

Developing the Science and Public Support Needed to Preserve the Devils River: A Case Study in Collaborative Conservation

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Abstract.—The Devils River is a groundwater-dominated, semiarid river in southwest Texas and considered one of the most pristine rivers in the state. It is one of the last strongholds for multiple species of regionally endemic freshwater fishes and mussels. However, groundwater pumping in the watershed poses an imminent threat to the river and its fragile ecosystem. Reductions in groundwater availability have the potential to result in concomitant reductions in spring discharge and thus instream flows. Base flow reductions would negatively impact many already imperiled aquatic species and degrade one of the state's most remote and scenic paddling and angling destinations. Development of a comprehensive basinwide fish and mussel conservation plan is ideal due to the relatively small size of the watershed. However, challenges include

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the isolated location of the river and the low proportion of publicly held lands for implementing on-the-ground conservation measures. To best determine science needs, focus resources, and increase informed stewardship of the river, the Texas Parks and Wildlife Department has partnered with governmental agencies, universities, nonprofit organizations, and landowners interested in preserving this unique resource. Through collaborative research aimed at a better understanding of groundwater–surface water interactions and instream flow needs of endemic species, and by building cooperative relationships with landowners and nonprofit conservation organizations, steps are underway to preserve the esthetic, ecological, and recreational values of the Devils River.

The Devils River, Texas

The Devils River, a spring-fed river in southwest Texas, is often described as the most pristine river in the state (Figure 1). It is also considered one of the last true wilderness paddling experiences in Texas and is revered for its biological, esthetic, 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 and a native fish conservation area by the Texas Parks and Wildlife Department (TPWD; El-Hage and Moulton 2001; Birdsong et al. 2019, this volume). The Devils River watershed spans five counties (Crockett, Edwards, Schleicher, Sutton, and Val Verde; Figure 2); however, the perennially flowing reach of the Devils River is entirely contained within Val Verde County, Texas. Pecan Springs, located in central Val Verde County, is considered the headwaters of the river due to its consistent flow (USFWS 1999). While the Devils River is typically characterized as 145 km in length, the perennial reach of the river flows approximately 97 km to its confluence with the Rio Grande at Amistad Reservoir (Figure 2). The river is a gaining stream over its entire length (Green et al. 2014), receiving groundwater discharge from numerous springs (Brune 1981; Abolt et al. 2018).

The Devils River occurs at the juncture of the Chihuahuan Desert, South Texas Plains, and Edwards Plateau ecoregions (Figure 2; Griffith et al. 2004). This unique

intersection of arid desert, brushland, and karst topography provides diverse habitat types that support numerous aquatic and terrestrial species, including several regional endemics classified as threatened or endangered by the TPWD and U.S. Fish and Wildlife Service (USFWS). The Devils River and its major tributary, Dolan Creek (Figure 2), are home to four state-threatened (ST) fish species: Proserpine Shiner *Cyprinella proserpina*, Devils River Minnow *Dionda diaboli*, Conchos Pupfish *Cyprinodon eximius*, and Rio Grande Darter *Etheostoma grahami* (Figure 3; El-Hage and Moulton 2001). The Devils River Minnow was also listed as federally threatened (FT) 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 (Garrett et al. 1992; USFWS 1999). The Devils River is also home to Texas hornshell *Popenaias popeii* (Figure 3), the only native mussel species known to occur in the river (Howells 2014; Randklev et al. 2018). Texas hornshell was listed as federally endangered (FE) 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 2018a).

The river and riparian corridor are utilized by several state and federally listed bird species, including the black-capped vireo *Vireo atricapilla* (state-endangered [SE]), tropical parula *Parula pitiayumi* (ST),



Figure 1. The Devils River in Val Verde County, Texas. Photograph by Clinton Robertson, Texas Parks and Wildlife Department.

interior least tern *Sterna antillarum athalassos* (SE, FE), and zone-tailed hawk *Buteo albonotatus* (ST) (El-Hage and Moulton 2001). The Devils River corridor is also home to the Texas snowbell *Styrax platanifolius texanus* (SE, FE), a riparian shrub (USFWS 2008) and the Tobusch fishhook cactus *Sclerocactus brevihamatus tobuschii* (SE, FT), a species known to occur in flood-prone riparian areas (TPWD 1995; USFWS 2018b). Additionally, the Devils River watershed is located along a major migratory path for the monarch butterfly *Danaus plexippus* (Reppert et al. 2010), which is under review for federal listing (USFWS 2014). The watershed is 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). Springs and streams in the watershed are also home to an undescribed

species of salamander *Eurycea* sp. and several rare, regionally endemic invertebrates (TNC 2004; USFWS 2017).

Arguably the largest threat currently facing the river and the many species that depend on it is the potential for declining groundwater levels, which in turn impact spring discharge and river flows (TNC 2004). Water quality in the Devils River has historically ranked as excellent when compared to standards established by the Texas Commission on Environmental Quality (TCEQ; TCEQ 2004). This high-quality surface water can in part be attributed to the many springs along the river's length (Brune 1981) and the rural, undeveloped nature of the watershed (Anderson et al. 2014). Springs supply the river with the majority of its base flow and, via Amistad Reservoir, provide approximately 15% of the water needed for municipal and agricultural water supplies in the lower Rio

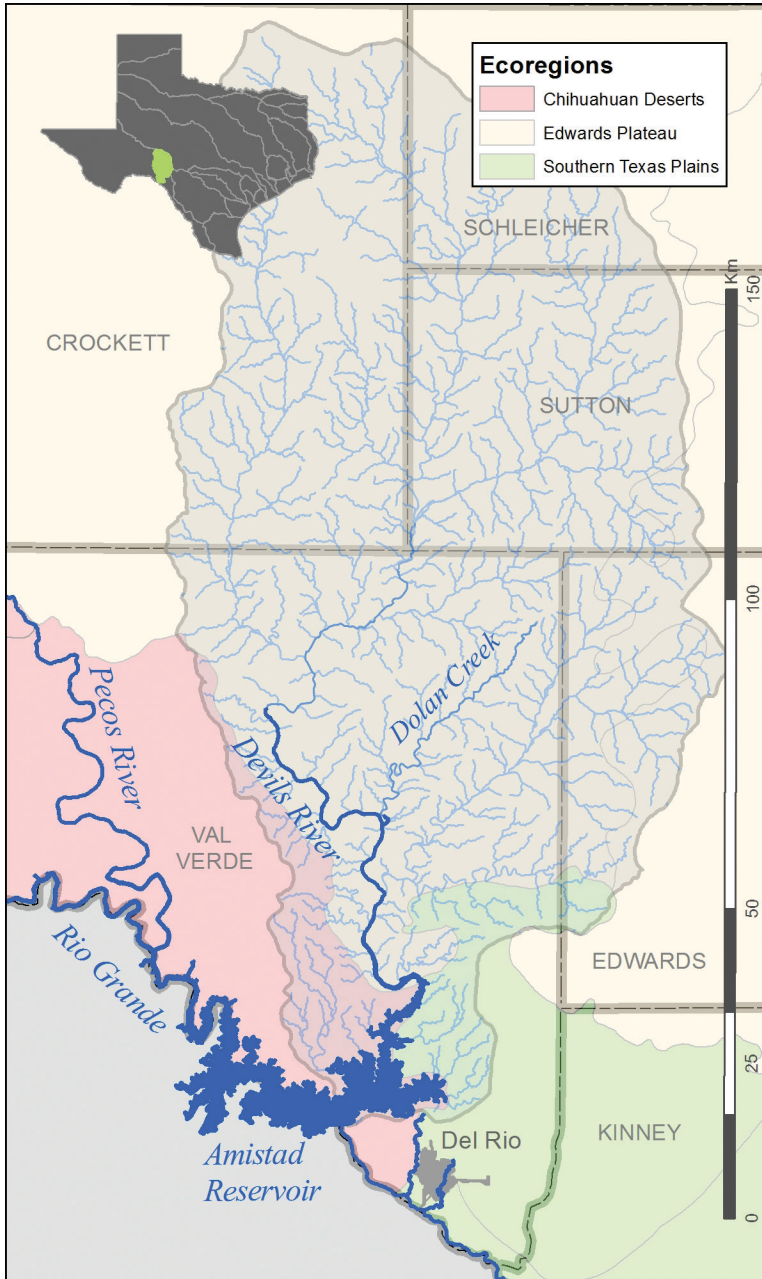


Figure 2. Watershed area, ecoregions, and perennially flowing reaches (darker blue line) of the Devils River, Texas.

Grande valley (Green et al. 2014). While discharge from these springs provides an oasis of high-quality water in an otherwise arid environment, it also makes the river vulnerable to reductions in base flow from reduced

groundwater availability. In addition to a predicted 73% increase in human population between 2020 and 2070, Texas is projected to suffer a 24% decrease in groundwater availability statewide (TWDB 2017). This



Figure 3. Listed fish and mussel species inhabiting the Devils River from top left to right are Rio Grande Darter (state-threatened [ST]), Devils River Minnow (ST, federal-threatened [FT]), and Proserpine Shiner (ST); and from bottom left to right are Conchos Pupfish (ST), Texas hornshell (ST, federal-endangered [FE]), and Texas hornshell in situ. Photographs by Sarah Robertson, Texas Parks and Wildlife Department.

decline is largely due to reduced supply from the Ogallala and Gulf Coast aquifers; however, when coupled with increasing municipal, manufacturing, and energy water demands across the state (TWDB 2017), the chance for increased pressure on other aquifers, such as the Edwards-Trinity Plateau Aquifer that feeds the Devils River, becomes reasonably foreseeable—especially if groundwater were pumped and exported out of the basin.

Additional threats include watershed alteration, introduction and expansion of invasive species, and increased recreational use. Land use within the watershed has historically been composed of large-acreage cattle, sheep, and goat ranches. Chronic 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; TNC 2004; TPWD 2010). Increases in bare ground has the potential to increase surface runoff and decrease groundwater recharge (Brune 1981).

Fragmentation and changes in land use on some of the historically large ranches in the watershed have had an impact on the river. Some of these lands have been sold for housing developments, which, when overseen with limited regulation, pose potential threats to the river through point-source pollution from faulty septic systems (McQuillan 2004; TNC 2004). Degradation of groundwater quality from contamination may be exacerbated by the high-permeability karstic nature of the Edwards-Trinity Plateau Aquifer (Katz et al. 2010). Other ranches have shifted from domestic livestock to exotic game. Escapement of exotic ungulates from these ranches has resulted in the establishment of feral populations of, most notably, axis deer *Cervus axis* and aoudad or Barbary sheep *Ammotragus lervia*. The addition of exotic ungulates to the Devils River landscape has increased the abundance of foraging species in an already sensitive and overgrazed system. The proliferation of these exotic grazing species re-

duces forage diversity for native species and increases runoff with associated potential for increased suspended sediment loadings to the river (TPWD 2010). Increased runoff and lack of vegetation contribute to further reductions in groundwater infiltration. Several exotic aquatic species have also become established, including Common Carp *Cyprinus carpio*, Blue Tilapia *Oreochromis aureus*, Asian clam *Corbicula fluminea*, and red-rim melania *Melanoides tuberculatus*.

In the face of these challenges, there is an urgent need for a holistic river and watershed management plan supported by multidisciplinary studies (Stoffels et al. 2018). Stakeholder involvement is paramount for the successful adoption and application of conservation measures (Reed 2008; Ulibarri 2018), especially in development of instream flow recommendations (Poff et al. 2003; Richter et al. 2006; TIFP 2008; Conallin et al. 2018). This chapter presents collaborative efforts by stakeholders, consisting of state agencies, nongovernmental organizations, universities, and landowners, to preserve the unique esthetic, ecological, recreational, and economic values of the Devils River. Conservation efforts in the Devils River watershed have focused on development of watershed-based partnerships, implementation of best practices in watershed stewardship, management of river recreation for sustainable use, and advancement of scientific understanding of river and watershed processes, with an emphasis on quantification of hydrologic relationships among groundwater levels, spring discharge, and instream flows.

Building Partnerships

The terrestrial landscape of Texas is more than 95% privately owned (Anderson et al. 2014). Private land ownership can make access to publicly owned rivers for on-the-ground research challenging; however, it also presents an opportunity to engage landowners on a topic in which they are person-

ally invested: river conservation. Resource managers and researchers can build mutually beneficial partnerships with property owners who are personally vested in river stewardship, although building these connections is not without challenges. In the Devils River watershed, stakeholders often have conflicting views on river and groundwater management and recreational access and use (e.g., paddling and camping). Along with these conflicting views, there is also often an inherent distrust among landowners of government agencies, conservation organizations, and even other landowners. However, if all vested parties can come together in support of a common goal, such as the belief that the Devils River warrants protection for future generations, then steps can be made to advance collaborative efforts toward that goal.

Prior to 1988, the Devils River riparian corridor was entirely privately owned. In 1988, the TPWD purchased an 80-km² ranch now known as the Del Norte Unit of the Devils River State Natural Area (DRSNA; Figures 4 and 5). This land acquisition provided protection for approximately 1.6 km of riparian corridor and one of the largest spring complexes on the river, Finegan Springs (Figure 5; TPWD 2012a). The purchase provided public access to this unique resource for the first time.

The Nature Conservancy (TNC) began further protection efforts along the Devils River in 1991 with acquisition of the 19-km² Dolan Falls Preserve, located adjacent to the DRSNA–Del Norte Unit (Figure 4). The Nature Conservancy continued these efforts from 1990 until 2005 through protection of more than 70 km² of land in fee title and nearly 500 km² of land in conservation easements or other protections. This included further protection for the DRSNA in the form of a conservation easement that provided permanent protection to upland, riparian, and riverine habitats. Another property that TNC protected through use

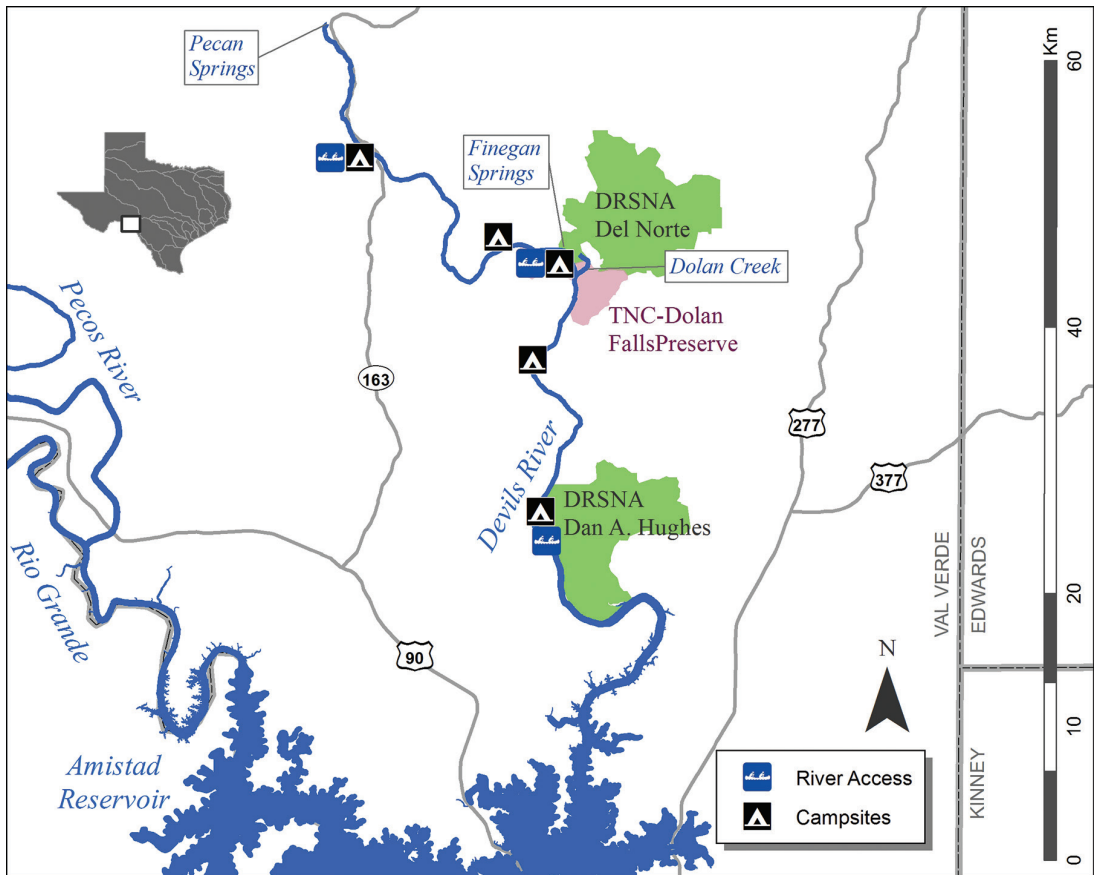


Figure 4. Perennial portion of the Devils River with public access points, paddler camps, and points of interest in Val Verde County, Texas

of a conservation easement was a 73-km² ranch that bordered 16.5 km of the Devils River just upstream of Lake Amistad. In 2011, through the help of many partners, the TPWD acquired this property and named it the Dan A. Hughes Unit. The property is located approximately 21 km downstream of the Del Norte Unit and together the two properties make up the DRSNA (Figures 4 and 6; TPWD 2012a).

The acquisition of the Dan A. Hughes Unit made the TPWD one of the largest land holders in the watershed. The agency has a vested interest in conservation of the river as a landowner and as a state agency entrusted with the management and conservation of natural and cultural resources. Further-

more, the TPWD sought to author a plan for the integrated management of both units, keeping in mind the vision for holistic management of the entire watershed (TPWD 2012a). Success for such a plan was contingent on the input and support from stakeholders invested in the long-term health of the river. With this in mind, the TPWD chartered the Devils River Working Group (DRWG) in 2010 to provide input and feedback to the agency regarding strategies for protection of the river and surrounding watershed, information valuable to the TPWD to inform management of the two units of the DRSNA (TPWD 2012a).

To represent the broad interests and perspectives of the stakeholder communi-



Figure 5. View of the Devils River with The Nature Conservancy's Dolan Falls Preserve on the left and Texas Parks and Wildlife Department's (TPWD) Devils River State Natural Area–Del Norte Unit on the right with an inset of an individual spring in the Finegan Springs complex, which is one of the largest contributors to base flows on the river. Photographs by Earl Nottingham, TPWD.



Figure 6. The Devils River at the Dan A. Hughes Unit of Texas Parks and Wildlife Department's (TPWD) Devils River State Natural Area. Photograph by Clinton Robertson, TPWD.

ty, landowners, paddlers, anglers, DRSNA staff, researchers, conservation-oriented nonprofits, and recreational outfitters were appointed. The official charge of the working group was to identify issues of concern regarding sustainability of the resource, outline goals to address concerns, and identify specific management actions to achieve those goals.

The DRWG outlined the following conservation goals (reprinted from TPWD 2012a):

1. Protection of the river's water quality and quantity,
2. Protection of the river's ecological integrity and biota,
3. Protection of cultural resources along the river corridor,
4. Management of public access to the river,
5. Management to keep the river free of trash and waste,
6. Maintenance of the river's wilderness experience, and
7. Increased public outreach and education.

The DRWG also documented several challenges to achieving these goals, including land fragmentation, incomplete science, and nonnative species. Last, the group provided an outline of recommended actions to the TPWD (reprinted from TPWD 2012a):

1. Continue to seek input from a coalition of vested stakeholders,
2. Develop a comprehensive Devils River use management plan,
3. Develop a river access permit system,
4. Explore the feasibility of acquiring management control over Baker's Crossing (a put-in access point located along a public roadway),
5. Develop a comprehensive education and outreach campaign to inform the public of good recreational river stewardship practices,
6. Increase law enforcement presence on the river,

7. Have TPWD Commission members visit the state natural area complex,
8. Develop a volunteer river patrol program to monitor river use and health,
9. Support consolidation and gathering of scientific data on the river,
10. Continue working with partners to minimize land fragmentation,
11. Increase penalties for damage to cultural and natural resources, and
12. Implement fisheries management policies that support sustainable populations of fish.

Of these 12 recommendations, at the top of the list was the recommendation for continued dialogue among the TPWD and vested stakeholders. This recommendation was arguably the most critical, as without input and support from the varied interests within the watershed, many of the other goals set forth could not be achieved. For example, without the support of landowners, science conducted in the watershed would be primarily limited to the DRSNA, which is not necessarily an accurate representation of the entirety of the river or watershed. Additionally, landowners provide invaluable first-hand knowledge of the river, both historical and present day, giving resource managers an improved basis for recommending conservation actions.

Following this recommendation, the TPWD formed the Devils River Working Group II (DRWG II; TPWD 2014). The DRWG II was tasked with further detailing recommendations of the DRWG and identifying additional strategies to support the long-term health of the river. The DRWG II was similarly composed of watershed landowners, recreational users, land and river conservation leaders, and TPWD personnel. The DRWG II presented an updated list of recommendations to the TPWD in 2014 (TPWD 2014), including establishing regulations, campsites, and paddler education materials to reduce recreational impacts; supporting hydrology, recreation, and fish-

eries studies; compiling all historical and current Devils River-related research; encouraging landowners to employ best conservation practices; encouraging conservation easements within the watershed; and promoting catch and release of native fishes.

These working groups set the stage for increased communication and understanding among groups of stakeholders, who in the past have had opposing viewpoints on management of the river. Increased dialogue among landowners, agency staff, recreational users, and conservation-based nonprofit organizations has led to the formation of new partnerships focused around the desire to carry out recommended actions identified by the working groups. This includes a partnership between the TPWD and the Devils River Conservancy (DRC), a landowner-driven conservation advocacy nonprofit organization. In an effort to continue the dialogue

among stakeholders, the TPWD and DRC initiated educational outreach workshops (Figure 7), production of a paddler manual promoting good river stewardship practices and ongoing scientific research. Historically, much of the research conducted on the Devils River did not involve private property and landowners; however, the DRC is now connecting the TPWD and other agency and university researchers with property owners to discuss and conduct ongoing science in the watershed.

One way the DRC is making these connections is by holding joint DRC, TPWD, and landowner paddle trips. These 48-km paddle trips occur twice a year with the objectives of evaluating recreational impacts and engaging landowners (DRC 2016, 2017a, 2017b). Over a 4-d period, participants pick up litter, document illegal fires and campsites, document and remove invasive species,



Figure 7. The Devils River Conservancy and Texas Parks and Wildlife Department have partnered together to put on workshops and organize paddle trips for landowners, agency staff, and nonprofit staff. Workshop topics promote implementation of best management practices and a better understanding of the resource and have included best rural road building practices (top left) and the aquatic life of the Devils River (top right, bottom left). Biannual paddle trips (bottom right) focus on trash removal, documentation of recreational impacts, and increased dialog between partners.

qualitatively document the general health of the river, and discuss river conservation issues (Figure 7). Bringing together resource managers and landowners on the river is arguably the most important part of these trips and has fostered open discussions and facilitated opportunities for future collaboration. Furthermore, it directly aligns with the vision outlined in the working group reports (TPWD 2012a, 2014).

Another recommendation outlined in the DRWG II report is that the TPWD continue to support science needs in the watershed by compiling existing data and conduct and fund new research to fill data gaps (TPWD 2014). A central repository does not currently exist for data, manuscripts, and technical reports generated through those research projects, making it difficult to outline data gaps and prioritize research needs. This situation has also made it difficult to assess population trends due to the inability to compare species data over time. To help remedy this, the TPWD is working with DRC to compile published manuscripts, agency publications, gray literature, technical presentations, raw data, historical photographs, and other pertinent data and information. The goal of this project is to house all compiled materials in a searchable database platform with a Web-based interface that will allow it to be utilized by partners to inform research priorities and conservation actions and provide a better overall understanding of the resource.

The need to collect more data to inform conservation efforts in the watershed is crucial. To determine the most urgent research needs, the TPWD and TNC pooled knowledge of existing research within the Devils River watershed and have worked to collaboratively fund research to fill priority data needs. Like the TPWD, TNC has a dual interest in the Devils River, both as a conservation advocate and a landowner, and has long been involved in research and conservation in the watershed.

In the early 2000s, TNC coordinated early conservation planning efforts with an array of partners, including the TPWD, other state and federal agencies, and landowners. The resulting plan (TNC 2004) guided many initial conservation efforts in the watershed. It sought to complement land protection with the following primary recommendations: enhance black-capped vireo populations and Texas snowbell populations, reduce nonnative fish species, maintain or enhance the condition and beauty of riparian gallery woodlands, and promote public recreation that protects natural resources and quality of life for residents.

In 2006, TNC, the TPWD, and the Environmental Defense Fund updated the original conservation plan to prioritize aquatic conservation and research efforts. Priorities included a springs inventory and biological assessment; establishment of groundwater monitoring wells; characterization of the instream flow regime; and a watershed-wide aquifer characterization, water budget, and groundwater model. This plan led to the establishment of several ongoing monitoring efforts that have supported collaborations among TNC, the TPWD, Texas A&M University (TAMU), Texas State University (TSU), the USFWS, the U.S. Geological Survey, the Texas Water Development Board (TWDB), the TCEQ, and The University of Texas at Austin (UT Austin) Bureau of Economic Geology (Valdes Cantu and Winemiller 1997; TCEQ 2004; Kollaus and Bonner 2012; Robertson et al. 2016; USFWS 2017; Abolt et al. 2018).

Partnerships have been vital to furthering conservation and guiding investments in science in the Devils River watershed. While statewide agencies such as the TPWD often bring scientific expertise, funding, and other resources to fulfill research, restoration, or education objectives, they often lack the time necessary to successfully accomplish all the goals set forth within a targeted watershed. Partnerships between

state agencies and local nonprofit conservation organizations are an effective way to accomplish localized goals. Additionally, opening dialogues with other entities that are also funding research in the watershed is critical to ensure that research efforts are not duplicative and that the timeliest needs are prioritized and addressed.

Managing Sustainable Recreation

Two of the major concerns expressed by landowners have been increasing litter and trespassing along the river, which have been attributed to an increase in recreational access and use by paddlers. These concerns were documented in the DRWG I and DRWG II reports and led the TPWD to create the Devils River Access Permit (DRAP) as a mechanism to manage recreational use in a sustainable manner (TPWD 2012a, 2014). The DRAP is required of any paddler accessing or camping along the river at either unit of the DRSNA. This allows the TPWD to monitor and limit usage to a sustainable level and educate paddlers on river use etiquette and river stewardship practices prior to their trip, through educational materials provided to them with their permits.

Data collected in association with the DRAP confirms that recreation on the Devils River is increasing. From 2013 to 2017, issuance of permits increased 300% for single-day permits ($n = 67$ in 2013; $n = 200$ in 2017) and 200% for overnight permits ($n = 767$ in 2013; $n = 1,464$ in 2017; TPWD 2018). These numbers only include paddlers utilizing the TPWD's DRAP system. It is unknown how many paddlers utilized the river over that time through an unlicensed outfitter or by self-shuttling without a permit, both of which are known to occur. Increased recreational use can be attributed to several factors, including increased public access, increased media and advertising, and an overall increase in paddle sports participation in Texas (TPWD 2018).

Beyond the DRAP, the TPWD has employed several methods to manage recreational use and encourage river stewardship. Increased law enforcement allows officers to stop undesirable behavior, such as trespassing, littering, unauthorized ground fires, and other illegal activities that threaten the health of the river, as well as disseminate information on the resource and how paddlers can protect the river while still enjoying it (TPWD 2018).

A second measure employed by the TPWD to reduce recreational impacts was the addition of two new paddler campsites, bringing the total number of public campsites along the river to five (Figure 4; TPWD 2018). Prior to the addition of those two new paddler campsites, exit survey results from permit holders indicated that the average paddler traveled 8–16 km/d during a multiday canoe or kayak trip. Meanwhile, the average distance between public river access points was 25 km (TPWD 2018). This meant that most paddlers were finding alternative camping locations to complete their trip, and given that most of the properties adjacent to the river are privately owned, paddlers were limited to camping on islands or within the gradient boundary (i.e., the dividing line between the public streambed and private riparian property) to avoid trespassing. There are few islands large enough for camping, and determining the location of the gradient boundary can be difficult; therefore, this lack of clearly defined legal campsites led to conflicts between paddlers and riparian landowners.

As trespassing complaints increased, the TPWD recognized the need to develop two additional paddler campsites to reduce the distance between public access points. The goal of the campsites was to provide paddlers with additional legal camping options, leading to fewer landowner–paddler conflicts and a more enjoyable paddler experience. The challenge of establishing new campsites was the fact that the river is

bordered by private lands in these reaches and the TPWD did not have the resources to purchase and manage new properties. Rather than purchase additional public lands in the watershed, in 2016 the TPWD's Inland Fisheries and State Parks divisions partnered to utilize the TPWD's River Access and Conservation Areas (RACA) program to lease private property for the establishment of two new campsites. The RACA program utilizes funding from the Texas Parks and Wildlife Foundation, U.S. Department of Agriculture's Voluntary Public Access and Habitat Incentive Program, and Sport Fish Restoration Recreational Boating Access Grant Program to provide anglers and paddlers with public river access across private lands. Given the goals of the RACA-supported campsites on the Devils River, the TPWD restricted access to paddle-up camping with a one-night limit.

Another challenge was landowner perceptions that the TPWD was opening the new sites to encourage increased recreation rather than to better manage existing recreation. Anticipating potential backlash, the TPWD sought recommendations and input from the DRC prior to securing the lease agreements with cooperating private landowners. Although somewhat hesitant that additional paddler campsites would encourage increased visitation, the DRC recognized that these new campsites had the potential to condense paddler overnight locations, potentially reducing trespassing and related riparian degradation on private lands. The DRC endorsed the new sites on a 1-year trial basis, and in return, the TPWD agreed to follow up and seek the DRC's input in evaluation of the campsites after the initial year, prior to lease renewals (TPWD 2018).

During the first year of use, more than 500 paddlers (37% of all permitted paddlers) utilized the new paddler campsites (TPWD 2018). In a report by the TPWD evaluating the pilot project, recreational usage was compared with river citations issued dur-

ing the initial 10 months of site usage in 2017 versus the same 10-month period the prior year. Despite increased river usage and increased river patrols, there was a decrease in the number of citations issued. This included a decrease in the number of trespassing and littering violations, issues of special concern to landowners. The DRC provided a letter of support for continuation of the paddler campsites noting that

they have served to consolidate human impacts, alleviate trespassing and encourage a high standard of river ethics by visitors.

The DRC went on to say they are grateful for the DRAP and new paddler camps and

It is crucial to the long-term protection of the Devils River from recreational abuse and over-use that stakeholders continue to collaborate in promoting the highest standard of river ethics.

Based on the data and feedback compiled, the TPWD renewed the lease of the two new paddler campsites. In addition to positive feedback from landowners, the TPWD received positive feedback from paddlers utilizing the new campsites. The feedback reaffirmed that these sites have provided an enjoyable paddler experience and reduced conflicts between paddlers and landowners. The TPWD and DRC intend to continue to work together to monitor and evaluate the effectiveness of the paddler campsites in meeting their intended goals and to determine whether additional paddler campsites are warranted.

Science as the Foundation for Conservation

The time spent building trust and developing partnerships with landholders in the watershed has allowed for expanded opportunities to conduct the science needed to guide conservation. Due to the richness of endemic species that occur in the Devils River watershed, the area has long been a fo-

cal point for ecological research. River sustainability requires an understanding of the instream flow regime necessary to maintain ecological functions and processes (Annear et al. 2004). Instream flow science requires a multidisciplinary approach. To identify environmental flow needs for the Devils River, hydrology, biology, geomorphology, water quality, and connectivity must all be considered (Annear et al. 2004). The Devils River flows over and interacts with a karst aquifer system; thus, instream flows are intrinsically linked with groundwater availability and the interaction between groundwater and surface water.

Current threats to groundwater availability in the Devils River watershed are primarily centered on lack of regulation and increasing water demands. High-quality groundwater can be taken from one part of the state and exported to other parts where it is needed. Much of Texas is arid or semiarid, and urban areas in these regions will likely need additional water supply given forecasted increases in their populations. Municipal water demand in Texas is anticipated to increase from 6.4×10^{12} m³ per year in 2020 to 10.4×10^{12} m³ in 2070 (TWDB 2017). Texas groundwater law states that, under rule of capture, any individual has the right to pump an unlimited amount of groundwater from their property (Bath 1999), which can hinder conservation efforts of groundwater-dependent streams. Exceptions exist in areas where groundwater conservation districts (GCDs) have been established to provide regulatory authority over the management of groundwater; however, Val Verde County is not currently governed by a district. In recent years, there have been proposals to pump substantial volumes of groundwater from the Devils River watershed to support municipal water demands in urban centers such as the cities of San Antonio, Texas and San Angelo, Texas (Satija 2014). While this would be expected to have detrimental effects on the Devils River ecosystem, the

science is lacking to model the quantity of groundwater pumped before impacts occur and how those impacts would be manifested. Groundwater–surface water interaction is just one facet of the science still needed to inform protection of the Devils River, although it is currently considered the most pressing need. State agencies, nonprofit conservation organizations, and university researchers have had an increased level of cooperation and collaboration over the past 5 years to coordinate and align research in the watershed with the goal of addressing the question of how much water the Devils River needs to sustain a functioning ecological system.

Biological monitoring

Annual longitudinal fish surveys were conducted by the TPWD from 2000 to 2004 (TPWD, unpublished data). This monitoring, along with research by TAMU (Valdes Cantu and Winemiller 1997; Robertson and Winemiller 2001, 2003), TSU (Kollaus and Bonner 2012; Robertson et al. 2016), and the USFWS (Phillips et al. 2011), provide an important baseline of fish data prior to the 2011–2012 drought. In 2011, the TPWD compiled a report summarizing historical fisheries surveys in the Devils River watershed and outlining recommended fisheries management strategies (TPWD 2011). Hindrances to effective fisheries management included sport fish regulations that varied by river reach, nonstandardized fisheries data collection, limited data on aquatic habitat and riparian condition, and the threat exotic species pose to the listed fish species in the Devils River (TPWD 2011). Recommendations to address those issues included standardization of the frequency, timing, location, and gear employed in the collection of fisheries data in the Devils River. In response, a Devils River standardized aquatic monitoring plan was developed (TPWD 2012b). Components of this plan included mapping of aquatic habitats, annual fish assemblage sampling,

genetic monitoring for target species, black bass monitoring, and riparian evaluations.

In 2012, the TPWD and TNC began standardized monitoring of the fish communities in the Devils River and Dolan Creek. Sites were selected to encompass available habitats and collect species representative of the Devils River. Fish were collected using seines from representative mesohabitats (i.e., riffle, run, pool, and backwater), and aquatic habitat parameters were measured within each sampled mesohabitat (TPWD, unpublished data).

Annual fish community monitoring has continued with some minor changes, including the inclusion of gill nets to better document larger species such as Longnose Gar *Lepisosteus osseus*, Headwater Catfish *Ictalurus lupus*, and Largemouth Bass *Micropterus salmoides*. Additionally, methods have been refined to include collection of the various habitat parameters at each seine haul and gill net location to collect data at a fine enough resolution to allow for development of habitat suitability criteria.

In 2017, the TPWD began longitudinal surveys, which, when completed, will document species distribution and habitat use in 85 km of river for three focal species: Devils River Minnow, Conchos Pupfish, and Texas hornshell (Figure 3). The Devils River Minnow (ST, FT) is vulnerable to potential impacts due to its narrow distribution and reliance on imperiled spring-fed streams (Garrett et al. 2002; Jelks et al. 2008). It is assumed that this species has already been extirpated from several streams and likely only remains in the Devils River, Dolan Creek, San Felipe Creek, and Pinto Creek in Texas, with an unknown distribution in Mexico (Garrett et al. 2004).

The Conchos Pupfish (ST) was selected also based on its narrow distribution, as well as its unique habitat use. It is only known to occur in Alamito Creek (Presidio County), the Devils River, and Dolan Creek in Texas and in the Rio Conchos watershed in Mexico

(Garrett et al. 2005; Hubbs et al. 2008). In the Devils River and Dolan Creek, Conchos Pupfish primarily utilize shallow (25–150 mm) margin habitats on inundated bedrock shelves (TPWD, unpublished data). The primary conservation concern for this species is dewatering of shelf habitats in times of reduced flow. It is currently unknown what habitats this species utilizes during times in which these shallow-margin shelf habitats are unavailable and if other habitats can support the species long term.

The distribution of Texas hornshell (ST, FE) is limited to the Rio Grande basin of Texas, New Mexico, and northern Mexico (USFWS 2018a), and until recently, little was known about its status in the Devils River (Howells 1996; Karatayev et al. 2012). Recent collections have found that habitat preference of Texas hornshell in the Devils River (shallow riffles and runs; TPWD, unpublished data) makes them particularly vulnerable during periods of reduced flows, which can lead to stranding or increased predation by raccoon *Procyon lotor* (USFWS 2018a). Because Texas hornshell utilizes shallow water habitats, it is likely that developing flow recommendations for this species will in turn serve as protection for most, if not all, fish species in the river.

The TPWD and TNC recognize the importance of collecting a long-term monitoring data set using standardized sampling methodologies and plan to continue annual fish community monitoring on the Devils River and Dolan Creek and longitudinal surveys for focal species every 3 to 5 years. The development of long-term data sets is an important tool for monitoring species abundance and can be used to evaluate potential impacts to the ecosystem, especially given future water availability concerns.

Understanding the relationship between habitat and surface water

The first effort to model habitat availability as a function of Devils River discharge was

made as part of Texas' environmental flows process in the Rio Grande basin. The Upper Rio Grande Bay and Basin Expert Science Team (URGBBEST) developed habitat suitability criteria for 10 Devils River fishes and, with assistance from the TPWD and TWDB, coordinated development of a one-dimensional hydraulics model (TES 2012) to estimate the amount of instream habitat maintained by the recommended flow regime (URGBBEST 2012). The habitat model was developed for the Devils River adjacent to the Dolan Falls Preserve, and model simulations concluded that the range of base flows recommended by the URGBBEST would provide adequate habitats for the fishes studied. This work was an important component of the flow recommendations (URGBBEST 2012) that were adopted by the TCEQ as flow standards for the Devils River.

In an effort to refine and expand upon URGBBEST recommendations, the TPWD partnered with TSU in 2012 to develop a two-dimensional habitat model for Devils River Minnow and nine other priority native fishes in two additional reaches of the Devils River at DRSNA–Del Norte Unit and one reach of Dolan Creek at the Dolan Falls Preserve (Hardy 2014).

Extreme drought during the study period (2013) resulted in relatively stable discharges in the Devils River (upstream reach: 0.54–0.94 m³/s; downstream reach: 1.14–1.63 m³/s). In combination with flat instream bathymetry within the study reaches, these historically low flows limited inferences regarding changes in available suitable habitat under variable flow conditions. Moderate declines in available suitable habitat for Devils River Minnow as instream flow increased were predicted by the model at the downstream Devils River study site. However, changes in depth or velocity predicted by the model were narrow under the observed discharges, and results at this site may not be indicative of actual changes. Changes in available suitable habitat at the upstream

Devils River site were inconsequential. At the Dolan Creek site, habitat could not be modeled because variability in flow observed during data collection trips was insufficient to develop the stage-discharge relationship needed to calibrate the hydraulic model. It was recommended that additional physical habitat data be collected under a wider range of discharges for the model to more effectively predict changes in instream habitat availability.

Based on recommendations from Hardy (2014), and foreseeing future applications of the data, the TPWD partnered with UT Austin to collect airborne Light Detection and Ranging (Lidar) bathymetry data for the entire perennial reach of the Devils River and most of Dolan Creek. These data will produce a digital elevation model of both the surface and subsurface (to depths of 3 m), as well as riparian vegetation densities that will allow researchers to develop better hydraulic models for longer contiguous reaches of river. This combined bathymetric, topographic, and visual imagery survey of approximately 70 km of the stream can be used as a primary input for instream habitat models, assessing instream flow targets and mapping aquatic vegetation, which provides important habitat for Devils River Minnow (Robertson et al. 2016).

Understanding groundwater–surface water interactions

Essential to developing effective instream flow recommendations in groundwater-dependent streams is an understanding of how variations in groundwater level affect spring discharge and how groundwater inputs maintain instream flows. Hydrogeologic research efforts (e.g., Veni 1995, 1996; Mace et al. 2004; LBG-Guyton Associates 2005, 2009) have resulted in a conceptual understanding of aquifer connections in the watershed and provided basis for recent advances. Simulation models of groundwater flow and aquifer–surface water connections

are an important tool in understanding aquifer systems and evaluating groundwater management scenarios. The Devils River has been the focus of several recent modeling efforts (EcoKai Environmental Inc. 2014; Green et al. 2014) with the goal of better understanding potential effects of proposed pumping scenarios on the Devils River and downstream water supply in the Rio Grande. A coupled groundwater–surface water model developed by the Southwest Research Institute (Green et al. 2015; Toll et al. 2017) that includes conceptualization of preferential flow paths (Green et al. 2014) provides the best current tool for relating aquifer dynamics to instream flows. Simulations of three pumping scenarios (Toll et al. 2017) suggest that current low levels of pumping may have already had significant effects on the river, especially considering low recharge rates (Green et al. 2012). Thus, expanded pumping in sensitive areas above the river's headwaters could significantly reduce river flows.

To strengthen understanding of these relationships and further refine groundwater models, the TPWD partnered with UT Austin in 2015 to collect hydrologic data needed to understand the relationships among groundwater, spring discharge, surface water, and aquatic habitats of Devils River Minnow, Texas hornshell, and other species of conservation interest. Specifically, the goals of this study are to measure groundwater levels to understand baseline groundwater variability; monitor spring and stream water salinity (e.g., conductivity) and temperature to understand rainfall-runoff and spring flow relationships affecting streamflow; record temporal water temperature changes in Devils River Minnow habitat; measure diurnal thalweg water temperature variations; develop a stage-discharge relationship, enabling calculation of spring discharge; understand the influence of climate variability on aquatic habitat by monitoring meteorological parameters; measure substrate temperature and stream stage at

three riffles where Texas hornshell has been detected; and collect thermal infrared imagery of surface water temperature around spring discharge sites (see Abolt et al. 2018).

The hydrologic data generated by this study will be directly used by the TPWD and USFWS to implement key components of a recovery plan for Texas hornshell (upon completion by the USFWS) and the Devils River Minnow recovery plan (USFWS 2005), including development of a groundwater management plan for streamflow protection that ensures protection for the Devils River. The results of the hydrology study will inform management of threats to Texas hornshell identified in the Texas hornshell species status assessment (USFWS 2018c). To this end, study results will be conveyed to state, federal, and local stakeholders to increase opportunities for successful conservation of aquatic habitats for the Devils River Minnow, Texas hornshell, and other species of interest (TPWD 2012c; Cohen et al. 2018) in the Devils River.

Discussion and Future Conservation Steps

While much progress has been made over the past decade to build partnerships, strengthen scientific research efforts in the watershed, align research priorities, and promote river stewardship by recreational users of the Devils River, more work is needed to conserve this special resource. Partners should continue to cooperate on delivery of conservation goals that have been established through collaborative stakeholder processes, such as the DRWG and DRWG II. Reconvening a DRWG every 5 to 10 years would support timely reevaluation of conservation strategies, priorities, and threats.

Continuing to develop working relationships with landowners is of the utmost importance in any watershed that is predominately privately owned. The Devils River watershed, with its many large ranches and relatively few property owners, offers

a unique opportunity to reach a large portion of the watershed through educational events and landowner meetings. These relationships are mutually beneficial and help ensure that conservation objectives are relevant and achievable.

The issue regarding creation of a GCD to protect the Devils River continues to be discussed. This is especially important as various entities continue to draft proposals to develop groundwater resources in the county. In Texas, the authority to establish GCDs resides with the state legislature or TCEQ. To ensure that the state can make an informed decision about creation of a GCD, partners must work together to focus research on understanding groundwater and surface water relationships and effects on instream habitat. More importantly, they must be able to communicate the science to decision makers effectively. The use of instream flow science tools, such as hydraulic habitat models in conjunction with groundwater–surface water simulation models, is necessary to inform groundwater management.

In the past decade, communication and cooperation among state agencies, conservation-based nonprofit organizations, universities, and landowners has increased substantially to the benefit of the resource. As river conservation efforts in Texas have shifted toward a holistic, watershed approach in recent years, conservation efforts in the Devils River have also shifted toward endeavors inclusive of all vested stakeholders.

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Multispecies and Watershed Approaches to Freshwater Fish Conservation

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