ASSESSMENT OF MUSSEL AND FISH COMMUNITIES IN A NORTHERN CHIHUAHUA DESERT STREAM WITH RECOMMENDATIONS ON BIOMONITORING

by

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DEDICATION

Dedicated to Paul Thomas Wolter and Alan Thomas Wolter, the two people who taught me everything I knew about the natural world before I made my way here. On my mind and in my heart, with every fish I catch.

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Thank you to Dr. Bonner for allowing me the opportunity to gain valuable research and field experience during my undergrad, as well as reiterating the idea that if you love what you do, you'll never work a day in your life.

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ABSTRACT

The Delaware River, located in the northern Chihuahua Desert of Texas and New Mexico, is a moderately saline tributary of the middle Pecos River and provides habitat for state-listed and federally-listed aquatic organisms. Oil and gas extraction has increased within the northern Chihuahua Desert with over 51,000 oil and gas wells drilled within and near the Delaware River basin since 2012. Purposes of this study were to document existing mussel and fish communities within the Delaware River -Texas Reach, a reach of the river poorly documented in the past because of limited access, and to develop a biomonitoring plan for future assessment of stream health within the river. Study objectives were to quantity riverine habitats, mussels, and fishes within the Delaware River across multiple sites and years and to validate the appropriateness of using regionalized Indices of Biotic Integrity (IBI) for biomonitoring. Three reaches were sampled across seasons between 2016 and 2020. Live freshwater mussels were not detected among the nine sites, but multiple long-dead valves of the Texas Hornshell *Popenaias popeii* were found. Fish communities shifted from upstream to downstream, attributed to a longitudinal specific conductance gradient with fresher water upstream and more saline water downstream. A total of 16,027 fishes was collected and 13 species were identified among 143 mesohabitats. Fish communities shifted from upstream to downstream, attributed to a longitudinal specific conductance gradient with fresher water upstream and more saline water downstream. The most abundant species was Mexican Tetra *Astyanax mexicanus* in the Spring season and *Cyprinella lutrensis* in the Summer season. Notable fishes included populations of the state-listed Headwater Catfish *Ictalurus lupus* but was hybridized with the Channel Catfish *Ictalurus punctatus,* and

Gray Redhorse *Moxostoma congestum*. Gray Redhorse was recently introduced into the Delaware River to serve as the host fish for Texas Hornshell (Bivalvia). Two regionalized IBIs metrics (i.e., Desert Ecoregion, Western High Plains and Southwestern Tablelands Plains ecoregions) were assessed on the Delaware River mainstem communities. Delaware River fish communities were more similar (mean Renkonen Similarity Indices among metrics: 43%) to the Western High Plains and Southwestern Tablelands Plains ecoregions metrics than to the Desert Ecoregion metrics (10%). Consequently, I recommend the use of the Western High Plains and Southwestern Tablelands Plains ecoregions metrics for future biomonitoring of the Delaware River.

I. ASSESSMENT OF MUSSEL AND FISH COMMUNITIES IN A NORTHERN CHIHUAHUA DESERT STREAM WITH RECOMMENDATIONS ON BIOMONITORING

Introduction

The Chihuahua Desert supports a large aquatic community of endemic microbes (Souza et al 2006), semi-aquatic vegetation (Zavala-Hurtado and Jiménez 2020), freshwater mussels (Randklev et al. 2018), and fishes (Williams et al. 1985). A common theme among occurrences of endemic forms is their association with permanent surface waters, supplied by groundwater sources with a wide range in salinity. In the northern edge of the Chihuahua Desert, the Pecos River drainage bisects fresh to saline groundwaters of various strata layers, with the most saline groundwater coming from Permian-age strata layers, as the river flows to its confluence with the Rio Grande (Houston et al. 2019). Two Pecos River tributaries (i.e., Black River in New Mexico, Delaware River in Texas and New Mexico) are the last two perennially flowing tributaries with freshwater (<3,000 µS/cm) before salinities greatly increase (8,000 - 20,000 µS/cm) in the mainstem Pecos River near Malaga Bend in New Mexico (Houston et al. 2019).

Black River (Eddy County, NM) supports a unique aquatic community of mussel and fishes. The northern most distribution of the Texas Hornshell *Popenaias popeii* is in the Black River (Randklev et al. 2018). Spring-associated fishes, more commonly found in streams originating from Trinity-Edwards groundwater, include the Gray Redhorse *Moxostoma congestum*, Roundnose Minnows *Dionda*, and Greenthroat Darter *Etheostoma lepidum* (Crowley and Sublette 1987). Groundwater from runoff from the Guadalupe Mountains is sufficient to support perennially flows and permanency of freshwater (<1800 µS/cm) in the Black River. Delaware River (Culberson County,

Texas; Eddy County, NM) historically supported Texas Hornshell (Lang 2001), currently supports a reintroduced population of Texas Hornshell (USFWS 2016), and supports a similar fish community of fishes but without the spring-associated species (Brandenburg et al. 2011). Groundwater source is Permian-age strata layers with higher salt content than the Black River. Specific conductance ranges between 2,500 and 3,500 µS/cm. However, information about the Delaware River aquatic community is limited to public lands on the lower reach of the Delaware River in New Mexico, except for the report of six species of fishes catalogued in a museum (Hendrickson and Cohen, 2015) taken from private lands on the Delaware River-Texas Reach.

Purposes of this study were to assess the aquatic community and habitats in the Delaware River-Texas Reach and to assess applicability of regionalized indices of biotic integrity (IBI, Linam et al. 2002) for biomonitoring of the Delaware River. Oil and gas extraction has increased within the northern Chihuahua Desert with over 51,000 oil and gas wells drilled within and near the Delaware River basin since 2012. Therefore, regionalized IBIs could provide an assessment of stream health into the future. Study objectives were to quantify fish and mussel communities and their habitat associations among multiple sites and dates and to evaluate two regionalized indices of biotic integrity (i.e., Southern Deserts ecoregion and Western High Plains and Southwestern Tablelands ecoregions) as potential metrics for future biomonitoring.

Methods

Study Area

Delaware River drainage originates on the eastern slope of Guadalupe Mountains (Culberson County, Texas) and terminates about 100 km downstream into the Pecos River (Eddy County, New Mexico). The Delaware River-Texas Reach were split into three additional reaches: Upper, Middle, and Lower. Surface flows are intermittent from its origin for about 40 km and range from intermittent to perennial within the Upper Reach (40 to 55 km from origin), Middle Reach (55 to 70 km), Lower Reach (70 to 85 km), and New Mexico Reach (85 to 100 km). The current Delaware River channel bisects a mix of Holocene deposits and Permian sandstones, siltstones, and limestones, most notably Bell Canyon formation within the Upper Reach, Castile Formation in the Middle Reach, Rustler Formation in the Lower Reach, and Rustler Formation and Holocene deposits in the New Mexico Reach (US Geological Survey 2015). Fresh to brackish groundwater emerges as seeps and springs within the Bell Canyon Formation (Uliana 2001, Brune 2002), Castile Formation (Brune 2002, Stafford 2013), and Rustler Formation (Boghici and Broekhoven 2001). As a condition of sampling the Delaware River-Texas reach via private property access, locations of specific sites and a map of the area cannot be shared publicly.

Field collections:

Field collections were made to quantify aquatic biota, water quality, and stream habitat characteristics in May, June, and August 2016 and in March, August, and December of 2020. Sites were selected to represent a longitudinal gradient along the perennially flowing Delaware River-Texas Reach in Culberson County, Texas. Three reaches were delineated within the basin based on stream geomorphology and gradient.

Upper Reach was located upstream from Ranch to Market (RM) 652 and consisted of sites with gently sloping gradients, well defined riffle, run, and pool geomorphic units, and substrate sizes ranging from silt to bedrock. Middle Reach was located downstream from RM 652 and also consisted of sites with gently sloping gradients, diversity of geomorphic units, and substrate sizes ranging from clay to cobble. Middle Reach generally terminated at a point where the river became a lower gradient stream. Lower Reach was within the low gradient section of the river. Riffle habitats were well defined, but runs and pools habitats were less distinct, consisting of slower current velocities, greater water depths, deeper silt substrates, and more cobble substrates.

Multiple mainstem and tributary (when available) sites were selected within each reach. In 2016 and in 2020, fishes were quantified by geomorphic units (i.e., backwater, pool, run, and riffle) and sampled with a common-sense seine (3 m x 1.8 m, mesh size: 3.2 mm) or bag seine (5 m × 1.8 m, mesh size = 3.2 mm) with single to multiple passes or used as a block seine for downstream substrate kick. Current velocity and water depth were quantified for each geomorphic unit with multiple point estimates using a Marsh-McBirney Flow-Mate Model 2000 flow meter and incremental wading rod. Percent substrate, percent large woody debris, and percent vegetation coverage were visually estimated. Water quality parameters were measured with a YSI water quality multi-probe. Measured parameters were water temperature (°C), dissolved oxygen (mg/l), specific conductance (µS/cm), and pH. Length and width of geomorphic unit or area sampled with seines were recorded. Fishes were identified to species (Hubbs et al. 2008). Vouchers were taken at each site, anesthetized with MS-222, and fixed in 10% formalin. Fishes were taken in accordance with Texas Parks and Wildlife Department Scientific

Permit Number SPR-0601-159 and Texas State University Institute of Animal Care and Use Committee Protocol 7359. Muscle tissues were taken from 29 individuals identified as Headwater Catfish based on morphological characteristics. Genetics analysis indicated that the Headwater Catfish were not pure but rather hybrids with Channel Catfish *Ictalurus punctatus* (Dijar Lutz-Carrillo, Texas Parks and Wildlife, unpublished data). Freshwater mussels were surveyed using timed searches with both visual and tactile search methods. Shallow habitats were surveyed with the aid of a mask and snorkel. In 2016, surface-supplied-air from a Brownie's Third Lung Hookah System was used to allow divers to survey deeper areas. Although surveys were focused on identifying live mussels, any shell material found was also noted.

Principal components (PCA) analysis was used to assess linear combinations of habitat characteristics and water quality at the reach scale. Mesohabitats were denoted as dummy variables, whereas the remaining quantitative data were z-transformed (Krebs 1999). Canonical correspondence analysis (CCA) was used to assess patterns in habitat associations of the Delaware River fish community.

Scoring criteria from two regionalized indices of biotic integrity (Linam et al. 2002) were evaluated for the Delaware River of Texas: Southern Deserts (Ecoregion 24) and Western High Plains and Southwestern Tablelands (Ecoregions 25 and 26). Geographically, Delaware River of Texas is in the Southern Desert Ecoregion. However, least disturbed reference sites used in developing scoring criteria for Southern Deserts included three locations (i.e., Independence Creek, Live Oak Creek, and Devils River) with a diverse fish community, including many spring-associated fishes (Craig et al. 2018), that are dependent on voluminous freshwater outflows from Trinity-Edwards

aquifers. In contrast, least disturbed references sites used in developing scoring criteria for Western High Plains and Southwestern Tablelands were located in areas without the voluminous freshwater inflows from Trinity-Edwards aquifers, and therefore, potentially reflect more similar habitat features (e.g., water permanency, water quality) with the Delaware River fish community. To assess which ecoregion scoring criteria (i.e., Southern Deserts or Western High Plains and Southwestern Tablelands) would be more appropriate for assessing the biotic integrity of the Delaware River fish community, composite fish communities (i.e., species and counts across all sampling locations) were summed from the Delaware River (mainstem only; tributaries excluded), Southern Deserts reference streams, and Western High Plains and Southwestern Tablelands reference streams. The resulting three fish communities were compared with Renkonen Similarity indices (RSI; Renkonen 1938). Comparisons were similarities among over all fish communities and similarities among the following scoring metrics: native cyprinid community, sunfish community, omnivore community, invertivore community, non-native fish community, and the tolerant fish community. The more appropriate ecoregion to use for assessing the biotic integrity in the Delaware River was determined by which of the ecoregions had greater similarities with the overall Delaware River fish community and fish community scoring metrics (e.g., native, sunfish, omnivore).

Results

Median flows were 0.10 m^3/s (range: 0 – 42.5 m^3/s) in 2016 and 0 m^3/s (range: 0 – 0.09 m^3/s) in 2020 in the Delaware River (USGS Station 08408500). In 2016, flow in the upper reach was connected at times to the middle and lower reaches of the Delaware

River in Texas. In 2020, upper reach was disconnected from the middle and lower reaches. Also during 2020, flowing water was observed year round in the middle reach, whereas flowing water was rarely observed in the lower reach, forming a series of disconnected mesohabitats.

Reaches of the Delaware River of Texas generally consisted of a single incised channel with a series of shallow and slow-moving riffle, run, and pool mesohabitats. Among mainstem reaches, the Upper Reach mainstem had the swiftest mean (± 1 SD) current velocities (0.24 ± 0.19); whereas Lower Reach mainstem had the slowest mean current velocities (0.15; ± 0.18) (Table 1). Mean (± 1 SD) depth ranged between 0.9 m (± 0.07) at the Upper Reach mainstem to 1.6 m at the Middle and Lower mainstems sites. Silt was the most dominant substrate type, ranging from 54% in the Upper Reach to 77% in the Middle Reach. Percent vegetation was similar among reaches, with emergent vegetation (i.e., *Typha*) most abundant at the Middle Reach. Among water quality variables, specific conductance differed the most across reaches with lower mean (± 1 SD) specific conductance (1,325 µS/cm ± 142) observed at the Upper Reach mainstem and greater mean specific conductance at the Middle Reach (2,793 µS/cm ± 249) and Lower Reach (2,994 µS/cm ± 712). Among tributaries, mean specific conductance was greater in Upper Reach Tributary 1 (3,690 µS/cm ± 1,744) and Middle Reach Tributary 3 (7,929 µS/cm ± 5,664) than in the mainstem reaches. However, flows from Middle Reach Tributary 3 was disconnected from the mainstem during 2020, at least at the surface.

Principal components axes I and II explained 30% of the total variation in habitat and water quality variables among reaches (Figure 1). Principal component axis I

explained 19% of total variation and represented a current velocity, substrate, and depth gradient. Strongest loadings along PCA axis I were silt (-1.8), depth (-1.5), pool mesohabitat (-1.4), gravel (1.6), riffle mesohabitat (1.83), and current velocity (1.9). Principal component axis II explained 11% of total variation and represented a vegetation, mesohabitat, and specific conductance gradient. Strongest loadings were vegetation (-2.3), run mesohabitat (-2.1), percent *Chara* (-1.7), bedrock (0.8), specific conductance (1.3), and pool mesohabitat (1.70). Among mainstem sites, Upper Reach consisted of swifter current velocities, greater number of riffle mesohabitats, and gravel substrates than Middle and Lower reaches, which consisted of more silt substrates, greater number of pool mesohabitats, and greater depths. Upper Reach Tributary 1 was deeper and with more silt than Upper Reach Mainstem. Middle Reach Tributary 2 and Tributary 3 were deeper and with more silt than Middle Reach Mainstem. Middle Reach Tributary 3 had more bedrock and greater specific conductance than Middle Reach Mainstem.

A total of 16,027 individuals among 13 species of fishes was taken from the Delaware River of Texas in 2016 and 2020 (Table 2). Two species (Common Carp *Cyprinus carpio* and Spotted Bass *Micropterus punctulatus*) are considered non-native species. Among mainstem and tributaries reaches, Red Shiner *Cyprinella lutrensis* was the most abundant (34% in relative abundance), followed by Mexican Tetra *Astyanax mexicanus* (32%), and Fathead Minnow *Pimephales promelas* (23%). Species richness among reaches ranged from 2 species in Upper Reach Tributary 1 and Middle Reach Tributary 3 to 12 species in Lower Reach. Most abundant by reach was Mexican Tetra in Upper Reach mainstem, Tributary 1, and Middle Reach Tributary 2, Red Shiner in

Middle Reach mainstem and Lower Reach, and Fathead Minnow in Middle Reach Tributary 3. Notable collections included the state-listed Headwater Catfish *Ictalurus lupus* (N = 94), taken primarily from the Middle Reach mainstem (2.4% in relative abundance) and Gray Redhorse *Moxostoma congestum* (N = 22) taken from the Lower Reach.

Canonical correspondence model explained 50% (F = 3.7; $P < 0.01$) of the spatial and temporal variation in fish community structure based on habitat and water quality characteristics among reaches (Figure 2). Variables strongly corresponding with CCA axis I were Lower Reach (bi-plot score: -0.52), emergent vegetation (-0.32), depth (-0.31), Middle Reach mainstem (-0.28), Middle Reach Tributary 3 (0.30), bedrock (0.36), Upper Reach Tributary 1 (0.37), and Upper Reach mainstem (0.66). Variables strongly corresponding with CCA axis II were percent vegetation (-0.51), percent *Chara* (-0.49), current velocity (-0.43), specific conductance (-0.67) and Middle Reach Tributary 3 (0.81). Plains Killifish *Fundulus zebrinus* and Mexican Tetra were positively associated with CCA axis I with Plains Killifish being more abundant in the more saline Middle Reach Tributary 3 and Upper Reach Tributary 1 and with Mexican Tetra being more abundant in the swifter current velocities of the Upper and Middle reaches and in Middle Reach Tributary 2. All other fishes were negatively associated with CCA axis I (i.e., reaches with greater water depths, moderate to saline waters). Fathead Minnow was more abundant species found at Middle Reach Tributary 3 and second most abundant species at the Lower Reach, strongly associated with higher specific conductance. Remaining fishes were more abundant within the Middle Reach (e.g., Headwater Catfish,

Black Bullhead *Ameiurus melas*), Lower Reach (e.g., Gray Redhorse, Bluegill *Lepomis macrochirus*), or in both reaches (e.g., Red Shiner, Green Sunfish *Lepomis cyanellus*).

Among bivalves, six shells were found, representing two species: Asian Clam *Corbicula* and Texas Hornshell. Asian Clam shells were observed at all three mainstem reaches. One dead Texas Hornshell with complete valves was observed with the Middle Reach Mainstem. An additional mussel fragment was observed at the Lower Reach mainstem. The fragment was positively not an Asian Clam shell.

Composite fish community consisted of 13 species and 16,207 individuals from the Delaware River, 32 species and 4,860 individuals from Southern Deserts reference streams, and 15 species and 1,306 individuals from the Western High Plains and Southwestern Tablelands references streams. Renkonen Similarity Index was 29 between Delaware River and Western High Plains and Southwestern Tablelands, with the greatest contributor being the high abundances of Red Shiners, and 8 between Delaware River and Southern Deserts. Among scoring metrics, mean (± 1 SE) RSI was 46 (±16.5; range: 0 – 100) between Delaware River and Western High Plains and Southwestern Tablelands ecoregions fish community and 9.8 (± 3.7; range 0.4 – 26) between Delaware River and Southern Deserts ecoregion fish community. Primary contributors to greater similarities between Delaware and Western High Plains and Southwestern Tablelands ecoregions fish community were high abundances of Red Shiners for native cyprinids community and invertivore community, high abundances for Plains Killifish and Red Shiner for the tolerant community, and high abundances of Fathead Minnows for the omnivore community.

Discussion

Prior to 2016, six species of fishes were reported in museum records taken from the Delaware River of Texas (Hendrickson and Cohen 2015). Four species of fishes (i.e., Red Shiner, Fathead Minnow, Plains Killifish, and Green Sunfish) were taken from the Upper Reach in 1968, and four species of fishes (i.e., Red Shiner, Fathead Minnow, Mexican Tetra, Headwater Catfish) were taken from the Middle Reach in 1982. In contrast, Brandenburg et al. (2011) reported 21 species of fishes taken from the New Mexico Reach of the Delaware River, downstream of the lower reach in this study, between 1947 and 2008. Among the 13 species reported within the Delaware River in Texas, 12 were previously reported in the Delaware River within the New Mexico Reach. The one exception is Gray Redhorse, which was stocked in the New Mexico Reach along with Texas Hornshell (Dan Trujillo, NMDGF, personal communication). Among the additional 9 species reported by Brandenburg et al. (2011) from the New Mexico portion of the Delaware, all are reported in the Pecos River (Hoagstrom 2003) and likely represent an established or transitory use of the Delaware River-New Mexico Reach by species more common in the Pecos River. One additional notable observation from the Brandenburg et al. (2011) report: collections of Roundnose Minnow *Dionda episcopa* occurred only in the 1940s. Roundnose Minnow and *Dionda* in general are more common in tributaries of the main stem Pecos River of New Mexico and Texas (Sublette et al. 1990, Hubbs et al. 2008). Lack of detecting Roundnose Minnow in the more suitable lower salinity springs of the Upper Reach suggest that the 1947 collection likely was not a transient from upper reach of the Delaware River but a transient from another tributary within the Pecos River.

The current Delaware River channel bisects a mix of Holocene deposits and Permian sandstones, siltstones, and limestones, most notably Bell Canyon formation within the Upper Reach, Castile Formation in the Middle Reach, Rustler Formation in the Lower Reach, and Rustler Formation and Holocene deposits in the New Mexico Reach (US Geological Survey 2015). Fresh to brackish (1,325 - 7,929 µS/cm) groundwater emerges as seeps and springs within the Bell Canyon Formation (Uliana 2001, Brune 2002), Castile Formation (Brune 2002, Stafford 2013), and Rustler Formation (Boghici and Broekhoven 2001). North of the Delaware River in the Black River (Eddy County, NM), precipitation runoff from Guadalupe Mountains is captured in alluvium strata, providing a freshwater groundwater source that supports perennial surface flows to the Black River (Hale 1955). Upper reach of the Black River is freshwater (1,725 – 1,790 µS/cm) before becoming more saline (4,560 – 7,750 µS/cm) in the lower reach (Crowley and Sublette 1987). Black River supports 34 species of fishes with 25 species found in the upper reach. Species found in the Delaware River are the same ones reported in the Black River except for Headwater Catfish (McClure-Baker et al. 2010). South of the Delaware River in Salt Creek (Culberson and Reeves counties, TX), saline groundwaters from possibly Castile Canyon and Rustler formations produce highly saline surface waters (measurements unavailable) (Brune 1980). Salt Creek supports seven species of fishes (Hendrickson and Cohen 2015, T. Bonner, unpublished data) including two species (Red Shiner and Plains Killifish) found in the Delaware River. Among the last perennially flowing tributaries of the middle Pecos River (i.e., Black River, Delaware River) and ephemerally flowing Salt Creek, Delaware River fish community represents a unique community of fishes in the middle of a fresher water stream (Black River) and a

more saline water stream (Salt Creek), reflecting a natural gradient of salinity as Pecos River watersheds departs eolian and piedmont surface geology upstream and enters Permian surface geology downstream.

Habitat needs of the Texas Hornshell include flowing water >1.3 mg/l in dissolved oxygen and <40°C, clay to cobble substrates for burrowing, and undercut banks and large boulders for high flow refugee (see USFWS Species Status Assessment, 2016, and references therein). In the Black River (NM), Texas Hornshell was found in riffles, runs, and pools, among silt to bedrock substrates, and in riverbanks (Inoue et al. 2014). Saline waters > 4 PPT (~ 7,500 µS/cm) are considered unsuitable for Texas Hornshell for extended periods of time (Hart et al. 2019). Twenty-four species of fishes are reported as host for Texas Hornshell glochidia (Levine et al. 2012), including Gray Redhorse and Red Shiner. In this study, the one dead Texas Hornshell was observed in the Middle Reach. Middle Reach consisted of flowing water habitats with mean temperature (± 1 SD) of 17.0°C (± 8.5), mean specific conductance of 2,793 µS/cm (± 249), and mean dissolved oxygen of 7.2 mg/l (± 1.5). Habitats were riffle to pool mesohabitats, silt to bedrock substrates, with substantial undercut banks (not quantified in this study), which often contained Headwater Catfish. Red Shiner was the most abundant fish (44% in relative abundance) within the Middle Reach. Habitats within the Middle Reach appear to be suitable for the Texas Hornshell, although water permanency in this reach in unknown. Based on observations in December 2020, water was flowing through the Middle Reach with a maximum current velocity of 0.30 m/s, while no flow was observed at the Lower Reach or and at the USGS Station 08408500, located in New Mexico. As such, water permanency is more likely in the Delaware River near spring outflows of the

Upper Reach and Middle Reach than in the Lower Reach, but confirmation that the Delaware River maintains a wetted perimeter during periods of extreme low flow is still needed.

Biomonitoring, using Western High Plains and Southwestern Tablelands scoring metrics of Linam et al. (2002) as suggested herein, will complement ongoing water quality monitoring (Cimarex Energy-Delaware River Water Quality Project; http://delawareriverwaterquality.com/), enabling greater ability to detect biotic and abiotic changes in the aquatic environment related to natural and anthropogenic causes. The Delaware River provides independent, therefore redundant, populations of several species of concern, improving each species population viability. Currently, the Delaware River in Texas and New Mexico supports one federally listed species (Texas Hornshell), two species listed as endangered (Gray Redhorse) or threatened (Mexican Tetra) in New Mexico, and one species listed as threatened (Headwater Catfish although introgressed with Channel Catfish) in Texas. As such, the Delaware River is consistent with many other water bodies within the Chihuahua Desert by providing a permanent water source for Rio Grande basin endemics (e.g., Mexican Tetra) and other species associated with desert ecoregions.

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Table 1. Summary of stream characteristics and water quality taken from Delaware River- Texas Reach in 2016 and 2020.

	Upper Reach		Middle Reach			Lower Reach
	Mainstem	Tributary 1	Mainstem	Tributary 2	Tributary 3	Mainstem
N of habitat sampled	17	8	57	4	13	44
Area (m^2)	1,151	287	3,593	1,943	1,977	3,889
Mesohabitats						
% run	29	38	40	50	31	36
% riffle	41		23			23
% pool	29	63	37	50	69	39
% backwater						2
Substrates						
% clay				25		2.0
% silt	54	80	77	75	57	55
% sand	7		6		9	1
% gravel	25	3	8			10
% cobble	6	6	7		2	28
% boulder	1	1	1		9	4
% bedrock	7	11	2		22	
% large woody debris	1.5		1.0	1.5		0.8
% total vegetation	31	13	41	38		31
% *Chara*	40		23	75		35
% filamentous algae	16		12			16
% detrital algae	5.9		0.9			
% emergent vegetation	2.4	13	44			12
% submergent vegetation			0.9			13
% riparian vegetation			18			
Mean (± 1 SD) Temperature (°C)	22.4 (3.1)	19.6 (5.8)	17.0 (8.5)	19.0 (0.1)	17.8 (8.5)	19.2 (8.2)
Mean (± 1 SD) Dissolved oxygen (mg/l)	9.0 (1.3)	3.4 (1.6)	7.2 (1.3)	6.4 (1.5)	7.9 (0)	7.5 (1.2)
Mean (± 1 SD) Specific conductance (µS/cm)	1,325 (142)	3,690 (1,744)	2,793 (249)	2,264 (224)	7,929 (5,664)	2,994 (712)
Median pH	8.5	7.9	7.6	7.3	7.4	7.9
Mean (± 1 SD) Current velocity (m/sec)	0.24 (0.19)	0.04 (0.06)	0.19 (0.18)	0.07 (0.08)	0	0.15 (0.18)
Mean (± 1 SD) Depth (m)	0.9 (0.7)	1.1 (0.5)	1.6 (1.2)	1.2 (0.8)	1.5 (1.3)	1.6 (1.2)

Table 2. Percent (%) relative abundance of fishes and counts of mussels taken from the Delaware River-Texas Reach in 2016 and 2020.

	Upper Reach		Middle Reach			Lower Reach
	Mainstem	Tributary 1	Mainstem	Tributary 2	Tributary 3	Mainstem
Fishes (relative abundance, %)						
Gizzard Shad *Dorosoma cepedianum*			0.2			1.7
Common Carp *Cyprinus carpio*			0.5			0.2
Red Shiner *Cyprinella lutrensis*	9.7		44			49
Fathead Minnow *Pimephales promelas*	0.7		6.2		78	31
Gray Redhorse *Moxostoma congestum*						0.3
Mexican Tetra *Astyanax mexicanus*	77	61	43	86		14
Black Bullhead *Ameiurus melas*	0.2		0.6			<0.1
Headwater Catfish *Ictalurus lupus*			2.4			0.4
Plains Killifish *Fundulus zebrinus*	12	39	0.3	<0.1	22	
Green Sunfish *Lepomis cyanellus*	1.2		2.3	14		1.8
Bluegill *Lepomis macrochirus*						1.6
Spotted Bass *Micropterus punctulatus*						<0.1
Largemouth Bass *Micropterus salmoides*			0.8			0.1
Total N	2,423	616	2,611	858	1,178	8,341
Mussel (counts)						
Texas Hornshell *Popenaias popeii*						
Live						
Dead (complete valves)			1			
Mussel Shell Fragments (not *Corbicula*)						1
Asian Clam *Corbicula* shells	1		2			1

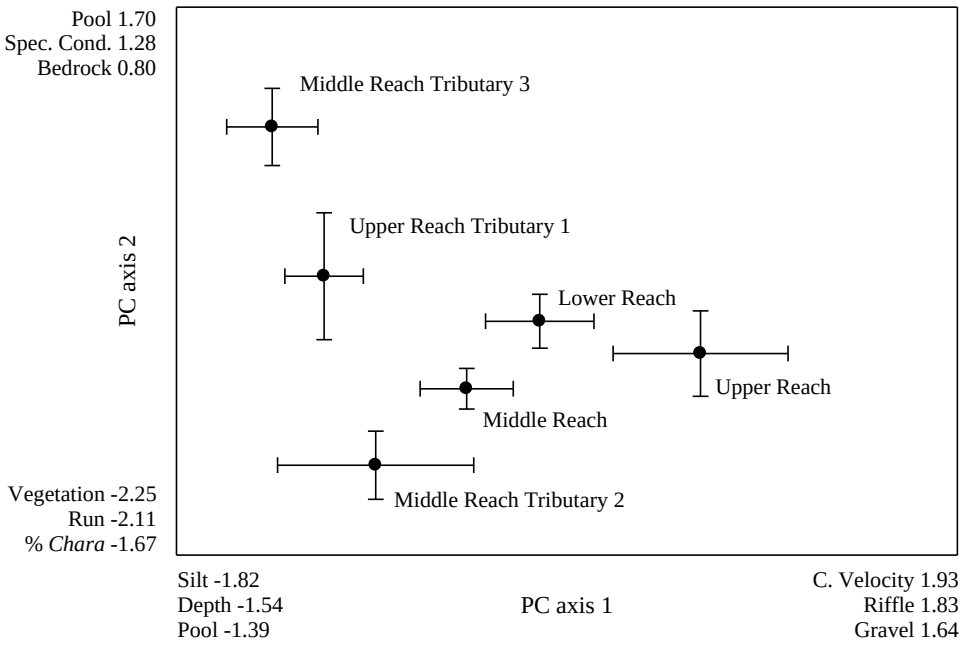

Figure 1. Principal component analysis bi-plots for water quality and habitat characteristics by reach and tributaries taken from the Delaware River-Texas Reach in 2016 and 2020. Black circle represents mean PC 1 and PC 2 score among all habitats within a reach or tributary. Error bars represent 1 SE of the mean.

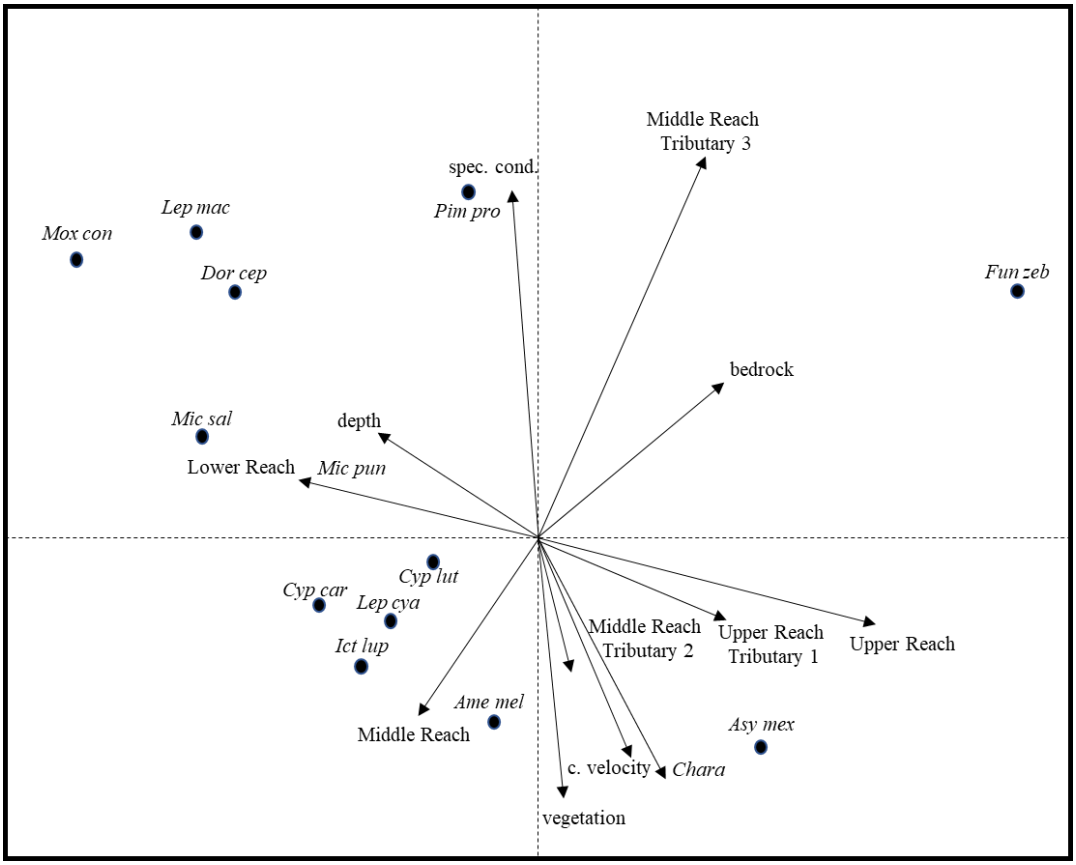

Figure 2. Canonical correspondence analysis bi-plots for fishes species and environmental variables and locations (i.e., reaches and tributaries) taken from the Delaware River-Texas Reach in 2016 and 2020. Species labels follow the first three letters of genus and species.

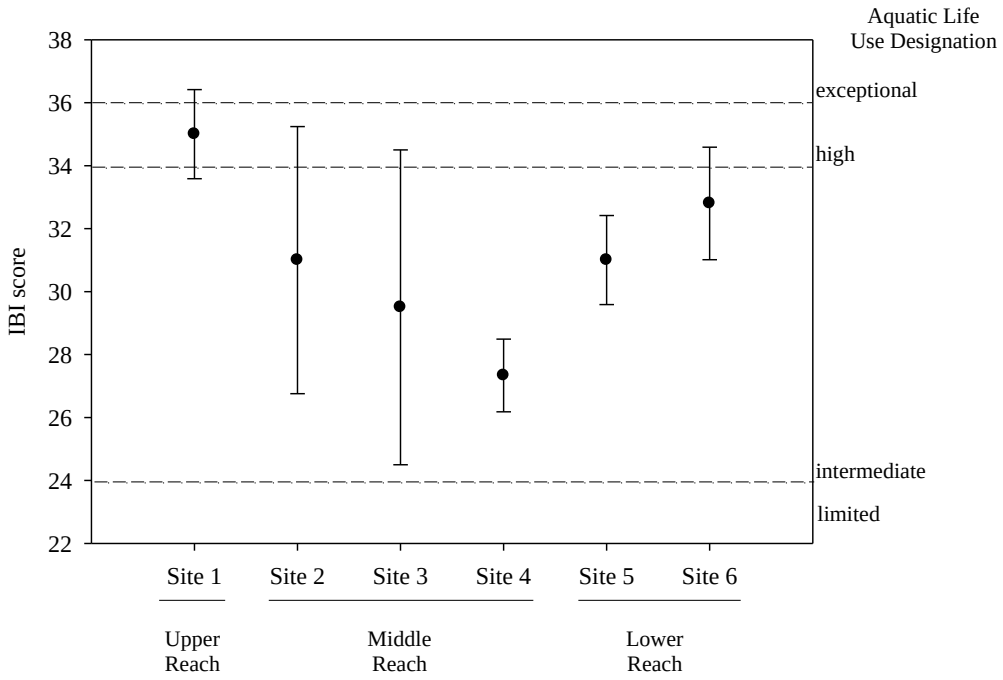

Figure 3. Mean (±1 SE) IBI scores per site within the Delaware River, 2016 – 2020. Dash lines denote Aquatic Life Use designations.