SPATIAL AND TEMPORAL PATTERNS IN A CHIHUAHUAN DESERT FISH ASSEMBLAGE

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CHAPTER I

SPATIAL AND TEMPORAL PATTERNS IN A CHIHUAHUAN DESERT FISH ASSEMBLAGE

ABSTRACT

Obligate riverine fishes in North America are decreasing in occurrence and abundance, particularly in semi-arid and arid regions of central and southwestern USA. Population declines of obligate riverine fishes frequently are associated with anthropogenic alterations of riverine environments. The purpose of this study was to quantify the relationship between riverine mesohabitats and fish occurrence and abundance in the Big Bend reach of the Rio Grande to assess possible mechanisms for obligate riverine fish's declines related to anthropogenic alterations. The Big Bend fish assemblage was sampled monthly from seven sites, collectively spanning about 200 river km of the Rio Grande. The fish assemblage differed spatially related to habitat differences among sites (CCA; $P<0.01$). Current velocity and depth were among the strongest abiotic parameters explaining fish assemblage segregation. Some obligate riverine fishes (i.e., *Rhinichthys cataractae, Macrhybopsis aestivalis*, *Notropis jemezanus,* and *Cycleptus* sp.) were strongly associated with specific riverine habitats, whereas some other riverine fishes (i.e., *Cyprinella lutrensis and Notropis braytoni*) were not. Habitat suitability estimates were calculated for juveniles and adults for abundant

fishes ($S = 4$) to further delineate current velocity and depth associations. The fish assemblage also differed temporally (ANOSIM; $P<0.01$) between wet and dry season seasonal changes were attributed to downstream movement of lentic-type fishes into the study area during the wet season (i.e., *Cyprinus carpio*, *Ictalurus furcatus*, *I. punctatus*, and *Menidia beryllina)*. This study demonstrated that fishes in the Big Bend reach were influenced by components of river flow (i.e., current velocity and depth) and by prior and distant alterations of the riverscape (i.e., instream reservoirs in Mexico). Information from this study can be used to estimate a flow prescription of the Big Bend reach for the maintenance and protection of the current fish assemblage. In addition, habitat estimates of these fishes, especially the imperiled or obligate riverine components of the fish assemblage, can be applied to other areas of the Rio Grande to restore fish assemblages previously impacted by anthropogenic alterations.

INTRODUCTION

Obligate riverine fishes, those dependant on lotic systems for all or part of their life history, are declining in abundance and distribution in response to alterations of natural flow regimes (Holden 1979; Winston et al. 1991; Platania and Altenbach 1998; Bonner and Wilde 2000). Alterations, such as dam construction and hydrologic diversions, modify physical, chemical, and biological components of rivers. Reductions in mean discharge and magnitude and frequency of scouring flood events affect channel morphology, sediment transport, substrates, and habitat types (Schmidt et al. 2003). Resulting water quality changes alter natural patterns in turbidity, temperature, and conductivity (Bain et al. 1988; Ligon et al. 1995; Poff et al. 1997; Richter et al. 1997;

Bunn and Athington 2002; Richter et al. 2003). These physical and chemical changes typically lead to increases in abundance of some fishes (Scott and Helfman 2001), which exacerbates the declines of obligate riverine fish abundance and distribution related to habitat alterations.

Over 50% of the inland fish species of concern in Texas occur in the Rio Grande drainage (Hubbs et al. 2008). Fish species that were historically common and widespread in the Rio Grande, now exhibit reduced abundance and distribution (Trevino-Robinson 1959; Hubbs et al. 1977; Edwards and Contreras-Balderas 1991; Edwards et al. 2002; Calamusso et al. 2005). In particular, populations of obligate riverine fishes are highly impacted (Anderson et al. 1995; Hubbs et al. 2008), The Rio Grande silvery minnow *Hybognathus amarus*, Rio Grande shiner *Notropis jemezanus*, Rio Grande blue sucker *Cycleptus* sp. and Rio Grande speckled chub *Macrhybopsis aestivalis* are currently extirpated from large portions of their historical ranges, and the phantom shiner *Notropis orca* and Rio Grande bluntnose shiner *Notropis simus simus* are now considered extinct (Bestgen and Platania 1990; Platania and Altenbach 1998; Hubbs et al. 2008).

Ichthyofauna changes in the Rio Grande are associated with anthropogenic activities that drastically alter the river from its natural state. Construction of reservoirs, channelization, hydrologic diversions for agricultural purposes, reduced water quality and quantity, ground water depletion, overgrazing, and introduction of non-native species are common in the Rio Grande watershed. In some reaches in New Mexico and far west Texas, the Rio Grande is periodically completely dewatered because of agricultural and municipality withdrawals (Calamusso et al. 2005); in other reaches, poor water quality and chemical pollution prompted advisories against water ingestion and fish consumption

(IBWC 2003; USGS 2004; Owens and Niemeyer 2005). This has led Calamusso et al. (2005) to suggest that fish conservation efforts in the Rio Grande mainstem should be abandoned, instead focusing conservation efforts only in the tributaries. Despite these extensive alterations and suggestion for abandonment, a few reaches within the Rio Grande drainage have relatively intact fish assemblages. In the lower Rio Grande, several obligate riverine fishes, including, *Cycleptus* sp., *Macrhybopsis aestivalis*, and the Tamaulipas shiner *Notropis braytoni*, persist in the reach from the confluence of the Rio Conchos to the confluence of the Pecos River (Edwards et al. 2002; Garrett 2002; Moring 2002; Edwards 2005).

The purposes of this study are to describe seasonal trends in abundance and habitat associations of fishes in the Big Bend reach of the Rio Grande, a section of the Rio Grande between the confluence of the Rio Conchos to the confluence of the Pecos River. Objectives of this study were to determine seasonal and longitudinal patterns in Rio Grande fish assemblage abundance and density and to quantify habitat associations. To date, historical trends in fish occurrence and abundance are documented for the lower Rio Grande of Texas (Hubbs 1958; Hubbs et al. 1977; Platania 1990; Edwards et al. 2002; Garrett 2002; Moring 2002; Edwards 2005); however, intra-annual variation in species abundance and habitat associations are lacking. Past studies within the Big Bend reach of the Rio Grande have found large bodied fish species in deeper run type geomorphic units and smaller bodies species in shallower areas with more varied current velocities (Moring 2002). I concentrated my sampling effort on these shallow areas because my goal was to assess habitat associations of small bodied obligate riverine cyprinids which form a large portion of the Rio Grande's biomass and of which many are

considered imperiled (Hubbs 1958; Hubbs et al. 1977; Platania 1990; Edwards et al. 2002; Garrett 2002; Moring 2002; Edwards 2005; TPWD 2005; Hubbs et al. 2008). Information provided on the Big Bend fish assemblage, specifically on the obligate riverine cyprinids, will improve capabilities to conserve, maintain, and possibly restore this and other reaches within the lower Rio Grande.

MATERIALS AND METHODS

Big Bend reach of the Rio Grande, between Presidio (TX) and the confluence of the Pecos River, primarily borders Big Bend Ranch State Park, Big Bend National Park (NP), and Black Gap Wildlife Management Area (WMA) or is managed by the National Parks Service as a Wild and Scenic River. The natural flow regime in the Big Bend reach is altered because of reductions in discharge attributed to upstream dam construction and dewatering in Mexico and the USA (Figure 1) (Hubbs et al. 1977; Moring, 2002; Edwards 2005). For example, the magnitude of 2-year flood recurrence is reduced by about 50% downstream from Rio Conchos and Rio Grande confluence since 1915 (Schmidt et al. 2003). Consequently, proportions of braided channels, shallow runs, riffles, and sand substrates are reduced, whereas the proportion of deep, sluggish runs with silt substrate has increased. However, diverse habitats persist, consisting of multiple geomorphic units (i.e., riffle, run, pool), limited areas of braided channels, and silt through boulder substrates (Hubbs et al. 1977; Armantrout 1998; Moring 2002; Goldstein and Meador 2004). Water quality has deteriorated, attributed to high nutrient loads from municipalities and agriculture along the Rio Conchos and Rio Grande near Presidio (TX),

but generally improves as the river flows through the Big Bend reach and into the lower Canyons (IBWC 2003; USGS 2004).

Seven sites were selected based on accessibility, longitudinal distribution, and availability of various types of geomorphic units. These sites spanned a distance of about 200 river km (Figure 2). At each site, geographic coordinates recorded with a Garmin GPSMAP 60CSx GPS unit in the UTM coordinate system, Zone 13 R, NAD 27. Main stem sampling sites were located near the confluence of Contrabando Creek (Site 1; E 612395, N 3239287), downstream from Santa Elena Canyon (Site 2; E 635271, N 3226912), near the USGS Gauging Station within Big Bend National Park (Site 3; E 656882, N 3212601), near Johnson Ranch campground of Big Bend NP (Site 4; E 658721, N 3211332), near the confluence of Tornillo Creek (Site 5; E 695091, N 3229250), upstream from Boquillas Canyon in Big Bend NP (Site 6; E 702576, N 3231651), and near the confluence of Maravillas Creek in Black Gap WMA (Site 7; E 715509, N 3272178). Study sites contain a mixture of geomorphic units at seinable depths and are bordered upstream and downstream by deep and sluggish runs. Riparian vegetation consisted of dense stands of exotic giant reed *Arundo donax* and salt cedar *Tamarix* sp. (Edwards 2005).

I collected fish and quantified habitat monthly from January through December 2006. Sites 3 and 4 were not sampled in July 2006 because of road inaccessibility. At each site, I established up to ten transects perpendicular to the stream bank (Simonson et al. 1994). The positions of transects was not static month to month. Along each transect, discrete geomorphic units (i.e., run, riffle, pool, side channel, backwater) were sampled with seine (3 m X 1.8 m; mesh size = 3.1 mm) hauls that were 5 m in length in a

downstream direction or one 5-m kick into a blocking seine. Transects were (>10 m) apart to avoid disturbing adjacent habitats. Twenty to sixty seines hauls or kicks were taken at each site and date (Matthews 1986; Dudley and Platania 1997). Captured fishes were identified to species (except larval *Lepomis*), enumerated measured to the nearest millimeter (total length) and released, except for voucher specimens in order to calculate relative abundance and catch per unit effort (CPUE) (number of fish collected per seine haul (m^2)). Within the area of the seine haul, current velocity (cm/sec; Marsh-McBirney, Inc. Flowmate model 2000) and depth (cm) were measured from two points on the short axis of the seine haul, and substrate type (Cummins 1962) was determined from 10 random points within the seine haul. Temperature (°C), specific conductivity (μS/cm), and pH was obtained from continuous monitoring station (Castolon C720; Texas Commission of Environmental Quality) located near Site 3. Hourly measurements were used to calculate monthly means (or median for pH) for January through December, 2006. Turbidity (NTU) was taken once at each site and sampling date with a YSI Model 660 multi-probe unit. Monthly means were calculated across sites.

Site and seasonal differences in habitat characteristics (i.e., mean current velocity, mean depth, percent substrate, and geomorphic unit type) among seine hauls were assessed with principal component analysis (PCA; SAS V. 9.1). Mean current velocity, mean depth, and percent substrate were Z-score transformed; dummy variables were used to denote geomorphic unit type. Fish assemblage similarity among sites was assessed with a pairwise Renkonen similarity index (Matthews and Marsh-Matthews 2006). Seasonal differences in fish occurrences and abundances were assessed with analysis of similarity (ANOSIM; Clarke 1993) using Bray-Curtis similarity indices in PRIMER

(version 6.1.6) (Bean et al. 2007). Abundances were fourth-root transformation to down weight highly abundant species and to recognize less abundant species (Clark and Green 1988). Canonical correspondence analysis (CCA; CANOCO V4.5; ter Braak 1986) was used to assess multivariate relationships between habitat characteristics and fish abundance. For all models, season was based on monsoonal precipitation cycles which peak in late summer and early fall: January through July and November through December (dry seasons 1 & 2), and August through October (wet season) (Figure 3). For species-specific assessments, current velocity and depth associations were quantified for two size class (<25 mm & >25 mm) of *Notropis braytoni*, *Macrhybopsis aestivalis*, and *Cyprinella lutrensis,* and one size class of *Rhinichthys cataractae* by using weighted averages. These species were found in sufficient numbers to assess current velocities and depths used relative to available habitats.

RESULTS

Seinable geomorphic units primarily consisted of runs (56 – 89% among sites) and riffles (2.7 – 25%). Among geomorphic units and sites, cobble was the dominant substrate (41% - 89%), except at Site 4, which had relatively large amounts of gravel (43%) and silt (33%) substrates. Sand, boulder, and bedrock comprised <15% of the available substrates across all sites (Table 1). Mean monthly turbidity ranged from 234.8 to 426.3 NTU. Mean (± 1 SD) monthly temperature and chemical parameters ranged between 11°C (± 1.6) and 29°C (± 2.5) for water temperature and between 953 (± 241.0) to 3,321 (± 404.8) μS/cm for specific conductivity. Median pH (range) was 7.0 (6.0 –

8.0). The flow regime during 2006 was typical for the reach temporally and in magnitude when compared to patterns measured since 1984 (Figure 3).

The first three axes of PCA explained 38.5% of the variation in habitat parameters. Axis I (15.5%) described a geomorphic unit gradient, with runs, water depth, and current velocity having highest negative loadings and riffles, side channels, backwaters, and silt substrate having highest positive loadings (Table 2). Axis II (13.8%) described primarily a substrate gradient, with cobble, riffles, and current velocity having highest negative loadings and silt and backwater having highest positive loadings. Axis III (9.3%) described another substrate gradient, with cobble and riffle having highest negative loadings and cobble, silt, and run having highest positive loadings. Among sites, mean PC habitat scores on axes I and II clustered into four groups: Site 1 with primarily shallow riffles and side channels; sites 2, 6, and 7 with runs, riffles, and cobble and silt substrates; sites 3 and 5 with more riffles and cobble substrates; and, site 4 with more backwaters and silt substrates (Figure 4). Mean PC habitat scores on axes III reflected a gradual gradient for sites 3, 7, and 1 from the other sites primarily based on low percentage (<12%) of gravel substrates. Among seasons, mean PC habitat scores were similar between dry and wet seasons on PC axis I, were higher in the wet season on PC axis II (more backwaters with silt substrate), and lower in the dry season on PC axis III (more run habitats with cobble substrates).

A total of 10,565 fishes representing 20 species were taken from seven sites. Species richness (S) was highest ($S = 19$) at Site 2 and was lowest at Site 5 ($S = 11$). *Cyprinella lutrensis* was most abundant across all sites (46%) and most abundant at sites 1 through 4, ranging from 45% (Site 2) to 69% (Site 1). Endemic *Notropis braytoni* was

the second most abundant across all sites (35%) and most abundant at sites 5 through 7, ranging from 40% (Site 7) to 51% (Site 5). Six imperiled taxa (*N. braytoni*, *N. chihuahua N. jemezanus*, *M. aestivalis*, *R. cataractae*, *Cycleptus* sp.; TPWD 2005; Hubbs et al. 2008) were taken from at least one site. Three non-native taxa (*Cyprinus carpio*, *Menidia beryllina,* and *Fundulus zebrinus*) were taken and represented <1% of the total assemblage; an additional non-native fish (*Oreochromis aureus)* was observed during a fish kill in December, 2006 near Site 2. The assemblage was dominated (>80% relative abundance) by two species. Imperiled fishes, excluding *N. braytoni*, composed 4% of the assemblage. Among all sites, catch per unit effort of fish was lowest (159 x 10^{-3}) at Site 3 and highest (447 x 10^{-3}) at Site 6. Highest CPUE by species and site was *N. braytoni* at Site 5 (218 x 10^{-3}) and Site 6 (207 x 10^{-3}), followed by *C. lutrensis* at Site 6 (194 x 10^{-3}) and at Site 4 (171 x 10^{-3}) (Table 3).

Fish assemblage exhibited significant variation among sites and between seasons. Fish assemblage similarities were >80% among sites 1, 3, and 4, and among sites 5, 6, and 7, attributed to dominance of *Cyprinella lutrensis* (51 - 69% at sites 1, 3, and 4) and dominance of *Notropis braytoni* (40 - 50% at sites 5, 6, and 7). Site 2 was least similar to other sites, dominated by *Cyprinella lutrensis* (45%), followed by *Notropis braytoni* (26%), as well as the highest abundances of *Notropis chihuahua* and *Notropis jemezanus* along with the only occurrence of *Rhinichthys cataractae*. Fish assemblages also differed (ANOSIM, R = 0.467, $P < 0.01$) among seasons. Abundances and densities (CPUE) of *Cyprinella lutrensis*, *Notropis braytoni*, and *Carpiodes carpio* decreased and densities of *Cyprinus carpio*, *Ictalurus furcatus*, *I. punctatus*, and *Menidia beryllina* increased between Dry Season 1 and the Wet Season. Abundances and densities of *Cyprinus*

carpio, *Ictaluras furcatus*, *I. punctatus* decreased and densities of *Notropis braytoni*, *Carpiodes carpio*, and *Gambusia affinis* increased between Wet Season and Dry Season 2. Assemblage after the Wet Season (i.e., comparison between Dry Season 1 and 2) had lower abundances and densities of *Cyprinella lutrensis*, *Macrhybopsis aestivalis*, *I. furcatus*, and *I. punctatus* and higher abundances and densities of *Gambusia affinis* and *Menidia beryllina* (Table 4).

A total of 12% of the taxonomic variation (CCA; $P < 0.01$) was explained by habitat parameters. Axis I described a current velocity and geomorphic unit gradient with swifter current velocities, runs, and riffles having positive loadings, and backwater, side channel, and shallow depths having negative loadings. Axis II described a depth, geomorphic unit and substrate gradient with deeper water and backwaters with silt substrate having positive loadings and shallow water and gravel to cobble substrates having negative loadings on Axis II. Fishes with strong habitat associations were *Rhinichthys cataractae,* associated with riffles and cobble substrates, *Ictalurus furcatus*, *I. punctatus, Pylodictis olivaris, Macrhybopsis aestivalis*, *Notropis jemezanus,* and *Cycleptus* sp., associated with runs and with swift current velocities, *Notropis chihuahua*, *Gambusia affinis,* and *Carpiodes carpio*, associated with backwaters and silt substrates, and *Fundulus zebrinus*, associated with pools. Abundant fishes without strong habitat associations included *Cyprinella lutrensis*, *Notropis braytoni*, and *Astyanax mexicanus* (Figure 5).

Among the common cyprinids, species segregation and size groups differed among current velocity and depth gradients (Figure 6). Mean current velocity (±SE) of smaller fish (<25 mm) was 0.10 m/s (±0.04) for *Notropis braytoni* ($N = 390$), 0.10 m/s

(±0.03) for *Cyprinella lutrensis* (N = 1,168), and 0.17 m/s (±0.06) for *Macrhybopsis aestivalis* (N = 14). Mean depth (±SE) of smaller fish was 0.26 m (±0.04) for *Notropis braytoni*, 0.26 m (±0.04) for *Cyprinella lutrensis*, and 0.17 m (±0.04) for *Macrhybopsis aestivalis*. Larger fishes shifted to swifter current velocities. Mean current velocity (±SE) of larger fish (>25 mm) was 0.30 m/s (±0.06) for *Notropis braytoni* (N = 2,003), 0.19 m/s (±0.04) for *Cyprinella lutrensis* (N = 2,172), 0.68 m/s (±0.08) for *Rhinichthys cataractae* (N = 38) and 0.48 m/s (±0.06) for *Macrhybopsis aestivalis* (N = 279). Shifts to greater depths only occurred with *Macrhybopsis aestivalis* (0.38 m; ±0.04).

DISCUSSION

Occurrences and abundances of fishes reported in this study were similar to those taken in past collections (Table 5; Hubbs 1958; Hubbs et al. 1977; Platania 1990; Garrett 2002, Edwards et al. 2002; Moring 2002; Edwards 2005). Taxa not taken in this study were two fishes (*Campostoma ornatum* and *Dionda episcopa*) that are typically found in tributaries of the Rio Grande (Thomas et al. 2007), and nine fishes that were historically uncommon in occurrence ($\leq$ 3 of 8 collections since 1954). Relative abundances of fishes generally were within reported abundance variability of fishes taken from the Big Bend reach (Hubbs 1958; Hubbs et al. 1977; Platania 1990; Garrett 2002, Edwards et al. 2002; Moring 2002; Edwards 2005). Notable exceptions included three riverine fishes (*Notropis jemezanus*, *Ictiobus bubalus*, and *Cycleptus* sp.), which had lower abundances in this study compared to historical abundances, when present. Possible population declines of these three riverine taxa are consistent with other riverine fishes that were historically found in the Big Bend reach but are now extinct (*Notropis simus simus* and

Notropis orca) or extirpated (*Hybognathus amarus*) (Hubbs et al. 2008). In contrast, relative abundance increased for *Cyprinella lutrensis* since the 1970s and for *Notropis braytoni* since the mid-1990s in the Big Bend reach. Despite these changes, the fish assemblage retains more of its integrity in the Big Bend reach relative to other reaches in the Rio Grande mainstem and lower Pecos River, where many of the obligate riverine taxa, such as *Notropis braytoni, Macrhybopsis aestivalis, N. jemezanus, Rhinichthys cataractae* and *Cycleptus* sp., are extirpated or in low abundance (Sublette et al. 1990; Edwards and Contreras-Balderas 1991; Contreras-Balderas et al. 2002; Hoagstrom 2003; Calamusso et al. 2005).

Fish occurrences, abundances, and distributions were explained, in part, by habitat and season. Among habitat parameters, fishes were segregated primarily along a current velocity and geomorphic unit gradient. *Rhinichthys cataractae*, *Notropis jemezanus*, juvenile catfishes (*Pylodictis olivaris*, *Ictalurus punctatus*, and *I. furcatus*), juvenile *Cycleptus* sp., and *Macrhybopsis aestivalis* were specialized in their habitat associations, generally found in swifter current velocities and in run or riffle habitats. Likewise, juvenile *Notropis chihuahua*, *Gambusia affinis*, *Fundulus zebrinus*, and *Lepisosteus osseus* were often associated with low current velocities habitats, such as backwaters, pools, and side channels with silt substrate. Several taxa, including two of the most abundant fishes (*Cyprinella lutrensis* and *Notropis braytoni*), exhibited generalist habitat traits and often were found in pools, side channels, runs, and riffles. Segregation also was observed along current velocity and depth gradients between age groups (i.e., juveniles and adults) of conspecifics. Segregation along current velocity, depth, and geomorphic units gradients is common among riverine assemblages (Herbert and

Gelwick 2003; Barko et al. 2004; Li and Gelwick 2005) and is necessary to maintain an ecologically intact and functioning riverine assemblage (Schlosser 1991; Ward 1998). Likewise, season, or more specifically seasonal flow pulses, influenced fish occurrence and abundance in this study. *Ictaluras punctatus, I. furcatus, Gambusia affinis, Cyprinus carpio* and *Menidia beryllina* were more abundant during or after high flow pulses. Increases in abundance were attributed presumably to downstream displacement of reservoir fishes in the Rio Conchos (Ward and Stanford 1979; Schultz et al. 2003), whereas *Cyprinella lutrensis* and *Macrhybopsis aestivalis* were less abundant after the high flow pulses, attributed presumably to downstream displacement of riverine fishes (Schultz et al. 2003) or due to the increased mortality of post spawning adults (Bestgen et al. 1989). Occurrence of reservoir fishes in the Big Bend reach attributed to downstream displacement during flow pulses is not natural, and their occurrence can negatively impact riverine taxa (Meffe 1985; Marsh and Brooks 1989; Douglas et al. 1994; Marsh and Douglas 1997; Dudley and Matter 2000; Schultz et al. 2003; however, their presence illustrates some of the benefits of seasonal flow pulses and an intact riverscape (Ward and Stanford 1995; Poff et al. 1997; Fausch 2002)--local species pools are influenced by regional species pools (Heoinghaus et al. 2007) and local energy sources can be derived from distant sources (Karr 1991).

Modification to natural flow regimes through impoundments and water withdrawals disrupt ecological and biological processes in large rivers by altering physical habitat components, including fragmenting longitudinal habitats, homogenizing stream geomorphology, and lessening seasonal peak flows (Poff et al. 1997; Hughes et al. 2005). Throughout the Rio Grande drainage, modifications of flow regimes are

associated with extirpations of several fishes and increases of habitat generalist, lentic specialists, and exotic taxa (Sublette et al. 1990; Edwards and Contreras-Balderas 1991; Contreras-Balderas et al. 2002; Hoagstrom 2003; Calamusso et al. 2005). Changes in fish assemblage in the Big Bend reach are consistent with the trends with the extirpation of *Hybognathus amarus* and possibly declining populations of *Notropis jemezanus* and *Cycleptus* sp. and increasing populations of red shiners and Tamaulipas shiners (habitat generalists), inland silversides (lentic specialists), and common carp (exotic taxa). Yet, major modifications to the natural flow regime occur substantial distances upstream, with water withdrawals in the lower Rio Conchos and Presidio, TX, area of Mexico and USA (about 150 km upstream) and large dams in the Rio Conchos (about 250 km upstream) and the Rio Grande (600 km upstream). Consequently, protection, management, and restoration for biotic integrity or species will be cumbersome, given that the sources of flow modifications are distant and crossing state and international boundaries. Nevertheless, adequate flows must be ensured through the Big Bend reach. If not, I predict based on the results of this study that further reductions in flow will compress current velocity, depth, and geomorphic unit gradients that currently structure habitat segregation and likely lead to further loss of fish taxa or species abundance (Bonner and Wilde 2000; Aarts et al. 2004).

Physical habitat alterations are not the only threat to the fish assemblage in the Big Bend reach of the Rio Grande. Chemical pollution and nutrient enrichment, likely the causes of periodic fish kills, are concerns as well (Davis 1980c; Miyamoto et al. 1995; IBWC 2003; Edwards 2005; Marfurt 2007). High chemical and nutrient levels have been documented in the Rio Grande in the area associated with the confluence of

the Rio Conchos and the urban areas of Presidio, Texas and Ojinaga, Chihuahua (IBWC 2003). Five fish kills and three pollution complaints were reported in the Big Bend reach of the Rio Grande encompassed in this study from 1983 to 2006. Three of the reported fish kills were located in or in the vicinity of Santa Elena Canyon (TPWD 2008). This complicates management downstream of these areas in that even with quality habitat and flows for fish species, water quality issues from upstream watersheds, much of which is located in Mexico, can negatively impact the fish assemblage in Big Bend National Park and other protected areas along the reach.

The Rio Grande is the 5th longest in North America and ranks 24th in length globally (Dahm et al. 2005). The ichthyofauna has a high level of endemism and although highly impacted overall, it retains some areas of refuge for these species. The troubled history of the Rio Grande is unfortunately common to large rivers globally. The plight of the world's large rivers has become a concern not only to the scientific community due to the purely ecological services they provide to aquatic and terrestrial organisms (Naiman et al. 1993; Richter et al. 2003) but to society as well. Societal goods and services supplied by rivers include fresh water supply, hydroelectric power, fish for consumption, fertilization of floodplains and deltas, stabilization and building of deltas through deposition of sediment, pollutant dilution and transportation , water purification, the dispersal and storage of flood pulses and recreation (Postel and Carpenter 1997; Brismar 2002). River restoration efforts, even in impacted systems, that maintain riverine species as well as societal goods and services, although difficult and costly, are possible when an adaptive management plan is implemented by the multiple stakeholders

involved (Valdez and Muth 2005). This study and others are necessary steps in the overall goal of implementation of large river conservation and restoration efforts.

TABLE 1. Overall and per site relative abundance of geomorphic units and substrate types encountered from January 2006 through December 2006 in the Big Bend reach of the Rio Grande.

Site #	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Total
N of seine hauls	349	467	256	338	389	303	291	2393
Percent geomorphic unit								
Run	55.6	74.9	89.1	88.8	74.7	79.2	82.5	77.8
Riffle	24.8	15	5.5	2.7	22.2	11.6	6.2	12.6
Side channel	3.5	5.8	3.1	2.1	1.3	0.3	5.2	3.0
Backwater	6.1	1.1	1.2	3.6	—	3	2.4	2.5
Pool	8.6	1.5	1.2	1.8	0.5	0.3	1.4	2.2
Eddy	1.4	1.7	—	1.2	1.3	5.6	2.4	1.9
Percent substrate								
Cobble	50.7	40.7	88.5	5.5	65	53.3	59.7	51.9
Gravel	8.2	38.7	7.1	43.1	27.9	30.7	11.1	23.8
Silt	13.9	12.1	3.7	33.2	3.2	10	15.6	13.1
Boulder	15.4	1.5	0.4	3.9	1.5	0.3	13.4	5.2
Sand	0.9	7	—	14.3	2.2	5.7	0.1	4.3
Bedrock	10.9	—	0.3	—	0.2	—	0.1	1.6

TABLE 2. PCA loadings from axes I, II and III and the % variance explained for geomorphic units and substrate types encountered from January 2006 through December 2006 in the Big Bend reach of the Rio Grande.

	PCA		
Parameter	I	II	III
Current velocity (m/s)	**-0.300**	**-0.333**	0.247
Depth (m)	**-0.370**	0.160	-0.144
Run	**-0.581**	0.111	**-0.223**
Riffle	**0.360**	**-0.397**	**0.327**
Side channel	**0.240**	0.145	0.056
Backwater	0.222	**0.211**	-0.069
Pool	0.191	0.154	-0.087
Eddy	0.129	0.055	-0.026
Boulder (%)	0.072	-0.071	-0.061
Cobble (%)	-0.005	**-0.544**	**-0.449**
Gravel (%)	-0.229	0.188	**0.638**
Sand (%)	-0.118	0.193	0.166
Silt (%)	**0.246**	**0.475**	**-0.249**
% Variance explained	15.5	13.8	9.3

TABLE 3. Overall and per site relative abundance (A) and catch per unit effort (CPUE x 10^{-3}) (B) of ichthyofauna encountered from January 2006 through December 2006 in the Big Bend reach of the Rio Grande. *Lepomis species* (*L. megalotis and L. cyanellus*).

A.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Total
Lepisosteus osseus	—	0.1	0.3	0.2	—	0.1	1	0.1
Cyprinella lutrensis	69	45	51	60	32	43	40	46
Cyprinus carpio	0 3	2	1	0.3	0.4	0.2	1	1
Macrhybopsis aestivalis	2	6	7	5	2	2	0.4	3
Notropis braytoni	20	26	19	20	51	46	40	35
Notropis chihuahua	—	1	—	0.1	—	—	—	0.1
Notropis jemezanus	—	0.2	—	0.1	—	—	—	0.1
Rhinichthys cataractae	—	2	—	—	—	—	—	0.4
Carpiodes carpio	2	10	2	6	4	1	1	4
Ictiobus bubalus	—	—	—	0.1	—	—	—	0.02
Cycleptus sp.	0.1	0.1	—	—	—	1	1	0.2
Astyanax mexicanus	1	0.2	1	0.1	2	1	6	1
Ictaluras furcatus	2	1	1	2	2	1	4	2
Ictaluras punctatus	2	2	3	1	4	2	2	2
Pylodictis olivaris	0.1	1	1	—	—	0.3	1	0.3
Fundulus zebrinus	—	2	1	0.1	0.4	—	0.1	1
Gambusia affinis	2	1	11	5	3	2	2	3
Menidia beryllina	—	2	0.2	0.1	1	0.3	1	1
Lepomis species	0.1	0.2	1	0.4	—	—	1	0.2
Total *N*	1,225	1,938	611	1,441	2,511	2,033	806	10,565

B.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Lepisosteus osseus	—	0.1	1	1	—	0.4	1
Cyprinella lutrensis	161	124	82	171	137	194	74
Cyprinus carpio	1	5	2	1	2	1	1
Macrhybopsis aestivalis	4	17	12	13	7	8	1
Notropis braytoni	48	72	30	57	218	207	75
Notropis chihuahua	—	2	—	0.2	—	—	—
Notropis jemezanus	—	0.4	—	0.2	—	—	—
Rhinichthys cataractae	—	5	—	—	—	—	—
Carpiodes carpio	4	27	2	18	16	3	2
Ictiobus bubalus	—	—	—	0.2	—	—	—
Cycleptus sp.	0.2	0 3	—	—	0.2	3	1
Astyanax mexicanus	1	0.4	2	0.2	9	5	11
Ictaluras furcatus	6	2	2	5	6	6	8
Ictaluras punctatus	4	4	5	3	19	8	4
Pylodictis olivaris	0.2	1	2	—	0.2	1	1
Fundulus zebrinus	—	5	1	0.4	2	—	0.2
Gambusia affinis	5	4	18	14	12	8	4
Menidia beryllina	—	5	0.3	0.2	2	1	1
Lepomis species	0.2	0.4	1	1	0.2	—	1
Total	234	277	159	284	430	447	185

TABLE 4. Seasonal relative abundance (A) and catch per unit effort (CPUE x 10^{-3}) (B)of ichthyofauna encountered from January 2006 through December 2006 in the Big Bend reach of the Rio Grande.

		Relative Abundance		
A.	Species	Dry season 1	Wet season	Dry season 2
	Lepisosteus osseus	0.1	0.3	—
	Cyprinella lutrensis	50	37	38
	Cyprinus carpio	0.4	2	—
	Macrhybopsis aestivalis	4	2	2
	Notropis braytoni	33	36	42
	Notropis chihuahua	0.2	—	0.1
	Notropis jemezanus	0.1	—	—
	Rhinichthys cataractae	0.4	0.5	0.1
	Carpiodes carpio	4	1	5
	Ictiobus bubalus	0.03	—	—
	Cycleptus sp.	0.3	0.1	0.1
	Astyanax mexicanus	1	2	2
	Ictaluras furcatus	1	4	—
	Ictaluras punctatus	1	9	0.2
	Pylodictis olivaris	0.2	1	0.5
	Fundulus zebrinus	1	0.2	0.4
	Gambusia affinis	2	2	7
	Menidia beryllina	—	1	3
	Lepomis species	0.2	0.3	—
	Total *N*	7353	1724	1488

B.	Season	Dry season 1	Wet season	Dry season 2
	N of seine hauls	1452	514	427
	Lepisosteus osseus	0.5	1	—
	Cyprinella lutrensis	170	83	88
	Cyprinus carpio	1	5	—
	Macrhybopsis aestivalis	12	5	5
	Notropis braytoni	112	80	98
	Notropis chihuahua	1	—	0.2
	Notropis jemezanus	0.2	—	—
	Rhinichthys cataractae	1	1	0.3
	Carpiodes carpio	15	3	12
	Ictiobus bubalus	0.1	—	—
	Cycleptus sp.	1	0.1	0.2
	Astyanax mexicanus	4	4	4
	Ictaluras furcatus	5	9	—
	Ictaluras punctatus	4	21	0.5
	Pylodictis olivaris	1	1	1
	Fundulus zebrinus	2	0.4	1
	Gambusia affinis	8	5	16
	Menidia beryllina	—	3	6
	Lepomis species	1	1	—
	Total	338	224	232

TABLE 5. Historical fish assemblage with relative abundances from the Big Bend reach of the Rio Grande. X indicates species was present.

Species	1954	1977	1990	1992	1993	1999	2004	2006
Lepisosteus osseus	1	0.1	0.1	—	—	1	1	0.1
Dorosoma cepedianum	—	2	—	—	—	1	0.2	—
Campostoma ornatum	—	—	—	—	0.01	—	—	—
Cyprinella lutrensis	1	19	77	62	87	27	16	46
Cyprinus carpio	1	0.2	0.1	1	—	2	0.2	1
Dionda episcopa	—	—	—	—	—	—	0.03	—
Macrhybopsis aestivalis	1	3	0.3	—	1	10	0.03	3
Notropis braytoni	16	2	2	0.2	2	25	59	35
Notropis chihuahua	—	0.1	—	2	0.02	—	—	0.1
Notropis jemezanus	7	3	1	—	0.3	7	—	0.05
Notropis stramineus	—	—	—	—	0.2	—	—	—
Pimephales promelas	—	0.1	—	5	0.2	—	—	—
Rhinichthys cataractae	—	58	9	—	0.4	1	0.2	0.4
Carpiodes carpio	20	0.5	4	11	—	5	10	4
Ictiobus bubalus	1	—	—	—	2	0.2	0.4	0.02
Cycleptus sp.	—	4	—	—	—	3	—	0.2
Moxostoma austrinum	—	—	—	1	0.02	—	—	—
Astyanax mexicanus	1	1	2	1	0.01	—	7	1
Ictaluras furcatus	45	1	—	1	0.2	5	2	2
Ictaluras lupus	—	—	—	0.1	0.02	—	0.4	—
Ictaluras punctatus	1	1	0.1	0.1	0.04	3	—	2
Pylodictis olivaris	4	0.3	0.1	1	0.03	5	0.4	0.3
Cyprinodon eximius	—	0.3	—	—	—	—	—	—
Fundulus zebrinus	—	—	—	0.2	—	1	0.1	1
Gambusia affinis	1	3	2	—	7	0.2	3	3
Menidia beryllina	—	1	2	6	0.3	—	—	1
Morone chrysops	—	—	0.1	0.3	—	—	—	—
Lepomis species	—	0.5	0.2	0.1	0.2	1	0.3	0.2
Micropterus salmoides	—	0.1	—	1	—	—	—	—
Aplodinotus grunniens	—	—	—	—	—	0.2	0.03	—
Oreochromis aureus	—	—	—	8	—	—	—	X
Total *N*	152	2077	1376	992	8964	474	3044	10565

References: Hubbs 1958; Hubbs et al. 1977; Platania 1990; Edwards et al. 2002; Moring 2002; Edwards 2005; Heard 2006, this study.

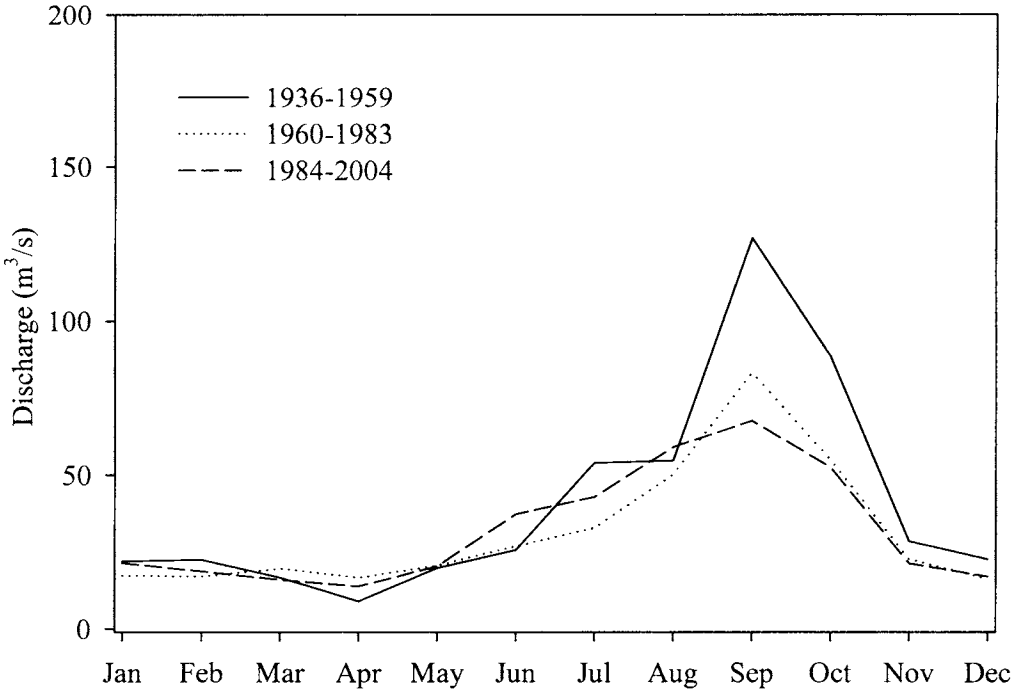

FIGURE 1. Historical average discharge rates from Johnson Ranch (IBWC) gauging station, Big Bend reach, Rio Grande.

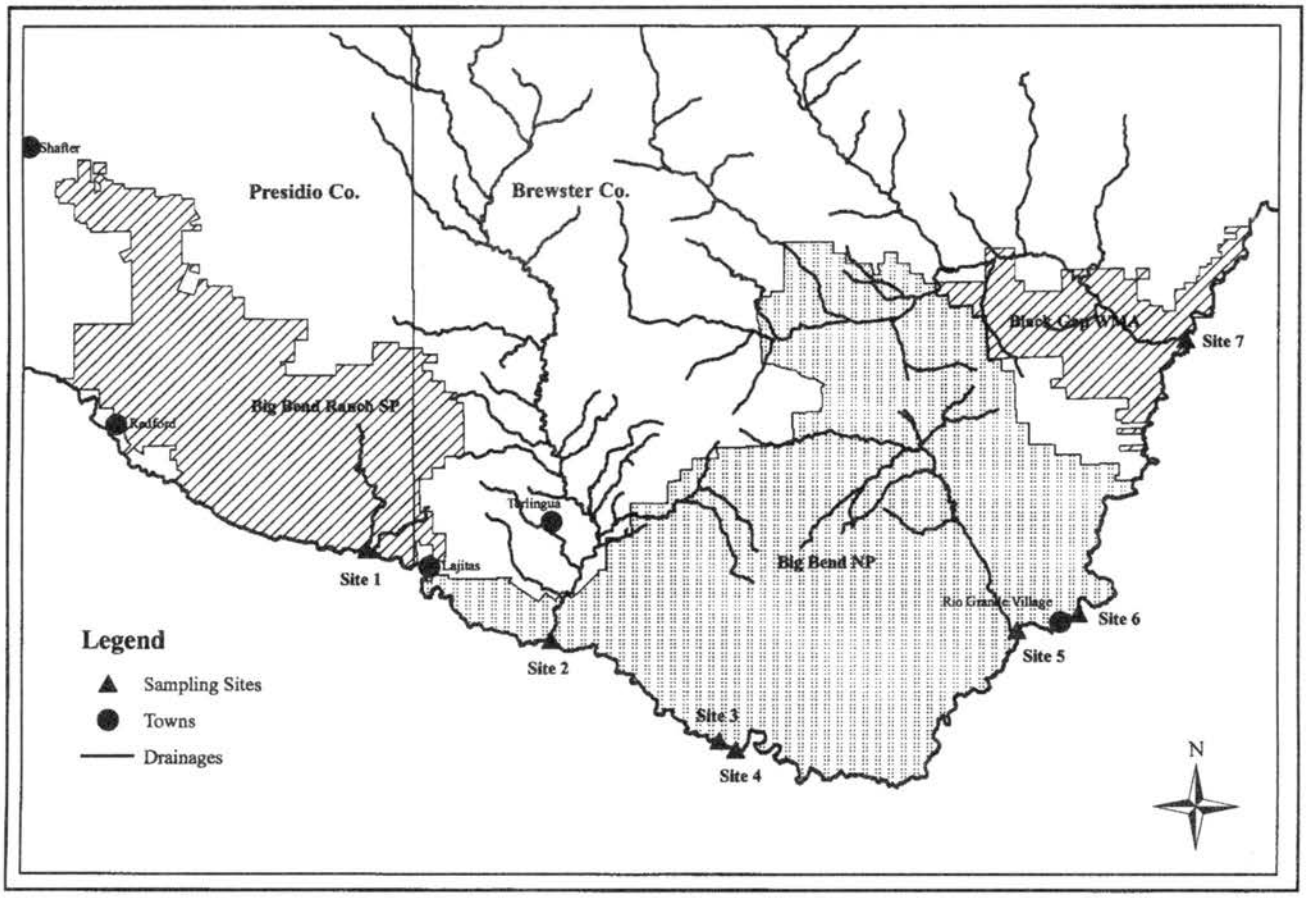

FIGURE 2. Map of study area and sampling sites, Big Bend reach, Rio Grande, January 2007 through December 2007.

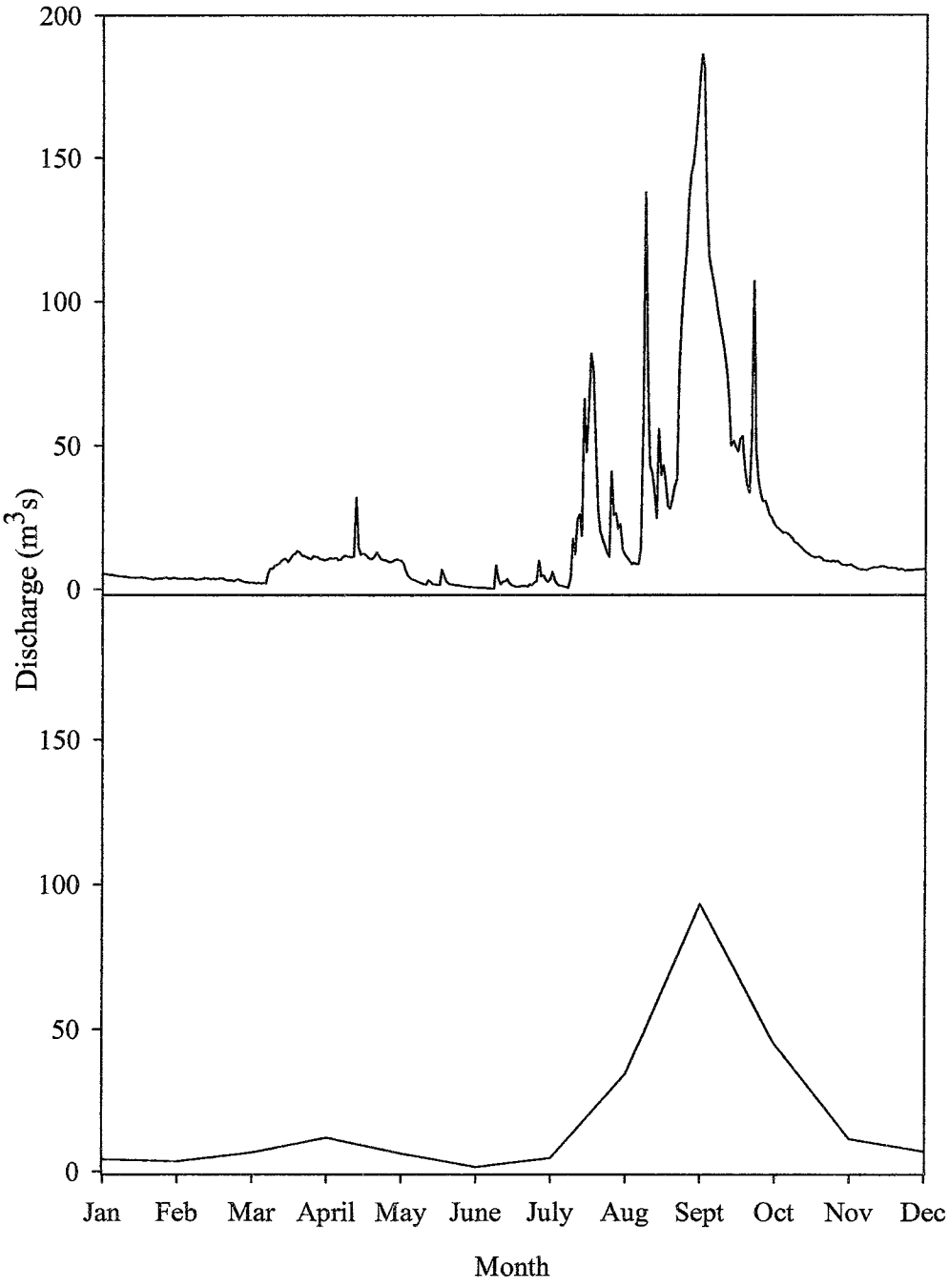

FIGURE 3. Daily average and monthly Average discharge rates from Johnson Ranch (IBWC) gauging station, Big Bend Reach, Rio Grande, January 2007 through December 2007.

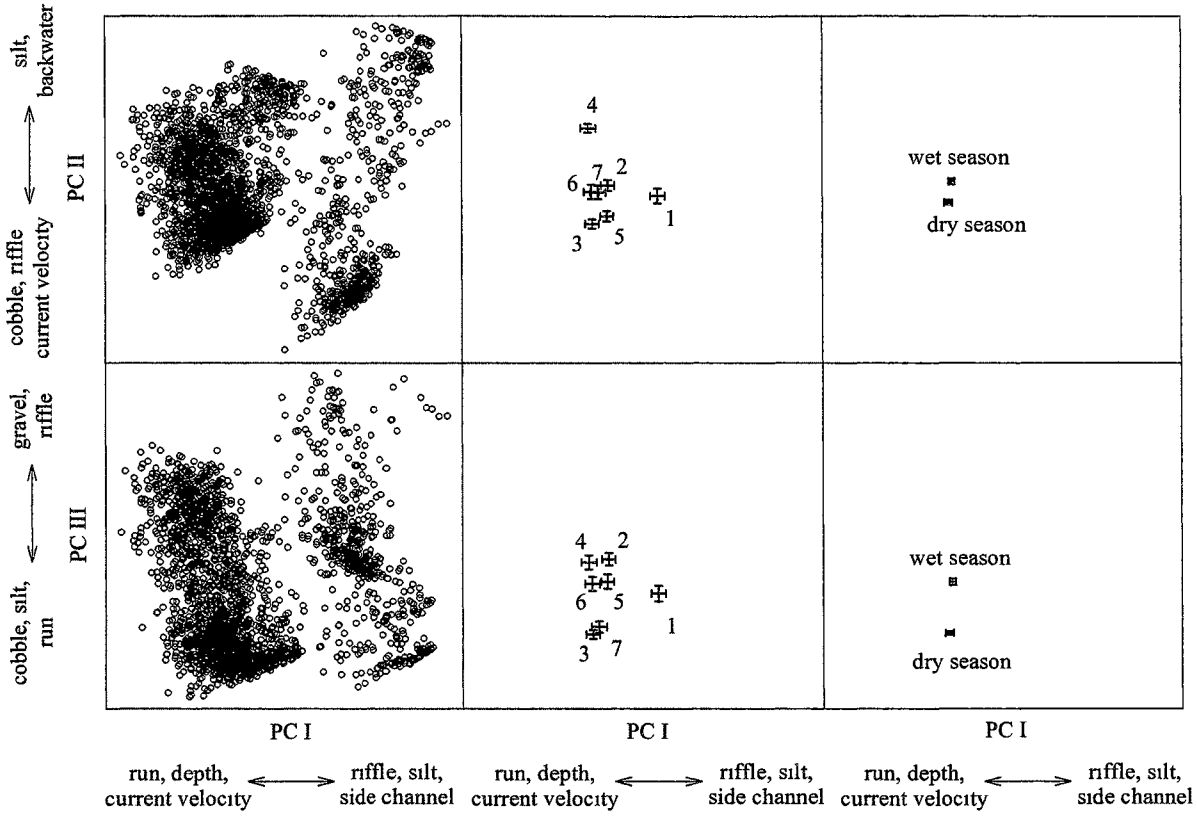

FIGURE 4. Plots of all samples in relation to habitat parameters with higher loadings on PCA axes I, II and III (left) and the average scores with standard error bars for site (center) and season (right) from PCA axes I, II and III. Big Bend Reach, Rio Grande, January 2007 through December 2007.

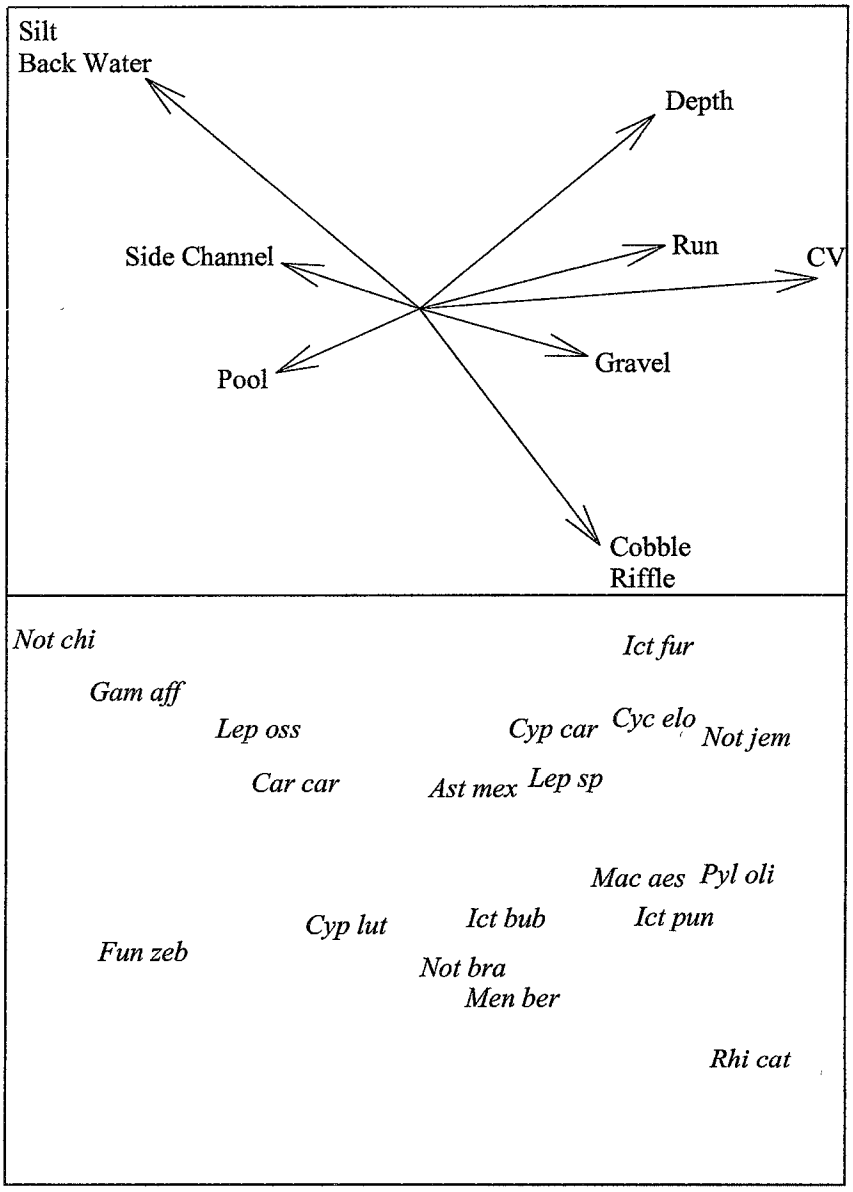

FIGURE 5. Simplified Canonical Correspondence Analysis (CCA) ordination plot for habitat associations of the fish assemblage of the Big Bend Reach, Rio Grande, January 2007 through December 2007. *Lep oss (Lepisosteus osseus); Cyp lut (Cyprinella lutrensis); Cyp car (Cyprinus carpio); Mac aes (Macrhybopsis aestivalis); Not bra (Notropis braytoni); Not chi (Notropis chihuahua); Not jem (Notropis jemezanus); Rhi cat (Rhinichthys cataractae); Car car (Carpoides carpio); Ict bub (Ictiobus bubalus); Cyc elo (Cycleptus elongatus); Ast mex (Astyanax mexicanus); Ict fur (Ictaluras furcatus); Ict pun (Ictaluras punctatus); Pyl oli (Pylodictis olivaris); Fun zeb (Fundulus zebrinus); Gam aff (Gambusia affinis); Men ber (Menidia beryllina); Lep* sp *(Lepomis species).*

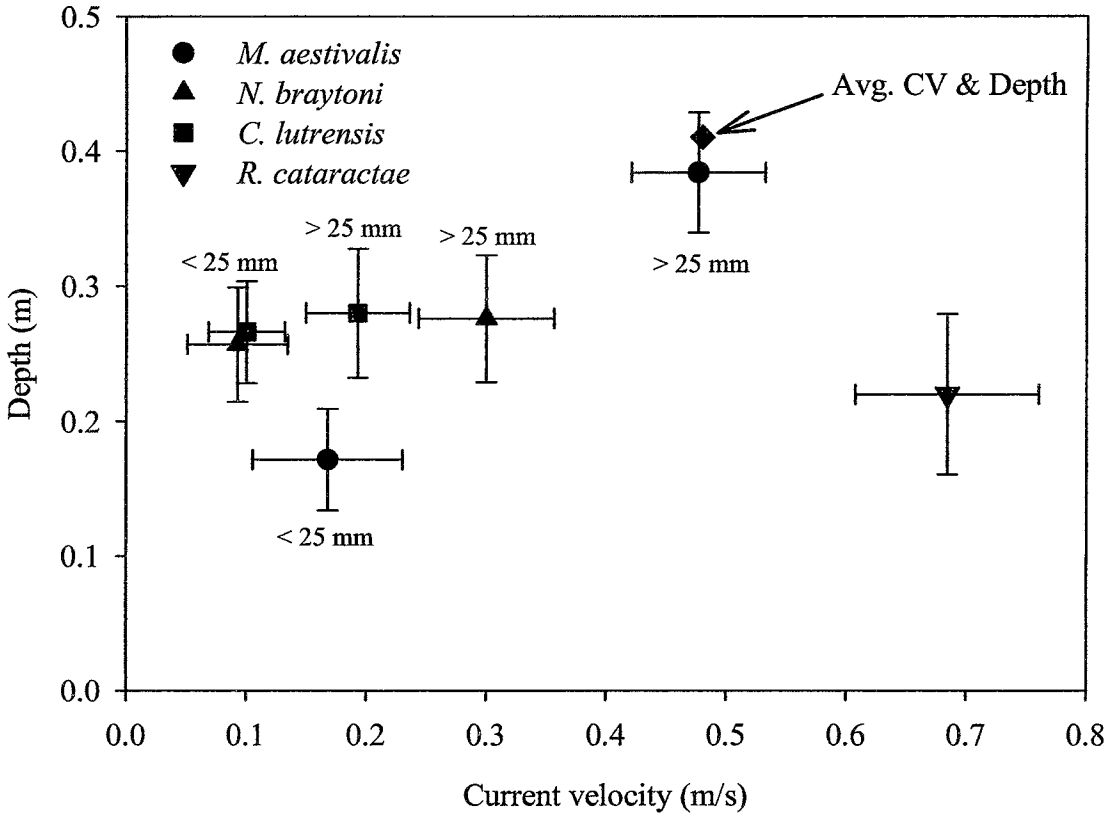

FIGURE 6. Weighted mean (± SE) of current velocity (m/s) and depth (m) associations for *Rhinichthys cataractae* and two size classes (< 25 mm & >25 mm) of *Notropis braytoni, Macrhybopsis aestivalis* and *Cyprinella lutrensis* along with the average current velocity and depth from all samples combined in the Big Bend Reach, Rio Grande, January 2007 through December 2007.

WORKS CITED

Aarts B. G. W., F. W. B. Van Den Brink, and P. H. Nienhuis. 2003. Habitat loss as the main cause of the slow recovery of fish faunas of regulated large rivers in Europe: The transversal floodplain gradient. River Research and Applications 20:3-23.

Anderson, A. A., C. Hubbs, K. O. Winemiller, and R. J. Edwards. 1995. Texas freshwater fish assemblages following three decades of environmental change. Southwestern Naturalist 40(3):314-21.

Armantrout, N. B., Compiler. 1998. Glossary of Aquatic Habitat Inventory Terminology. American Fisheries Society, Bethesda, Maryland.

Bain, M. B., J. T. Finn, and H. E. Brooke. 1988. Streamflow regulation and fish community structure. Ecology 69:382-392.

Barko, V. A., M. W. Palmer, D. P. Herzog, and B. S. Ickes. 2004. Influential environmental gradients and spatiotemporal patterns of fish assemblages in the unimpounded upper Mississippi River. The American Midland Naturalist 152(2):369-385.

Bean, P. T., T. H. Bonner, and B. M. Littrell. 2007. Spatial and temporal patterns in the fish assemblage of the Blanco River. Texas Journal of Science 59(3):179-200.

Bestgen, K. R., and S. P. Platania. 1990. Extirpation of *Notropis simus simus* Cope and *Notropis orca* Woolman (Pisces: Cyprinidae) from the Rio Grande in New Mexico: with notes on their life history. Occasional papers of the Museum of Southwestern Biology, University of New Mexico 6:1-8.

Bestgen K. R., S. P. Platania, J. E. Brooks, and D. L. Propst. 1989. Dispersal and life history traits of *Notropis girardi* (Cypriniformes: Cyprinidae), introduced into the Pecos River, New Mexico. American Midland Naturalist 122(2):228-235.

Bestgen, K. R., and S. P. Platania. 1988. The ichthyofauna and aquatic habitats of the Rio Grande from the New Mexico-Texas border to Big Bend National Park. A report submitted to the U.S. Fish and Wildlife Service, Office of Endangered Species, Albuquerque, NM.

Bonner, T. H., and G. R. Wilde. 2000. Changes in the Canadian River fish assemblage associated with reservoir construction. Journal of Freshwater Ecology 15(2):189-198.

Brismar, A. 2002. River systems as providers of goods and services: A basis for comparing desired and undesired effects of large dam projects. Environmental management 29:598-609.Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492-507.

Contreras-Balderas, S., R. J. Edwards, M. Lozano-Vilano, and M. E. García-Ramírez. 2002. Fish biodiversity changes in the lower Rio Grande/Río Bravo, 1953-1996. Reviews in Fish Biology and Fisheries 12:219-240.

Calamusso, B., J. N. Rinne, and R. J. Edwards. 2005. Historic changes in the Rio Grande fish fauna: Status, threats, and management of native species. Pages 205-223 in J. N. Rinne, R. M. Hughes, and B. Calamusso, editors. Historical changes in large river fish assemblages of the Americas. American Fisheries Society, Symposium 45, Bethesda, Maryland.

Clark, K. R., and R. H. Green. 1988. Statistical design and analysis for a 'biological effects' study. Marine Ecology Progress Series 46:213-226.

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18:117-143.

Cummins, K. W. 1962. Evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist 67:477-504.

Davis, J. R. 1980. Species composition and diversity of benthic macroinvertebrates in the upper Rio Grande, Texas. The Southwestern Naturalist 25, no. 2: 137-150.

Dahm, C. N., R. J. Edwards, and F. P. Gelwick. 2005. Gulf Coast Rivers of the Southwestern United States. Pages 181-215 in A. C. Benke, C. E. Cushing, editors. Rivers of North America. Elsevier Academic Press, Burlington, Massachusetts.

Douglas, M. E., P. C. Marsh, and W. L. Minckley. 1994. Indigenous fishes of the western North America and the hypothesis of competitive displacement *Meda fulgida* (Cyprinidae) as a case study. Copeia 1994:9-19.

Dudley, R. K., and W. J. Matter. 2000. Effects of small green sunfish (*Lepomis cyanellus*) on recruitment of Gila chub (*Gila intermedia*) in Sabino Creek, Arizona. Southwestern Naturalist 45:24-29.

Dudley, R. K., and S. P. Platania. 1997. Habitat use of Rio Grande silvery minnow. Report to the N.M. Department of Game and Fish, Santa Fe, and U.S. Bureau of Reclamation, Albuquerque, New Mexico.

Edwards, R. J. 2005. Feasibility of reintroducing Rio Grande silvery minnows *Hybognathus amarus* to the Rio Grande, Big Bend region, Texas. Final report to the U.S. Fish and Wildlife Service.

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

Edwards, R. J., and S. Contreras-Balderas 1991. Historical changes in the ichthyofauna of the lower Rio Grande (Río Bravo del Norte), Texas and Mexico. Southwestern Naturalist 36(2):201-212.

Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. Bioscience 52:1-16.

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

Garrett, C. L. 2002. Historic and current ichthyofauna of the Rio Grande and associated tributaries within Big Bend National Park and the Lower Canyons. Unpublished M.S. thesis, Sul Ross State University, Alpine, Texas.

Goldstein, R. M., and M. R. Meador. 2004. Comparisons of fish species traits from small streams to large rivers. Transactions of the American Fisheries Society. 133:971-983.

Heoinghaus, D. J., K. O. Winemiller, and J. S. Birnbaum. 2007. Local and regional determinants of stream fish assemblage structure: inferences based on taxonomic vs. functional groups. Journal of Biogeography 34:324-338.

Herbert, M. H., and F. P. Gelwick. 2003. Spatial variation of headwater fish assemblages explained by hydrologic variability and upstream effects of impoundment. Copeia 2003(2):273-284

Hoagstrom C. W. 2003. Historical and recent fish fauna of the lower Pecos River. In: G. P. Garrett and N. L. Allen, editors. Aquatic fauna of the Northern Chihuahuan Desert. Special Publications Number 46, Museum, Texas Tech University, Lubbock. pp. 91-109.

Holden, P. B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. Pages 54-74 in Ecology of Regulated Streams. J. V. Ward and J. A. Stanford, editors. Plenum, New York.

Hubbs, C. 1958. List of fishes known or expected to belong to the fauna of Big Bend National park. Unpublished report to Big Bend Natural History Association.

Hubbs, C., R. R. Miller, R. J. Edwards, K. W. Thompson, E. Marsh, G. P. Garrett, G. L. Powell, D. J. Morris, and R. W. Zerr. 1977. Fishes inhabiting the Rio Grande, Texas and Mexico, between El Paso and the Pecos confluence. In: Johnson RR, Jones DA, technical coordinators. Importance, preservation, and management of riparian habitat: a symposium. 1977. USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM: 43 pp 91-97.

Hubbs, C., R. J., Edwards, and G. P. Garrett. 2008. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Journal of Science 43(4):1-87.

Hughes, R. M., J. N. Rinne, and B. Calamusso. 2005. Introduction to historical changes in large river fish assemblages of the Americas. Pages 1-12 in J. N. Rinne, R. M. Hughes, and B. Calamusso, editors. Historical changes in large river fish assemblages of the Americas. American Fisheries Society, Symposium 45, Bethesda, Maryland.

International Boundary and Water Commission United States and Mexico 2003 Annual Report. 2003. http://www.ibwc.state.gov/Files/2003_report.pdf

International Boundary and Water Commission historical Rio Grande discharge data. http://www.ibwc.state.gov/wad/DDQJOHNS.htm

Karr, J. R. 1991. Biological integrity: a long neglected aspect of water resource management. Ecological Applications 1:66-84.

Ligon, F. K., W. E. Dietrich, and W. J. Trush. 1995. Downstream ecological effects of dams. Bioscience 45:183-195.

Li, R. Y., and F. P. Gelwick. 2005. The relationship of environmental factors to spatial and temporal variation of fish assemblages in a floodplain river in Texas, USA. Ecology of Freshwater Fish 14(4):319-330.

Lyons, J. 2005. Fish assemblage structure, composition, and biotic integrity of the Wisconsin River. Pages 345-363 in J. N. Rinne, R. M. Hughes, and B. Calamusso, editors. Historical changes in large river fish assemblages of the Americas. American Fisheries Society, Symposium 45, Bethesda, Maryland.

Maret, T. R., and C. A. Mebane. 2005. Historical and current perspectives on fish assemblages of the Snake River, Idaho and Wyoming. Pages 41-59 in J. N. Rinne, R. M. Hughes, and B. Calamusso, editors. Historical changes in large river fish assemblages of the Americas. American Fisheries Society, Symposium 45, Bethesda, Maryland.

Marfurt, R. K. 2007. Macroinvertebrate abundance and habitat associations in the Big Bend Region of the Rio Grande and comments on the life history of *Corydalis cornutus*. Unpublished M.S. thesis, Texas State University, San Marcos, Texas.

Marsh, P. C., and J. L. Brooks. 1989. Predation by ictalurid catfishes as a deterrent to re-establishment of introduced razorback suckers. Southwestern Naturalist 34:188-195.

Marsh, P. C., and M. E. Douglas. 1997. Predation by introduced fishes on endangered humpback chub and other species in the Little Colorado River, Arizona. Transactions of the American Fisheries Society 126:343-346.

Matthews, W. J. and L. G. Hill. 1980. Habitat partitioning in the fish community of a Southwestern river. Southwestern Naturalist 25(1):51-56.

Matthews, W. J. 1986. Fish faunal structure in an Ozark stream: Stability, persistence and a catastrophic flood. Copeia 2:388-397.

Matthews, W. J., and E. Marsh-Matthews. 2006. Persistence of fish species in pools of a small stream of the Southern Great Plains. Copeia 4:696-710.

Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: a case study. Southwestern Naturalist 30:173-187.

Miller, R. R. 1961. Man and the changing fish fauna of the American Southwest. Papers of the Michigan Academy of Science 46:365-404.

Moring, J. B. 2002. Baseline assessment of instream and riparian-zone biological resources on the Rio Grande in and near Big Bend National Park, Texas. USGS Water-Resources Investigations Report 02-4106.

Miyamoto, S., L. B. Fenn, and D. Swietlik. 1995. Flow, salts, and trace elements in the Rio Grande: A review. Texas Water Resources Institute Technical Report, TR-169:1-30.

Naiman, R. J., H. Décamps, and M. Pollack. 1993 The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3(2):209-212.

Onorato, D. P., R. A. Angus, and K. R. Marion 1998 Comparison of a small-mesh seine and a backpack electroshocker for evaluating fish populations in a North-Central Alabama stream. North American Journal of Fisheries Management 18:361-373.

Postel, S., and S. Carpenter. 1997. Freshwater ecosystem services. Pages 195-214 in G. Daily, editor. Nature's Services. Island Press, Washington, D.C.

Platania, S. P. 1990. The ichthyofauna of the Rio Grande drainage, Texas and Mexico, from Boquillas to San Ignacio. U.S. Fish and Wildlife Service, Region 2, Final Report.

Platania, S. P., and C. S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande Basin cyprinids. Copeia 3:559-569.

Poff, N. L., J. D. Allan, M. B. Bain, J. R Karr., K. L. Prestegard, D. B. Richter, R. E. Sparks, and J. C. Stomberg 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47:769-784.

Poff, N. L., J. D. Olden, D. M. Merritt, and D. M. Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. Proceedings of the National Academy of Sciences of the United States of America 104:5732-5737.

Richter, B. D., R. Mathews, D. L. Harrison, and R. Wigington. 2003. Ecologically sustainable water management: managing river flows for ecological integrity. Ecological Applications 13:206-224.

Richter, B. D., D. P. Braun, M. A. Mendelson, and L. L. Master. 1997. Threats to imperiled freshwater fauna. Conservation Biology 11:1081-1093.

Runyan, D. T. 2007. Fish assemblage changes in Western Gulf Slope drainages: an historical perspective and distribution and diet of larval and juvenile fishes in the Rio Grande, Texas Unpublished M.S. thesis, Texas State University, San Marcos, Texas.

Schlosser, I. J. 1991. Stream fish ecology: A landscape perspective. Bioscience 41(10): 704-712.

Schmidt, J. C., B. L. Everitt, and G. A. Richard. 2003. Hydrology and geomorphology of the Rio Grande and implications for river restoration. Aquatic fauna of the Northern Chihuahuan Desert. Special Publications Number 46, Texas Tech University pp 25–45.

Schultz, A. A., O. E. Maughan, S. A. Bonar, and W. J. Matter. 2003. Effects of flooding on abundance of native and nonnative fishes downstream from a small impoundment. North American Journal of Fisheries Management 23:503-511.

Scott, M. C., and G. S. Helfman. 2001. Native invasions, homogenization, and the mismeasure of integrity of fish assemblages. Fisheries 26:6-15.

Simonson, T. D., J. Lyons, and P. D. Kanehl. 1994. Quantifying fish habitat in streams: Transect spacing, sample size, and a proposed framework. North American Journal of Fisheries Management 14:607-615.

Sublette, J. E., M.D. Hatch, and M. Sublette. 1990. The Fishes of New Mexico. University of New Mexico Press, New Mexico.

ter Braak, C. J. F. 1986. Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis in ecology. Ecology 67:1167-1179.

Thomas, C., T. H. Bonner, and B. G. Whiteside. 2007. Freshwater fishes of Texas: A field guide. Texas A&M Press, College Station.

Texas Parks and Wildlife Department. 2008. Pollution Response Inventory and Species Mortality. TPWD's Fish Kill and Pollution Complaint Database.

Texas Parks and Wildlife Department. 2005. Texas Comprehensive Wildlife Conservation Strategy. Austin, Texas.

Trevino-Robinson, D. 1959. The ichthyofauna of the lower Rio Grande, Texas and Mexico. Copeia 1959:253-6.

U. S. Geological Survey. 2004. Biomonitoring of environmental status and trends (BEST) program: Environmental contaminants and their effects on fish in the Rio Grande Basin. Scientific Investigations Report 2004-5108.

Valdez, R. A., and R. T. Muth. 2005. Pages 157-204 in J. N. Rinne, R. M. Hughes, and B. Calamusso, editors. Historical changes in large river fish assemblages of the Americas. American Fisheries Society, Symposium 45, Bethesda, Maryland.

Ward, J. V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. Biological Conservation 83(3):269-278.

Ward, J. V., and J. A. Stanford. 1979. The ecology of regulated streams. Plenum Press, New York.

Ward, J. V., and J. A. Stanford. 1995. The serial discontinuity concept: Extending the model to floodplain rivers. Regulated Rivers: Research & Management 10:159-168.

Williams, C. S., and T. H. Bonner. 2006. Habitat associations, life history and diet of the Sabine shiner *Notropis sabinae* in an East Texas drainage. American Midland Naturalist 155:84-102.

Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society. 120:98-105.

VITA

Thomas Charles Heard was born in Houston, Texas in 1970. Tom is the (surprise) sixth child of Robert and Shirley Heard. He attended Saint Francis De Sales Catholic elementary and junior high school. Tom then attended Saint Thomas High School and graduated in 1988. After a few years of various work and educational experiences throughout Texas, he began attending Southwest Texas State University (now Texas State University – San Marcos) in 1991 and earned his BA in Geography (Natural Resources and Environmental Studies) in 1996. In 1998, Tom married Suzy Staggs and celebrated 10 years of marriage during the summer of 2008. In the fall of 2004, Tom began working for Dr. Timothy Bonner on Casey Williams' PhD project on the Lower Brazos River. After much prodding from his supervisors and associates in New Mexico and at Texas State, he took on a master's degree under Dr. Bonner. At the time of this thesis's submission, Tom was working for Rocky Mountain Research Station (USFS) in New Mexico.

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