 2011; Merritt and Poff 2010; Shafroth et. al. 2010; Stromberg et. al. 2007).

In the Guadalupe and San Antonio Rivers, Central Edwards Plateau Rivers, and Southern Edwards Plateau Rivers NFCAs, TPWD has partnered with The Nature Conservancy, Hill Country Alliance, Texas Department of Transportation, river authorities, local municipalities, and more than 400 cooperating riparian landowners to implement large-scale management of Giant Reed along 200 km of the Blanco, Guadalupe, Medina, Nueces, and Pedernales rivers and their tributaries. In the Blanco and Pedernales rivers, the scope of these efforts was expanded to include mapping of other invasive plants and restoration planting to augment passive recolonization. Biological monitoring sites were also established along Barons Creek, a tributary of the Pedernales River, to evaluate effects of control efforts on riparian plant communities, fish and invertebrate communities, water quality and quantity, and channel morphology. Similar efforts to implement large-scale control of river cane and to reestablish native riparian vegetation are being implemented by the National Park Service, World Wildlife Fund, Rio Grande Joint Venture, and TPWD in the Upper Big Bend and Lower Big Bend NFCAs.

In the Upper Brazos River NFCA, TPWD has partnered with the U.S. Fish and Wildlife Service Partners for Fish and Wildlife Program, Texas A&M AgriLife, Texas Tech University, University of Texas at Austin, and approximately 50 riparian landowners to manage 2,711 ha of Saltcedar, focusing initial efforts along 286 km of the Double Mountain Fork of the Brazos River. Aerial surveys of Saltcedar were completed throughout the entire Upper Brazos River NFCA, and control efforts were expanded to the Salt Fork of the Brazos River in 2018, with restoration planting of cottonwood *Salix populus* currently in the planning stages. Research is being conducted in partnership with the University of Texas at Austin Bureau of Economic Geology to evaluate the effects of Saltcedar control on water budget, water quality, river channel morphology, and riparian plant communities (Mayes et. al., in press).

In the Central Edwards Plateau Rivers NFCA, TPWD has partnered with the Texas Tech University Llano River Field Station, Llano River Watershed Alliance, cooperating landowners, and volunteers to implement management of invasive elephant ear *Colocasia esculenta* along more than 80 km of the Llano River and Gorman Creek. Partners have also implemented management of Giant Reed at the South Llano River State Park. Restoration plantings and changes to stewardship practices implemented at the South Llano River and Colorado Bend state parks will be used to provide demonstration sites for outreach to increase awareness of the negative impacts of invasive riparian plants.

NFCA Goal 5 – Organize and Facilitate Conservation Partnership Networks

Conservation partnerships formed to help deliver conservation actions within NFCAs of Texas were previously described above within the section profiling conservation planning within NFCAs of the southwestern USA.

NFCA Goal 6 – Establish Conservation Demonstration Areas

Through a partnership among TPWD, Texas Council of Fly Fishers International, Keep Texas Beautiful, Devils River Conservancy, Llano River Watershed Alliance, Hill Country Alliance, All Water Guides, Colorado River Alliance, and other local partners, an extensive list of service-oriented river stewardship projects has been organized and conducted within Texas NFCAs. River stewardship projects have consisted of river-wide trash cleanups (Figures 18 and 19), invasive fish and plant removal, planting of native trees and reseeding of erosional banks, establishment of nature trails, installation of educational kiosks, and creation of paddler manuals and other educational resources for river users. Partners have hosted river stewardship workshops for landowners and local communities in order to demonstrate and promote best management practices for conservation of riparian and instream habitats.

River stewardship projects have primarily been conducted in reaches of river where public river access is supported through partnerships with local communities or through lease agreements with willing riparian landowners (Figure 24). The intent of the TPWD-supported river access areas is to facilitate nature-oriented recreation on Texas rivers (e.g., paddling, kayak fishing, wildlife-viewing) and to demonstrate and encourage best practices in the management and conservation of instream and riparian habitats. During 2016-2018, lease payments and habitat improvements were funded through a grant provided by the U.S. Department of Agriculture's Voluntary Public Access and Habitat Incentive Program. Lease agreements between TPWD and cooperating landowners supported public river access and conservation demonstration at 15 riparian properties within Texas NFCAs. These properties enabled paddling and kayak fishing within approximately 274 km of the NFCAs and served as a catalyst for grassroots involvement in river stewardship activities.

Partnering landowners cooperated with TPWD and local conservation organizations to assemble resource conservation plans and deliver habitat improvements and recreational enhancements (e.g., trail maintenance, development of primitive campsites for river users) at the riparian properties. In partnership with All Water Guides, a central Texas flying fishing guide service, and Keep Texas Beautiful, a state-based non-profit organization with numerous local chapters, 25 community outreach and service projects were conducted at the

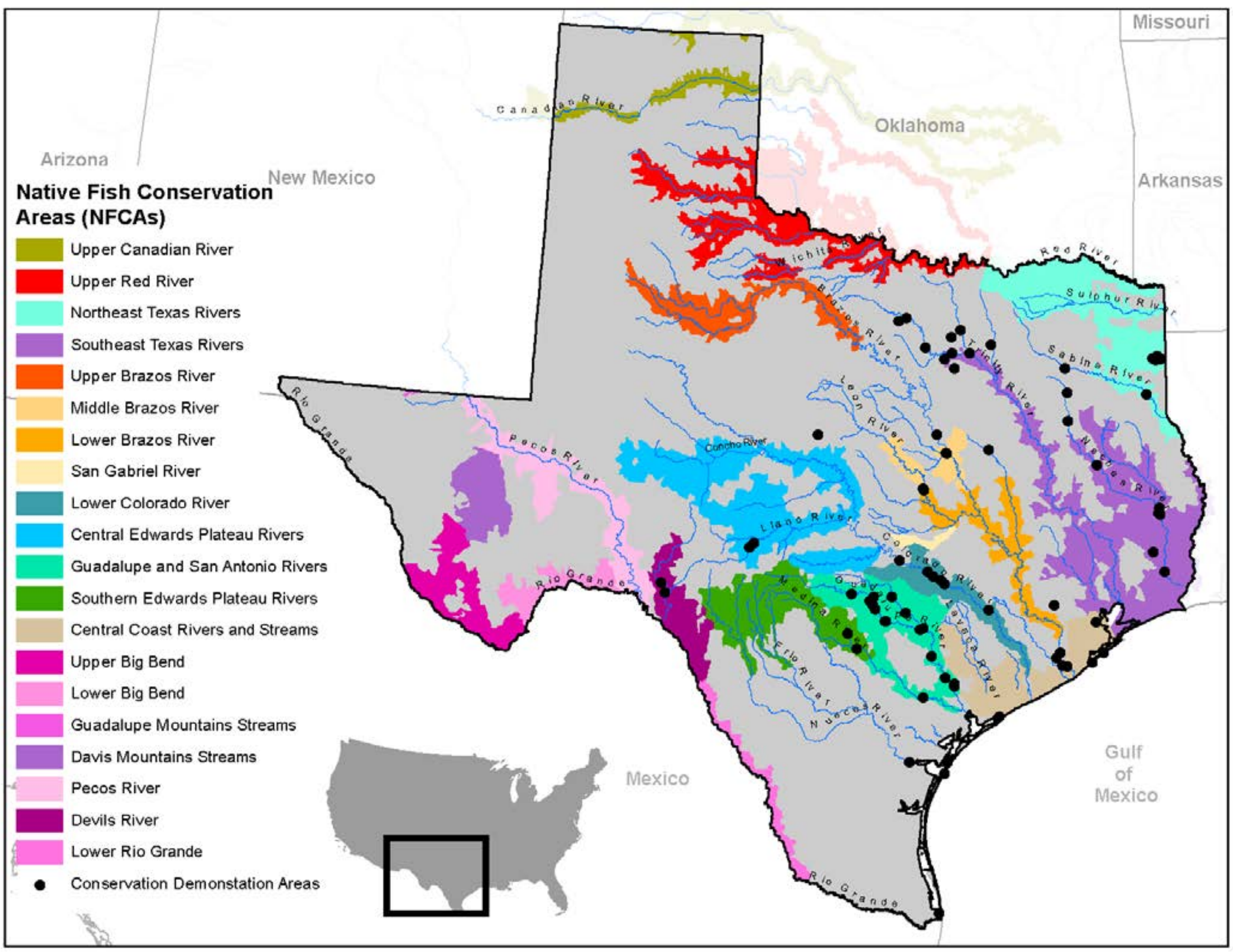

Figure 24 - Public river access sites that serve as conservation demonstration areas for engaging, demonstrating, and promoting river stewardship to landowners, recreational users, and the public.

river access areas located within the Lower Colorado River (Figures 25 and 26), Guadalupe and San Antonio Rivers, and Southeast Texas Rivers NFCAs. Outreach events promoted river stewardship to 611 attendees. Service projects were supported by 364 volunteers and resulted in removal of 682 tires and approximately 2,500 kg of litter and 450 kg of recyclables.

In the Central Edwards Plateau Rivers NFCA, TPWD partnered with the Hill Country Alliance, Llano River Watershed Alliance, and Texas Council of Fly Fishers International to conduct river-wide trash cleanups, install an informational kiosk and monofilament fishing line recycling bin, install protective caging to support recruitment of native riparian seedlings and saplings (decimated by herbivory by non-native ungulates), and broadcast native riparian seed mix on bare, erosional river banks. A series of public "town hall" conversations were also organized in the Central Edwards Plateau Rivers NFCA. These aired on Texas Public Radio, and involved a dialogue among the general public, landowners, elected officials, and subject matter experts on river conservation topics such as groundwater management, invasive species management, riparian restoration, conservation easements, and ecosystem services. Partners also produced a 14-minute video on the importance of effective riparian management in promoting river resilience, hosted workshops on riparian management, rotational grazing of livestock, and preservation of natural landscapes (through conservation easements), and organized a series of Wild and Scenic Film Festivals that further promoted river conservation through inspirational videos on topics such as protection and restoration of wild lands and waters and biodiversity conservation.

In the Guadalupe and San Antonio Rivers NFCA, a riparian conservation demonstration area was established on the Blanco River in partnership with the Lady Bird Johnson Wildflower Center and cooperating landowners. Stewardship practices implemented at the site have included native plant seeding and installation; extensive tree plantings; invasive species control; assimilation of woody debris and root wads into site design; soil compaction remediation for seep restoration; and installation of native turf grasses for access areas. Guided tours of the site began in spring 2018 and are expected to continue, with 50 land managers to date having received hands-on instruction in riparian stewardship practices.

In the Devils River NFCA (Figure 27), TPWD partnered with the Devils River Conservancy to conduct four river-wide trash cleanups, invasive fish removal, and outreach to paddlers and landowners. Outreach included production of a Devils River paddler manual and accompanying video that promote recreational etiquette and river stewardship practices. Partners also organized two river stewardship workshops that engaged Devils River

Figure 25 - TPWD staff remove trash during a cleanup of the Lower Colorado River Native Fish Conservation Area.

Figure 26 - Trash removed by TPWD and partners during a cleanup of the Lower Colorado River Native Fish Conservation Area.

landowners in demonstration of riparian and land management practices that support healthy rivers.

Figure 27 - Devils River Native Fish Conservation Area, located near Del Rio, TX.

The Texas Council of Fly Fishers International played an active role in supporting identification of specific reaches of rivers where anglers desired improved access, and in establishing and maintaining positive relationships with cooperating landowners of the leasing program. The organization also distributed 5,000 citrus fruit bags (used for river trash cleanups) to their network of 20 local fly fishing clubs located throughout the state. The clubs conducted river trash cleanups in conjunction with routine club fishing trips to the access areas.

In 2018, TPWD was awarded a grant from the U.S. Fish and Wildlife Service Sport Fish Restoration Recreational Boating Access Grant Program in the amount of $240,000 dollars that will allow for establishment of additional river access and conservation demonstration areas on rivers throughout the state. The grant is expected to support 20 lease agreements with private riparian landowners, opening approximately 322 km of rivers for paddling and kayak fishing. The grant will also add 20 new and maintain 133 existing river access areas supported through partnerships with local communities, providing 1,081 km of paddling and kayak fishing on Texas rivers. More than half of those river access areas occur within Texas NFCAs, and through cooperation with local communities, TPWD intends to utilize these access areas (riparian properties) and the recreationally-accessible reaches of river as conservation demonstration areas. In addition to the variety of service-oriented stewardship projects referenced above, these reaches of river were recently prioritized by TPWD for management of invasive riparian plants, with an emphasis on management of the problematic species referenced within the summary for Goal 4.

NFCA Goal 7 – Conduct Research to Fill Critical Science Needs

Since completion of the initial Texas NFCAs prioritization in 2013, TPWD has invested approximately $3 million dollars in State Wildlife Grant funding to fill critical science needs for conservation of freshwater fish SGCN in Texas NFCAs. A primary emphasis of this research has been to quantify flow-ecology relationships for flow-dependent fishes, freshwater mussels, and riparian productivity within highly managed and regulated river reaches (i.e., downstream of reservoirs). This research is ongoing in the Guadalupe and San Antonio Rivers, Middle Brazos River, Lower Brazos River, Lower Colorado River, and Southeast Texas Rivers NFCAs. Results (see TIFP 2018 and SARA 2017) are expected to inform strategies for environmental flow restoration and protection, adaptive management of environmental flow standards, and related management of river flows and reservoir water levels.

In the Devils River NFCA, similar investments of State Wildlife Grant funding have been made to improve understanding of the relationships among groundwater levels, spring discharge, river flows, and habitat conditions for fish and freshwater mussel SGCN (Robertson et al., in press). Potential establishment of a Groundwater Management District for the portion of the Edwards-Trinity Aquifer that is the source of spring discharge and base flows in the Devils River NFCA has been contemplated by the Texas State Legislature. Meanwhile, the comprehensive science needed to inform such actions has historically been lacking. Over the past five years, TPWD and partners have prioritized investments of State Wildlife Grant funding within the Devils River NFCA to provide the science needed to ensure consideration of the instream flow needs of native fishes and mussels, their habitats, and river recreation in water management decisions for this spring-dominated system.

In the Guadalupe Mountains Streams NFCA, TPWD partnered with Trout Unlimited and the U.S. Geological Survey New Mexico Cooperative Fish and Wildlife Research Unit in 2013-2014 to assess the potential for repatriation of Rio Grande Cutthroat Trout *Oncorhynchus clarki virginalis* and Rio Grande Chub *Gila pandora* into McKittrick Creek (Zeigler and Caldwell 2017), a stream that currently hosts a non-native population of Rainbow Trout *Oncorhynchus mykiss* (Garrett and Matlock 1991).

Additional research supported by State Wildlife Grants within Texas NFCAs has centered on filling critical science needs in the life history, distribution, and status of freshwater fish SGCN. This included ongoing research to address the status and distribution of American Eel *Anguilla rostrata* in the Central Coast Rivers and Streams NFCA and the status of Chihuahua Catfish *Ictalurus sp.* and other regionally endemic fish SGCN in the Central Edwards Plateau Rivers, Southern Edwards Plateau Rivers, Devils River, Pecos River, Davis Mountains Streams, Upper Big Bend, and Lower Big Bend NFCAs.

Priority research needs identified at NFCA conservation planning workshops have also been communicated to other science funding programs. For example, priority research needs identified during the conservation planning workshops held for the Central Edwards Plateau Rivers, Upper Brazos River, Upper Canadian River, and Upper Red River NFCAs (conducted in fall 2015 and winter 2016) were presented to the Steering Committee of the Great Plains Landscape Conservation Cooperative in spring 2016. The Great Plains Landscape Conservation Cooperative adopted a subset of those priority research needs for their spring 2016 request for proposals, emphasizing the desire to receive proposals for projects that would examine opportunities for water leases, water rights acquisition, and voluntary incentive-based programs to achieve flow restoration targets within those four NFCAs.

NFCA Goal 8 – Monitor Conservation Outcomes and Perform Adaptive Management

To fill data gaps and monitor status and trends of fish SGCN within Texas NFCAs, TPWD and the University of Texas at Austin collaborated on development and implementation of an aquatic gap sampling program. Initiated in 2013 in conjunction with the pilot phase of the Texas NFCAs prioritization, the partnership has surveyed 187 locations within Texas NFCAs (Figure 28). This has resulted in 46,617 museum-vouchered fish specimens and 316 corresponding tissue samples deposited and permanently housed at the

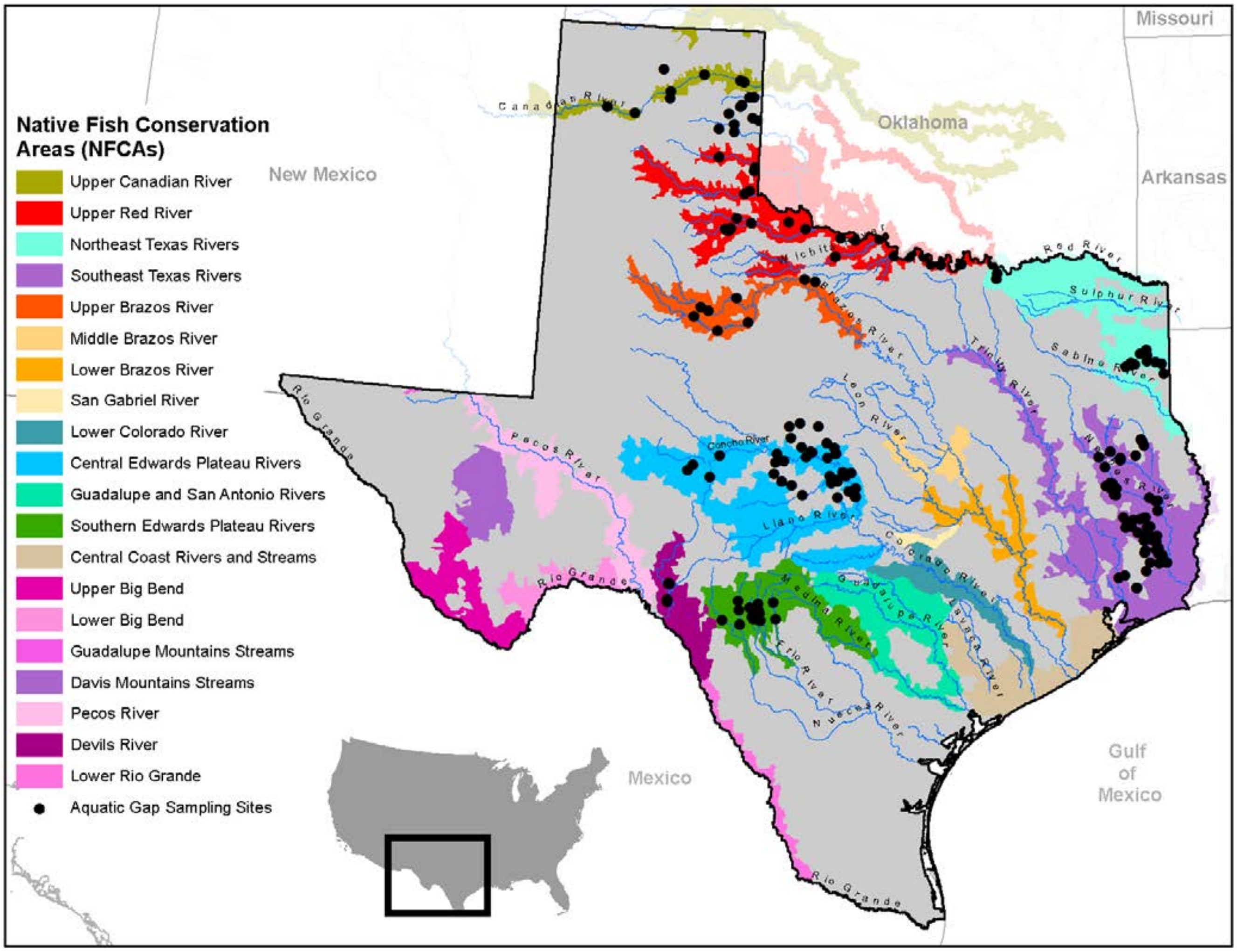

Figure 28 - Locations of aquatic gap sampling conducted by TPWD and the University of Texas at Austin within Texas Native Fish Conservation Areas.

University of Texas at Austin Biodiversity Collections. Surveys resulted in the addition of one new species to the state's faunal list (i.e., Bigeye Shiner *Notropis boops*), records of rarely collected fishes (e.g., Pallid Shiner *Hybopsis amnis*, Cypress Minnow *Hybognathus hayi*, Emerald Shiner *Notropis atherinoides*, Arkansas River Shiner *Notropis girardi*), and records representing range expansions for native (i.e., Least Killifish *Heterandria Formosa*) and invasive species (i.e., Sheepshead Minnow and Gulf Killifish in the Red River). Surveys have also provided evidence of range reductions (e.g., Suckermouth Minnow *Phenacobius mirabilis*, Red River Pupfish *Cyprinodon rubrofluviatilis*, Pallid Shiner, and Emerald Shiner) and possible extirpations (e.g., Flathead Chub *Platygobio gracilis*) from the state.

Aquatic gap sampling has supported data-driven recommendations to multiple TPWD-managed State Parks (i.e., Colorado Bend, Garner, and Village Creek) and Wildlife Management Areas (i.e., Alabama Creek, Alazan Bayou, Gene Howe, and Matador), increasing consideration of native fishes and their habitats in site management plans (TPWD 2015, 2016, 2017, 2018; Cohen et al. 2018). Surveys conducted in the Northeast Texas Rivers NFCA supported monitoring and evaluation of the effectiveness of the Cypress Basin Flows Agreement, which was previously referenced under Goal 3. Restoration of the natural flow regime in the Cypress Basin is expected to improve instream and riparian habitats, support repatriation of Paddlefish, and benefit conservation of other fish SGCN.

Aquatic gap sampling reports are accessible from the TPWD River Studies Reports web page (https://tpwd.texas.gov/landwater/water/conservation/fwresources/reports.phtml) for portions of the following NFCAs: Upper Canadian River NFCA, Northeast Texas Rivers NFCA (Cypress Basin), Southeast Texas Rivers NFCA (Neches River and Village Creek), and Southern Edwards Plateau Rivers NFCA (Frio River and North Fork Guadalupe River). Aquatic gap sampling reports for the Upper Red River NFCA and San Gabriel River NFCA are expected to be posted to the web page by 2019.

Native Fish Conservation Areas as a Climate Adaptation Strategy

The purpose of the U.S. National Fish, Wildlife and Plants Climate Adaptation Strategy (National Climate Adaptation Strategy; NFWPCAP 2012) is to inform and enable natural resource professionals and other decision makers to take action to conserve fish, wildlife, plants, and ecosystem functions, as well as the human uses, values and benefits those natural systems provide, in a changing climate. The National Climate Adaptation Strategy details the current and expected future impacts of climate change on the eight major ecosystem types in the USA. Additionally, it identifies actions that can be taken to enhance the resiliency of fish, wildlife, and their habitats under changing conditions. Those actions are organized under the seven primary goals of the National Climate Adaptation Strategy outlined in Table 12.

The National Climate Adaptation Strategy emphasizes management of habitats for resiliency as a primary strategy for supporting fish and wildlife adaptation to climate change. Consistent with the recommendations of the National Climate Adaptation Strategy, the NFCA goals and implementation strategies (Table 4) emphasize management of watersheds and habitats for ecological resiliency. Summaries provided above of efforts to address NFCA Goals (e.g., protect and maintain intact habitats, restore altered habitats, restore instream and floodplain connectivity) offer insights into the types of activities being undertaken by cooperators within NFCAs of the southwestern USA to enhance the resiliency of freshwater systems and conserve native fishes in the face of climate change.

As natural resources managers plan and prepare for the current and anticipated effects of climate change, the NFCAs approach offers a case study in engagement of the broader community of conservation practitioners to "scale up" investments in conservation planning and delivery to enhance resiliency of ecological systems. Many of those investments represent proactive, voluntary measures to address threats to fish and wildlife resources, emphasizing conservation and management of natural landscapes, watershed processes, habitats, species, and ecosystems in a manner that enhances their resiliency and adaptive capacity. This holistic approach has been adopted by TPWD and conservation partners in Texas in response to the multitude of interrelated natural and anthropogenic stressors affecting fish and wildlife resources, including climate change.

Table 12 - Goals of the National Climate Adaptation Strategy (NFWPCAP 2012).

(1) Conserve habitat to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate
(2) Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate
(3) Enhance capacity for effective management in a changing climate
(4) Support adaptive management in a changing climate through integrated observation and monitoring and improved decision support tools
(5) Increase knowledge and information on impacts and responses of fish, wildlife, and plants to a changing climate
(6) Increase awareness and motivate action to safeguard fish, wildlife, and plants in a changing climate
(7) Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate

Transferability to Other States and Regions of the USA

NFCAs represent a strategic, science-based approach to planning and delivery of multispecies, watershed approaches to freshwater fish conservation. The NFCAs prioritization and conservation planning processes have served as the impetus for increased, focused, and sustained investments (e.g., research, monitoring, habitat restoration and protection) in native fish conservation within priority freshwater systems of the southwestern USA. Furthermore, NFCAs have enhanced communication and fostered collaboration among non-governmental organizations, universities, and state and federal agencies, and have facilitated the leveraging of staff, expertise, project funding, and other resources toward delivery of proactive, voluntary conservation projects.

As state fish and wildlife agencies and their partners plan and prepare for an anticipated increase in available funding for conservation of SGCN through the Recovering America's Wildlife Act (H.R. 4647), Texas NFCAs offer a successful case study in engagement of the broader community of conservation practitioners to increase investments in conservation planning and delivery. The voluntary investments in habitat restoration, habitat protection, invasive species management, and other conservation actions within Texas NFCAs have complemented traditional state-based native fish conservation efforts, which have primarily involved reactive, regulatory activities (e.g., permitting of non-game fish collection, permitting of fish stocking in public waters, permitting of dredging and other instream habitat disturbances) and consultation with other agencies on water management and watershed development projects seeking state or federal permits through requirements of the U.S. Clean Water Act, U.S. National Environmental Policy Act, or other state and federal laws (e.g., water rights permitting, hydropower relicensing, dam construction, urban development). The majority of the technical and financial resources that have supported the conservation actions within Texas NFCAs are accessible to fish and wildlife agencies throughout the USA. As such, this report offers a case study that we believe to be transferable to other U.S. states, and that is particularly relevant to those states that, similar to Texas, consist predominately of privately-owned lands.

Native Fish Conservation Network Website

To learn more about the NFCA approach, please visit http://nativefishconservation.org. The website offers additional insights into the multispecies aquatic assessments and conservation planning process referenced in this report, further characterizes NFCAs of the U.S. southwest and U.S. Great Plains, offers an interactive map of priority conservation projects identified during conservation planning workshops, and outlines additional project-specific information including cooperators, expected results and benefits, estimated project cost, and project status (i.e., suggested, ongoing, or completed).

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Devils River Native Fish Conservation Area

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