Canadian River Basin Bioassessment

Sarah Robertson, Melissa Parker, Gordon Linam, Clinton Robertson, Archis Grubh
Texas Parks and Wildlife Department, Inland Fisheries Division

AND

Melissa Casarez
University of Texas at Austin, Biodiversity Collections

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Texas Parks and Wildlife Department, Inland Fisheries Division: Karim Aziz and Kevin Mayes

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EXECUTIVE SUMMARY

One bioassessment study area and seven supplemental fish collection sites were sampled in the Canadian River Basin in Oldham, Potter, Hutchinson, Roberts, and Hemphill counties, Texas during the fall of 2015. The bioassessment study area was located at Gene Howe Wildlife Management Area (GHWMA) near Canadian, TX and included sites on the Canadian River and adjacent oxbow lakes. Fish, mussel, riparian, and macroinvertebrate assemblage data were collected from the Canadian River at GHWMA. Additionally, fish assemblage sampling took place at the oxbow lakes and supplemental fish collection sites throughout the basin. This data was collected in an effort to support management needs of GHWMA, expansion of recreational initiatives such as the Texas Parks and Wildlife Department's (TPWD) Texas Paddling Trails and River Access and Conservation Area programs, and inform future research and conservation efforts through TPWD's Native Fish Conservation Area initiative.

Overall, 23 species of fish, 22 benthic macroinvertebrate taxa, one species of crayfish, and 12 riparian plant taxa were documented from the basin. Two of three potential Species of Greatest Conservation Need fishes were collected: Arkansas River Shiner and Peppered Chub. Arkansas River Shiner is also listed as state and federally threatened. One non-native fish species (Common Carp) was collected.

The fish community in the Canadian River at GHWMA was given an exceptional regionalized Index of Biotic Integrity aquatic life use rating and received the highest possible score for all metrics except for catch-per-seine haul. Despite this, several previously collected prairie fishes characteristic of the Canadian River were not collected downstream of Lake Meredith: Plains Minnow, Arkansas River Shiner, Peppered Chub, Flathead Chub, and Red River Pupfish.

No live freshwater mussels or shell material was collected, suggesting mussels have not occurred at sites sampled anytime in the recent past. This is typical of the Canadian River Basin in Texas which has historically supported low mussel species richness and abundance.

Benthic macroinvertebrates were collected from the Canadian River at GHWMA. These collections contained a high proportion of caddisfly and mayfly taxa, signifying that the system is healthy enough to support sensitive taxa. The aquatic life use score calculated from these collections was categorized as high. One species of crayfish was documented during this study.

Plant species identified from the Canadian River riparian corridor at GHWMA were consistent with previous assessments of the area. Physical and hydrologic alterations of the Canadian River in Texas have created conditions suitable for invasion of non-native riparian species. Russian olive, saltcedar, and the newly documented ravenna grass were found in moderate abundances at GHWMA. The Canadian River study site at GHWMA was also evaluated for overall stream health using a modified stream visual assessment protocol and was rated as having good stream health.

This study found relatively high fish and benthic macroinvertebrate species richness within GHWMA; however, aquatic communities in the basin face imminent threats consistent with rivers throughout the Great Plains, including dewatering, habitat degradation and fragmentation, and an increasing abundance of invasive species. Opportunities to remove non-native species, restore the natural flow regime, and modify or remove instream barriers should be considered to improve conditions for native species in this ecosystem.

INTRODUCTION

Study Area

Canadian River: 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 shallow, sandy, braided channels. The Canadian River Basin totals 312,221 km^2 and has 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 potential ecologically significant stream segments based upon riparian conservation areas and the presence of imperiled species and unique biological communities. The Canadian River in Texas was also identified as a Native Fish Conservation Area in recent conservation planning efforts conducted through the Great Plains Landscape Conservation Cooperative (Labay and Hendrickson 2014).

> Gene Howe Wildlife Management Area: Gene Howe Wildlife Management Area (GHWMA) is comprised of 21.83 km^2 (5,394 acres) of rolling sandy grassland hills and Canadian River bottomlands. GHWMA is located outside of Canadian, TX in Hemphill County (TPWD 2016b). GHWMA is bordered by approximately 1.1 km of the Canadian River and contains several floodplain oxbow lakes. Although wildlife management and hunting are the primary purpose of GHWMA, the unit also offers additional recreational activities including primitive camping, hiking, horseback riding, and fishing.

Survey and Management History

Biological Surveys: The Canadian River is home to several imperiled species of fish that when coupled with close proximity to universities conducting aquatic research have made it the site of numerous fish community studies. Recent fish-related research in the Texas portion of the river includes studies on historical trends in relative abundance, life history work on 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).

Aquatic research at GHWMA has been conducted by West Texas A&M University (WTAMU) faculty and students since 2007 (Dr. Richard Kazmaier, WTAMU, personal communication). This work includes baseline inventories of fishes, amphibians, and reptiles, in addition to research focused on aquatic turtles. The university also uses GHWMA as an outdoor classroom to teach students biological sampling techniques. Most aquatic research within GHWMA conducted by WTAMU focused on the oxbow lakes, with minimal sampling conducted in the mainstem Canadian River.

Limited freshwater mussel survey data is available from the Canadian River Basin; however, historical data suggests the basin has supported few mussel species occurring in low abundance. Freshwater mussel surveys (Howells 1996) conducted in 1995 at two sites on Lake Meredith and five sites on the Canadian River, including one site near GHWMA, found no live native freshwater mussels.

Surveys of benthic macroinvertebrates include a study by the U.S. Fish and Wildlife Service in 2011 in which over 13,000 individuals representing 70 benthic macroinvertebrate taxa were collected from five sites in Texas and one site in New Mexico (Giggleman et al. 2002). No crayfish surveys from the Texas portion of the river were found.

The most recent riparian studies in Texas focused on distribution and water use by the invasive saltcedar *Tamarix* spp. (Kiniry et al. 2003; White et al. 2003). No comprehensive riparian surveys were found.

Imperiled Species: Historical fish collections from the Canadian River Basin in Texas contain three fish species currently identified by TPWD (2012) as Species of Greatest Conservation need (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). No freshwater mussel SGCN have been reported from the Canadian River Basin in Texas (TPWD 2008).

Sport Fish Harvest Regulations: Sport fishes in the Canadian River and its tributaries are managed under statewide freshwater fishing regulations (TPWD 2016c).

Fish Stockings: The only recorded TPWD stocking on the Canadian River took place in 1973. This event stocked 1,500 Channel Catfish *Ictalurus punctatus* into the Canadian River at an unknown location (TPWD 2016d). Since 1965 numerous TPWD fish stockings have taken place in Lake Meredith which included Largemouth Bass *Micropterus salmoides*, Smallmouth Bass *Micropterus dolomieu*, White Crappie *Pomoxis annularis*, Black Crappie *Pomoxis nigromaculatus*, Blue Catfish *Ictalurus furcatus*, Channel Catfish, Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, Bluegill *Lepomis macrochirus*, Walleye *Sander vitreus*, Flathead Catfish *Pylodictis olivaris*, and Yellow Perch *Perca flavescens* (TPWD 2016d).

Water Quality: The Texas Commission on Environmental Quality (TCEQ) report 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).

STUDY SITES

The Canadian River Basin bioassessment included sampling at one bioassessment study area (GHWMA) and seven supplemental fish collection sites (Figure 1; Table 1). The study area at GHWMA (Figure 2) included one comprehensive study site on the Canadian River (Site A) in which data was collected on the fish community, mussel assemblage, riparian community, water quality, macroinvertebrate assemblage, and overall stream health, and two sites on oxbow lakes where fish assemblage data was collected (Sites B and C). Supplemental fish assemblage sites included four additional mainstem Canadian River sites (Sites 1, 2, 4, and 7) and three tributary sites (Sites 3, 5, and 6).

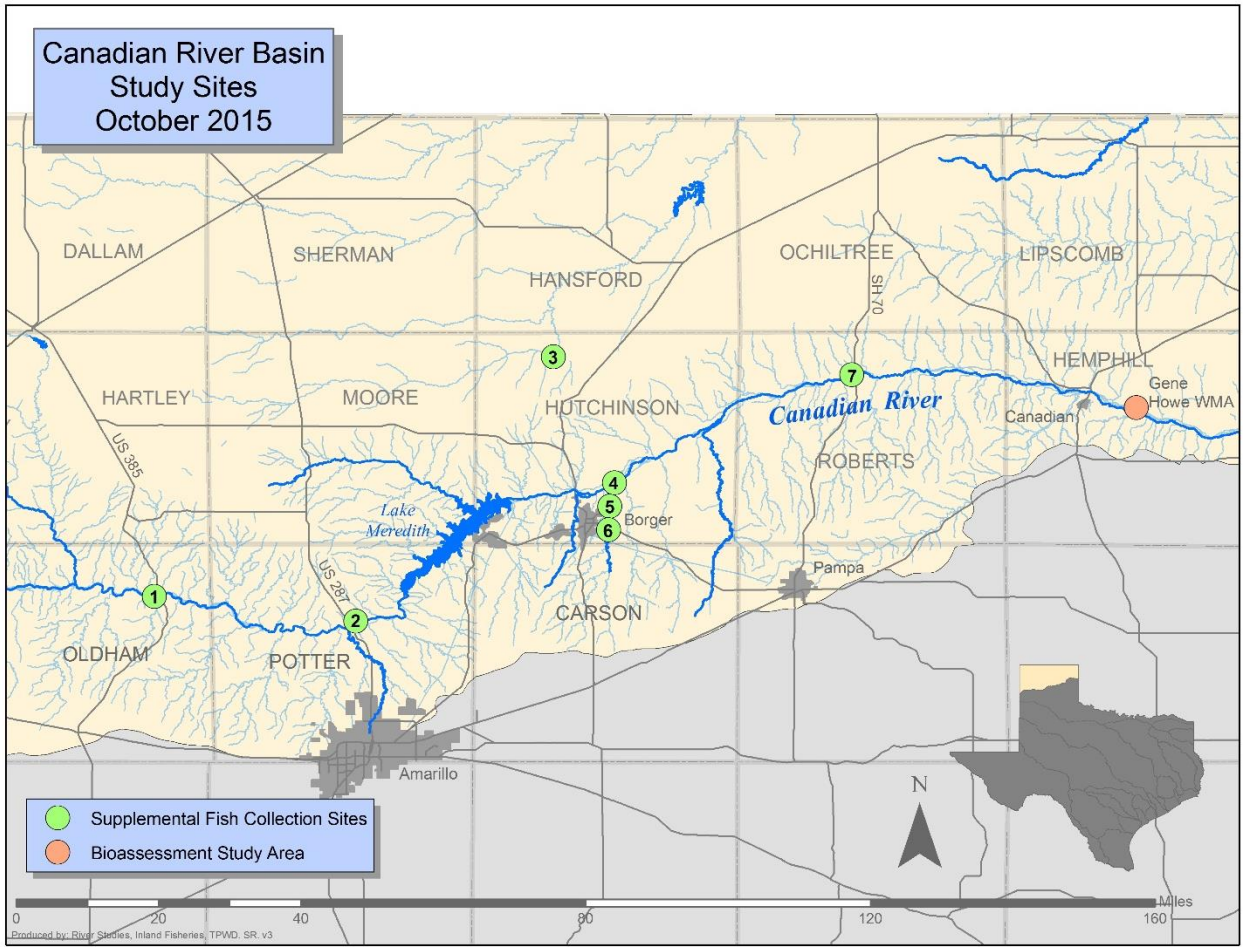

FIGURE 1.—Locations of Canadian River Basin data collection sites in Oldham, Potter, Hutchinson, Roberts, and Hemphill counties, TX. See Table 1 for site location information.

TABLE 1.—Canadian River Basin study site locations and the type of data collected at each site during October 2015 in Oldham, Potter, Hutchinson, Roberts, and Hemphill counties, TX.

Site	Location	Coordinates	Sampling Date	Fish	Mussels	Stream Health	Riparian	Macro-Invertebrates
Bioassessment Study Area Sites								
A	Canadian River at Gene Howe WMA	35.89765, -100.26965	10/5/2015	x	x	x	x	x
B	Oxbow 1 at Gene Howe WMA	35.90207, -100.27729	10/5/2015	x				
C	Oxbow 2 at Gene Howe WMA	35.91271, -100.31894	10/5/2015	x				
Supplemental Fish Collection Sites								
1	Canadian River at US 385	35.51837, -102.27420	10/4/2015	x	x			
2	Canadian River at US 287	35.46830, -101.86420	10/4/2015	x	x			
3	South Palo Duro Creek at CR 136	36.00613, -101.46274	10/4/2015	x				
4	Canadian River at Plemons Rd.	35.74741, -101.34718	10/4/2015	x				
5	Dixon Creek at CR V	35.74339, -101.34172	10/4/2015	x				
6	Dixon Creek at SH 152	35.66465, -101.35125	10/4/2015	x				
7	Canadian River at SH 70	35.96931, -1010.8558	10/4/2015	x				

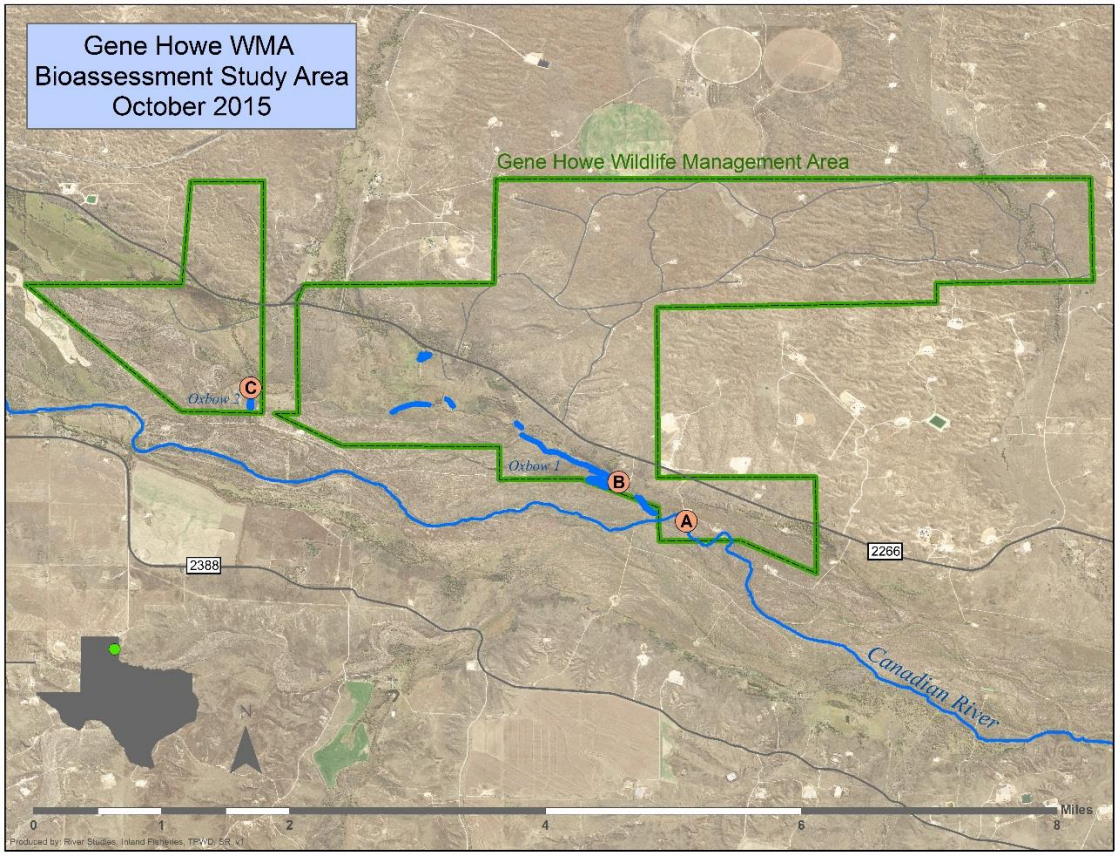

FIGURE 2.—Locations of study sites within the bioassessment study area at Gene Howe Wildlife Management Area, Hemphill County, TX. See Table 1 for site location information.

Canadian River

The study site on the Canadian River at GHWMA (Site A) was 1.1 km long with a moderately wide, wetted channel (width ranging from 10-20 m) dominated by flowing, shallow water habitats, sandy substrates, and little instream cover (Figure 3). Fish assemblage data was collected from four additional sites on the Canadian River upstream of GHWMA. Photographs for these sites are included in the supplemental fish collection section.

FIGURE 3.—Instream habitats found within Site A on the Canadian River at Gene Howe Wildlife Management Area were similar throughout the site. The left photo shows a wide channel and the right photo shows a narrow channel, both with sandy substrates and little instream cover.

Oxbow Lakes

Several floodplain oxbow lakes exist at GHWMA (Figure 2). Fish were sampled in two oxbow lakes during this bioassessment (Sites B and C). The oxbow at Site B was approximately 1,000 m long and ranged from 10-30 m wide. The oxbow at Site C was smaller at approximately 330 m long and averaging 20 m wide. Both oxbows were dominated by silty substrates and had no flow during the study (Figure 4).

FIGURE 4.—Oxbow lake habitats typical of Site B (left) and Site C (right) on the Gene Howe Wildlife Management Area have no flow and predominately silty substrates. See Table 1 for specific site location information.

Supplemental Fish Collection Sites

Seven supplemental fish collection sites were sampled throughout the Canadian River Basin in Oldham, Potter, Hutchinson, and Roberts counties, TX (Sites 1-7; Figure 1; Table 1). These included four additional sites on the Canadian River (two upstream and two downstream of Lake Meredith) and three sites on two tributaries (South Palo Duro Creek and Dixon Creek). Photos of each site are included to provide reference to site conditions at the time of sampling (Figure 5).

FIGURE 5.—Supplemental fish collection sites 1-7 which were sampled in October 2015. Photos are labeled with the corresponding site numbers in Table 1.

WATER QUALITY AND QUANTITY

Methods: Point measurements for water temperature, specific conductivity, dissolved oxygen, and pH were recorded using a YSI multi-parameter water quality sonde at Sites 1, 2, and A on the Canadian River. Total dissolved solids (TDS) concentrations were calculated by multiplying specific conductivity by 0.64 (Atekwana et al. 2004). Data were verified using TCEQ quality assurance procedures (TCEQ 2014b). Point measurements were evaluated in context of the surface water quality standards (TCEQ 2014a).

Results and Discussion: The Canadian River upstream of Lake Meredith (Segment 0103) has been listed as impaired by TCEQ because of chloride concentration standard exceedances (TCEQ 2014a) since 2006. According to the Red River Authority of Texas (RRA 2016), high chloride concentrations have been attributed to naturally occurring salt deposits and the invasion of non-native saltcedar. Since 2004, the Canadian River Municipal Water Authority has been actively managing saltcedar (RRA 2016). A use concern for bacteria is also documented due to one instance of a standard exceedance (TCEQ 2014a).

Segment 0101 (Canadian River below Lake Meredith) has concerns for screening level exceedances for ammonia and chlorophyll-*a*, as well as concern for the near non-attainment for depressed dissolved oxygen (TCEQ 2014a). The elevated levels of chlorophyll-*a* are likely related to depressed dissolved oxygen values. Similar to the upstream segment, a single impairment for bacteria was also reported. The bioassessment study area at GHWMA is located within this segment.

Water temperature, pH, and dissolved oxygen measurements recorded during this study were within designated water quality standards (Tables 2 and 3). While no standard exists for specific conductivity, it can be used as a means of indirectly measuring TDS. Based upon specific conductivity, TDS was also within established standards (Tables 2 and 3). Bacteria and metals were not evaluated during this study.

TABLE 2. —Water quality data collected from Sites 1 and 2 on the Canadian River on October 4, 2015 at 1133 and 1728 hrs, respectively. TCEQ water quality standards for Segment 0103 are reported for comparison (TCEQ 2014a).

Site	Temperature (°C)	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Dissolved Oxygen (mg/L)	pH
Site 1	14.3	2980	1907	9.3	8.4
Site 2	16.4	2572	1646	9.0	8.4
TCEQ Standard	≤ 35	N/A	≤4500	24 hr min: ≥3	6.5-9.0

TABLE 3. —Water quality data collected from Site A on the Canadian River at the Gene Howe Wildlife Management Area (Hemphill County, TX) on October 5, 2015 at 1500 hrs. TCEQ water quality standards for Segment 0101 are reported for comparison (TCEQ 2014a).

Site	Temperature (°C)	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Dissolved Oxygen (mg/L)	pH
Site A	19.1	2535	1622	9.6	8.4
TCEQ Standard	≤ 35	N/A	5000	24 hr min: ≥3	6.5-9.0

Stream discharge at the time of sampling was considerably more than what is typical of historical streamflow during October. According to data reported from USGS gages 07227500 (Canadian River near Amarillo, TX) and 07228000 (Canadian River near Canadian, TX), discharge during the sampling period was 70 and 45 cfs, respectively. Monthly median discharge for October at the USGS gage near Amarillo for the period of record (1938-2015) is 54 cfs. October monthly median discharge from the USGS gage near Canadian (1964-2014) is 23 cfs.

FISH ASSEMBLAGE

Gene Howe Wildlife Management Area Study Area (Sites A-C)

Methods: Fish were collected from Site A on the Canadian River at GHWMA on October 5, 2015. Seines were the only gear type utilized during this effort due to shallow habitats and high conductivity that rendered electrofishing ineffective. Expanding upon TCEQ sampling protocols (2014b), a minimum sampling effort of 10 seine hauls was utilized, with additional hauls added until no new species were collected.

Fish were also collected from two oxbow lake sites within GHWMA (Sites B and C) on October 5, 2015 using a combination of seines and 15.25 m long experimental mesh gill nets. Sampling was conducted until all available habitats were sampled and no new species were collected.

For all sites sampled at GHWMA, large fish were identified to species, measured, photographed, and released. Smaller specimens were fixed in a 10% solution of formalin for identification and enumeration in the laboratory. All fish were examined for external deformities, disease, lesions, tumors, and skeletal abnormalities. Vouchered specimens were permanently archived at the University of Texas' Biodiversity Collections in Austin, TX. Data will be available online through the Fishes of Texas Project (Hendrickson and Cohen 2015).

Regionalized Index of Biotic Integrity (IBI) metrics developed for streams in the Western High Plains and Southwestern Tablelands ecoregions (Linam et al. 2002) were calculated for Site A on the Canadian River. The IBI provides a means of assessing fish assemblage health as it relates to water quality impacts in relation to reference fish communities within the same ecoregion. Results are reported as an aquatic life use and possible rankings include exceptional, high, intermediate, and limited.

Results and Discussion: A total of 453 individuals comprising 16 fish species were collected throughout GHWMA on October 5, 2015 (Table 4). Site A on the Canadian River and Site B, one of the oxbow lakes, both yielded 12 species, while Site C, a second oxbow lake, yielded six species. Waterbodies at GHWMA had high species richness within the centrarchid family, with a total of seven species collected during this study including bass, crappie, and sunfish. Bluegill was the most abundant sunfish species across all sites (Figure 6). Centrarchid species were the most evenly distributed taxa throughout GHWMA, with bass and sunfish being the only taxa found across all three sites.

TABLE 4.— Abundance of fish collected by species for all gear types combined by site from Gene Howe Wildlife Management Area (WMA) on October 5, 2015, in Hemphill County, TX. Fish species collected from Gene Howe WMA by West Texas A&M University (WTAMU) researchers from 2007 through 2014 using a variety of gear types is presented for comparison (Dr. Richard Kazmaier, WTAMU, personal communication).

Family	Scientific name	Common name	**WTAMU** *Gene Howe WMA*	**Site A** *Canadian River*	**Site B** *Oxbow #1*	**Site C** *Oxbow #2*
Lepisosteidae	*Lepisosteus oculatus*	Spotted Gar	X		4	2
Clupeidae	*Dorosoma cepedianum*	Gizzard Shad			1	
Cyprinidae	*Cyprinella lutrensis*	Red Shiner		82		
	Cyprinus carpio	Common Carp	X	1	1	
	Notemigonus crysoleucas	Golden Shiner	X	1	3	
	Notropis stramineus	Sand Shiner	X	79		
	Phenacobius mirabilis	Suckermouth Minnow		2		
Ictaluridae	*Ameiurus melas*	Black Bullhead	X			
	Ameiurus natalis	Yellow Bullhead	X			
Fundulidae	*Fundulus kansae*	Northern Plains Killifish	X	1		
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	X	97	3	
Cyprinodontidae	*Cyprinodon rubrofluviatilis*	Red River Pupfish	X			
Centrarchidae	*Lepomis cyanellus*	Green Sunfish	X	9	1	2
	Lepomis gulosus	Warmouth	X	2	2	10
	Lepomis humilis	Orangespotted Sunfish	X			
	Lepomis macrochirus	Bluegill	X	39	25	14
	Lepomis megalotis	Longear Sunfish	X	2	4	
	Lepomis microlophus	Redear Sunfish	X		3	5
	Lepomis sp.	Unknown juvenile sunfish				33
	Micropterus salmoides	Largemouth Bass	X	17	6	1
	Pomoxis nigromaculatus	Black Crappie	X		1	
	Number of species collected		**17**	**12**	**12**	**6**
	Number of individuals collected			**332**	**54**	**67**

Four native cyprinid species were collected from the Canadian River at GHWMA, with Red Shiner *Cyprinella lutrensis* being the most abundant (Figure 6; Table 4). Collections from oxbow lakes added no additional cyprinid species. One non-native cyprinid species, Common Carp *Cyprinus carpio*, was collected from the Canadian River and one of the oxbow lakes at GHWMA in low numbers. This was the only non-native fish species collected during sampling in the Wildlife Management Area.

FIGURE 6.—The three most abundant species collected from the Canadian River (Site A) followed by the most abundant species collected from the sampled oxbows (Sites B and C) at Gene Howe Wildlife Mangament Area on October 5, 2015 from left to right are Western Mosquitofish, Red Shiner, Sand Shiner, and Bluegill.

Species collected during this bioassessment were similar to a fish species list for GHWMA developed by WTAMU. Professors and students have documented fish collected at GHWMA since 2007 (Dr. Kazmaier, WTAMU, personal communication). Collections by WTAMU were made using a variety of gear types including modified fyke nets, hoop nets, minnow traps, and seines.

The most recent collections by the university occured in 2014 and over an 8-year period, researchers documented 17 species of fish (Table 4). When compared to WTAMU's collections, this 2015 assessment added three species for GHWMA (Gizzard Shad *Dorosoma cepedianum*, Red Shiner, and Suckermouth Minnow *Phenacobius mirabilis*), but failed to collect four species previously documented by WTAMU (Yellow Bullhead *Ameiurus natalis*, Black Bullhead *Ameiurus melas*, Red River Pupfish, and Orangespotted Sunfish *Lepomis humilis*). Sampling methodology, sampling frequency, and gear type may account for these differences. WTAMU used a wider variety of gear types and focused primarily on the oxbow lakes, while this study employed only two gear types and concentrated more effort on the mainstem Canandian River. Overall, both studies contribute to a fish species richness of 20 for GHWMA.

The Canadian River at GHWMA received an exceptional aquatic life use score based upon data collected during the October 5, 2015 sampling event using the regionalized Index of Biotic Integrity (IBI) (Table 5). This reach of river received the highest possible metric score of five for species richness, number of native cyprinid species, number of sunfish species, percent of invertivore individuals and omnivore individuals, percent of non-native individuals, and percent of diseased or anomalous individuals. Only one metric received less than a perfect score: number of individuals per seine haul.

TABLE 5.—Regionalized Index of Biotic Integrity results for fish collected from the Canadian River at Gene Howe Wildlife Management Area on October 5, 2015 in Hemphill County, TX.

Canadian River @ Gene Howe WMA, Hemphill Co.					
Collector: Mayes, Aziz, Casarez, et. al.			**October-15**	**Ecoregions 25 & 26**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	6500			
Species Richness and Composition	Number of Fish Species	12	Number of Fish Species	12	5
	Number of Native Cyprinid Species	4	Number of Native Cyprinid Species	4	5
	Number of Benthic Invertivore Species	0	Number of Sunfish Species	4	5
	Number of Sunfish Species	4	% of Individuals as Omnivores	0.3	5
	Number of Intolerant Species	0	% of Individuals as Invertivores	91.3	5
Trophic Composition	Number of Individuals as Omnivores	1	Number of Individuals/seine haul	22.1	3
	Number of Individuals as Invertivores	303	% of Individuals as Non-native Species	0.3	5
Fish Abundance and Condition	Number of Individuals (Seine)	332	% of Individuals With Disease/Anomaly	0.0	5
	Number of Individuals in Sample	332			
	# of Individuals as Non-native species	1			
	# of Individuals With Disease/Anomaly	0			
			Index of Biotic Integrity Numeric Score:		**38**
			Index of Biotic Integrity Classification:		**Exceptional**

It should be noted, the Canadian River Basin is much larger than any of the stream watersheds that were used to develop the IBI criteria for this ecoregion. Linam et al. (2002) used primarily minimally-impacted tributary streams with relatively small watershed areas as reference streams; watershed areas ranged from 174 to 2,124 km^2 for streams in these ecoregions. Wolf Creek, a tributary of the North Canadian River, had the largest area and was the only reference stream in the Canadian River Basin. The entire watershed area of the Canadian River upstream of GHWMA is over 47,000 km^2; however, for the purpose of calculating the IBI a basin size of 6,500 km^2 was used which is the watershed area between Lake Meredith and GHWMA. Since releases from Lake Meredith are highly regulated and have been minimal in recent years, it in essence resets the watershed size for the purpose of calculating an IBI therefore, the smaller area was used.

The IBI is primarily designed to evaluate the fish assemblage in relation to water quality impacts, and although the IBI indicates water quality is suitable, other issues appear to be negatively affecting the fish assemblage. Data collected during this study noted significant species absences from the Canadian River below Lake Meredith. In particular, several species classified as fluvial specialist have been absent from this and past collections by other researchers downstream of Lake Meredith. These species include Peppered Chub, Arkansas River Shiner, Plains Minnow *Hybognathus placitus*, and Flathead Chub *Platygobio gracilis*.

Additional Canadian River Fish Collection Sites (Sites 1, 2, 4, and 7)

Methods: In addition to the Canadian River sampling at GHWMA on October 5, 2015 (Site A), fish were collected from four additional sites (Sites 1, 2, 4, and 7) on the Canadian River on October 4, 2015 (Figure 1; Table 1; Figure 5). The purpose of this additional effort was to update fish data by revisiting sites sampled by TPWD 20 years prior in September 1995 to assess the status of SGCN species. Methods for fish collections included a minimum of 10 seine hauls in a representative sample of available mesohabitats at each site. If a new species was collected on the last seine haul, additional hauls were conducted until no new species were collected.

All fish collected were identified, recorded, and released or taken back to the laboratory for processing. All retained fish were preserved in buffered 10% formalin, verified in the lab, and are permanently housed at the Biodiversity Collections at the University of Texas in Austin. Tissues were also taken from many specimens and are held in their Genetic Resources Collection. All records will be made available through the online Fishes of Texas database (Hendrickson and Cohen 2015) as well as via major online biodiversity data providers (GBIF – www.gbif.org, VertNet – www.vertnet.org, and FishNet2 – www.fishnet2.net). Photo vouchers of species collected can be viewed online at the Fishes of Texas Project page on iNaturalist (http://www.inaturalist.org/projects/fishes-of-texas).

Temporal and longitudinal patterns in fish assemblages were analyzed using PRIMER v.7 statistical software (Clarke and Gorley 2015). Differences in assemblage structure were tested for significance using the analysis of similarity (ANOSIM) test and the primary species contributing to assemblage differences were identified using the similarity of percentages (SIMPER) method. Non-metric multidimensional scaling analysis was run using Primer statistical software on all Canadian River fish samples collected during this study and the matching sites sampled in 1995 by TPWD to analyze temporal and longitudinal shifts in the fish assemblage.

Results and Discussion: A total of 951 individuals representing five families and 15 species were collected across the four additional sites on the Canadian River on October 4, 2015 (Table 6), bringing the total species richness for the Canadian River across five sites during this study to 18. In comparison 27 species were reported by Bonner and Wilde (2000) from 1954-1996. Similar to GHWMA collections, the most dominant fishes across Canadian River sites were Red Shiner and Western Mosquitofish *Gambusia affinis*, both of which are generalist species, capable of surviving and reproducing in a variety of habitats (Matthews and Hill 1980; Pflieger 1997).

TABLE 6.—Abundance of fish collected by species by site from the Canadian River on in September 1995 and October 2015, in Oldham, Potter, Hutchinson, and Roberts counties, TX. Effort in number of seine hauls is provided below sampling year for each site and relative abundance percentages are provided in parenthesis adjacent to actual abundance throughout the table. 1995 data is unpublished Texas Parks and Wildlife Department data collected by R. Moss, R. Kleinsasser, K. Saunders, D. Bowles, J. Kraii, J. Hoy, and E. Altena.

			Site 1 *US 385*		**Site 2** *US 287*		**Site 4** *Plemmons Rd*	**Site 7** *SH 70*	
Family	**Scientific name**	**Common name**	**10/4/2015** 10 hauls	**9/12/1995** 17 hauls	**10/4/2015** 10 hauls	**9/12/1995** 16 hauls	**10/4/2015** 5 hauls	**10/4/2015** 10 hauls	**9/13/1995** 17 hauls
Cyprinidae	*Cyprinella lutrensis*	Red Shiner	198 (56.5)	11 (3.8)	108 (25.5)	217 (34.3)	18 (23.0)	59 (59)	246 (54.8)
	Cyprinus carpio	Common Carp	2 (0.6)	1 (0.4)					1 (0.2)
	Hybognathus placitus	Plains Minnow	33 (9.4)	43 (14.8)	9 (2.1)	94 (14.8)			
	*Macrhybopsis tetranema**	Peppered Chub	23 (6.6)	44 (15.1)	3 (0.7)	109 (17.2)			
	Notropis atherinoides	Emerald Shiner							3 (0.7)
	Notropis girardi	Arkansas River Shiner	15 (4.3)	142 (48.8)	47 (11.1)	77 (12.1)			
	Notropis stramineus	Sand Shiner			8 (1.9)		2 (2.6)	14 (14)	105 (23.4)
	Phenacobius mirabilis	Suckermouth Minnow					6 (7.7)	2 (2)	7 (1.6)
	Pimephales promelas	Fathead Minnow	8 (2.3)		8 (1.9)				5 (1.1)
	Pimephales vigilax	Bullhead Minnow				15 (2.4)			
	Platygobio gracilis	Flathead Chub		28 (9.6)		88 (13.9)			
Ictaluridae	*Ameiurus natalis*	Yellow Bullhead			1 (0.3)	1 (0.2)			
	Ictalurus punctatus	Channel Catfish	5 (1.4)	5 (1.7)		12 (1.9)			
	Pylodictus olivaris	Flathead Catfish		1 (0.3)		2 (0.3)			
Fundulidae	*Fundulus kansae***	Northern Plains Killifish	13 (3.7)	12 (4.1)	12 (2.8)	3 (0.5)			10 (2.2)
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	52 (14.9)	4 (1.4)	226 (53.4)	13 (2.1)	33 (42.3)	17 (17)	67 (14.9)
Cyprinodontidae	*Cyprinodon rubrofluviatilis*	Red River Pupfish							2 (0.4)
Centrarchidae	*Lepomis cyanellus*	Green Sunfish	1 (0.3)		1 (0.3)	2 (0.3)	17 (21.8)		
	Lepomis macrochirus	Bluegill						5 (5)	
	Micropterus salmoides	Largemouth Bass					2 (2.6)	3 (3)	3 (0.7)
	Number of species collected		**10**	**10**	**10**	**12**	**6**	**6**	**10**
	Number of individuals collected		**350**	**291**	**423**	**633**	**78**	**100**	**449**

* Formerly recognized as *Macrhybopsis australis* in the Canadian River Basin. Was identified in the 1995 TPWD surveys as such.
** Formerly recognized as *Fundulus zebrinus* in the Canadian River Basin. Was identified in the 1995 TPWD surveys as such.

Fish assemblages in the Canadian River grouped longitudinally (Figure 7), with dissimilarity occurring between sites upstream and downstream of Lake Meredith (p = 0.03). Dissimilarities are attributed to higher proportions of fluvial specialist minnow species and catfish upstream of the reservoir versus higher numbers of bass and sunfish, considered generalist species, downstream of the reservoir.

Temporally, the 1995 and 2015 collections show separation (Figure 7); however, this was not significant (p = 0.20). In 1995 collections, Plains Minnow, Arkansas River Shiner, and Peppered Chub were found to be among the most abundant species at sites upstream of Lake Meredith (Sites 1 and 2). These species consistently dropped in relative abundance when compared to the present study. Plains Minnow, which historically dominated the fish assemblage of the Canadian River (Lewis and Dalquest 1955; Bonner and Wilde 2000), has recently only been found upstream of Lake Meredith. Additionally, Flathead Chub, first reported in Texas in 1954 and common in 1995 surveys at sites upstream of Lake Meredith, was absent from all collections during this study and may be extirpated from Texas (Dr. Gene Wilde, Texas Tech University, personal communication). Additional sampling is needed temporally and spatially to substantiate fish community shifts and species extirpations.

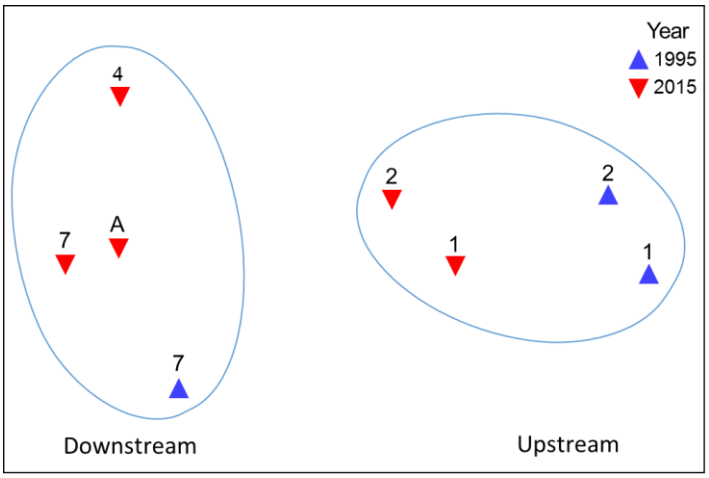

FIGURE 7.—Multidimensional scaling plot of fish assemblages for each site sampled by the Texas Parks and Wildlife Department during 1995 and 2015 on the Canadian River.

These four species are fluvial specialists, meaning that flowing water is essential to reproduction and recruitment. In particular, these minnows belong to the pelagic broadcast spawning reproductive guild. Pelagic broadcast spawning cyprinids release semi-buoyant eggs which must remain suspended and drift downstream long enough to develop into free-swimming larval fish. This prevents suffocation of eggs and settlement of larvae. High flow pulses synchronize spawning and provide sufficient flow to keep eggs suspended for successful recruitment (Durham and Wilde 2008). Due to their short life span (2-3 years), successful recruitment must occur regularly in order to maintain viable, resilient populations. Reduced flow pulses due to reservoir operations and drought have likely contributed to recent declines in populations of these species in the Canadian River and throughout their native range.

River fragment length is also a key biological factor contributing to recruitment of pelagic broadcast spawning fish species. A minimum fragment length is required to allow the semi-buoyant eggs and

larvae enough distance to transform into free-swimming fish. Perkin and Gido (2011) predicted Arkansas River Shiner require a minimum stream length of 217 km for population persistence; Peppered Chub (205 km est.); Flathead Chub (183 km); and Plains Minnow (115 km). The Canadian River length between Ute dam in New Mexico and the impounded waters of Lake Meredith is 220 km, exceeding the minimum fragment length predicted for successful recruitment. Downstream of Lake Meredith, the Canadian River flows unimpeded for 214 km, meeting the minimum fragment lengths for three of these species as predicted by Perkin and Gido and coming just short on the fourth. However, mean annual streamflow has declined by 76% (Bonner and Wilde 2000) leading to further reduction in stream connectivity during dry years. Altered hydrology due to impoundments, drought, and groundwater pumping have been implicated in the decline of many broadcast spawning minnows throughout the Great Plains (Perkin et al. 2014; Senecal et al. 2015).

Tributary Fish Collection Sites (Sites 3, 5, and 6)

Methods: On October 4, 2015, two tributaries (Dixon Creek and South Palo Duro Creek) in the Canadian River system were sampled for fishes at three locations (Figure1; Table 1). The only gear type used was one 6' x 10' 3/16 in mesh seine. Electrofishing was prohibited due to chance collection of the federally listed Arkansas River Shiner, and other gear types were not practical for the available habitat. There were few Canadian River Basin tributaries available to sample due to a paucity of public access sites and a lack of water. At sampled sites, all available mesohabitats were thoroughly seined until no new species were found. A representative subset of all collected fish for each site were preserved in a buffered 10% formalin solution and taken back to the laboratory for identification, enumeration, and archiving at the University of Texas Biodiversity Collections in Austin, Texas. Fish tissues were taken opportunistically from voucher specimens to be deposited into the university's Genetic Resources Collection. Photo vouchers were taken as well, and can be viewed online at the Fishes of Texas Project page on iNaturalist (http://www.inaturalist.org/projects/fishes-of-texas). These data will also be made available on the Fishes of Texas website (www.fishesoftexas.org) and through primary online biodiversity data providers (GBIF, VerNet, Fishnet2).

Results and Discussion: A total of 10 species were collected from tributary sites (Table 7). Collections are reported as presence/absence instead of abundance because effort was not standardized. Dixon Creek yielded the greatest species richness, with seven species at the SH 152 crossing and five species at CR V (nine species total). Only two species were found at the South Palo Duro Creek site, likely related to its location in the headwaters of the Palo Duro Creek Watershed.

Green Sunfish *Lepomis cyanellus* was collected at all three sites. Western Mosquitofish and Common Carp were collected at the two Dixon Creek locations (Figure 8). Common Carp was the most abundant species and also the only non-native found. The most represented family was Centrarchidae, producing five species. Cyprinid diversity was low in the tributaries, with three species detected. It is difficult to know if this is typical for the system, as historical records for the basin in the Texas are scarce (Hendrickson and Cohen 2015). However, Bonner and Wilde (2000) noted significant changes in assemblage, specifically for cyprinids, to the nearby reach of the Canadian River as a result of alterations in river volume and morphology since construction of Lake Meredith Dam. This in turn could have effected diversity of tributary systems downstream of Lake Meredith.

TABLE 7.—Fish species collected from Canadian tributary sites on October 4, 2015. Species presence data collected by the Texas Commission on Environmental Quality from Dixon Creek in 2002 and 2003 is included for reference.

Family	Scientific Name	Common Name	**Site 3** *S Palo Duro Creek*	**Site 5** *Dixon Creek at CR V*	**Site 6** *Dixon Creek at SH 152*	**TCEQ** *Dixon Creek 2002-03*
Cyprinidae	*Cyprinella lutrensis*	Red Shiner		X		X
	Cyprinus carpio	Common Carp		X	X	X
	Notropis stramineus	Sand Shiner				X
	Phenacobius mirabilis	Suckermouth Minnow		X		X
	Pimephales promelas	Fathead Minnow	X			X
Fundulidae	*Fundulus kansae*	Northern Plains Killifish				X
Poeciliidae	*Gambusia affinis*	Western Mosquitofish		X	X	X
Cyprinodontidae	*Cyprinodon rubrofluvatilis*	Red River Pupfish				X
Centrarchidae	*Lepomis cyanellus*	Green Sunfish	X	X	X	X
	Lepomis humilis	Orangespotted Sunfish			X	X
	Lepomis macrochirus	Bluegill			X	X
	Lepomis megalotis	Longear Sunfish			X	X
	Micropterus salmoides	Largemouth Bass			X	X
	Number of species collected		**2**	**5**	**7**	**13**

FIGURE 8.—Some of the most abundant species collected from tributaries of the Canadian River, shown from left to right are: Common Carp, Green Sunfish, Western Mosquitofish, and Largemouth Bass.

A 2002-2003 TCEQ study at Dixon Creek (unpublished; specimens were deposited with the University of Texas Biodiversity Collections and archived under TNHC Accession# 2013-08; Table 7) collected similar species to these recent collections; however, TCEQ's study also collected Sand Shiner *Notropis stramineus*. Overall, no new species were added to the basin checklist from the tributary sites, but one additional species was added to the species list for this study: Orangespotted Sunfish.

Summary of Fish Collection Data

A total of 1,484 individuals comprising 23 fish species were collected during this study. Historically (1949 – present), 33 species have been collected from the Canadian River Basin in Texas (Hendrickson and Cohen 2015; Bonner and Wilde 2000; Dr. Kazmaier, WTAMU, personal communication). Species not collected during this bioassessment include Black Bullhead, River Carpsucker *Caprodes carpio*, Red River Pupfish, Inland Silverside *Menidia beryllina*, White Bass *Morone chrysops*, Emerald Shiner *Notropis atherinoides*, Logperch *Percina caprodes*, Bullhead Minnow *Pimephales vigilax*, Flathead Chub, and White Crappie. No new species were added to the historical species list for the basin. It is important to note that this historical fish occurrence list is derived from sites on the Canadian River, tributaries, and oxbow lakes, but does not contain data from Lake Meredith which supports additional stocked species.

A total of 18 species were collected from five sites on the mainstem Canadian River (Sites A, 1, 2, 4, and 7), 12 species from oxbow lakes near the Canadian River (Sites B and C), and 10 species from all tributary sites (Sites 3, 5, and 6). Tributary sites added one additional species (Orangespotted Sunfish) and oxbow lakes added four (Gizzard Shad, Spotted Gar *Lepisosteus oculatus*, Redear Sunfish *Lepomis microlophus*, and Black Crappie) (Figure 9). Seven species, most being minnow species, were unique to the mainstem Canadian River (Yellow Bullhead, Northern Plains Killifish *Fundulus kansae*, Plains Minnow, Channel Catfish, Peppered Chub, Arkansas River Shiner, and Sand Shiner) (Figure 10).

FIGURE 9.—Representative fish species collected in the tributaries and oxbow lakes, but absent from mainstem collections shown from left to right: Orangespotted Sunfish, Spotted Gar, and Redear Sunfish.

FIGURE 10.—Representative fish species unique to the mainstem Canadian River shown from left to right: Northern Plains Killifish, Sand Shiner, Channel Catfish, and Peppered Chub.

Overall, this study documented a high percentage of species found throughout the basin historically (70%); however, the absence of some fluvial specialists which were historically present and decreased abundance of others is concerning. This likely signifies degradation of habitat, reduced linear connectivity, and a modified flow regime. The high precentage of generalist species collected during this study, such as Red Shiner and Western Mosquitofish, corroborates a likely decline in habitat quality and connectivity throughout the Canadian River in Texas.

MUSSEL ASSEMBLAGE

Methods: Mussels were surveyed for two person-hours using tactile searches in all available mesohabitat types (Strayer and Smith 2003) at Site A on the Canadian River. In addition to timed surveys at Site A, visual bank surveys were also conducted at Sites 1 and 2 on the Canadian River upstream of Lake Meredith.

Results and Discussion: No live mussels were collected, nor was any shell material observed from Site A on the Canadian River. Likewise, visual searches at Sites 1 and 2 found no live mussels or shell material. The only bivalve species detected during searches was Asian Clam *Corbicula* sp. at GHWMA.

Historically, the Canadian River Basin is known to be depauperate of freshwater mussel species with only three documented species occurring typically in low abundance (TWPD 2008). Previous surveys (Howells 1996) were also unsuccessful in finding live mussels at the same sites surveyed during this

study (Sites 1 and 2) upstream of Lake Meredith, as well as a site near GHWMA (US 83) downstream of Lake Meredith. Shifting sand substrates dominate river habitat throughout the Canadian River Basin and are not preferred by most mussel species. Several species known to occur in these types of habitats (Giant Floater *Pyganodon grandis*, Paper Pondshell *Utterbackia imbecillis*, and Yellow Sandshell *Lampsilis teres*) were historically documented in the basin (TPWD 2008); however, a lack of shell material during this survey suggests these species have not occurred at study sites for many years, if ever.

BENTHIC MACROINVERTEBRATE ASSEMBLAGE

Methods: Aquatic macroinvertebrates were collected from the Canadian River at GHWMA (Site A) using a D-frame kick net following procedures in TCEQ's surface water quality monitoring procedures handbook (TCEQ 2014b). Riffles were not present in the study are; therefore, three samples were collected from available habitat. Due to high amounts of detritus in sampled habitats, collections were wholly preserved in 70% ethanol for sorting and identification in the laboratory. After all macroinvertebrates were identified and enumerated, a randomly selected subsample of 175 individuals was used to calculate a Benthic Macroinvertebrate Index of Biotic Integrity (BIBI). All individuals were assigned a number and a random number generator was used to select 175 of those for the BIBI. BIBI metrics were calculated and scored to determine the aquatic life use score (TCEQ 2014b).

Results and Discussion: A total of 407 benthic macroinvertebrates comprised of 22 taxa in six orders and 17 families (Table 8) were collected and identified from the Canadian River at GHWMA (Site A). The most abundant macroinvertebrate taxa were caddisflies (Order: Trichoptera, 30% relative abundance) and dragonflies/damselflies (Order: Odonata, 28%). Odonata also had the highest richness, with six genera represented.

The BIBI calculated from the subsample resulted in a score of 32. This puts the benthic macroinvertebrate community at this site in the aquatic life use category of high (Table 9). This assemblage scored highest in three categories with a score of 4 out of 4: percent dominant functional feeding group, percent collector gatherers, and percent Elmidae. Two metrics received the lowest score of 1: percent Trichoptera as Hydropsychidae and number of non-insect taxa. The BIBI score of high corroborates the fish IBI score finding that water quality is not impacting the aquatic community at GHWMA.

TABLE 8. — Macroinvertebrates with their associated abundances and trophic guilds collected from the Canadian River at Gene Howe Wildlife Management Area, October 5, 2015. Trophic guilds are abbreviated: collector gatherer (CG), filtering collector (FC), predator (P), scraper (SCR), and shredder (SHR). Life stages are abbreviated as: adult (A) and larval (L).

Order	Family	Genus	Stage	Trophic Guild	Total
Amphipoda	Taltridae	*Hyalella*		CG/SHR	9
Coleoptera	Dytiscidae	*Coptotomus*	A	P	1
	Elmidae	*Microcylloepus*	L	SCR/CG	2
		Stenelmis	L	SCR/CG	21
	Hydrochidae	*Hydrophilus*	L	P	1
	Hydrophilidae	*Berosus*	A	CG	2
			L	P	3
Diptera	Chironomidae			P/CG/FC	46
	Ephydridae			P	1
	Simuliidae			FC	2
Ephemeroptera	Baetidae	*Fallceon*		SCR/CG	40
		Paracloeodes		SCR/CG	3
		Pseudocloeon		SCR/CG	7
	Oligoneuriidae	*Isonychia*		FC	17
	Tricorythidae	*Tricorythodes*		CG	14
Odonata	Calopterygidae	*Hetaerina*		P	15
	Coenagrionidae	*Argia*		P	7
	Gomphidae	*Arigomphus*		P	3
		Erpetogomphus		P	74
		Progomphus		P	13
	Macromiidae	*Macromia*		P	2
Trichoptera	Hydropsychidae	*Hydropsyche*		FC	113
	Leptoceridae	*Nectopsyche*		SHR/CG/P	11
Number of taxa collected					**22**
Number of individuals collected					**407**

TABLE 9. — Metrics and scoring criteria for kick samples collected using the rapid bioassessment protocol for benthic macroinvertebrates at Canadian River at Gene Howe Wildlife Management Area, October 5, 2015.

Metric	Total	*Score
Taxa Richness	22	4
EPT Taxa Abundance	7	3
Biotic Index (HBI)	4.29	3
% Chironomidae	12	2
% Dominant Taxon	25.71	3
% Dominant FFG	35.43	4
% Predators	35.43	2
Intolerant: Tolerant Taxa	2.80	2
% Trichoptera as Hydropsychidae	93.75	1
# Non-Insect Taxa	1.00	1
% Collector Gatherers	18.86	4
% Elmidae	6.29	4
Total Score		**33**
Aquatic Life Use		**High**

** Metrics are scored from low to high quality on a scale of 1-4.*

CRAYFISH

Methods: No dedicated crayfish sampling took place during this study; however, as crayfish are an understudied taxa in Texas we documented species encountered. All crayfish captured while seining were photo-vouchered for species identification. Photo vouchers and locality information were placed on the website iNaturalist (http://www.inaturalist.org/) for species verification. We thank Dan Johnson for his immense help in identifying crayfish collected during this study.

Results and Discussion: One species of crayfish was collected during this study, Southern Plains Crayfish *Procambarus simulans* (Figure 11). The Southern Plains Crayfish was collected from the Canadian River at Site 4 and Dixon Creek at Site 5. This species is considered stable in Texas and facing no current threats; however, it is cited as needing more research to verify this (Crandall 2010).

FIGURE 11.—Lateral and dorsal views of the Southern Plains Crayfish, collected from the Canadian River and Dixon Creek on October 4, 2015.

RIPARIAN ASSEMBLAGE

Methods: A qualitative visual assessment of the Canadian River riparian area was conducted within the study reach at GHWMA on October 5, 2015 to obtain a basic understanding of the overall functioning condition of the riparian area and dominant and non-native species.

Results and Discussion: A review of the Texas Ecosystem Analytical Mapper Project (TEAM) database identified the following riparian vegetative community types as being present within and surrounding the GHWMA: High Plains- Floodplain Deciduous Forest, High Plains- Riparian Herbaceous Vegetation, High Plains- Riparian Hardwood Forest, High Plains- Riparian Deciduous Shrubland, and High Plains- Floodplain Hardwood-Juniper Forest (TPWD 2017). Descriptions of these vegetative community types can be found on the TEAM webpage (http://tpwd.texas.gov/gis/team/). Plants identified during this assessment are consistent with the plants listed within these community types, to include: Russian olive *Elaeagnus angustifolia*, netleaf hackberry *Celtis reticulata*, saltcedar, buttonbush *Cephalanthus occidentalis*, spikerush *Eleocharis* sp., bermuda grass *Cynodon dactylon*, three square bulrush *Schoenoplectus pungens*, creeping primrose willow *Ludwegia repens*, pluchea *Pluchea* sp., cocklebur *Xanthium* sp., nutsedge *Cyperus esculentus*, and common reed *Phragmites* sp.

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 1800’s 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, which can out-compete and displace native vegetation. Invasive saltcedar may now be the dominant species within the High Plains- Floodplain Deciduous Forest and the High Plains- Riparian Hardwood Forest ecosystem types, and may be a significant component of the High Plains- Floodplain Hardwood-Juniper Forest riparian vegetative community type.

A new plant invading the Canadian River riparian corridor was documented during the bioassessment, ravenna grass *Saccharum ravannae*. Singhurst et al. 2010 recommended the occurrence of this species be monitored in Texas to determine if it will become a permanent part of the state's flora and possibly a serious invasive species. Because root structure is such an important component to erosion prevention and control in riparian systems, it is recommended that any control of invasive species be carefully thought out and done in incremental, rather than large scale stages. Invasive species control plans should be comprehensive and incorporate a long range strategy and monitoring component.

STREAM HEALTH

Methods: To obtain a snapshot of riparian habitat and overall stream condition, a modified Stream Visual Assessment Protocol (SVAP2) (TPWD 2015) was conducted at GHWMA on October 5, 2015 (Table 10). The modified SVAP2 is based on the SVAP protocol created by the Natural Resources Conservation Service (NRCS 1998), but includes updates to make it more relevant to Texas streams. This protocol allows for a basic level of ecological assessment to qualitatively evaluate the condition of aquatic ecosystems associated with wadeable streams. The modified SVAP2 utilizes scores from thirteen major scoring elements including: channel condition, hydrologic alteration, bank stability, riparian area quantity, riparian area quality, water appearance, nutrient enrichment, barriers to aquatic species movement, stream habitat complexity, pools, aquatic invertebrate community, riffle embeddedness, and salinity. After scoring each element, scores are summed and divided by the number of elements to provide an overall SVAP2 score. Scores are graded as follows: 1-2.9 = Severely Degraded, 3-4.9 = Poor, 5 to 6.9 = Fair, 7 to 8.9 = Good, 9 to 10 = Excellent. It is important to note these scores are based on characteristics of a particular stream reach and are not making a statement on the health of the entire stream. The utility in this protocol is that a discrete stream reach can be monitored over time to determine if the general health of the ecosystem is improving, declining, or maintaining.

Results and Discussion: Overall stream health rated as "Good" (SVAP2 Score=7.8, Table 10). This value can be used as a general statement about the state of the stream environment at GHWMA, meaning that the Canadian River is functioning well at this site as shown by the overall score. The two lowest element scores within the SVAP2 assessment were hydrologic alteration and riparian area quality. While it is not possible for GHWMA to implement changes to improve the hydrologic alteration score, GHWMA may be able to maintain or improve the riparian area quality score. The score of a 5 on this element was directly related to the presence of invasive species being common (>20% but <50% cover).

TABLE 10.—Element scores from the Stream Visual Assessment Protocol (SVAP2) conducted at the Gene Howe Wildlife Management Area on October 5, 2015. Element scores are rated from 1 (severely degraded) to 10 (excellent). The average of the element scores is listed as the stream health score.

Element	Score
Channel Condition	8
Hydrologic Alteration	5.5
Bank Stability	8.5
Riparian Area Quantity	7.5
Riparian Area Quality	5
Water Appearance	9
Nutrient Enrichment	8
Barriers to Movement	10
Stream Habitat Complexity	10
Pools	n/a
Aquatic Invertebrate Community	8
Riffle Embeddedness	n/a
Salinity	6
Stream Health Score	**7.8**

Monitoring and possible control of invasive plant species could potentially be implemented by GHWMA staff if it fits into their overall land management objectives; however, if control is decided upon, it should be done as part of a comprehensive, long range management plan conducted in incremental phases. Riparian areas are sensitive environments that require special management considerations due to their value in erosion control, sediment buffering, shade potential (temperature buffering), cover, and food supply. Any plans to eradicate or control invasive vegetation would need to be carefully thought out and monitored to ensure these functions are not diminished.

IMPERILED SPECIES

Two SGCN fishes were collected during this study: Peppered Chub (NatureServe Global Conservation Status: G1-critically imperiled; NatureServe 2015) and Arkansas River Shiner (G2-imperiled) (Figure 12). Both species were only collected from sites upstream of Lake Meredith. Historically Peppered Chub occurred throughout the Upper Arkansas River Basin in Colorado, Kansas, New Mexico, Oklahoma, and Texas; however, this species has been extirpated from approximately 90 percent of its historic range and is now restricted to portions of the Canadian River Basin in Texas and New Mexico and the Ninnescah River in Kansas (NatureServe 2015). Reduced streamflow, both from drought and anthropogenic impacts, and instream barriers are listed as threats to Peppered Chub populations (NatureServe 2015). This study found reduced numbers from the previous TPWD study in 1995. Individuals collected ranged in total length from 34-66 mm (Figure 13). Based on previous length-frequency analysis, this range suggests the presence of two to three age classes (Bonner and Wilde 2000).

The Arkansas River Shiner is listed as federally and state threatened in Texas. This species was originally abundantly found throughout portions of the Arkansas River Basin in New Mexico, Texas, Oklahoma, and Kansas; however, it has been extirpated throughout portions of its range in each of those states (NatureServe 2015). Threats facing the Arkansas River Shiner are similar to those listed above for the Peppered Chub, with impacts from reservoir construction listed as one of the most detrimental (NatureServe 2015). Individuals collected ranged in total length from 20-54 mm (Figure 13).

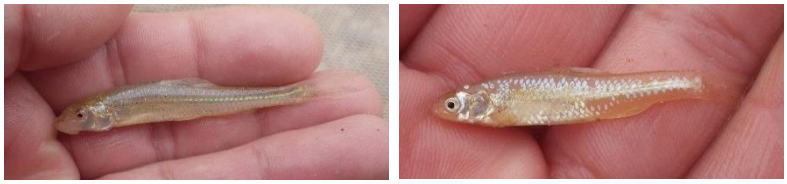

FIGURE 12.—Photos of imperiled species collected during this study: Peppered Chub from Site 1 on the Canadian River (left) and Arkansas River Shiner collected from Site 2 on the Canadian River (right).

One other SGCN fish species is reported in historical fish collections of the Canadian River Basin in Texas, but was not collected during this study: Red River Pupfish (G5- secure). Historical collections show Red River Pupfish from several locations in the basin, including collections in 1972 and 1987 at Site 7 on the Canadian River from this study (Hendrickson and Cohen 2015). It should be noted that populations of this species in the Canadian River Basin are thought to be introduced (Page and Burr 2011).

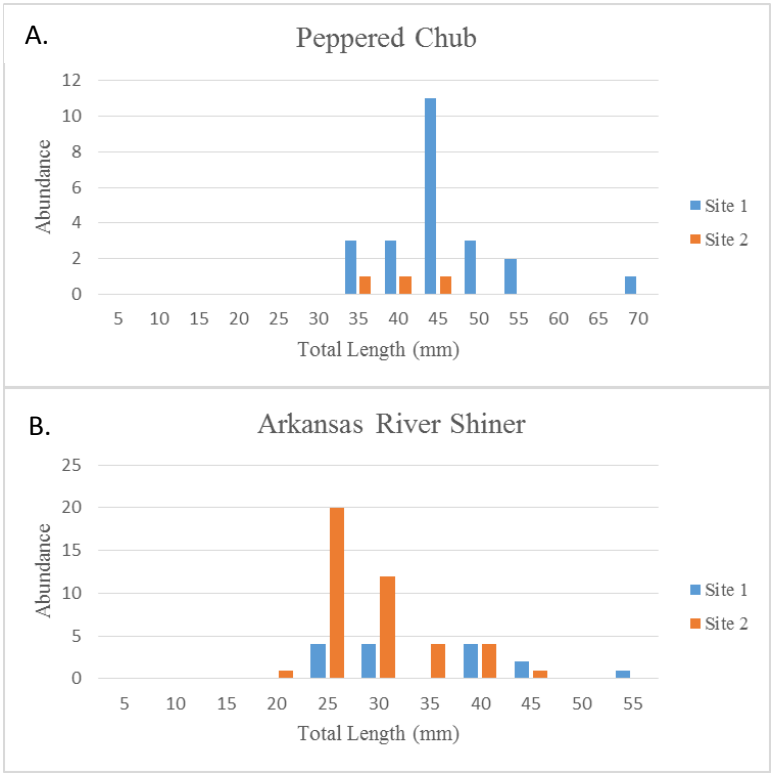

FIGURE 13.— Length frequency histogram of A. Peppered Chub and B. Arkansas River Shiner collected from two sites on the Canadian River upstream of Lake Meredith in Texas on October 4, 2015. Location of sites 1 and 2 are identified in Table 1.

RECREATIONAL ACCESS

The Canadian River in Texas is primarily bordered by privately-owned ranch lands; however, public access is available at several locations along the river for bank fishing and wade fishing. Except under high-flow conditions, the river does not provide suitable depths for kayaking or boating and thus has no public boat ramps or established paddling trails. The majority of access points on the Canadian River in Texas occur at road crossings. Access information is provided in Figure 14 and Table 11. In addition to road crossings, additional public access is available through the Lake Meredith National Recreation Area (NRA; Figure 14; Table 11). The GHWMA (Figure 14; Table 11), provides public access to approximately 1.13 km of Canadian River frontage and several oxbow lakes for fishing and wildlife viewing. All of these sites provide some bank fishing opportunities and two provide camping access. Several locations that provide access to the river were omitted as they were deemed unsuitable for public access: Plemmons Rd. provided minimal river access due to fencing and SH 136 was dry at the time of this study.

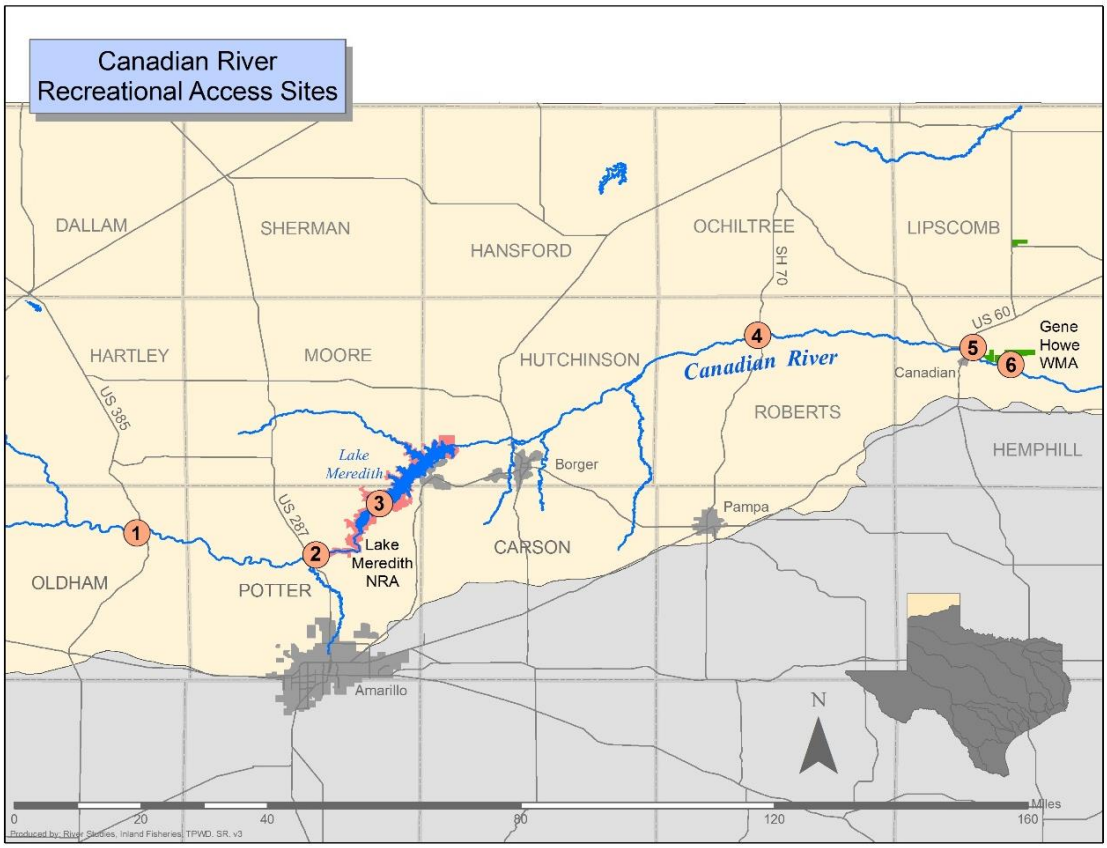

FIGURE 14.—Canadian River public recreational access locations in Texas. See Table 11 for site information.

TABLE 11.—List of Canadian River public access locations in Texas. See Figure 14 for locations.

Site Name	Location	Fee Charged	Use	Controlling Authority	Comments
1. US 385	35.51837, -102.27420	free	bank fishing	Texas Department of Transportation (TXDOT)	
2. US 287	35.46830, -101.86420	free	bank fishing	TXDOT	
3. Lake Meredith National Recreation Area	36.00613, -101.46271	fees have been suspended until 2018; call afterwards	bank fishing, boating, kayaking, camping	National Park Service	access to Lake Meredith and the Canadian River up and downstream
4. SH 70	35.96931, -100.85580	free	bank fishing	TXDOT	streamflow and sport fish habitat was minimal during this study
5. SH 60	35.74741, -101.34718	free	bank fishing	TXDOT	
6. Gene Howe Wildlife Management Area	35.90237, -100.27740	$12/year*	bank fishing, primitive camping	Texas Parks & Wildlife Department	

* Permits must be purchased prior to visit at a TPWD license retailer. Those aged 16 and under are free with a permitted adult.

SPORT FISHING OPPORTUNITIES

Two species of sport fish were collected from GHWMA: Largemouth Bass and Black Crappie (Figure 15). While only one Black Crappie was collected, Largemouth Bass were found at all three sites at GHWMA, with the highest abundances occurring in the river (Table 4). None of the Largemouth Bass collected were of harvestable size; however, no targeted sport fish sampling occurred during this study. In addition to these two species, five species of sunfish were collected at GHWMA that offer additional angling opportunities. In particular, high numbers of Bluegill were collected across all sampled sites at GHWMA and was the most abundant species collected from both of the oxbow sites (Sites B and C).

FIGURE 15.— Fish species that offer angling opportunities within Gene Howe Wildlife Management Area include from left to right: Largemouth Bass, Warmouth, Bluegill, and Green Sunfish.

Largemouth Bass were also collected from Sites 4 and 7 on the Canadian River; however, none were collected from sites upstream of Lake Meredith (Table 6). Low catch rates and sizes of sport fish species make most of the Canadian River less than desirable for fishing. This is most likely due to the nature of prairie streams which typically lack deep water habitats and instream cover. Based on data collected during this study, it appears that of the public access sites within the basin, Lake Meredith NRA and GHWMA are the most suitable for fishing.

SUMMARY AND RECOMMENDATIONS

Canadian River Basin

Fish assemblage sampling occurred at five sites on the Canadian River, three tributary sites, and two oxbow lakes. Overall, 23 species of fish were collected from 10 sites throughout the watershed, including those sites at GHWMA. These collections included two SGCN fish species (Peppered Chub and Arkansas River Shiner). The third SGCN fish, Red River Pupfish, was not collected. One non-native fish species was collected from several locations throughout the basin: Common Carp.

There are notable differences between this study and TPWD's 1995 collections at the same sites, including a decline in fluvial specialists and imperiled species upstream of Lake Meredith, and an absence of four broadcast spawning minnows downstream of Lake Meredith. Also noted was an overall increase in relative abundance of Red Shiner originally documented by Bonner and Wilde (2000). More intensive collection efforts, especially downstream of Lake Meredith, are needed to evaluate if Arkansas River Shiner, Peppered Chub, Flathead Chub, and Plains Minnow have actually been extirpated from this portion of river.

There are several Canadian River public access locations throughout the panhandle of Texas including public road crossings, Lake Meredith NRA, and GHWMA; however, low flows that prohibit paddling and limit deep water habitats constrain recreational activities. The area most suitable for kayak and boat fishing in the basin is Lake Meredith NRA. Alternatively, GHWMA provides bank fishing access on both the Canadian River and various oxbow lakes.

Gene Howe Wildlife Management Area

Sixteen species of fish, no freshwater mussels, 22 aquatic macroinvertebrate taxa, and 12 riparian plant taxa were documented. The study site on the Canadian River at GHWMA received an exceptional aquatic life use score for the fish community based on the regionalized IBI. While no fish species collected from GHWMA were classified as SGCN, several species of interest were collected including several that present some angling opportunity including Largemouth Bass and sunfish species.

Overall, stream health was categorized by the SVAP2 as good for the study reach on the Canadian River at GHWMA. In particular, this reach of river scored high due to the lack of instream barriers to movement of aquatic species, high stream complexity, and good water appearance. Water quality data collected from the Canadian River at GHWMA met established water quality standards for point measurements. Exceptional and high ratings from the fish and invertebrate IBIs, respectively, support that water quality is not impairing aquatic communities at this site. Metrics that ranked lowest for this reach of river were riparian area quality due to a high percentage of non-native species and hydrologic alteration due to large-scale effects from Lake Meredith and smaller-scale alterations due to the presence of those non-native riparian species.

Recommendations

While the riparian area was mostly intact throughout GHWMA, the presence of known disruptive invasive species such as saltcedar is concerning. Saltcedar is known to use large amounts of water and form dense monocultures which impact stream geomorphology and hydrology (TPWD 2016f). Due to the hardy nature of saltcedar and ease of propagation, any removal plan must be considered long-term and include a robust monitoring effort. Currently, GHWMA employs chemical and mechanical means to control saltcedar and Russian olive (Chip Ruthven, TPWD, personal communication). While not introduced at GHWMA, the salt cedar leaf beetle (Diorhabda spp.) has been released at several locations in the Texas panhandle and defoliation as a result of this biological control was extensive in 2012 and 2013 including some activity at GHWMA; however, since that time beetle activity has diminished (Chip Ruthven, TPWD, personal communication). While no dense monocultures of saltcedar or Russian olive were observed along the river, the presence of numerous saltcedar seedlings on sand bars bordering the river were noted. The TPWD Invasive Species Program is a good resource for consultation on removal methods and potential funding avenues to aid these efforts.

The Canadian River Basin in Texas has several well-used recreational sites open to the public. Low flows and the braided, meandering nature of this sandy stream make it largely unsuitable for a paddling trail. Given the paucity of sport fish species encountered, leasing of additional access for angling is unwarranted.

River fragmentation, hydrologic alteration, drought, habitat degradation, and an increasing abundance of native and non-native invaders all continue to pose threats to this and other Great Plains river ecosystems. Increasing salinity in the basin due to saltcedar and low water availability has already contributed to fish kills attributed to golden algal blooms in Lake Meredith. Further encroachment of saltcedar and limited water availability increase the likelihood of similar kills occurring on the Canadian River.

This study supports previous collections and professional opinion, that SGCN fluvial specialist fish species (Arkansas River Shiner, Flathead Chub, Plains Minnow, and Peppered Chub) are less abundant than previously documented in the Canadian River in Texas, particularly downstream of Lake Meredith where none were collected during this study. It is recommended that monitoring efforts continue in the basin with an effort to expand fish assemblage sampling to additional sites. It is also recommended that research regarding habitat and spawning needs of these species continue. This work coupled with a longitudinal connectivity assessment would help prioritize stream habitat improvements in the basin. Lastly, it is recommended that opportunities to enhance longitudinal connectivity, restore a natural flow regime, and manage aquatic and riparian invasive species be sought and promoted throughout the basin.

LITERATURE CITED

Atekwana, E.A., R.S. Roew, E. Atekwana, D.D. Werkema, Jr., and F.D. Legall. 2004. The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon. Journal of Applied Geophysics 56:281–294.

Bonner, T.H., and G.R. Wilde. 2000. Changes in the Canadian River fish assemblage associated with reservoir construction. Journal of Freshwater Ecology 15: 189-198.

Clarke, K.R., and R.N. Gorley. 2015. PRIMER v7: user manual/tutorial. PRIMER-E. Plymouth. 296 pp.

Crandall, K.A. 2010. *Procambarus simulans*. The IUCN red list of threatened species 2010. Available: http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153927A4564924.en. (November 2016).

Durham, B.W., and G.R. Wilde. 2005. Relationship between hatch date and first-summer growth of five species of prairie stream cyprinids. Environmental Biology of Fishes 72: 45-54.

Durham, B.W., and G.R. Wilde. 2006. Influence of stream discharge on reproductive success of a prairie stream fish assemblage. Transactions of the American Fisheries Society 135: 1644-1653.

Durham, B.W., and G.R. Wilde. 2008. Composition and abundance of drifting fish larvae in the Canadian River, Texas. Journal of Freshwater Ecology 23: 273-280.

Giggleman, C.M., M.P. Armstrong, O.R. Bocanegra, and J.M. Lewis. 2002. The impact of anthropogenic discharges on Arkansas River Shiner (*Notropis girardi*) habitat within the South Canadian River Watershed in the Texas Panhandle, Texas 2001-2002. U.S. Fish and Wildlife Service, Arlington, TX. 122 pp.

Hendrickson, D.A., and A.E. Cohen. 2015. Fishes of Texas project database (version 2.0). Available: doi: 10.17603/C3WC70. (November 2016).

Howells, R.G. 1996. Distributional surveys of freshwater bivalves in Texas: progress report for 1995. Texas Parks and Wildlife Department, Austin, TX. 45pp.

Kiniry, J.R., J.R. Williams, K.M. Schmidt, and L.D. White. 2003. Simulating water use by saltcedar with the EPIC model. Pages 69-78. Proceedings saltcedar and water resources in the west symposium, Texas Agricultural Experiment Station and Texas Cooperative Extension, San Angelo, TX.

L.W. Reed Consultants, Inc. 1995. Summary of threatened and endangered species surveys completed for the D.S.E. El Paso pipeline project. L.W. Reed Consultants, Inc., Fort Collins, CO.

Labay, B.J., and D.A. Hendrickson. 2014. Final report: conservation assessment and mapping products for GPLCC priority fish taxa. Submitted to the United States Department of Interior, Fish and Wildlife Service, Great Plains Landscape Conservation Cooperative. University of Texas, Austin, TX. Available: http://hdl.handle.net/2152/27744. December 31, 2014.

Larson, R.D., A.A. Echelle, and A.V. Zale. 1991. Life history and distribution of the Arkansas River Shiner in Oklahoma. Final Report Federal Aid Project E-8. Oklahoma Department of Wildlife Conservation, Oklahoma City, OK.

Lewis, L.D., and W.W. Dalquest. 1955. Final Report Federal Aid Project F-&-R-2. Texas Game, Fish, and Oyster Commission, Austin, TX.

Linam, G.W., L.J. Kleinsasser, and K.B. Mayes. 2002. Regionalization of the index of biotic integrity for Texas streams. River Studies Report No. 17. Texas Parks and Wildlife Department, Austin, TX. Available: http://tpwd.texas.gov/publications/pwdpubs/media/pwd_rp_t3200_1086.pdf. (March 2016).

Matthews, W.M., and L.G. Hill. 1980. Habitat partitioning in the fish community of a southwestern river. Southwestern Naturalist 25: 51-66.

NatureServe. 2015. NatureServe Explorer. An online encyclopedia of life. Version 7.1. NatureServe, Arlington, VA. Available: http://explorer.natureserve.org. (November 2016).

NPS (National Park Service). 2010. The nationwide rivers inventory. United States Department of the Interior, Washington, D.C. Available: https://www.nps.gov/ncrc/programs/rtca/nri/index.html. (March 2016).

NRCS (Natural Resources Conservation Service). 1998. Stream visual assessment protocol. NWCC-TN-99-1. West National Technology Support Center, Portland, OR.

Page, L.M., and B.M. Burr. 2011. A field guide to freshwater fishes of North American north of Mexico. Houghton Mifflin Company. Boston, MA. 663 pp.

Perkin, J.S., and K.B. Gido. 2011. Stream fragmentation thresholds for a reproductive guild of Great Plains fishes. Fisheries 36: 371-383.

Perkin, J.S., K.B. Gido, K.H. Costigan, M.D. Daniels, and E.R. Johnson. 2014. Fragmentation and drying ratchet down Great Plains stream fish diversity. Aquatic Conservation: Marine and Freshwater Ecosystems 25: 500–516.

Pflieger, W.L. 1997. The fishes of Missouri. Missouri Department of Conservation. Jefferson City, MO. 372 pp.

RRA (Red River Authority of Texas). 2016. 2016 basin highlights report: an overview of water quality throughout the Canadian and Red River basins. RRA, Wichita Falls, TX. 46 pp.

Senecal, A.C., A.W. Walters, and W.A. Hubert. 2015. Historical data reveal fish assemblage shifts in an unregulated prairie river. Ecosphere 6:287. Available: http://dx.doi.org/10.1890/ES14-00361.1

Singhurst, J.R., J.N. Mink, and W.C. Holmes. 2010. New and noteworthy plants of Texas. Phytologia. 92: 249-255. Available: https://tpwd.texas.gov/huntwild/wild/research/highlights/taxa/publications/Singhurst_etal_2010_NewNoteworthy.pdf.

Strayer, D.L., and D.R. Smith. 2003. A guide to sampling freshwater mussel populations. American Fisheries Society, Bethesda, MD.

TCEQ (Texas Commission on Environmental Quality). 2014a. 2014 Texas integrated report for the Clean Water Act sections 305(b) and 303(d). TCEQ, Austin, TX. Available at: https://www.tceq.texas.gov/waterquality/assessment/14twqi/14basinlist. (November2016).

TCEQ (Texas Commission on Environmental Quality). 2014b. Surface water quality monitoring procedures, volume 2: methods for collecting and analyzing biological assemblage and habitat data. TCEQ, Austin, TX. Available: https://www.tceq.texas.gov/publications/rg/rg-415. (March 2016).

TPWD (Texas Parks and Wildlife Department). 2008. Texas Mussel Watch: freshwater mussels of Texas distribution chart. TPWD, Austin, TX.

TPWD (Texas Parks and Wildlife Department). 2012. Texas conservation action plan: species of greatest conservation need list and rare communities lists. TPWD, Austin, TX. Available: http://www.tpwd.state.tx.us/landwater/land/tcap/sgcn.phtml. (November 2016).

TPWD (Texas Parks and Wildlife Department). 2015. Upper Frio River basin bioassessment: Dry Frio and Frio rivers in Real and Uvalde counties, Texas. TPWD, Austin, TX. Available: http://tpwd.texas.gov/publications/pwdpubs/media/pwd_rp_t3200_1809.pdf. (March 2016).

TPWD (Texas Parks and Wildlife Department). 2016a. Ecologically significant stream segments. TPWD, Austin, TX. Available at: https://tpwd.texas.gov/landwater/water/conservation/water_resources/water_quantity/sigsegs/regiona.phtml. (November 2016).

TPWD (Texas Parks and Wildlife Department). 2016b. Gene Howe WMA. TPWD, Austin, TX. Available at: http://tpwd.texas.gov/huntwild/hunt/wma/find_a_wma/list/?id=8. (November 2016).

TPWD (Texas Parks and Wildlife Department). 2016c. 2016-2017 outdoor annual. TPWD, Austin, TX.

TPWD (Texas Parks and Wildlife Department). 2016d. GoFish internal server. TPWD, Austin, TX. (March 2016).

TPWD (Texas Parks and Wildlife Department). 2016e. Fish consumption bans and advisories. Available: https://tpwd.texas.gov/regulations/outdoor-annual/fishing/general-rules-regulations/fish-consumption-bans-and-advisories. (March 2016).

TPWD (Texas Parks and Wildlife Department). 2016f. Invaders: giant reed and salt cedar. Texas Parks and Wildlife Magazine, Austin, TX. Available: http://tpwmagazine.com/archive/2016/jul/scout2_invaders/ (January 2017).

TPWD (Texas Parks and Wildlife Department). 2017. Texas Ecosystem Analytical Mapper. TPWD, Austin, TX. Available: http://tpwd.texas.gov/gis/team/. (January 2017).

TSSWCB (Texas State Soil and Water Conservation Board). 2000. Canadian River watershed brush control planning, assessment and feasibility study. TSSWCB. Temple, TX.

USDOI (United States Department of the Interior). 2005. Endangered and threatened wildlife and plants; final designation of critical habitat for the Arkansas River Basin population of the Arkansas River Shiner (*Notropis girardi*); final rule. Federal Register 70: 59808-59846. Available: https://ecos.fws.gov/docs/federal_register/fr5149.pdf. (May 2017).

USDOI (United States Department of the Interior). 2009. Endangered and threatened wildlife and plants; partial 90-day finding on a petition to list 475 species in the southwestern United States as threatened or endangered with critical habitat; proposed rule. Federal Register 74: 66866-66905. Available: https://www.gpo.gov/fdsys/pkg/FR-2009-12-16/pdf/E9-29699.pdf#page=2. (May 2017).

White, L.D., K.B. Hays, and K.M. Schmidt. 2003. Water use by saltcedar and associated vegetation along selected rivers in Texas. Pages 49-68. Proceedings saltcedar and water resources in the west symposium. Texas Agricultural Experiment Station and Texas Cooperative Extension, San Angelo, TX.

Wilde, G.R., T.H. Bonner, and P.J. Zwank. 2001. Diets of the Arkansas River Shiner and Peppered Chub in the Canadian River, New Mexico and Texas. Journal of Freshwater Ecology 16: 403-410.

4200 Smith School Road ▪ Austin, Texas 78744
www.tpwd.texas.gov