SPATIOTEMPORAL PATTERNS OF FISH AND AQUATIC INSECTS IN AN INCREASINGLY URBANIZED WATERSHED OF CENTRAL TEXAS

THESIS

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ABSTRACT

SPATIOTEMPORAL PATTERNS OF FISH AND AQUATIC INSECTS IN AN INCREASINGLY URBANIZED WATERSHED OF CENTRAL TEXAS

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Aquatic systems in the Edwards Plateau region of Central Texas provide habitat for a large number of endemic fauna. Within the last decade, the Edwards Plateau region has experienced rapid human population growth and the effects of urbanization on water quality and quantity is a growing concern. Purposes of this study were to quantify aquatic insect communities and fish assemblages in the relatively undisturbed Pedernales River drainage of the Edwards Plateau, to assess factors influencing species occurrence and distribution through time, and identify current impacts of urbanization due to a number of land use changes and in-stream modifications. Nine sites (five mainstem sites and four tributary sites) were sampled seasonally for one year. The Pedernales River is a typical Edwards Plateau stream with bedrock and cobble substrates, moderate current velocity, and it is well oxygenated, clear, and temperate. Upper reaches had swifter current velocities and coarse substrates with decreasing substrate sizes and current velocities downstream. A total of 52 families from 10 orders of aquatic insects were identified and dipterans and ephemeropterans dominated the assemblage (66.6%). Aquatic insect diversity ranged from 1.50 – 2.38 and fish diversity ranged from 1.00 – 2.09; upper reaches had higher number of habitat specialists whereas lower reaches had more habitat generalists. Thirty-five species of fish were identified and Cyprinidae was the most abundant family, comprising 68.1% of the assemblage. Endemic species to the Edwards Plateau comprised 7.4% of the fish assemblage whereas introduced species collectively represented 4.8%. Effects of wastewater effluent were apparent in Barons Creek and the mainstem Pedernales River directly downstream of its confluence with higher numbers of generalist and pollutant tolerant taxa, such as Chironomidae and red shiner *Cyprinella lutrensis*. Environmental parameters, season, and site explained 71.1% of the variability within the aquatic insect community and 64.2% of the variability within the fish assemblage. This region is considered a priority for conservation and the Pedernales River is a system under various degrees of degradation. Predictive models from these data help understand how communities shift with increased urbanization and how distributions of endemic taxa will be affected when overlapped with some of the fastest growing metropolitan areas in the country.

CHAPTER I

SPATIOTEMPORAL PATTERNS OF FISH AND AQUATIC INSECTS IN AN INCREASINGLY URBANIZED WATERSHED OF CENTRAL TEXAS

INTRODUCTION

In lotic ecosystems, fish and aquatic insect abundances and distributions are determined by many factors (Hoeinghaus et al. 2007), including physical environment (Harrell 1978; Capone and Kushlan 1991), biogeography (Losos 1996), biotic interactions (Power et al. 1988; Matthews and Marsh-Matthews 2006), and life histories (Olden et al. 2006; Poff et al. 2006). Though all have integral roles in determining suitability of habitat for species, often the dominant force structuring aquatic communities is stream flow (Harrell 1978; Poff and Ward 1989). Stream flow regimes regulate channel morphology, substrate type, thermal conditions, resource availability, and habitat volume (Power et al. 1988; Poff and Allan 1995; Taylor and Warren 2001). Understanding how variation in stream flow and its correlates affect aquatic fauna temporally offers insight on fundamental biological-physical associations, better illustrating deterministic predictions for community organization (Matthews and Marsh-Matthews 2006; Hoeinghaus et al. 2007).

Watershed management and the development of instream flow recommendations depend on an understanding of how urbanization and instream anthropogenic modification relate to faunal community structure and environmental resiliency (Wang et al. 2001; Tharme 2003; Sullivan et al. 2006). In general, encroaching urbanization and instream modification threaten aquatic communities by longitudinally shifting community structure (Weaver and Garman 1994), increasing sedimentation and turbidity (Walters et al. 2003), decreasing infiltration with more impervious surfaces (Wang et al. 2001), dewatering stream reaches (Bowles and Arsuffi 1993), and disrupting natural hydrologic regimes (Poff and Allen 1995; Taylor and Warren 2001; Bean et al. 2007). The Edwards Plateau region of Central Texas contains five of the 100 fastest growing counties in the United States (Comal, Guadalupe, Hays, Kendall, and Williamson counties) and is located just west of the 10th fastest growing metropolitan area in the country, Austin (USCB 2008a; 2008b). This region boasts a number of regionally endemic taxa (Bowles and Arsuffi 1993) and is considered a priority for conservation due to the overlap of urbanization and agriculture with extraordinary species richness (Ricketts and Imhoff 2003). Information is needed on the instream biota of these watersheds within this region to make informed decisions and to quantitatively predict the relationship between urbanization and biological communities (Wang et al. 2001).

The Edwards Plateau is dominated by porous Cretaceous limestone where precipitation is responsible for aquifer recharge and streams are characterized by seasonal stream intermittency and large, short-lived flood events (Conner and Suttkus 1986; Bowles and Arsuffi 1993; Pendergrass 2006). These stream characteristics greatly influence much of the Edwards Plateau riverine communities, selecting through time a native fauna adept at coping with irregular high flow events (Harrell 1978; Matthews 1988; Blum and Valastro 1989). Located on the northeastern edge of the Edwards Plateau, the Pedernales River flows 176 km east through an uplifted section of Central

Texas into the Colorado River (Blum and Valastro 1989). The drainage area encompasses 3,300 km^2, the majority of which is located within Blanco and Gillespie counties but includes areas of Burnet, Hays, Kendall, Kerr, Kimble, and Travis counties (LCRA 2000).

The Pedernales River supports a number of regionally endemic aquatic taxa. The fish and aquatic insect assemblages include species with large geographic distributions as well as those finding their entire range limited within the Edwards Plateau (Conner and Suttkus 1986; Bowles and Arsuffi 1993). Natural variation in stream discharge is vital to native aquatic fauna (Taylor and Warren 2001) and the physical environment greatly influences aquatic communities (Poff and Allan 1995; Higgins 2005). Studies on the adjacent Blanco River demonstrated linkages between seasonality and physical habitat on structuring assemblages of both fish and macroinvertebrates (Bean 2006; Pendergrass 2006; Bean et al. 2007). Although the Pedernales River is a system of recreational, commercial, and environmental importance (Bowles and Arsuffi 1993; Leopold 2001), relatively little work has been conducted on the mainstem. Much of the previous work on fish and macroinvertebrates of the Pedernales River has been conducted at a broader level or has resided solely within the tributaries of the basin (Birnbaum 2005; Higgins 2005; Birnbaum et al. 2007). More temporal work is necessary to further understand connectivity of tributaries to the mainstem as important linkages exist in connections by way of: hydrological input, disturbance refugia, and source populations for obligate tributary, or in many cases, spring-associated taxa (Rice et al. 2001; Franssen et al. 2006; Birnbaum et al. 2007). The study objectives were to describe the environmental and spatial variation in community dynamics and assemblage structure for fish and aquatic insects in the Pedernales River basin. This study will provide baseline information for these fauna and their relationships with specific habitat that can be used for conservation efforts in the face of increasing threat of urbanization in the study area and adjacent watersheds.

MATERIALS AND METHODS

Nine sites within the Pedernales River basin were sampled in February, April, June, and November 2007. Five mainstem sites spanning the section of perennial flow in the Pedernales River (sites 1 – 5) and four major tributary sites; Live Oak Creek, Barons Creek, North Grape Creek, and Cypress Creek (Figure 1). Fish collections were made at all sites while aquatic insect collections were made at Pedernales River sites 2, 3, and 5, and Barons Creek and Cypress Creek. Pedernales River mainstem sites ranged in drainage area size from 2735.45 km^2 at site 5 to 513.65 km^2 at site 1 and tributary sites ranged from 274.40 km^2 at North Grape Creek to 83.20 km^2 at Barons Creek (Table 1).

Sites were sampled exhaustively for aquatic insects and fish, and effort was proportional to the dominant geomorphic unit levels (e.g., pool, riffle, run, backwater). For each geomorphic unit, current velocity and water depth was taken at a representative transect with a Marsh-McBirney Flow-Mate current velocity meter. In addition, length and width of the geomorphic unit was measured, and percent substrate composition was visually estimated and measured on a modified Wentworth scale (Cummins 1962). Stream discharge (m^3/s) on the Pedernales River for the sample year (1/1/2007 – 12/31/2007) and for the period of record (10/1/1938 – 9/30/2008) was obtained from the United States Geological Survey gauge near Johnson City (USGS Gauge I.D. 08153500).

At each site, temperature (°C), specific conductance (µS/cm), pH, dissolved oxygen (mg/L), and turbidity (nephelometric turbidity units [NTU]) were measured with a YSI Model 660 water quality sensor.

Aquatic insects were semi-quantitatively sampled using a 0.3-m wide D-frame kick net with 500-µm mesh for a total site effort of twenty 0.5-m jabs or kicks, equaling approximately 3.1 m^2 in total area per site effort. Aquatic insects were also quantitatively sampled at each site using a 0.5-m diameter Hess-type sampler with 363-µm mesh. Field protocol followed the United States Geological Survey National Water Quality Assessment Program (Moulton et al. 2002), the Environmental Protection Agency's Rapid Bioassessment (Barbour et al. 1999), and Courtemanch (1996). Samples were preserved on site with a 95% solution of ethanol and returned to the laboratory for identification and enumeration. Aquatic insect collections were subsampled to at least 240 (300 ± 20%) individuals in a "two-phase processing" technique (Vinson and Hawkins 1996; Barbour et al. 1999; Moulton et al. 2002). Samples were homogenized in a sorting pan and searched for "large-rare" taxa up to 10 minutes before the pan was affixed with a temporary grid of 5 cm square cells. Cells to be sorted were selected using a random numbers table and contents within selected cells were removed and transferred to a gridded petri dish. Organisms were separated from samples and enumerated until the fixed count number was met then preserved in a 70% solution of ethanol. Aquatic insects were identified to the lowest practical taxon, typically to family (Thorp and Covich 2001; King and Richardson 2002; Merritt et al. 2008). To maintain quality control, voucher specimens from the samples were independently verified (Barbour et al. 1999).

Fish were collected with multiple passes using a 2.4 x 1.8 m seine with 3.2-mm mesh and a Smith-Root backpack electrofisher. Fish were identified to species (Hubbs et al. 2008) and enumerated with total lengths taken from up to 30 individuals (Thomas et al. 2007). All fish were released on site except for voucher individuals, which were anesthetized in a lethal dose of tricaine methanesulfonate (MS-222) and preserved in a buffered 10% solution of formalin. In the case that individual fish displayed characteristics of multiple species, a hybrid category was created at the genus level but no genetic tests were run to confirm hybridization.

Environmental and assemblage data were analyzed using multivariate analyses, specifically Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA). PCA was used to look at how changes in physical habitat vary both spatially and temporally throughout the river basin and within each site (Matthews and Marsh-Matthews 2006). Seasonal and temperature dependent data (i.e., temperature, conductivity, dissolved oxygen, pH) were excluded from this analysis and missing values for depth and current velocity were estimated by the average depth and current velocity of similar geomorphic units at the site. Ordinal data was categorized as dummy variables and numerical data was z-score transformed (Krebs 1999). CCA was then used to examine relationships between habitat variables and faunal assemblage structure while limiting environmental variation, with included variance partitioning (Canoco 4.5, ter Braak 1986; Borcard et al. 1992). All families were included in the model for aquatic insects and in the model for fish, species considered rare (total abundance < 2 individuals) were omitted from the analyses (i.e., common carp *Cyprinus carpio*, longnose gar *Lepisosteus osseus*, blue catfish *Ictalurus furcatus*, black crappie *Pomoxis nigromaculatus*) and one anomalous sample of channel catfish *Ictalurus punctatus* (n =

482) was averaged from other seasonal samples from that site. Ordinal data was categorized as dummy variables.

RESULTS

Mainstem and tributary aquatic habitats were quantified from 99 geomorphic units taken in the Pedernales River basin. Among sites, geomorphic units were primarily runs (34%), riffles (31%), and pools (20%), with relatively shallow to moderate depths (range of seasonal means: 22.0 – 85.5 cm) and moderate current velocities (0.15 – 0.51 m/s) over primarily bedrock (27%), cobble (26%), and gravel (18%) substrates (Table 1). Water was temperate (range of annual means for all sites: 16.7 – 20.4°C), clear (0.35 – 10.0 NTU), slightly basic (8.1 – 8.5 pH), well oxygenated (6.6 – 11.5 mg/l), and with low specific conductance (0.53 – 0.95 μS/cm). Daily streamflows ranged from 0.48 m^3/s on March 6 to 1,124 m^3/s on August 17, 2007 (Figure 2). Mean daily streamflow in 2007 was ranked 7th highest among annual streamflows of record (1938 – 2008).

First two axes of PCA explained 23.1% of the total variation in environmental parameters among geomorphic units (Figure 3). Principal component I described a current velocity, geomorphic unit, and substrate gradient with current velocity (-1.99), riffles (-1.69), cobble (-1.12), submerged vegetation (1.34), pools (1.38), and sand (1.75) having the strongest loadings on the axis. Principal component II described a substrate and geomorphic unit size gradient with cobble (-1.97), riffles (-1.53), gravel (-1.11), turbidity (1.46), geomorphic unit width (1.47), and bedrock (2.29) having the strongest loadings along the axis. Geomorphic units from upstream sites (sites 1 and 2) generally consisted of swifter current velocities and gravel and cobble substrates, whereas geomorphic units from downstream sites (sites 3, 4 and 5) consisted of slower current velocities and proportionally more sand and bedrock substrates. Among tributary sites, geomorphic units in Live Oak Creek and Barons Creek generally consisted of sand and gravel substrates and submerged aquatic vegetation, geomorphic units in North Grape Creek generally consisted of swifter current velocities and cobble substrates, and geomorphic units in Cypress Creek consisted of swifter current velocities with primarily bedrock substrates.

A total of 9,999 aquatic insects identified from 10 orders and 52 families were collected from Pedernales River mainstem sites 2, 3, and 5 and Barons Creek and Cypress Creek. Among insect orders, Diptera was most abundant (48.3% in relative abundance), followed by Ephemeroptera (18.3%), Trichoptera (10.1%), and Coleoptera (7.7%). Among insect families, Chironomidae was most abundant (40.2%), followed by Leptohyphidae (12.3%), Baetidae (10.6%), Elmidae (6.9%), and Simuliidae (5.0%). Pedernales River mainstem sites consisted of 46 families (*S*), ranging from 31 to 35 families among sites. Shannon diversity (*H'*) ranged from 1.98 at site 3 to 2.38 at site 2, and Shannon evenness (*J'*) ranged from 0.57 at site 3 to 0.96 at site 2. Barons Creek and Cypress Creek both consisted of 31 families among sites with a Shannon diversity of 1.50 at Barons Creek and 2.30 at Cypress Creek and a Shannon evenness of 0.42 at Barons Creek and 0.67 at Cypress Creek. Fourteen families (Curculionidae, Dytiscidae, Entomobryidae, Isotomidae, Tanyderidae, Thaumaleidae, Baetiscidae, Siphlonuridae, Corixidae, Crambidae, Nocturidae, Lestidae, Perlidae, and Glossosomatidae) were unique to the Pedernales River mainstem sites 2, 3, and 5, whereas six families (Gyrinidae, Empididae, Belostomatidae, Mesoveliidae, Nepidae, and Protoneuridae) were unique to Barons Creek and Cypress Creek.

A total of 11,957 fish and 35 species were collected from the Pedernales River mainstem sites 1 – 5, Live Oak Creek, Barons Creek, North Grape Creek, and Cypress Creek. Cyprinidae was the most abundant family (68.1%), followed by Centrarchidae (15.3%), Ictaluridae (4.8%), and Poeciliidae (4.5%). Among species, blacktail shiner *Cyprinella venusta* was the most abundant (38.6% in relative abundance), followed by red shiner *Cyprinella lutrensis* (20.1%), central stoneroller *Campostoma anomalum* (5.0%), redbreast sunfish *Lepomis auritus* (4.7%), and western mosquitofish *Gambuisa affinis* (4.6%). Six species endemic to the Edwards Plateau (Guadalupe roundnose minnow *Dionda nigrotaeniata*, Texas shiner *Notropis amabilis*, gray redhorse *Moxostoma congestum*, Guadalupe bass *Micropterus treculii*, greenthroat darter *Etheostoma lepidum*, and Texas logperch *Percina carbonaria* [Hubbs et al. 2008]) were collected in the Pedernales River basin and comprised 7.4% of the fish assemblage. Introduced species (common carp, redbreast sunfish, and Rio Grande cichlid *Cichlasoma cyanoguttatum*) collectively represented 4.8% of the total species assemblage. Pedernales River mainstem sites consisted of 31 species (*S*), ranging from 14 to 22 species among sites. Shannon diversity (*H'*) ranged from 1.00 at site 5 to 1.90 at site 1, and Shannon evenness (*J'*) ranged from 0.32 at site 5 to 0.61 at site 1. Tributary sites consisted of 32 species, ranging from 14 to 25 species among sites. Shannon diversity ranged from 1.43 at Live Oak Creek to 2.09 at Barons Creek, and Shannon evenness ranged from 0.54 from Live Oak Creek to 0.64 at Barons Creek. Three species (longnose gar, inland silverside *Menidia beryllina*, and dusky darter *Percina sciera*) were found unique to the Pedernales River mainstem, whereas five species (common carp, black bullhead *Ameiurus melas*, yellow bullhead *A. natalis*, blue catfish, and black crappie) were unique to tributaries, primarily Barons Creek.

Environmental parameters, season, and site explained 71.1% of the variability within the aquatic insect community (total inertia = 2.5, sum of all eigenvalues = 1.8) among Pedernales River mainstem sites 2, 3, and 5 and Barons Creek and Cypress Creek (Figure 4). Pure effect of environmental parameters explained 38.1% ($P = 0.01$), pure effect of site explained 6.7% ($P = 0.06$), and pure effect of season explained 5.9% ($P = 0.10$) of the assemblage variation. Among pure effects and two-way and three-way interactions, factors with the strongest loadings on CCA axis I were mean current velocity (biplot score = -0.44), geomorphic unit width (-0.44), site 2 (-0.43), sand (0.42), Barons Creek (0.68), and conductivity (0.77). Factors with the strongest loadings on CCA axis II were cobble (-0.53), site 2 (-0.51), boulder (-0.30), bedrock (0.47), turbidity (0.49), and site 3 (0.66). Nepidae (biplot score = 1.78), Leptohyphidae (1.09), Crambidae (1.06), and Curculionidae (1.05) were positively associated with CCA I and were most abundant at Barons Creek where they were associated with higher conductivity and higher dissolved oxygen in slower current velocities over sand and gravel substrates. Nocturidae (-1.70), Perlidae (-1.65), Tanyderidae (-1.50), and Helicopsychidae (-1.10) were negatively associated with CCA I and were abundant at site 2 with swifter current velocities in wide riffles. Corixidae (2.14), Helicopsychidae (2.03), Nocturidae (1.60), and Haliplidae (1.81) were positively associated with CCA II and were abundant at site 3 closely following higher turbidity in swifter current velocities over bedrock. Glossosomatidae (-1.91), Lestidae (-1.38), Baetiscidae (-1.37), and Leptophlebiidae (-

1.14) were negatively associated with CCA II and were abundant at site 2 with swift current velocities in riffles over cobble and boulder.

Environmental parameters, season, and site explained 64.2% of the variability within the fish assemblage (total inertia = 4.1, sum of all eigenvalues = 2.6; Figure 5). Pure effect of environmental parameters explained 25.2% ($P < 0.01$), pure effect of site explained 13.6% ($P < 0.01$), and pure effect of season explained 6.4% ($P < 0.01$) of the assemblage variation. Among pure effects and two-way and three-way interactions, factors with the strongest loadings on CCA axis I were site 3 (biplot score = -0.69), turbidity (-0.53), dissolved oxygen (-0.48), riffle (0.37), cobble (0.40), and site 1 (0.60). Factors with the strongest loadings on CCA axis II were sand (-0.43), submerged vegetation (-0.32), and Barons Creek (-0.31), site 3 (0.42), cobble (0.47), site 1 (0.58). *Cyprinella* hybrids (-1.20), red shiner (-1.00), western mosquitofish (-0.87), and channel catfish (-0.71) were negatively associated with CCA I, specifically more abundant at site 3 with higher turbidity and dissolved oxygen. Texas shiner (2.09), mimic shiner *Notropis volucellus* (1.81), redear sunfish *Lepomis microlophus* (1.00), and yellow bullhead (0.91) were positively associated with CCA I and were most abundant at site 1 or Barons Creek in riffles with substrates of cobble and gravel. Similarly, Texas shiner (2.07), mimic shiner (1.79), and Texas logperch (0.68) were positively associated with CCA II and were found in swifter current velocities of riffles with cobble substrates at site 1. Dusky darter *Percina sciera* (-1.47), yellow bullhead (-1.26), orangethroat darter *Etheostoma spectabile* (-1.13), and central stoneroller (-1.06) were negatively associated with CCA II, where their abundance highest at site 5, Cypress Creek, Live Oak Creek, and Barons

Creek at greater depths with submerged aquatic vegetation, and sand and gravel substrates.

DISCUSSION

The aquatic insect assemblages of the Pedernales River and its tributaries are typical of those reported in other Edwards Plateau drainages, where mean annual aquatic insect diversity ranged from 1.50 to 2.38, species richness ranged from 31 to 35, and Chironomidae, Leptohyphidae, and Baetidae were the dominant families. Among a comparable study on the adjacent Blanco River, diversity ranged from 1.8 to 2.7 (genus level), species richness ranged from 23 to 37 (genus level), and Chironomidae, Philopotamidae, and Simuliidae all combined to comprise almost one-third of the collected macroinvertebrates (Pendergrass et al., in review). Both these streams are hydrologically influenced by spring flow with seasonal overland flow disturbances and both experience seasonal stream intermittency and have assemblages primarily consisting of collector-gatherers. In the nearby San Marcos River, a spring flow dominated system on the eastern edge of the Edwards Plateau, diversity ranged from 1.28 to 2.88, species richness ranged from 22 to 34, and assemblages of collector-gatherers and grazers (Fries and Bowles 2002). Similarities are also seen in other Edwards Plateau drainages such as the Devils River, where diversity ranged from 2.10 to 3.60 (genus level), species richness from 10 to 25 (genus level), and Leptohyphidae, Baetidae, and Hydropsychidae comprised 43.7% of the collected insect assemblage (Davis 1980c). The Devils River aquatic insect assemblage is predominantly seen as a western Edwards Plateau drainage though it does receive influence from southwestern and western Texas ecoregions where higher percentages of shredders, scrapers, and predators are typical (Davis 1980c). Macroinvertebrate assemblages within Edwards Plateau drainages collectively represent a transitional community, bordered by eastern drainages characterized by higher precipitation and less flashy aquatic systems and by western drainages characterized by less annual precipitation and more flashy aquatic systems. Family-level diversity in eastern drainages of Texas and Louisiana ranged from 1.93 to 3.10, species richness ranged from 40 to 58, and families of Chironomidae and Caenidae dominated the community (Williams et al. 2005). Lower gradients and loamier soils owe to a more temporally stable hydrograph, whereas, in western drainages of Texas and New Mexico diversity ranged 0.55 to 3.31 in the Rio Grande River (genus level), species richness ranged from 12 to 50 (genus level), and collector-filterer families adapted for greater temporal fluctuations in environmental conditions such as Chironomidae, Hydropsychidae, and Leptophlebiidae dominate the assemblage (Davis 1980a, 1980b). Intermediate disturbances, much like those seen in the Edwards Plateau, coupled with precipitation and spring flow input may explain differences in aquatic insect diversity and richness. Though evenness may be higher in less disturbed environments, allowing for competitive interaction and greater diversity (Huston 1979; Death and Winterbourn 1995), several endemic aquatic insect taxa are present amongst systems within the Edwards Plateau (Davis 1980c; Bowles and Arsuffi 1993). However, the scope of this study did not allow a taxonomic resolution fine enough to make comparisons and contrasts in rates of endemism and diversity across geographic gradients.

As with the aquatic insect assemblages, the fish assemblages of the Pedernales River and its tributaries were typical of the region and similar in composition to neighboring and regional drainages. Diversity ranged from 1.00 to 2.09, species richness ranged from 14 to 25, and Cyprinidae was the dominant family throughout the Pedernales River basin. Within the adjacent Blanco River, diversity ranged from 1.07 to 1.87, species richness ranged from 6.5 to 11.9, and Cyprinidae, Centrarchidae, and Poeciliidae were the dominant families (Bean et al. 2007). The Devils River had diversity that ranged from 1.39 to 2.74, species richness from 7 to 15, and the assemblage was dominated by five cyprinid species that nearly comprised 75-93% of the average biomass, pre and post-flood (Harrel 1978; Kollaus 2009). Streams in western drainages of Texas such as the Pecos River did not see major differences in diversity (1.79), species richness (24), or the dominant family of Cyprinidae compared with those of the Edwards Plateau (Bonner et al. 2005). Likewise, drainages in eastern Texas and Louisiana have species diversity ranging from 1.32 to 2.15, species richness ranging from 18 to 30, and an assemblage dominated by cyprinids (Williams et al. 2005). Abundance of cyprinids within drainages is common among fish assemblages throughout North America, as it is the most species rich family (Jelks et al. 2008). However, Edwards Plateau drainages support a larger than expected number of endemic forms (Conner and Suttkus 1986; Hubbs et al. 2008), likely associated with water permanency attributed to the regional karst aquifer (R. Maxwell, unpublished data). Several Edwards Plateau endemics persist among the Pedernales River sites and tributaries. Among those of special concern include Guadalupe roundnose minnow, burrhead chub *Macrhybopsis marconis*, gray redhorse, Guadalupe bass, and greenthroat darter (Hubbs et al. 2008; Jelks et al. 2008). Healthy populations of Guadalupe bass were found in the upper reaches, but non-introgressed Guadalupe bass are limited to a fraction of their original range and have been affected by mainstem Colorado River reservoirs and the introduction of smallmouth bass *Micropterus dolomieu* (Edwards 1980; Garrett 1991; Perkin et al. 2010). Burrhead chub and plains killifish *Fundulus zebrinus* were previously collected in the Pedernales River but undetected throughout sampling in this study (Birnbaum 2005; Eisenhour et al. 2004). Though likely that plains killifish are found further upstream in tributaries of the Pedernales River than sampling allowed in this study, exploratory sampling targeting habitats likely occupied by burrhead chub in the lower Pedernales River produced no individuals. The last record of burrhead chub in the Pedernales River was 1952 (Eisenhour et al. 2004) and it has been postulated that this species has been extirpated from the Pedernales River due to river impoundments near the confluence with the Colorado River.

The aquatic insect and fish assemblages within the Pedernales River and its tributaries were found to broadly segregate into two groups—habitat specialists and habitat generalists. Habitat specialists, such as Perlidae, Glossosomatidae, Texas shiner, and Texas logperch, were associated with riffle and run habitats of swifter streamflows, gravel and cobble substrates, and shallow depths in upper reaches. Habitat generalists, such as Chironomidae, Coenagrionidae, bullhead minnow, and redbreast sunfish, were associated with run and pool habitats with sluggish streamflows, bedrock and gravel. Several low-head dams influence streamflow, habitats, and connectivity in the middle reaches of the Pedernales River and its tributaries. Low-head dam diversions homogenize habitat and generalize the fish assemblages by creating a distinctly lentic environment and increasing turbidity while lowering dissolved oxygen (Bean et al. 2007). Consequently, Pedernales River fish assemblages show similar effects, attributed to anthropogenic modifications. In addition, generalist macroinvertebrates and fishes at site 3 and Barons Creek likely were influenced by receiving water with high nutrient loads from a waste water treatment plant located upstream of Barons Creek and enters the Pedernales River upstream from site 3. High nutrient loadings generally increase the number of generalist macroinvertebrates and fish in streams (Weaver and Garman 1994; Walters et al. 2003). Though downstream effects were influenced by higher stream discharges during this study (Strickland 2009), nutrient loadings were not so diluted or concentrated as to mask the effects indicated by higher percentages of abundance in generalists taxa at site 4 and site 5. Additionally, individuals visually estimated as hybrids of red shiner and blacktail shiner were collected at both site 3 and Barons Creek. Hubbs and Strawn (1956) had seen hybrids of these species on the Guadalupe River, TX downstream of heavy oilfield activity where turbidity was abnormally high. They postulated that the high turbidity was caused by excessive runoff decreasing species recognition during spawning. Walters et al. (2008) reported similar findings on the Coosa River, AL with positive correlations between hybridization of these two species and disturbance through increased agricultural land use.

Upstream areas of the Pedernales River mainstream and tributaries provided habitat for specialist taxa and therefore represent areas of high biotic diversity within the drainage. Areas with increased numbers of specialist taxa in the Pedernales River and its tributaries are characterized by the maintenance of groundwater discharge to support streamflow, increased habitat heterogeneity, and the lack of introduced taxa. The specialist taxa include those that are known to be sensitive to long-term environmental change. Habitat and the interrelated faunal communities were driven and constrained by environmental variation, of which, many of the natural disturbances still occur largely uninterrupted (e.g., large impoundments dampening high flow events). Within the study period several of these large-scale floods occurred between sampling collections while the faunal assemblages remained relatively unchanged. The large amount of significant variation explained in the CCA models for fish and aquatic insects suggests a strong association between species/family and habitat with patterns for organizations consistent between pre and post disturbance. Aquatic habitats with specialists and generalists provide predictive models to assess future influence of urbanization (i.e., modified flows, nutrient loading, dewatering of groundwater, sedimentation) and improved understanding of natural variability with relation to anthropogenic modification is necessary in better biomonitoring (Scott and Helfman 2001; Merritt et al. 2008).

The Pedernales River basin is being increasingly populated and nearby urban areas are growing at a tremendous rate (USCB 2008a; 2008b). With increases in urbanization and reduction of available resources and habitat through land use conversion and nutrient addition (Strickland 2009), it is likely that generalist and anthropogenic disturbance tolerant species will increase in range and abundance within the Pedernales River and its tributaries and taxa with more specific habitat and environmental needs will be replaced (McKinney and Lockwood 1999; Ricciardi and Rasmussen 1999; Walters et al. 2003). Long term changes in a system can lead to changes in trophic and assemblage structure, further altering the physicality of a stream (Allan and Flecker 1993; Weaver and Garman 1994; Ricciardi and Rasmussen 1999). Altered habitat and deterioration such as increased sediment loads and pollutants threaten many of the world's freshwater fishes and it is thought that freshwater fauna are disproportionately imperiled with regard to other North American fauna (Ricciardi and Rasmussen 1999; Walters et al. 2003). In western drainages of Texas, including the Colorado River, declines were seen for darters and minnows amongst other specialist-type taxa (Anderson et al. 1995). Additionally, characteristically similar streams that have experienced changes in land use (i.e., increases in urbanization and agriculture) have shown impacts to have a significant effect on aquifer recharge and soil water content (Bellot et al. 2001). In the Pedernales River, disturbances associated with wastewater treatment effluent and light agriculture may increase the number of pollutants and the pathways and volume of recharge into the aquifer (Strickland 2009). For species dependent on spring flow influence, these disturbances could have a profound effect on assemblage composition. In fish, it has been noted that the loss of a species can further increases in extinction and disrupt ecosystem functioning (Ricciardi and Rasmussen 1999). The Pedernales River fish and aquatic insect assemblages show a distinct separation between generalist and specialist taxa when comparing the headwaters to the furthest downstream sections, possibly exhibiting only some of the geographic variation often seen with changes in river size (Allan and Flecker 1993). With influences from urban areas and agriculture, the dichotomy between these species is blurred (i.e., less niche separation and increased interaction amongst specialists and generalists) and it is thought that distinctions between areas of the basin will become less clear. Geology and climate can ultimately determine species biodiversity (Wang et al. 2001) but at local levels water quality and habitat diversity prove vital. Inversely, an intact faunal assemblage can indicate exceptional water quality and be a measure for environmental health (Karr 1991). In managing for biodiversity within this region it will be necessary to increase habitat and structural diversity, both have been shown to create more niches (Brierley et al. 1999). It is also necessary to inventory and assess the diversity in a system (Lydeard and Mayden 1995) and identify and predict the effects human activities will have on the biological system (Wang et al. 2001; Oberdorff et al. 2002).

Table 1. Summary of the environmental and habitat parameters recorded at Pedernales River sites 1 – 5, Live Oak Creek (LC), Barons Creek (BC), North Grape Creek (GC), and Cypress Creek (CC) from February 2007 through November 2007. Environmental data are reported as means with standard errors (SE) and habitat data are reported as percentages.

	Pedernales River sites					Tributary			
	1	2	3	4	5	LC	BC	GC	CC
Drainage size (km^2)	513.65	912.69	1,278.29	1,738.86	2,735.45	97.70	83.20	274.40	132.74
Environmental parameters - mean (SE)									
Current velocity (m/s)	0.26 (0.05)	0.51 (0.09)	0.38 (0.06)	0.16 (0.05)	0.42 (0.10)	0.19 (0.04)	0.23 (0.06)	0.15 (0.04)	0.17 (0.05)
Depth (cm)	41.18 (6.07)	47.13 (5.17)	21.97 (2.37)	44.89 (5.77)	85.54 (14.89)	30.54 (2.72)	29.82 (6.15)	55.11 (7.21)	36.70 (6.47)
Temperature (°C)	18.49 (1.67)	18.55 (1.56)	20.02 (1.79)	19.17 (2.40)	18.58 (2.09)	16.71 (2.21)	20.11 (2.33)	20.44 (1.43)	18.17 (1.57)
Dissolved oxygen (mg/l)	8.16 (0.90)	9.23 (0.92)	11.51 (1.11)	9.89 (0.60)	8.99 (0.73)	7.51 (1.00)	10.61 (1.61)	7.0 (1.07)	6.58 (1.43)
Conductivity (mS/cm)	0.580 (0.014)	0.608 (0.011)	0.648 (0.017)	0.622 (0.022)	0.531 (0.019)	0.622 (0.007)	0.951 (0.041)	0.563 (0.009)	0.577 (0.011)
pH	8.31 (0.02)	8.33 (0.02)	8.47 (0.06)	8.34 (0.03)	8.41 (0.05)	8.14 (0.04)	8.52 (0.10)	8.32 (0.05)	8.17 (0.08)
Turbidity (NTU)	2.03 (0.38)	4.53 (0.72)	10.01 (1.53)	7.13 (1.49)	7.00 (1.66)	0.36 (0.15)	0.93 (0.40)	0.50 (0.15)	0.35 (0.13)
Habitat parameters - %									
Backwater	-	-	15.4	27.3	-	-	27.3	-	-
Eddy	-	-	-	9.1	12.5	-	-	-	-
Pool	33.3	21.4	-	27.3	25.0	20.0	9.1	33.3	12.5
Run	33.3	35.7	30.8	36.4	50.0	40.0	27.3	33.3	25.0
Side channel	-	-	23.1	-	-	-	-	-	12.5
Riffle	33.3	42.9	30.8	-	12.5	40.0	36.4	33.3	50.0
Silt	0.1	-	8.8	16.4	-	7.5	-	2.5	2.5
Clay	-	-	-	9.1	-	-	-	-	1.9
Sand	4.2	7.1	1.5	14.5	25.8	37.5	35.5	3.6	0.6
Gravel	34.2	19.3	3.1	2.7	5.6	39.0	30.0	17.7	5.6
Cobble	59.1	58.6	3.9	7.3	26.1	16.0	24.5	32.1	6.1
Boulder	2.5	13.9	8.6	0.9	23.8	-	5.5	33.9	0.8
Bedrock	-	1.1	74.2	49.1	18.8	-	4.5	10.3	82.5
Aquatic vegetation	3.0	3.0	-	-	2.0	9.0	10.0	2.0	9.0

Table 2. Relative abundances with calculated annual species richness (*S*), Shannon diversity (*H'*), and Shannon evenness (*J'*) of collected aquatic insect families at Pedernales River sites 2,3, and 5, Barons Creek (BC), and Cypress Creek (CC) from February 2007 through November 2007.

		Site				
Order	Family	2	3	5	BC	CC
Coleoptera	Curculionidae	-	-	0 09	-	-
	Dryopidae	0 22	0.04	0 38	-	0 58
	Dytiscidae	0 04	0.16	0.19	-	-
	Elmidae	8.03	6 68	1.33	2.25	22 08
	Gyrinidae	-	-	-	0.34	0.87
	Haliplidae	0.04	0 83	-	0.15	-
	Hydrophilidae	-	0 12	0.19	0.11	-
	Staphylinidae	-	0 04	-	-	0.10
Colembola	Entomobryidae	-	0 08	-	-	-
	Isotomidae	-	-	0.09	-	-
Diptera	Ceratopogonidae	0 04	0.28	2.56	0.15	1.64
	Chironomidae	28 76	44 36	43 75	51.20	27.97
	Empididae	-	-	-	-	0.48
	Simuliidae	12 22	1 55	10.04	0.41	1.16
	Stratiomyidae	-	-	-	0.08	0.77
	Tabanidae	-	-	0.28	0 23	0.19
	Tanyderidae	0 04	-	-	-	-
	Thaumaleidae	-	-	0.38	-	-
	Tipulidae	1.47	4 37	0.47	1.95	2.22
Ephemeroptera	Baetidae	13.17	14.90	9 75	5.07	8.49
	Baetiscidae	-	-	0 19	-	-
	Caenidae	0 15	0.36	3.69	0.45	0.87
	Heptageniidae	0 29	0.04	0.85	0.15	0.77
	Isonychiidae	5 76	1.23	0.38	0 04	-
	Leptohyphidae	5 36	2.82	5.11	30.14	15 14
	Leptophlebiidae	6.93	0.16	8.43	0.11	0 48
	Siphlonuridae	-	-	0.57	-	-
Hemiptera	Belostomatidae	-	-	-	0.04	-

		Site				
Order	Family	2	3	5	BC	CC
Hemiptera cont	Corixidae	-	0.04	-	-	-
	Mesoveliidae	-	-	-	0.04	0.10
	Naucoridae	0.81	0 95	0.38	0.04	0.48
	Nepidae	-	-	-	0.04	-
	Veliidae	0.04	0.48	0.76	0.45	0.68
Lepidoptera	Crambidae	-	-	0 09	0.04	-
	Nocturidae	-	0.04	-	-	-
	Pyralidae	0.04	0.40	-	0.45	0 29
Neuroptera	Corydalidae	0 51	0.44	0.38	0 04	-
Odonata	Aeshnidae	-	-	0 09	-	0.19
	Calopterygidae	0.15	0.20	0 09	0.15	0.48
	Coenagrionidae	2.09	1.23	1 23	0.90	3.86
	Gomphidae	0.18	0 52	0 19	1.28	0.39
	Lestidae	0.04	-	0.09	-	-
	Libellulidae	1.43	0 40	1.61	0.53	0 87
	Protoneuridae	-	-	-	-	0.29
Plecoptera	Perlidae	0.07	-	-	-	-
Trichoptera	Glossosomatidae	-	-	1.42	-	-
	Helicopsychidae	0 55	13.31	-	0.41	-
	Hydropsychidae	3 52	1.03	1.52	0.60	2 51
	Hydroptilidae	2.68	2 38	0.19	1 84	2.80
	Leptoceridae	0.55	0.44	0.76	0 30	0 68
	Philopotamidae	4.33	0.12	2.46	0 04	2.31
	Polycentropodidae	0.51	-	-	-	0 29
	Species richness (*S*)	31	32	35	33	31
	Shannon diversity (*H'*)	2 38	1 98	2.18	1.50	2 30
	Shannon eveness (*J'*)	0.69	0 57	0 61	0.43	0 67
	Total N	1,056	2,516	2,726	2,664	1,037

Table 3. Relative abundances with calculated annual species richness (*S*), Shannon diversity (*H'*), and Shannon evenness (*J'*) of collected fish species at Pedernales River sites 1 – 5, Live Oak Creek (LC), Barons Creek (BC), North Grape Creek (GC), and Cypress Creek (CC) from February 2007 through November 2007.

	Site								
Species	1	2	3	4	5	LC	BC	GC	CC
Lepisosteus osseus	-	-	-	0.07	-	-	-	-	-
Dorosoma cepedianum	-	-	-	1.02	-	-	0.12	-	-
Campostoma anomalum	0.17	1.52	0.58	-	-	17.40	3.32	4.65	41.76
Cyprinella lutrensis	0.58	22.22	61.23	4.49	16.31	0.13	29.18	2.04	0.14
Cyprinella venusta	30.50	54.74	10.32	79.18	58.10	58.50	16.13	58.47	9.32
Cyprinella hybrid	0.08	-	0.53	-	-	-	0.35	-	-
Cyprinus carpio	-	-	-	-	-	-	-	0.15	-
Dionda nigrotaeniata	0.33	-	-	-	-	1.34	-	-	-
Notropis amabilis	35.92	1.52	0.10	-	-	0.27	-	0.22	10.27
Notropis stramineus	0.17	0.47	0.10	-	-	1.20	-	-	-
Notropis volucellus	8.42	1.87	0.05	0.34	-	-	0.04	-	-
Pimephales vigilax	1.17	1.40	1.73	3.13	11.66	-	2.62	-	0.14
Carpiodes carpio	-	-	-	-	0.11	-	0.08	-	-
Moxostoma congestum	0.17	0.47	0.14	-	-	-	-	0.15	0.14
Ameiurus melas	-	-	-	-	-	-	0.39	-	-
Ameiurus natalis	-	-	-	-	-	-	0.08	-	1.35
Ictalurus furcatus	-	-	-	-	-	-	0.04	-	-
Ictalurus punctatus	0.25	0.82	2.16	-	0.54	-	19.06	1.24	0.27
Pylodictis olivaris	0.25	0.82	0.10	0.14	-	-	0.04	-	-
Menidia beryllina	-	-	-	0.07	0.86	-	-	-	-
Gambusia affinis	1.42	0.58	17.13	1.97	4.64	1.74	1.99	3.85	0.14
Lepomis auritus	3.58	0.70	0.53	0.34	0.43	5.09	13.52	7.42	2.30
Lepomis cyanellus	1.33	0.12	0.48	0.07	0.32	0.54	1.91	1.67	2.43
Lepomis gulosus	0.50	-	-	0.14	0.32	-	0.04	0.07	-
Lepomis humilis	-	-	0.43	0.68	-	-	1.88	0.07	-
Lepomis macrochirus	3.17	2.69	0.77	1.09	1.40	3.21	5.31	6.47	1.76
Lepomis megalotis	4.42	5.15	3.17	4.08	4.32	0.67	0.94	4.51	16.89
Lepomis microlophus	0.08	-	-	0.07	-	-	0.27	3.71	-
Lepomis hybrid	-	-	-	0.07	-	-	-	-	0.14
Micropterus salmoides	0.58	0.35	0.19	-	0.54	1.47	1.56	0.80	0.54
Micropterus treculii	0.50	1.29	0.10	0.41	0.43	0.13	0.78	1.67	9.19
Pomoxis nigromaculatus	-	-	-	-	-	-	0.04	-	-
Etheostoma lepidum	3.17	-	-	-	-	8.30	0.23	-	0.27
Etheostoma spectabile	-	-	-	1.36	-	-	-	0.87	2.97
Percina carbonaria	3.25	3.27	0.19	0.14	-	-	0.08	0.87	-
Percina sciera	-	-	-	0.14	-	-	-	-	-
Cichlasoma cyanoguttatum	-	-	-	1.02	-	-	-	1.09	-
Species richness (*S*)	23	18	20	14	22	14	26	20	18
Shannon diversity (*H'*)	1.90	1.57	1.33	1.39	1.00	1.43	2.09	1.70	1.85
Shannon eveness (*J'*)	0.61	0.54	0.45	0.53	0.32	0.54	0.64	0.57	0.64
Total N	1,200	855	2,084	1,470	926	747	2,560	1,375	740

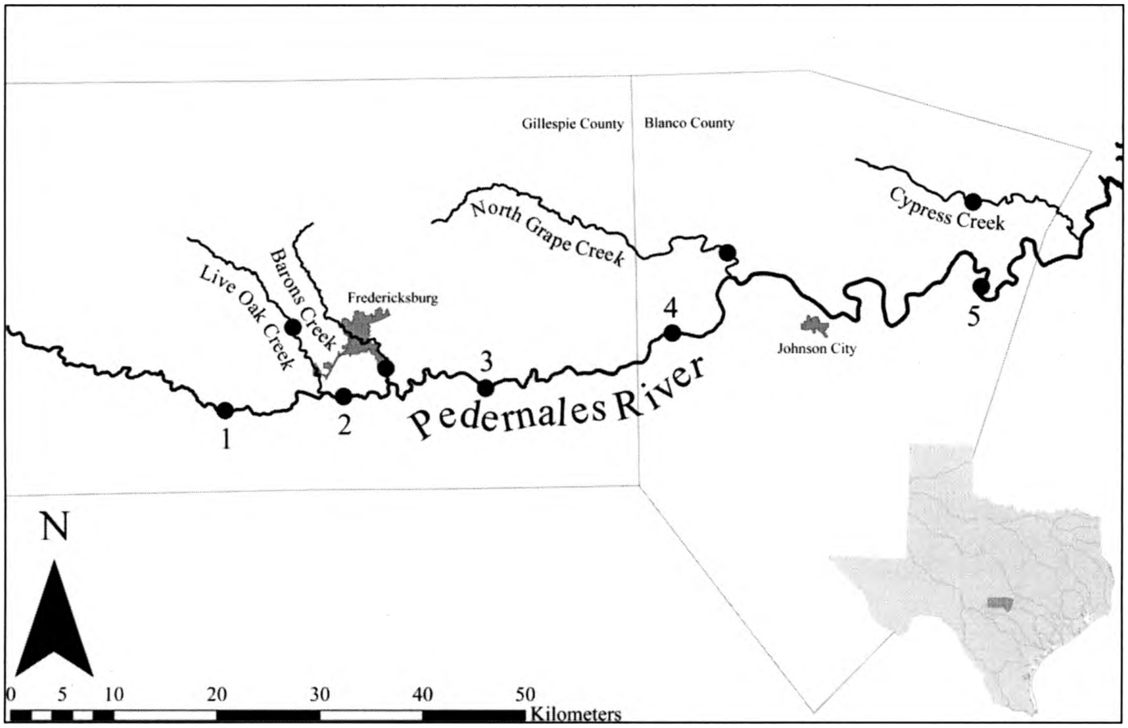

Figure 1. Sampling sites during the study period of 2007 for the Pedernales River and its tributaries Live Oak Creek, Barons Creek, North Grape Creek, and Cypress Creek with site locations indicated by black markers.

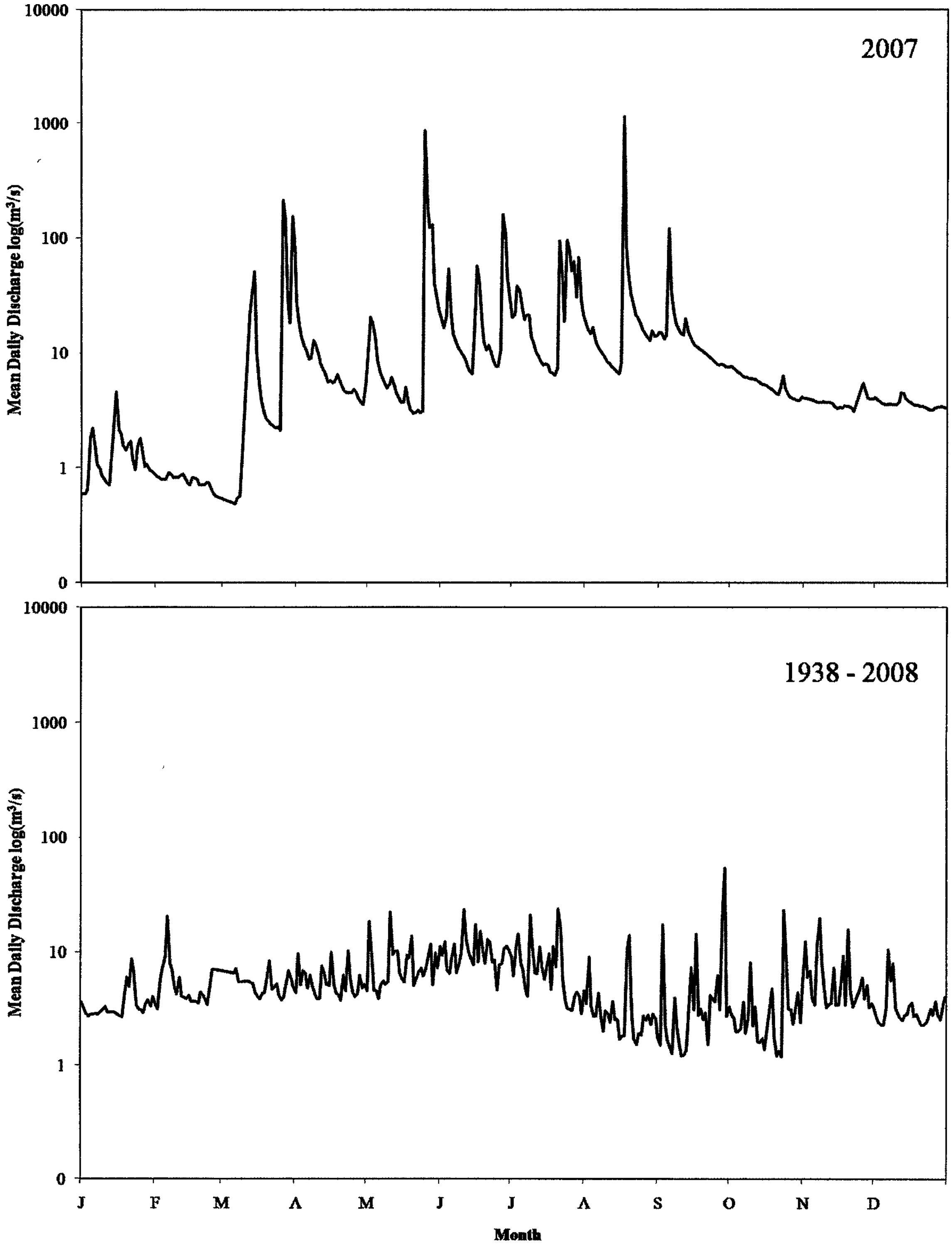

Figure 2. Log transformed mean daily stream discharge (m^3/s) for the Pedernales River at Johnson City, TX (USGS Gauge I.D. 08153500) for the study period 1/1/2007 – 12/31/2007 and the period of record 10/1/1938 – 9/30/2008.

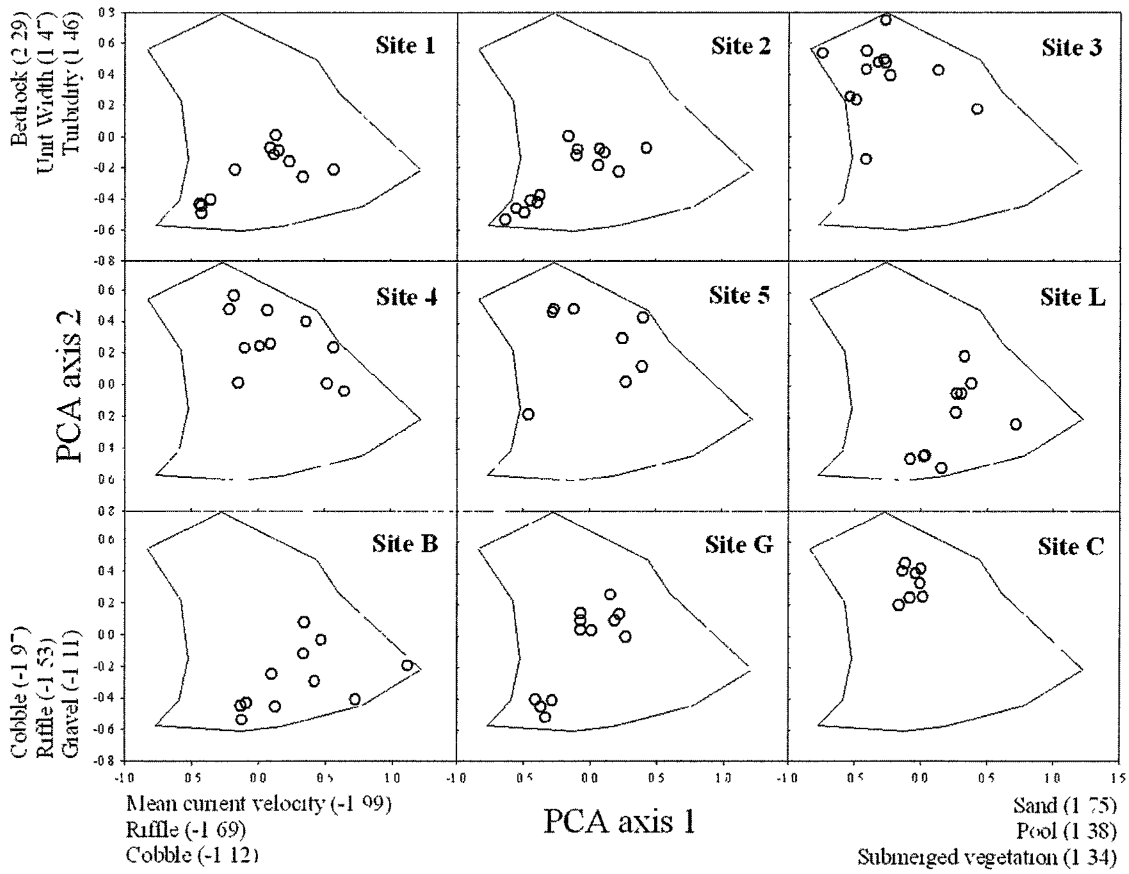

Figure 3. PCA of environmental parameters for the Pedernales River and its tributaries explained 23.1% of the variation seen spatially and temporally in sampled habitat. Individual geomorphic units are delineated by open markers.

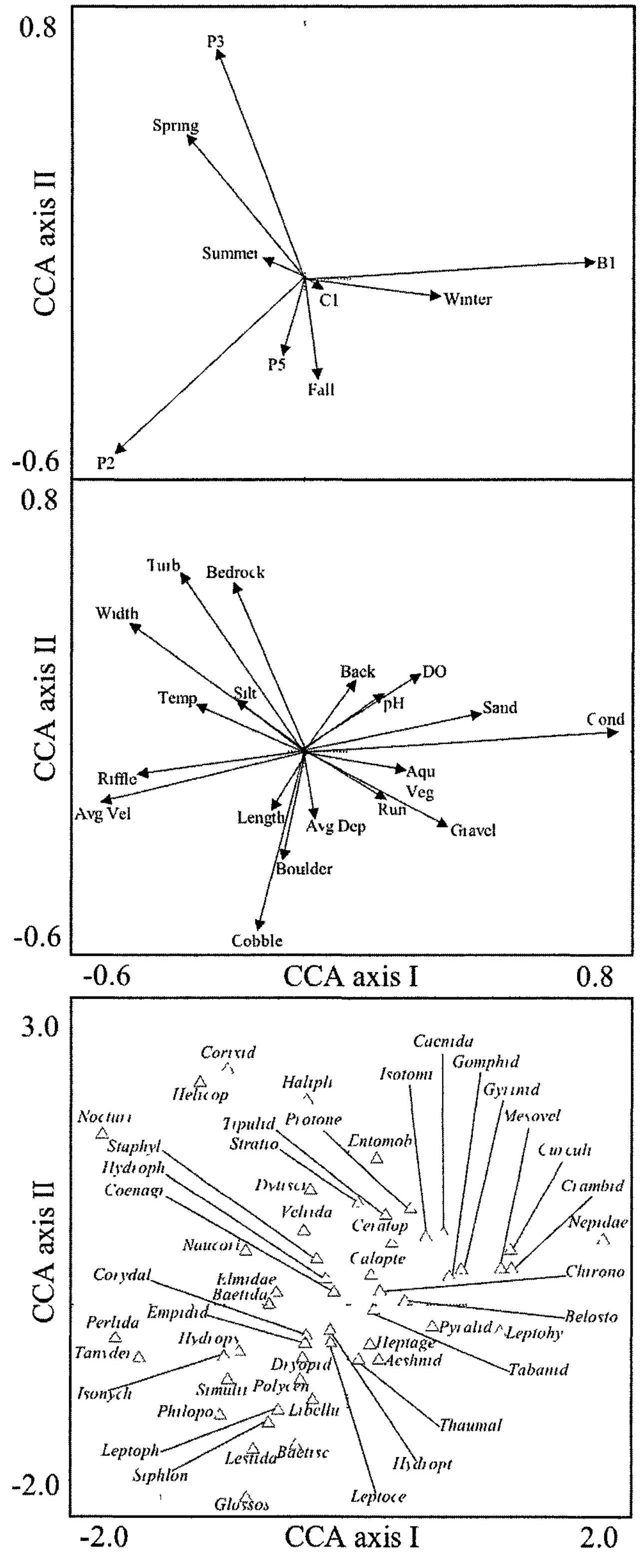

Figure 4. CCA showed 71.4% (TI = 2.4, SAE = 1.7) of the variation seen within the aquatic insect community for the Pedernales River and its tributaries could be explained by season, site, and environmental parameters. Aquatic insect labels are formatted as the first seven characters of the corresponding taxa family.

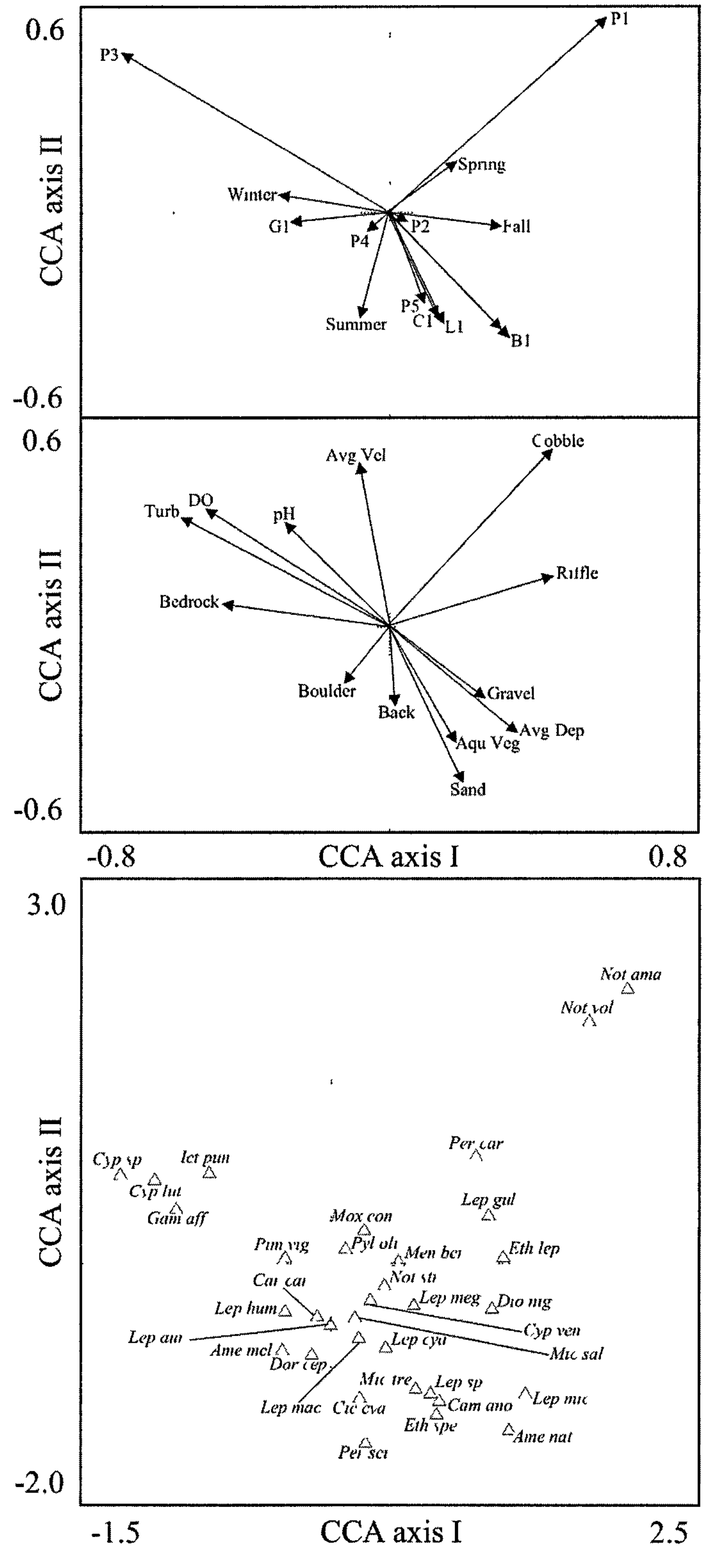

Figure 5. CCA showed 64.2% (TI = 4.1, SAE = 2.6) of the variation seen within the fish community for the Pedernales River and its tributaries could be explained by season, site, and environmental parameters. Fish labels are formatted as the first three characters of the corresponding taxa genus and species.

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