

PATTERNS AND HABITAT ASSOCIATIONS OF A DESERT SPRING FISH
ASSEMBLAGE AND RESPONSES TO A LARGE-SCALE FLOOD

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by

Jacqueline M. Watson, B.S.

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ABSTRACT

PATTERNS AND HABITAT ASSOCIATIONS OF A DESERT SPRING FISH ASSEMBLAGE AND RESPONSE TO A LARGE-SCALE FLOOD

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Jacqueline M. Watson, B. S.

Texas State University-San Marcos

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SUPERVISING PROFESSOR: TIMOTHY BONNER

I examined the spatial and temporal patterns and habitat associations of a desert spring fish assemblage from 2002 to 2005 in the minimally impacted Independence Creek drainage, a tributary of the Pecos River. During the third year, a large flood event (2,245 m³/s) inundated lower reaches of Independence Creek (mean discharge = 1.7 m³/s). The flood transformed the heavily vegetated, heterogeneous and slightly incised stream channel to a shallower, monotypic stream without streamside vegetation. Preflood Independence Creek consisted of 65% of spring endemic fishes, 24% of generalist fishes, and <1% of species common in the Pecos River. Environmental parameters explained 44% ($P<0.05$) of the fish assemblage variation. Among spring

endemics, multivariate ordination plots indicated strong habitat associations for *Etheostoma grahami* (riffle habitats) and ubiquitous habitat associations for *Cyprinella proserpina*, *Dionda episcopa* and *Notropis amabilis*. Post-flood Independence Creek consisted of 83% spring endemic fishes, 12% of generalist fishes, and 2% of species common in the Pecos River. Absolute and relative abundances of generalist fishes decreased attributed to downstream displacement. Absolute and relative abundances of Pecos River fishes increased attributed to habitat alterations (i.e., shallower depths, warmer water temperatures) within Independence Creek. Spring endemics were unaffected by the flood. Post-flood, multivariate fish-habitat associations shifted predictably from generally deeper habitats with silt and instream cover to shallower and slightly swifter habitats in side channels and riffles with gravel. However, the spatial arrangement among fishes was similar between preflood and post-flood distributions suggesting that spring endemics are highly resilient to perturbation. Information from this study will be used to manage and protect Independence Creek habitats and species of conservation concern, and to establish restoration standards in degraded spring-fed tributaries of the Rio Grande.

INTRODUCTION

Springs and spring-fed runs in the Trans-Pecos and Edwards Plateau regions of Texas are unique environments with persistent and thermally stable flows. Usually isolated from one another in endorheic basins or at least partially isolated by variable surface flows of river mainstems (Brune, 1981; Smith and Miller, 1986; Williams et al., 1989; Garrett et al., 2004), these spring systems provide media for speciation resulting in a large number of spring-adapted fishes (Williams et al., 1989; Bowles and Arsuffi, 1993; Hubbs, 1995; Grimm et al., 1997). Spring-adapted fishes form distinct assemblages even among spring systems that directly flow into mainstem rivers (Summer and Sargent, 1940; Hubbs, 1995). In the Guadalupe River drainage of south central Texas, spring endemics such as fountain darters *Etheostoma fonticola*, largespring gambusia *Gambusia geiseri* and Guadalupe roundnose minnows *Dionda nigrotaeniata* are concentrated in springs and spring runs and rarely found in mainstem rivers where flows are dominated by surface runoff (Hubbs, 2001). Conversely, mainstem fishes such as mimic shiners *Notropis volucellus*, speckled chubs *Macrhybopsis tetranema* and blacktail shiners *Cyprinella venusta* are common in mainstem rivers and absent or in low abundance in springs and spring runs (Kelsey, 1997). Distinct spring fish assemblages also are found in a number of other Trans-Pecos and Edwards Plateau drainages such as Pinto, Independence and Terlingua Creeks where mainstem fishes are rare except during

periods of environmental extremes (Rhodes and Hubbs, 1992; Hubbs, 1995; Garrett et al., 2004; Bonner et al., 2005).

Abiotic and biotic factors that maintain distinct spring fish assemblages and discriminate against the riverine fishes are poorly understood (Garrett et al., 2004; McDonald et al., in review). Generally ecological stability among spring systems is high and differs substantially from that of mainstem rivers. However, large springs like those in the Trans-Pecos and Edwards Plateau, with discharge up to 9 m³/s (Brune, 1981) and long spring runs (*e.g.*, 16 km), are susceptible to flash flooding by surface runoff. This susceptibility to hydrologic variability alters the ecological stability of the system. It is well documented however that alterations of the abiotic and biotic factors in spring environments such as excessive groundwater withdrawals, stream channel modifications and land use practices will negatively impact spring endemics (Brune, 1981; Edwards et al., 2002; Sharp et al., 2003). Consequently, 60% of the fishes listed as species of conservation concern in the Trans Pecos and Edwards Plateau drainages are spring endemics (Hubbs, 1990; Hubbs et al., 1991).

Floods alter chemical composition of water, physical habitat and biotic communities in streams (*e.g.*, Fisher and Minckley, 1978; Harrell, 1978; Collins et al., 1981; Matthews, 1986; Meffe and Minckley, 1987; Minckley and Meffe, 1987; Poff and Allan, 1995; Dudley and Matter, 1999). Stream fishes in variable mainstem rivers have morphological and behavioral attributes such as streamlined body shapes, larger pectoral fins, greater swimming abilities, use of interstitial spaces among substrate and rapid recolonization to resist the deleterious effects including downstream displacement during

floods (Harrell, 1978; Collins et al., 1981; Meffe, 1984; Matthews, 1986; Minckley and Deacon, 1991; Ward et al., 2003; Leavy, 2004). It should follow that fishes in relatively stable spring environments would not have similar attributes and would be less likely to persist in variable conditions associated with flooding. Studies that have examined the effects of flooding on fish assemblages include river reaches located distant from headwater reaches, partially spring-fed systems, intermittent stream reaches, streams with supplemental tributaries, second-order or larger and regulated streams (Fisher and Minckley, 1978; Harrell 1978; Collins et al., 1981; Fisher et al., 1982; Harvey, 1987; Meffe and Minckley, 1987; Matthews et al., 1988; Gelwick, 1990; Fausch and Bramblett, 1991; Dudley and Matter, 1999; Schultz et al., 2003). Few studies (Seegrist and Gard, 1972; Harrell, 1978) have focused on flood effects in unregulated springs and spring runs.

Independence Creek, the largest freshwater tributary of the lower Pecos River, consists of several large springs, numerous seeps and 16 km of spring run before its confluence with the Pecos River. It supports a diverse assemblage of Trans-Pecos and Edwards Plateau fishes including four of conservation concern, *Cyprinella proserpina*, *Etheostoma grahami*, *Notropis jemezianus* and *Ictalurus lupus*, and two drainage endemics, *Dionda episcopa* and *Notropis amabilis* (Hubbs et al., 1991). In contrast to the imperiled mainstems, tributaries and altered fish assemblages of the Rio Grande and Pecos River (Hoagstrom, 2003; Calamusso et al., 2005), the Independence Creek fish assemblage is representative of historical, unmodified spring-fed tributary assemblages (Bonner et al., 2005).

Objectives of this study were to describe spatial and temporal trends in the Independence Creek fish assemblage, to quantify habitat associations of the more common fishes and those of conservation concern, to assess population structure of fishes of conservation concern and to assess the effects of a large flood on habitat and fish assemblage. A study by Harrell (1978) quantified the effects of flooding on a similar fish assemblage in the Devils River. However, the Independence Creek flood (discharge rate: 2,245 m³/s) was considerably larger and in a much smaller drainage than the Devil's River flood (177 m³/s).

MATERIALS AND METHODS

Independence Creek (Terrell County, Texas) drains an area of 1,935 km². Caroline Springs, Vanderbeek Springs and smaller springs, fissures of the Cretaceous Edwards-Trinity aquifer (Brune, 1981; Karges, 2003; Sharp et al., 2003; Urbanczyk, 2003), provide perennial flows in the lower 16 km of the drainage. Streamside vegetation is dominated by associations of Walnut-Desert Willow, Saltcedar and Sawgrass-Willow (Webster, 1950). Modifications to the drainage include impoundment of Caroline Springs, stocking of sport fish (*Micropterus salmoides* and *I. punctatus*), two road crossings and surface water diversions for flood irrigation. Hydrology of Independence Creek is typical of flashy desert streams in the Rio Grande drainage. Mean (median) discharge is 1.7 (0.65) m³/s and large flood events (>2,000 m³/s) occur about every 25 years supported by anecdotal evidence (Chandler, 2004) (Appendix 1). In July 2004, a large flood event, caused by intense precipitation within Dry Creek channel, inundated

lower reaches of Independence Creek (Appendix 2). Peak discharge was estimated at 2,245 m³/s.

Six sites, from Independence Creek headwaters to confluence with the lower Pecos River, were sampled twice a year (Spring and Fall) between May 2002 and June 2005. One-time sampling occurred at a side channel beaver dam and Vanderbeek Spring in May 2002 and June 2003, respectively. Ten days following the July 2004 flood, sites 1, 3, and 5 were sampled. All six sites were sampled post-flood at 2.5 months in October 2004 and 10.5 months in June 2005. Collections were also taken from the two Caroline Springs recreational reservoirs and a spring outflow, approximately 675 m in length. At each site and date, fish from available geomorphic units (*e.g.*, runs, riffles, pools) were sampled with a Smith-Root Model 12-B POW backpack electrofisher (Vancouver, WA) and seines (1.2 by 1.8 m, mesh size: 3.2 mm; 1.8 by 2.4 m, mesh size: 3.2 mm). Multiple seine passes were made until number of individuals collected was greatly reduced and new species were no longer captured. Electrofishing was used to collect fish from areas where seining was difficult or ineffective (*e.g.*, undercut banks, around woody debris and large boulders and riffles). All fish were identified to species, enumerated and released, except for voucher specimens. Total length (mm) was measured and recorded for thirty individuals of each species at each site. Voucher specimens were anesthetized with MS-222 (80mg/l) and preserved in 10% formalin solution.

At each site, dissolved oxygen (mg/L), pH, water temperature (°C) and conductivity (µS/cm) were recorded using YSI Model 600 multiprobe meter (Yellow Springs, Ohio). For each geomorphic unit, percent substrate type, percent cover and

percent vegetation were visually estimated as a percent of total unit area (Taylor and Lienesch, 1996; Taylor and Warren, 2001). Total length (m) of each geomorphic unit was recorded. Width (m), three to four depth (cm) and current velocity (m/s) measurements were recorded from one transect per geomorphic unit and used to calculate mean depth and current velocity. Cross-sectional profiles for each site were mapped in May 2002 (preflood) and September 2005 (post-flood).

Relative abundance, density, taxa richness (S), diversity (H), evenness and turnover (Renkonen similarity index, RSI; Krebs, 1999) were calculated by site, date and collectively for preflood and post-flood to assess spatial and temporal patterns in the fish assemblage. Diversity was calculated using the Shannon-Weiner index (\log_e base) and evenness was calculated using Buzas and Gibson's E ($E = e^H/S$; Hayek and Buzas, 1997). Renkonen similarity indices were used as a measure for assemblage turnover (β -diversity) through time and between preflood and post-flood collections.

Canonical correspondence analysis (CCA; ter Braak, 1986) was used to analyze fish habitat associations for Independence Creek fishes with relative abundances $> 0.5\%$. Two separate CCA models were generated using two and a half years of preflood data and one year of post-flood data. A variance partitioning technique (Borcard et al., 1992; Magnan et al., 1994; Williams et al., 2005) was used to relate variation in the fish assemblage structure to three explanatory variables: physical habitat parameters, site and season. A third CCA model was used to detect multivariate shifts in habitat associations between preflood and post-flood samples.

Patterns in length frequency histograms, current velocity and depth associations were examined for four spring-endemic fishes, *C. proserpina*, *E. grahami*, *D. episcopa* and *N. amabilis*. Length frequency histograms were used to determine the occurrence of age-0 and adults fishes as a measure of reproductive success within Independence Creek. A pooled variance *t*-test (Zar, 1999) was used to detect significant post-flood changes in current velocity and depth associations. In May of 2002, state-listed threatened *E. grahami* ($n = 6$) and *C. proserpina* ($n = 20$) were vouchered. Food habitats of *E. grahami* and *C. proserpina* have not been described and are needed for future conservation of these species. Therefore, stomachs were removed and food items were identified to the lowest practical level of taxon identification.

RESULTS

Habitat characteristics and stream morphology

The perennial portion of Independence Creek basin consisted of three distinct aquatic environments: the Caroline Springs reservoirs, spring outflow, and Independence Creek. The two interconnected Caroline Springs reservoirs had a combined surface area of 5.5 ha, maximum depths of 3 m, and were densely vegetated. Reservoir substrates consisted of 70% sand and 30% silt. Separated from the reservoirs by a small concrete dam, the spring outflow was a narrow (range: 2 – 12 m) and shallow (<1 m) series of riffle, run and pool geomorphic units. Pools formed upstream of multiple man-made, boulder dams. Spring outflow substrate consisted of gravel and cobble in areas with

swift current velocity and of silt, gravel and abundant vegetation in areas with slow current velocity.

Habitat characteristics and channel morphology differed considerably between pre-flood and post-flood Independence Creek (Appendix 3). Preflood Independence Creek consisted of a single, incised channel at sites 1 through 4 (Appendix 4). Site 5 was generally a large pool upstream of a two-culvert road crossing, becoming a shallow run when elevated flow events eroded around the culverts. Site 6 consisted of braided channels that often shifted during high flow events observed during this study. Collectively, mean width (\pm SD) was 8.6 (10.1) m, and mean depth was 0.34 (0.19) m. Common geomorphic units were runs (50%), pools (39%) and riffles (7%). Substrate primarily consisted of gravel (39%), cobble (26%) and silt (22%). Filamentous algae were the only vegetation found in Independence Creek and abundant only in riffles. Post-flood Independence Creek shifted from a single channel to multiple braided channels at sites 2 through 4. Among sites 2 through 6 (Site 1 was not affected), these multiple channels were shallower (0.25 ± 0.19 m) and wider (12.7 ± 13.2 m). Common post-flood geomorphic units in Independence Creek were runs (58%) and riffles (33%). Post-flood substrate was primarily gravel (65%) and boulders (2%). Filamentous algae were absent.

Water quality parameters were less variable in the Caroline Springs reservoirs than in Independence Creek. Parameters (range) measured in Caroline Springs reservoirs were temperature (19 – 25°C), dissolved oxygen (7.2 – 9.5 mg/l), conductivity (798 – 863 μ S/cm) and pH (7.4 – 8.1). Parameters (range) measured in Independence Creek

were temperature (19 – 30°C), dissolved oxygen (1.6 – 9.1 mg/l), conductivity (890 – 1,375 $\mu\text{S}/\text{cm}$) and pH (7.4 – 8.6). High temperature (30°C) and low dissolved oxygen concentration (1.6 mg/l) were recorded from a backwater area in Independence Creek.

Fish assemblages

A total of 4,984 fishes representing 12 species and 8 families were captured from the Caroline Springs reservoirs (Appendix 5). Among collection dates, taxa richness ranged from 6 to 11, diversity from 1.1 to 1.9, evenness from 0.42 to 0.66 and turnover from 0.33 to 0.71. *Dionda episcopa* was the most abundant fish (30%) and the only cyprinid with the exception of a single *Ctenopharyngodon idella* collected during a reservoir catfish survey (Littrell et al., 2003). Other common fishes included *Astyanax mexicanus* (27%), *Gambusia* (26%), *Cichlasoma cyanoguttatum* (6.7%) and centrarchids (5.5%). Mean relative weight ($\pm\text{SD}$) of *Micropterus salmoides*, the most abundant centrarchid captured (3.9%), was 75 (22.5) indicating the bass were in poor condition. A total of 81 (1.6%) *Etheostoma grahami*, known only to occur in lotic habitats (Harrell, 1978; Bonner et al., 2005), was captured from shallow, shoreline areas with silt substrate.

A total of 5,636 fishes representing 10 species and 8 families were captured from the spring outflow. Among collection dates, taxa richness ranged from 4 to 9, diversity from 0.45 to 1.4, evenness from 0.26 to 0.71 and turnover from 0.08 to 0.75. *Gambusia* were the most abundant fishes (78%), followed by *A. mexicanus* (13%), *Diondia episcopa* (6%) and *Lucania parva* (3%). Among the two *Gambusia* species, *G. geiseri* was more abundant than *G. affinis* in the spring outflow, and less abundant than *G. affinis*

in Caroline Springs reservoirs and Independence Creek. Likewise, *Lucania parva* was most abundant in the spring outflow.

A total of 11,683 fishes representing 22 species and 10 families were collected from pre-flood Independence Creek. Among collection dates, taxa richness ranged from 14 to 18, diversity from 1.57 to 1.99, evenness from 0.25 to 0.43 and turnover from 0.45 to 0.70. Abundant fishes were *N. amabilis* (27%), *D. episcopa* (23%) and *C. proserpina* (15%), which collectively comprised 65% of the assemblage. Other species of conservation concern, *E. grahami* and *I. lupus* (<1.5% each) were collected consistently in low abundance. *Gambusia* (25%) and centrarchids (3%) were generally collected evenly among all sites. Four introduced fishes, *C. venusta*, *G. geiseri*, *Cyprinodon variegatus* and *L. auritus*, (collectively <10%) were collected at downstream sites furthest from spring sources.

A total of 8,385 fishes representing 22 species and 9 families were collected from post-flood Independence Creek. Among collection dates, taxa richness ranged from 14 to 21, diversity from 1.60 to 1.80, evenness from 0.28 to 0.33 and turnover from 0.75 to 0.79. The post-flood fish assemblage was 73% similar to the collective pre-flood fish assemblage 10 d after the flood event, 71% at 2.5 months and 83% at 10.5 months. Abundant spring run fishes were *N. amabilis* (33%), *D. episcopa* (31%) and *C. proserpina* (17%), which comprised 83% of the assemblage, and *E. grahami* and *I. lupus* were <1.1% each. *Gambusia* (9%) and centrarchid (1%) decreased at all sites, most notably at downstream sites. Collective abundance of five introduced species, *C. venusta*, *Cyprinus carpio*, *Fundulus grandis*, *G. geiseri* and *L. auritus*, was <3%, lower

than pre-flood. However, relative abundance of *C. venusta* increased from 0.14% pre-flood to 1.5% post-flood. Five common Pecos River species, *C. lutrensis*, *C. carpio*, *Pimephales promelas*, *P. vigilax* and *F. grandis*, not taken or in low abundance pre-flood, comprised 2.4% (n = 200 fishes) of the post-flood fish assemblage.

Habitat associations—pre-flood and post-flood Independence Creek

The first CCA model using pre-flood environmental parameters (habitat, site and season) explained 44% of the variation in the pre-flood fish assemblage. Specifically, pure effects of habitat explained 22% (F = 1.67; $P < 0.01$), site explained 12% (F = 2.77; $P < 0.01$) and season explained 1.6% (F = 2.34; $P = 0.03$) of fish assemblage variation. Shared variation (2-way and 3-way interactions) among variables that could not be partitioned explained 8.4% of the fish assemblage variation.

The first CCA axis described site, substrate and geomorphic unit gradients (Appendix 6). High positive loadings on CCA axis I were site 6 (0.69), maximum depths (0.46), water depth (0.40), Fall (0.33), pools (0.29), bedrock (0.25) and compacted gravel substrate (0.21). High negative loadings on CCA axis I were site 1 (-0.45), Spring (-0.33), vegetation (-0.30), Vanderbeek Spring (-0.28), cobble substrate (-0.26), backwater (-0.25) and riffles (-0.23). Species positively associated with CCA axis I (biplot scaling score) included *C. lutrensis* (2.20), *C. venusta* (1.46), *L. auritus* (0.70), *L. megalotis* (0.33), *N. amabilis* (0.32) and *C. proserpina* (0.26). Species negatively associated with CCA axis I included *E. grahami* (-0.69), *Gambusia* (-0.44), *D. episcopa* (-0.34), *C. cyanoguttatum* (-0.23), *I. lupus* (-0.13) and *A. mexicanus* (-0.13). The second environmental axis described current velocity, geomorphic unit and substrate gradients.

High positive loadings on CCA axis II were silt substrate (0.59), site 6 (0.44), backwater (0.35), stream width (0.29), site 5 (0.27), instream cover (0.26) and isolated pools (0.25). High negative loadings on CCA axis II were current velocity (-0.66), riffles (-0.36), site 3 (-0.35), bedrock substrate (-0.32), site 2 (-0.27), boulders (-0.23) and chutes (-0.22). Species positively associated with CCA axis II included *C. lutrensis* (1.14), *L. auritus* (0.89), *C. venusta* (0.57), *Gambusia* (0.40), *L. megalotis* (0.26), *C. cyanoguttatum* (0.11), and *D. episcopa* (0.11). Species negatively associated with CCA axis II included *E. grahami* (-0.56), *C. proserpina* (-0.39), *I. lupus* (-0.36), *N. amabilis* (-0.28) and *A. mexicanus* (-0.09).

The second CCA model using post-flood environmental parameters (habitat, site and season) explained 68% of the variation in the post-flood fish assemblage. Specifically, pure effects of habitat explained 36% ($F = 2.58$; $P < 0.01$), site explained 20% ($F = 5.28$; $P < 0.01$) and season explained 1.6% ($F = 2.13$; $P = 0.04$) of fish assemblage variation. Shared variation (2-way and 3-way interactions) among variables that could not be partitioned explained 10.4% of the fish assemblage variation.

Post-flood CCA axis I described a gradient between upstream and downstream sites, geomorphic units and substrate (Appendix 7). Positive centroids on this axis were backwater (0.47), silt (0.43), site 1 (0.40), isolated pools (0.24), run pool (0.23) and side channel (0.23) geomorphic units. Negative centroids on environmental axis one were site 6 (-0.67), current velocity (-0.38), water depth (-0.31), runs (-0.30), sand (-0.22), maximum depths (-0.18) and riffles (0.17). Species positively associated with CCA axis I included *Gambusia* (1.24), *C. cyanoguttatum* (0.85), *L. aurtius* (0.82), *E. grahami*

(0.49), *L. megalotis* (0.38), *D. episcopa* (0.27) and *A. mexicanus* (0.09). Species negatively associated with post-flood CCA axis I were *C. lutrensis* (-1.27), *C. venusta* (-0.75), *N. amabilis* (-0.38), *C. proserpina* (-0.22) and *I. lupus* (-0.08). Post-flood CCA axis II similarly described a gradient between upstream and downstream sites, geomorphic units and substrate. High positive centroids included site 6 (0.51), side channel (0.38) and backwater (0.37) geomorphic units, gravel (0.36) and silt (0.28) substrate, site 5 (0.27) and instream cover (0.20). Negative centroids included site 3 (-0.50), boulders (-0.33), maximum depth (-0.30), riffles (-0.29), water depth (-0.27), cobble (-0.24) and bedrock (-0.19) substrate. Species positively associated with this second axis were *C. lutrensis* (1.39), *C. cyanoguttatum* (0.73), *C. venusta* (0.55), *Gambusia* (0.38) and *D. episcopa* (0.16). Negatively associated species on post-flood CCA axis II included *I. lupus* (-0.58), *N. amabilis* (-0.40), *L. megalotis* (-0.30), *E. grahami* (-0.17), *C. proserpina* (-0.17), *A. mexicanus* (-0.12) and *L. auritus* (-0.07).

The third CCA model using pre-flood and post-flood environmental parameters (habitat only) explained 42% of the variation in the post-flood fish assemblage. The first CCA axis described habitat gradients in substrate, water depth and current velocity (Appendix 8). High positive centroids on CCA axis I were silt (0.61), maximum depth (0.57), water depth (0.47), instream cover (0.42) and pools (0.40). High negative centroids were gravel substrate (-0.58), side channel (-0.37) and riffle (-0.23) geomorphic units, boulders (-0.16) and current velocity (-0.14). Combined CCA axis II described a gradient in geomorphic units, substrate and current velocity. High positive centroids on the second axis were backwater (0.60), silt (0.40), isolated pool (0.38) and side channel

(0.35) geomorphic units and instream cover (0.31). Negative centroids on CCA axis II included current velocity (-0.53), riffles (-0.32), boulders (-0.32), bedrock (-0.30) and water depth (-0.30). Fish-habitat associations shifted predictably along CCA axis I from generally deeper habitats with silt and instream cover to shallower and slightly swifter habitats in side channels and riffles with gravel. Similar shifts were apparent for univariate current velocity and depth associations. *Cyprinella proserpina*, *D. episcopa*, *N. amabilis* and *E. grahami* were found at shallower depths ($P < 0.05$) post-flood when compared to their preflood distribution (Appendix 9). Shifts in current velocity associations were not significant, at least for the five species tested. Perhaps more interesting, relative spatial arrangement of fishes were similar between preflood and post-flood distributions. For example, preflood *L. auritus* was associated with greatest water depths, silt substrate and pools; post-flood *L. auritus* was still associated with greatest water depth although water depth was much shallower post-flood than preflood. *Dionda episcopa* were slightly more associated with side channels and backwater areas than other spring endemics preflood and post-flood. The ability to assemble in the same spatial arrangement after a major flood event suggests that fishes of Independence Creek were highly resilient to perturbation.

Population Biology

Multiple age groups, including age-0 fishes, were captured every year in Spring and Fall for *C. proserpina*, *D. episcopa*, *N. amabilis* and *E. grahami* (Appendix 10). Age-0 *C. proserpina* and *N. amabilis* were most common within lower reaches of

Independence Creek, age-0 *D. episcopa* were common among all sites, and age-0 *E. grahami* were found only in the upper reaches except for those captured in the Caroline Springs reservoirs. Persistent occurrences of adult fishes and presence of age-0 individuals suggests that the spring endemic fishes were completing life-cycles entirely within the spring-run environment. In addition, age-0 fishes (TL <30 mm) were collected for all species in Independence Creek except for common Pecos River species, *C. venusta*, *C. lutrensis*, *Cyprinus carpio*, *N. braytoni*, *Pimephales promelas*, *P. vigilax* and *Fundulus grandis*.

Stomach contents were examined in 4 male and 2 female *E. grahami* (TL range: 35-47mm) and 13 male and 7 female *C. proserpina* (TL range: 37-61). Dipterans were the most common item in stomachs (83%) of *E. grahami*, followed by trichopterans (33%), lepidoterans, hemipterans and ephemeropterans (17% each). One fish had an empty stomach. Dipterans were the most common item in stomachs (30%) of *C. proserpina*, followed by lepidopterans (20%), trichopterans (15%), ephemeropterans and coleopterans (5% each). Eight fish had empty stomachs.

DISCUSSION

Site, season and habitat parameters explained significant amounts of variation in pre-flood and post-flood fish assemblages of Independence Creek. Fishes with strong pre-flood site affinities were *E. grahami*, collected consistently at upstream sites, and *C. lutrensis*, *C. venusta* and *L. auritus* collected consistently at downstream sites. Fishes with strong post-flood site affinities were *C. lutrensis* and *C. venusta*, collected from

downstream sites, and *Gambusia* collected from unaltered site 1. Season explained a small amount of preflood and post-flood variation, with more *E. grahami* taken in Spring and *C. lutrensis* and *C. venusta* taken in Fall of preflood samples.

Only four species had strong habitat associations in preflood samples.

Etheostoma grahami was strongly associated with high current velocity riffles and runs with cobble and bedrock substrate. *Cyprinella lutrensis*, *C. venusta* and *L. auritus* were strongly associated with deeper, slower current velocity, pool and backwater habitats. Three spring endemics, *D. episcopa*, *N. amabilis* and *C. proserpina*, were collected from all sites but were more common at upstream sites preflood. *Dionda episcopa* was generally associated with run, pool and backwater geomorphic units and had the slowest current velocity association among the species of interest. *Notropis amabilis* was collected from all geomorphic units but were most common in pools and runs; among spring endemics, *N. amabilis* had the greatest depth association. *Cyprinella proserpina* was collected from all geomorphic units except backwaters and was most common in runs. The established preflood stream channel and modest variation in available habitat may be responsible for the lack of strong habitat associations in the abundant spring run fishes. Few species had strong post-flood habitat associations. *Cyprinella lutrensis* and *C. venusta* were strongly associated with slower, deeper runs and backwater units, although this habitat was less abundant. *Gambusia* were strongly associated with runs and pools with silt substrate, but only at the unaltered site 1.

Although changes to Independence Creek habitat were substantial, changes in the fish assemblage and habitat associations were minimal. Post-flood habitat associations

were similar to those of pre-flood and were generally predictable based on physical stream changes. Fish collected post-flood were associated with shallower, swifter habitats because the entire creek became shallower and swifter. Habitat associations of the spring run fishes are consistent with those found in the larger Devils River (Harrell, 1978; Valdes and Winemiller, 1997; Robertson and Winemiller 2003). Exceptions include *Dionda* and *N. amabilis*, which were not collected from pools in the Devils River (Valdes and Winemiller, 1997).

Preflood environmental parameters (habitat, site and season) in this study explained a lesser amount of assemblage variation (44%) than post-flood environmental parameters (68%) and in streams dominated by surface runoff (68 -78%; Williams, 2003; Williams et al., 2005). Season (<2%) had smaller influence (5 - 10%), habitat (22%) had similar influence (19 - 35%) and site (12%) had slightly higher influence on pre-flood Independence Creek than in more hydrological variable streams. Habitat associations theoretically should be stronger in more stable environments (i.e., spring systems) (Matthews, 1998), but was not supported by these comparisons. Likewise, biotic influences (interspecific competition and predation) should be less in more stable environments and yet unexplained variation (e.g., 56% in Independence Creek, usually attributed to biotic interactions not measured) was highest in the spring system. However, assemblage variation attributed to season in Independence Creek was lower than the more variable stream environments, which is consistent with thermally constant springs and the loss of seasonal variation in chemical parameters and fish population structure (Schenck and Whiteside, 1976; Groeger et al., 1997).

Three post-flood patterns in relative abundance and density were observed for the fishes of Independence Creek: no change, decreases, and increases. First, relative abundance and density of spring endemics, *N. amabilis*, *D. episcopa*, *C. proserpina* and *E. grahami*, did not change or at least remained within the range of observed pre-flood variation. Consequently, spring endemics that evolved in fairly stable environments, responded to the flood event similar to fishes that evolved in more hydrological variable systems (Meffe, 1984; Meffe and Minckley, 1987; Minckley and Meffe, 1987; Dudley and Matter, 1999). Swimming abilities of *N. amabilis* (60.8 cm/s) and *C. proserpina* (63.6 cm/s) are within range of swimming abilities for obligate riverine fishes (>50 cm/s) (Leavy, 2004). This suggests that a few of the spring endemics have evolved morphologically to persist in flood events. Swimming abilities of *E. grahami* (40 cm/s) and *D. episcopa* (17.8 cm/s), which are slower than those of obligate riverine fishes, suggests that a few of the spring endemics have evolved behaviors that allow persistence during flood events. Second, relative abundance and density of centrarchid and poeciliid species decreased in post-flood Independence Creek. Lentic adapted species, such as centrarchids and poeciliids, have lower swimming abilities than lotic adapted species (Ward et al., 2003; Leavy, 2004) and are commonly displaced downstream during large flood events (Meffe, 1984; Meffe and Minckley, 1987; Minckley and Deacon, 1991; Dudley and Matter, 1999). Periodic flooding and the removal of fishes such as centrarchids and poeciliids benefit rivers and Independence Creek by reducing potential competitors and predators. Third, relative abundance and density of Pecos River fishes (e.g., *C. lutrensis*, *C. venusta*, *C. carpio*, *F. grandis*, *P. promelas* and *P. vigilax*)

increased post-flood at downstream sites. These species rarely occur in Independence Creek (Bonner et al., 2005) and have the potential to compete with the spring endemics.

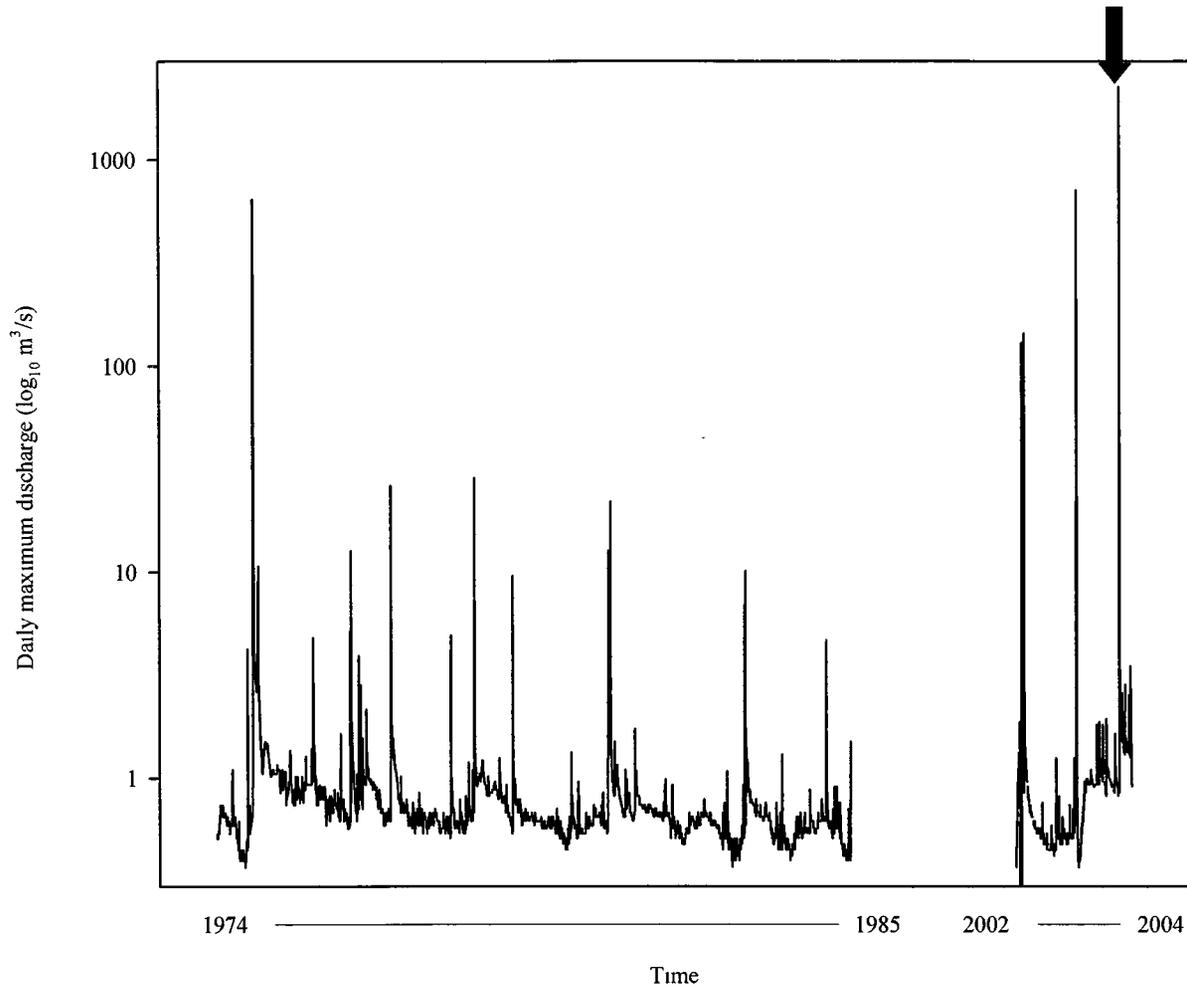
Despite the physical cohesiveness of the Pecos River and Independence Creek, these systems support two distinctly different fish assemblages. The Pecos River and its fish assemblage are highly modified via dams, dewatering and introduced species (Hoagstrom, 2003). Anthropogenic modifications within the Pecos River have produced an assemblage of cosmopolitan species (*e.g.*, *C. lutrensis*, *C. venusta* and *P. vigilax*) and a remnant of the native fish assemblage. Fishes of Independence Creek rarely are found in the Pecos River mainstem (Rhodes and Hubbs, 1992), sustainable wholly within the spring run systems, and therefore not dependent upon the Pecos River except as a means of dispersion and recolonization into other spring systems. In contrast, fishes of the highly modified Pecos River assemblage at times are dependent upon Independence Creek, moving into the creek after floods or when river conditions are unfavorable (Rhodes and Hubbs, 1992). During normal conditions, Pecos River fishes are rarely found in Independence Creek, possibly attributed to water chemistry and temperature differences (Echelle et al., 1972; Matthews, 1985; Taylor et al., 1996) between Independence Creek and Pecos River. In fact, Pecos River fishes were more abundant in Independence Creek once post-flood habitats become shallower and warmer, weakly supporting the water temperature theory.

Movement of Pecos River fishes into Independence Creek is problematic if populations become established, especially if mean water temperatures rise because of declines in spring discharge—a common problem in many Trans-Pecos and Edwards

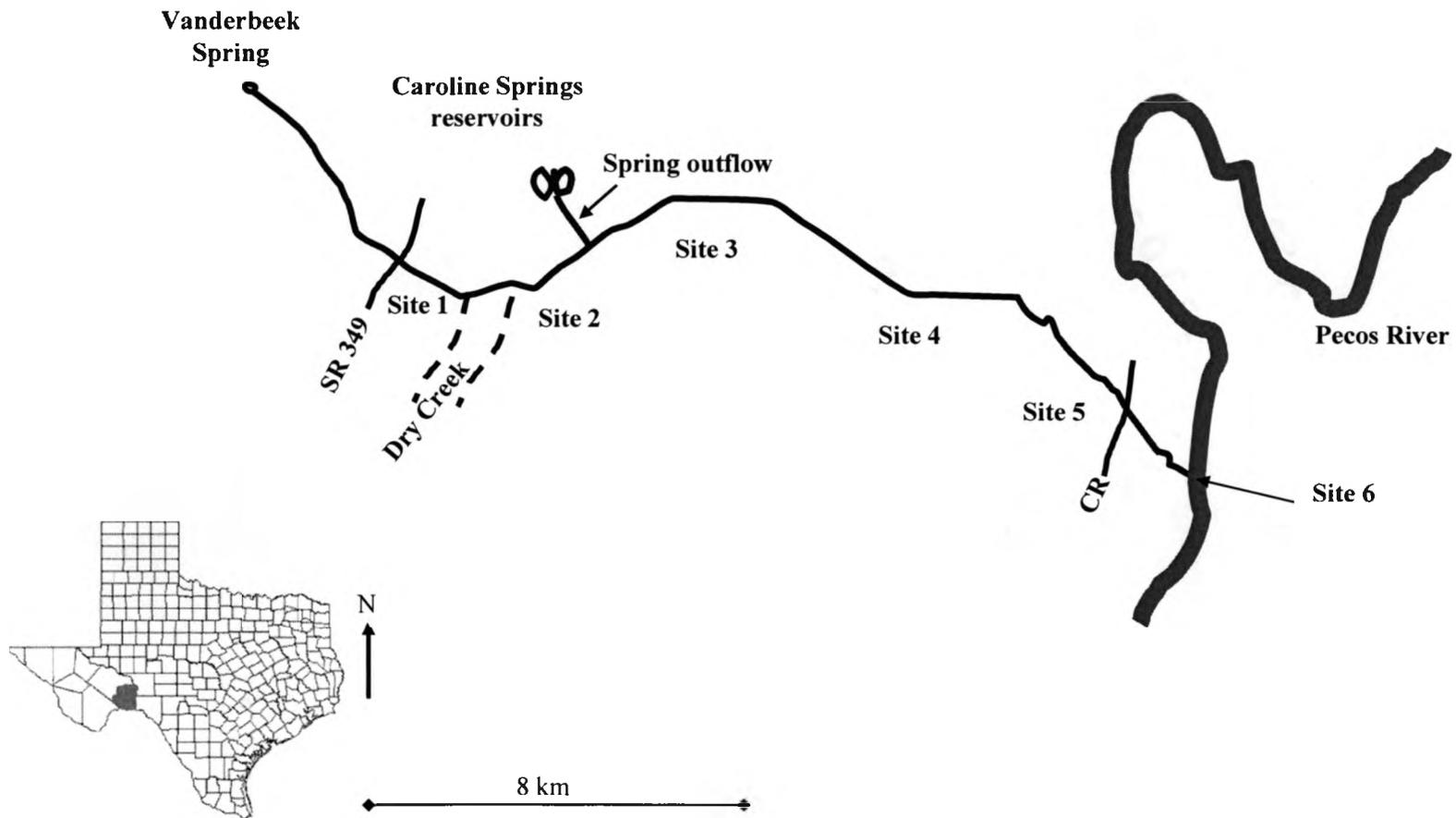
Plateau springs. Pecos River fishes (i.e., native invaders; Scott and Helfman, 2001) would increase competition and predation. Physical barriers are used in other drainages to prevent undesirable and highly modified mainstem fish assemblages from entering sensitive and ecologically diverse tributaries (Thompson and Rahel, 1998; Novinger and Rahel, 2003; Ward et al., 2003). A similar management technique might be considered on Independence Creek although the road crossing and culverts at Site 5 likely already have served as a physical barrier for Pecos River fish movement into Independence Creek. Therefore I recommend the continual maintenance of the road crossing.

Extensive documentation exists to support the fact that native riverine species require natural flow regimes in order to persist (*e.g.*, Minckley and Meffe, 1987; Minckley and Deacon, 1991; Poff et al. 1997; Richter et al., 1997; Labbe and Fausch 2000). Anthropogenic modifications have created a dim outlook for the future of native riverine species and spring run endemics. Specifically, the Rio Grande drainage has been subjected to substantial habitat alteration, pollution, dewatering and introductions of nonnative fishes. With the realization that large rivers may be beyond feasible restoration efforts, focus is turning to tributaries and the management of intact, unmodified assemblages (Edwards et al., 2002; Calamusso et al., 2005). If the future of native riverine species relies on tributaries, studies examining the interaction of fishes within tributary systems and species biology are imperative for sustainability and conservation management of endemic fishes.

APPENDICES



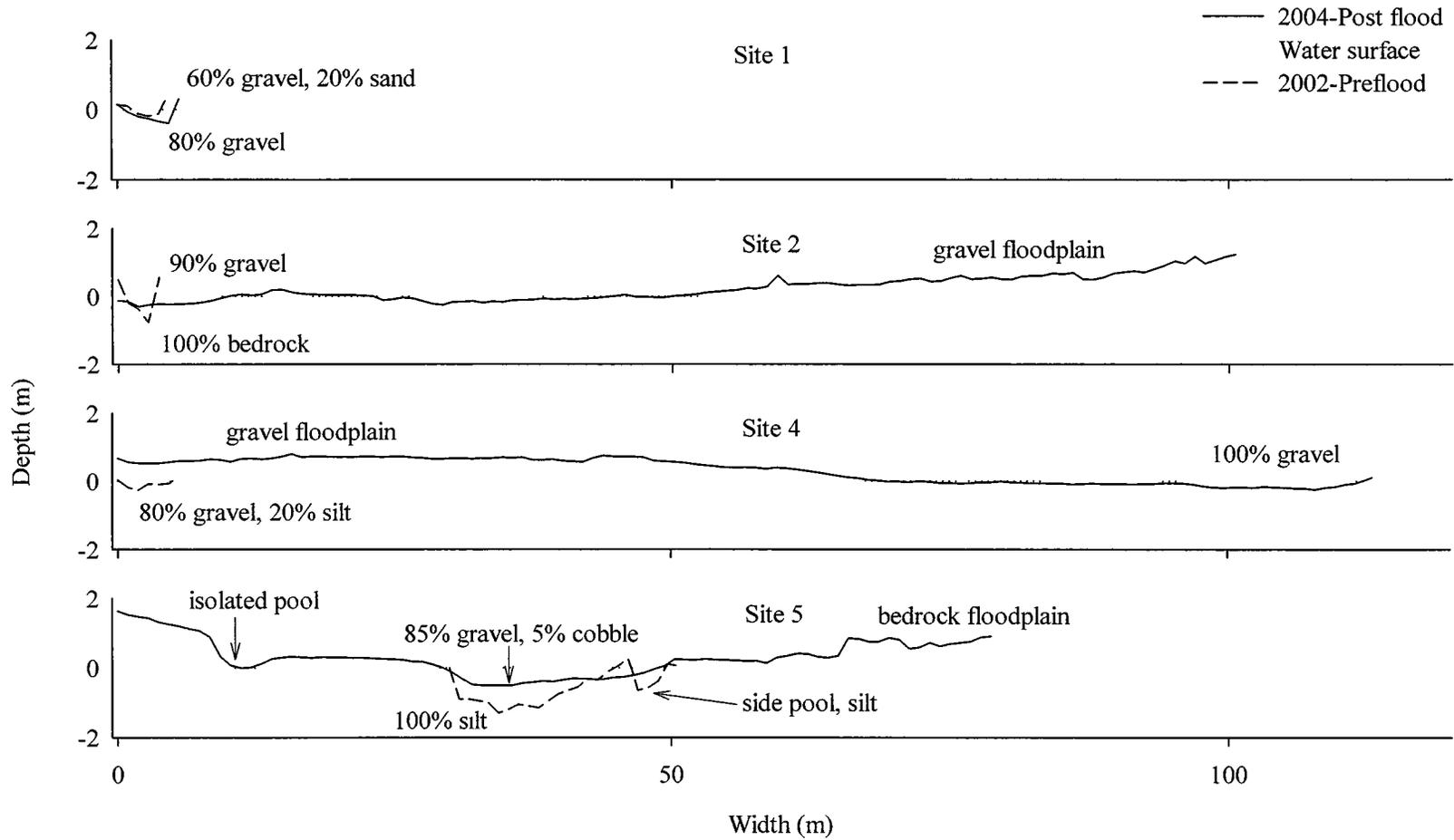
Appendix 1. USGS discharge data from Independence Creek gauging station (08447020). The break in data between 1985 and 2002 is a period when this gauging station was not operating. The black arrow indicates the July 2004 flood discussed in this study.



Appendix 2. Site map of Independence Creek, Terrell County, Texas. Solid lines upstream of site 1 and down stream of site 5 indicate road crossings. The double dashed lines indicate Dry Creek where flood waters entered Independence Creek.

Appendix 3. Physical habitat characteristics of Independence Creek during pre-flood (May 2002 – June 2004) and post-flood (August 2004 – June 2005) collections.

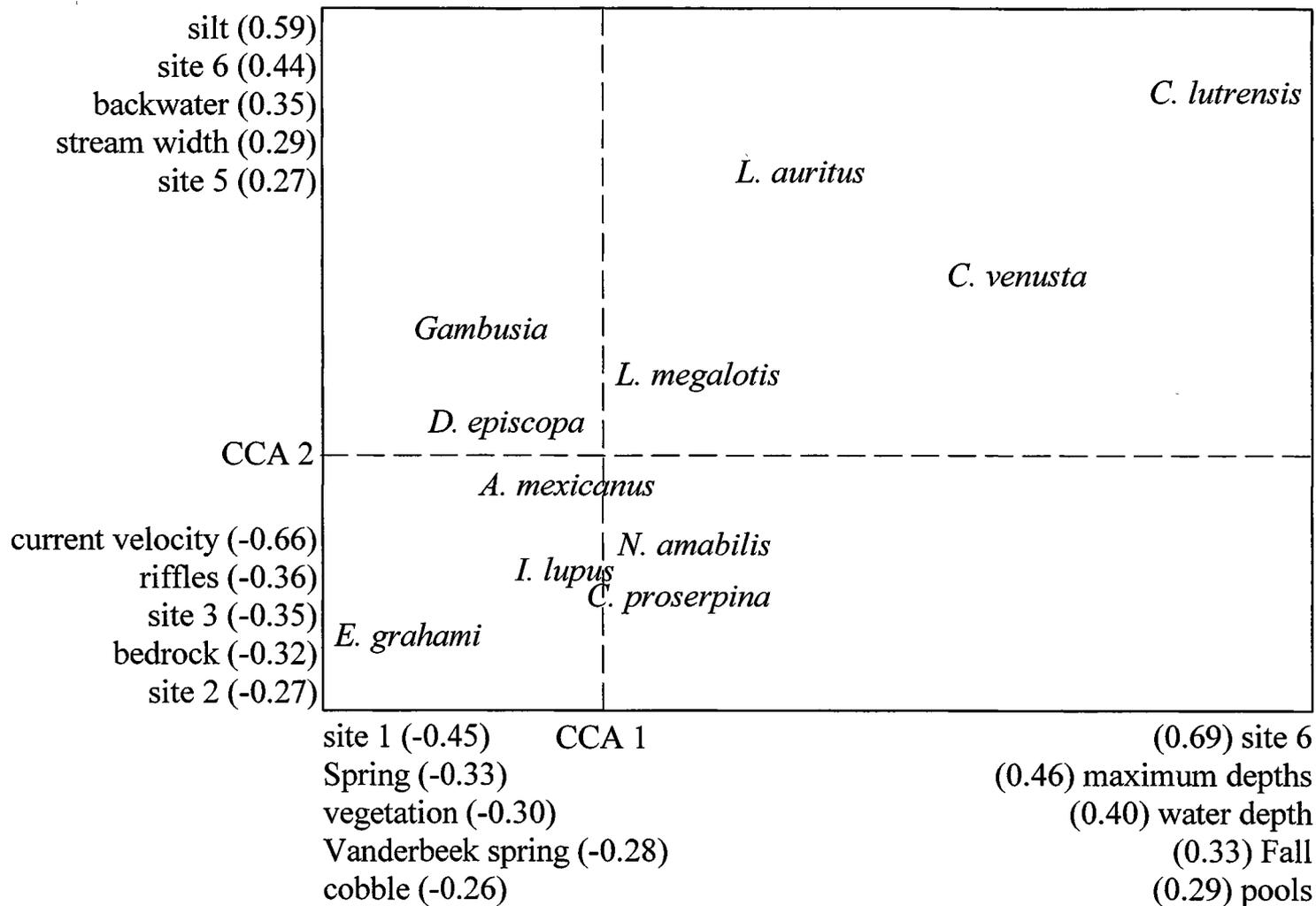
	Preflood	Post-flood
Mean channel width (m) (\pm SD)	8.6 (10.1)	12.7 (13.2)
Mean depth (m) (\pm SD)	0.3 (0.2)	0.3 (0.2)
Mean current velocity (m/s) (\pm SD)	0.3 (0.3)	0.4 (0.2)
Substrate (%)		
gravel	39	65
cobble	26	26
silt	22	<0.5
bedrock	12	7
sand	<0.5	<0.1
boulders	<0.5	2
detritus	<0.1	0
Geomorphic units (%)		
run	50	58
pool	39	7
riffle	7	33
chute	2	0
side channel	1	<1
backwater	1	<1



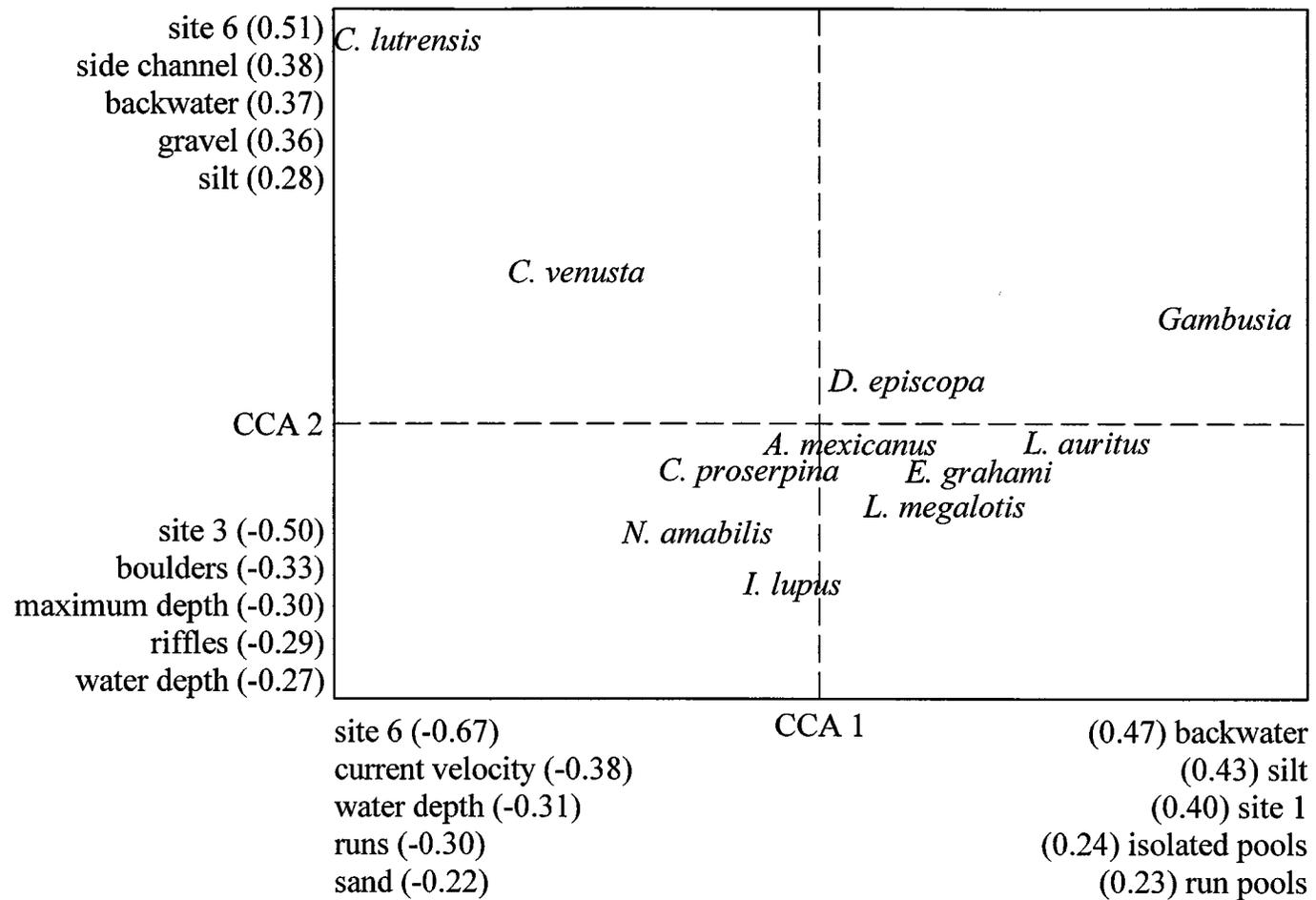
Appendix 4. Surveyed stream channel of Independence Creek. Descriptions written above the water line are post-flood (September 2005) conditions and below water line are pre-flood (May 2002).

Appendix 5. Relative abundance (%), taxa richness, and mean monthly (\pm SE) Shannon-Weiner diversity, Buzas and Gibson's evenness and turnover (Renkonen similarity index) of fishes collected from preflood and post-flood Independence Creek, spring outflow and reservoirs (May 2002 – June 2005).

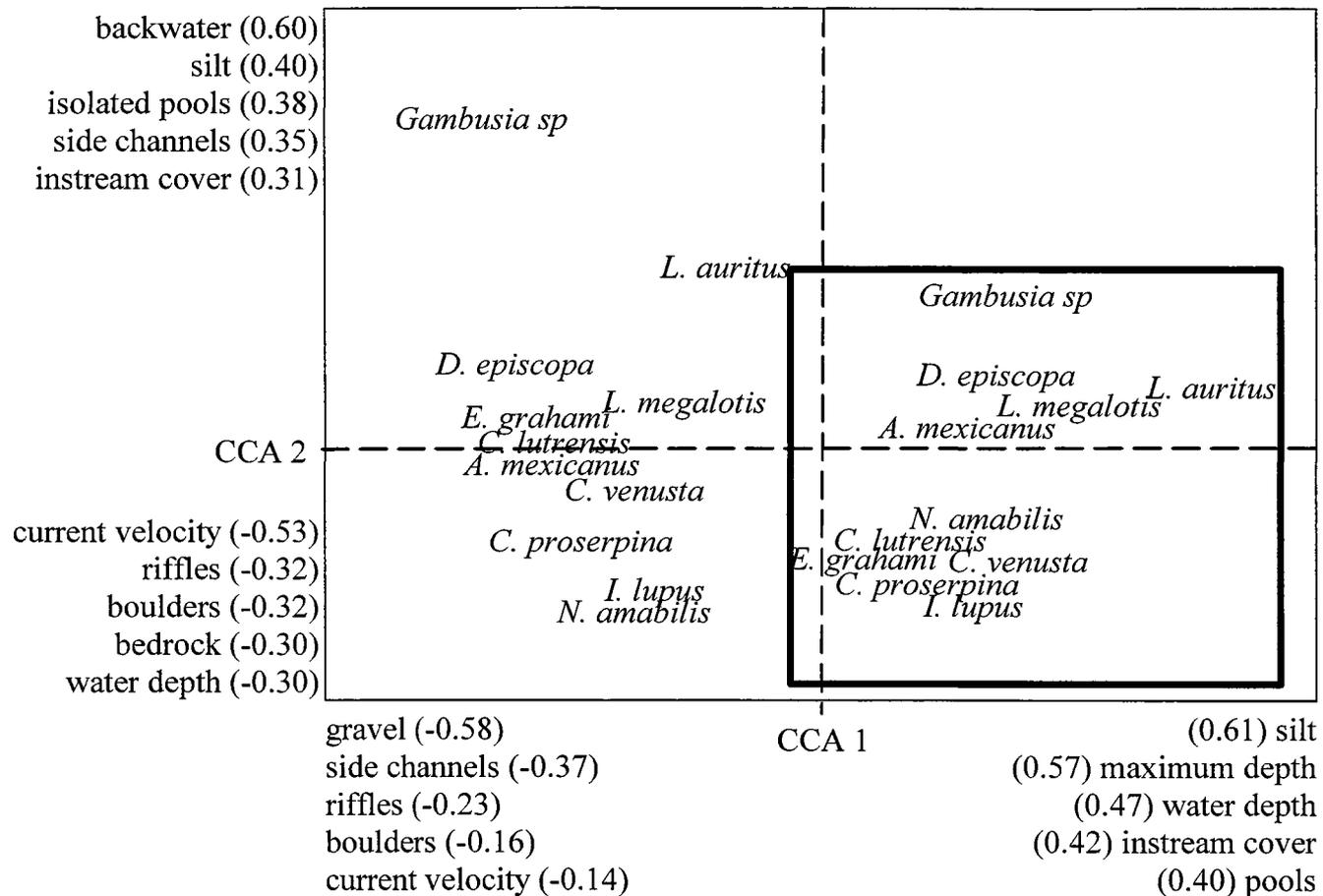
Species	Preflood	Post-flood	Spring outflow	Reservoirs
<i>Cyprinella lutrensis</i>	0.9	2.3		
<i>Cyprinella proserpina</i>	15.1	16.6		
<i>Cyprinella venusta</i>	0.1	1.5		
<i>Cyprinus carpio</i>		<0.1		
<i>Dionda episcopa</i>	22.5	31.0	5.7	30.2
<i>Notropis amabilis</i>	27.3	32.6		
<i>Notropis braytoni</i>	<0.1	0.1		
<i>Pimephales promelas</i>		<0.1		
<i>Pimephales vigilax</i>		<0.1		
<i>Moxostoma congestum</i>	0.2	<0.1		<0.1
<i>Astyanax mexicanus</i>	1.4	3.0	13.0	27.0
<i>Ictalurus sp.</i>	<0.1	0.4		2.6
<i>Ictalurus lupus</i>	0.7	0.9	0.2	
<i>Ictalurus punctatus</i>				0.1
<i>Pylodictis olivaris</i>	<0.1	<0.1		
<i>Fundulus grandis</i>		<0.1		
<i>Fundulus zebrinus</i>	0.8	0.1		
<i>Lucania parva</i>	0.1		3.0	
<i>Gambusia sp.</i>	5.3	2.5	48.0	10.6
<i>Gambusia affinis</i>	12.5	4.8	11.3	9.6
<i>Gambusia geiseri</i>	7.4	1.2	18.3	6.1
<i>Cyprinodon variegatus</i>	0.2			
<i>Lepomis sp.</i>	0.2	0.5		0.1
<i>Lepomis auritus</i>	2.0	0.2		0.4
<i>Lepomis cyanellus</i>	<0.1			0.4
<i>Lepomis macrochirus</i>	0.1			
<i>Lepomis megalotis</i>	0.8	0.5	0.3	0.7
<i>Micropterus salmoides</i>	0.4	0.1	<0.1	3.9
<i>Etheostoma grahami</i>	1.3	1.0	0.1	1.6
<i>Cichlasoma cyanoguttatum</i>	0.6	0.5	0.1	6.7
<i>N</i> =	11,683	8,385	5,636	4,984
Taxa richness	22	22	10	12
Diversity (mean \pm SD)	1.84 \pm 0.17	1.69 \pm 0.10	0.98 \pm 0.37	1.52 \pm 0.26
Evenness (mean \pm SD)	0.34 \pm 0.08	0.31 \pm 0.03	0.43 \pm 0.15	0.50 \pm 0.08
Turnover (mean \pm SD)	0.57 \pm 0.11	0.77 \pm 0.03	0.53 \pm 0.24	0.48 \pm 0.12



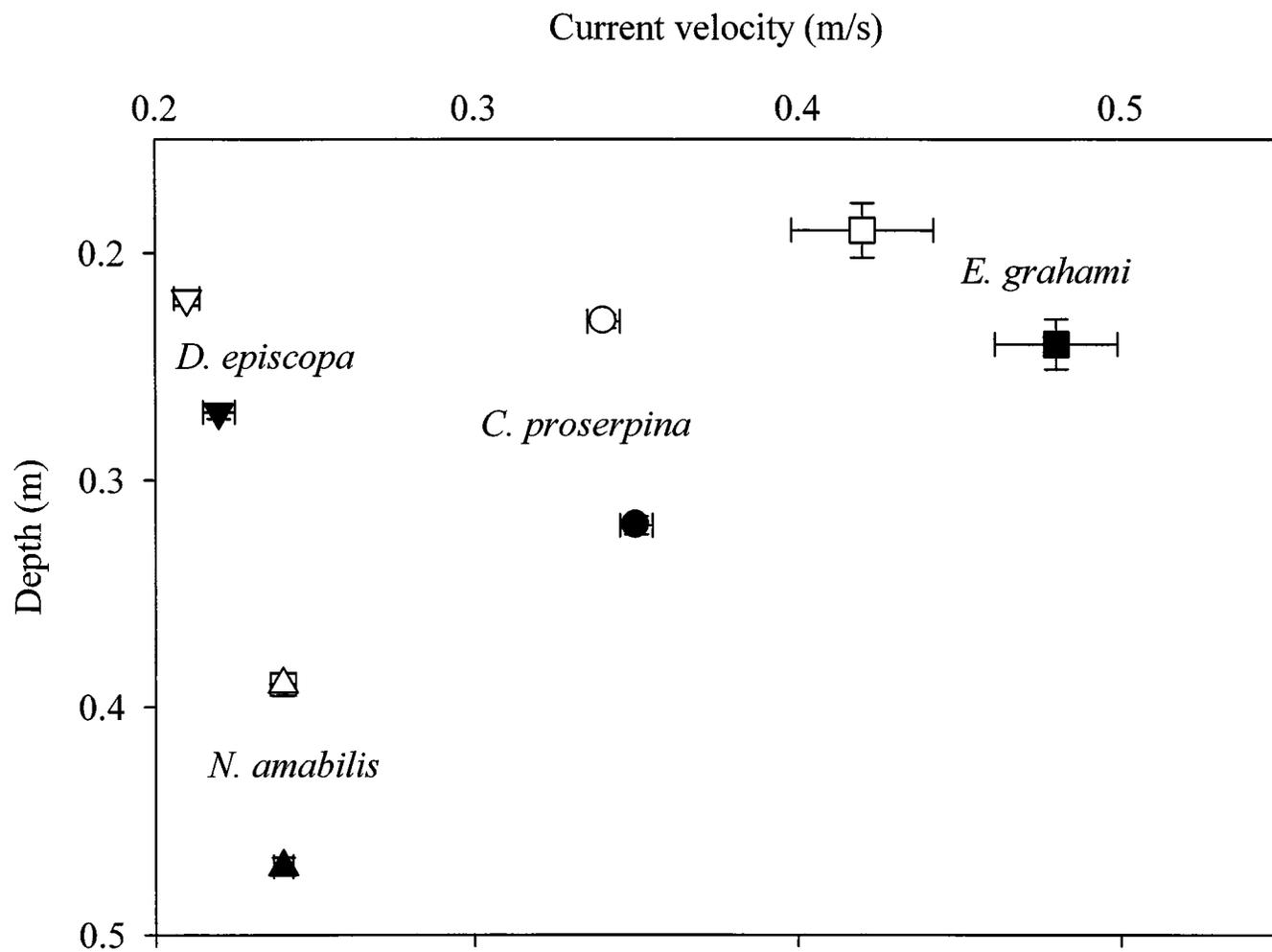
Appendix 6. Canonical correspondence ordination plot for fishes and environmental parameters collected from preflood Independence Creek (May 2002- June 2004).



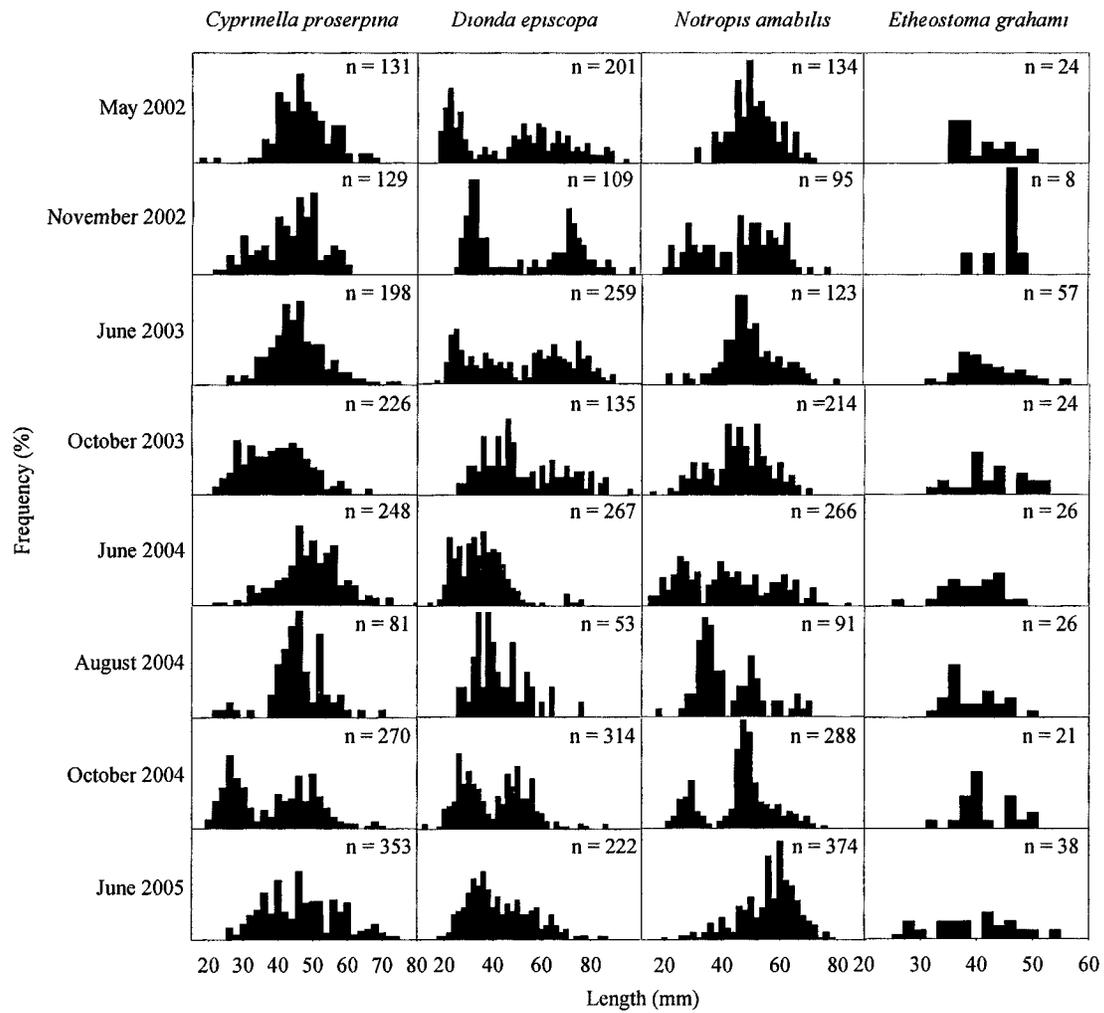
Appendix 7. Canonical correspondence ordination plot for fishes and environmental parameters collected from post-flood Independence Creek (August 2004 – June 2005).



Appendix 8. Canonical correspondence analysis biplot for fishes and environmental parameters collected from pre and post-flood Independence Creek (May 2002 – June 2005). Fishes collected pre-flood are enclosed in the black box.



Appendix 9. Mean (\pm SE) current velocity (m/s) and depth (m) for five species of interest collected from Independence Creek. Preflood means are indicated by solid symbols and post-flood by open symbols.



Appendix 10. Length frequency histograms for spring endemics of Independence Creek (May 2002 – June 2005).

LITERATURE CITED

- BONNER, T. H., C. THOMAS, C. S. WILLIAMS, AND J. P. KARGES. 2005. Temporal assessment of a west Texas stream fish assemblage. *Southwestern Naturalist*, 50:74-78
- BORCARD, D., P. LEGENDRE, AND P. DRAPEAU. 1992. Partialling out the spatial component of ecological variation. *Ecology*, 73:1045-1055.
- BOWLES, D. E., AND T. L. ARSUFFI. 1993. Karst aquatic ecosystems of the Edwards Plateau region of central Texas, USA: a consideration of their importance, threats to their existence, and efforts for their conservation. *Aquatic Conservation Marine and Freshwater Ecosystems*, 3:317-329.
- BRUNE, G. 1981. Springs of Texas, Volume 1. Branch-Smith, Inc. Fort Worth, Texas.
- 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. *American Fisheries Society Symposium*, 45:205-223.
- CHANDLER, C. 2004. On Independence Creek: the story of a Texas ranch. Texas Tech University Press, Lubbock, Texas.
- COLLINS, J. P., C. YOUNG, J. HOWELL, AND W. L. MINCKLEY. 1981. Impact of flooding in a Sonoran Desert stream, including elimination of an endangered fish population (*Poeciliopsis o. occidentalis*, Poeciliidae). *Southwestern Naturalist*, 26:415-423.
- DUDLEY, R. K., AND W. J. MATTER. 1999. Effects of a record flood on fishes in Sabino Creek, Arizona. *Southwestern Naturalist*, 44:218-221.
- EHELLE, A. A., A. F. ECHELLE, AND L. G. HILL. 1972. Interspecific interactions and limiting factors of abundance and distribution in the Red River pupfish, *Cyprinodon rubrofluviatilis*. *American Midland Naturalist*, 88:109-130.
- 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.

- FAUSCH, K. D., AND R. C. BRAMBLETT. 1991. Disturbance and fish communities in intermittent tributaries of a western Great Plains river. *Copeia*, 1991:659-674.
- FISHER, S. G., L. J. GRAY, N. B. GRIMM, AND D. E. BUSCH. 1982. Temporal succession in a desert stream ecosystem following flash flooding. *Ecological Monographs*, 52:93-110.
- FISHER, S. G., AND W. L. MINCKLEY. 1978. Chemical characteristics of a desert stream in flash flood. *Journal of Arid Environments*, 1:25-33.
- GARRETT, G. P., R. J. EDWARDS, AND C. HUBBS. 2004. Discovery of a new population of Devils River minnow (*Dionda diaboli*), with implications for conservation of the species. *Southwestern Naturalist*, 49:435-441.
- GELWICK, F. P. 1990. Longitudinal and temporal comparisons of riffle and pool fish assemblages in a northeastern Oklahoma Ozark stream. *Copeia*, 1990:1072-1082.
- GRIMM, N. B. A., A. CHACON, C. N. DAHM, S. W. HOSTETLER, O. T. LIND, P. L. STARKWEATHER, AND W. W. WURSTBAUGH. 1997. Sensitivity of aquatic ecosystems to climatic and anthropogenic changes: the basin and range, American southwest and Mexico. *Hydrological Processes*, 11:1023-1041.
- GROEGER, A. W., P. F. BROWN, T. E. TIETJEN, T. C. KELSEY. 1997. Water quality of the San Marcos River. *Texas Journal of Science*, 49:279-294.
- HARRELL, H. L. 1978. Response of the Devils River (Texas) fish community to flooding. *Copeia*, 1978:60-68.
- HARVEY, B. C. 1987. Susceptibility of young-of-the-year fishes to downstream displacement by flooding. *Transactions of the American Fisheries Society*, 116:851-855.
- HAYEK, L. C., AND M. A. BUZAS. 1997. Surveying natural populations. Columbia University, Press, New York.
- HOAGSTROM, C. W. 2003. Historical and recent fish fauna of the lower Pecos River, p. 91-109. In Garrett, G. P. and N. L. Allen (eds). Aquatic fauna of the Northern Chihuahuan Desert. Special Publications Number 46, Museum, Texas Tech University.
- HUBBS, C. 1990. Declining fishes of the Chihuahuan Desert. *Papers from the Third Symposium on Resources of the Chihuahuan Desert Region, United States and Mexico*, Chihuahuan Desert Research Institute, 89-96.

- HUBBS, C. 1995. Springs and spring runs as unique aquatic systems. *Copeia*, 1995:989-991.
- HUBBS, C. 2001. Environmental correlates to the abundance of spring-adapted versus stream-adapted fishes. *Texas Journal of Science*, 53:299-326.
- HUBBS, C., R. J. EDWARDS, AND G. P. GARRETT. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. *Texas Journal of Science, Supplement*, 43:1-56.
- KARGES, J. 2003. Aquatic conservation and The Nature Conservancy in west Texas, p. 141-150. *In*: G. P. Garrett and N. L. Allan (eds.). Aquatic fauna of the northern Chihuahuan Desert. Special Publications Number 46, Museum, Texas Tech University, Lubbock.
- KELSEY, T. 1997. Fish community structure and water quality assessment (index of biotic integrity) of the San Marcos River, Texas. MS thesis, Texas State University-San Marcos, Texas.
- KREBS, C. J. 1999. Ecological methodology, 2nd edition. Benjamin/Cummings, Menlo Park, California.
- LABBE, T. R., AND K. D. FAUSCH. 2000. Dynamics of intermittent stream habitat regulate persistence of a threatened fish at multiple scales. *Ecological Applications*, 10:1774-1791.
- LEAVY, T. R. 2004. Relationships among swimming ability, habitat use, and morphology of freshwater fishes from Texas and Louisiana. MS thesis, Texas State University-San Marcos, Texas.
- LITRELL, B. M., C. THOMAS, C. S. WILLIAMS, AND T. H. BONNER. 2003. Gut content analysis of the headwater catfish *Ictalurus lupus* from two west Texas streams. *Texas Journal of Science*, 55:323-328.
- MAGNAN, P. M., A. RODRIGUEZ, P. LEGENDRE, AND S. LACASSE. 1994. Dietary variation in a freshwater fish species: relative contributions of biotic interactions, abiotic factors, and spatial structure. *Canadian Journal of Fisheries and Aquatic Science*, 51:2856-2865.
- MATTHEWS, W. J. 1985. Distribution of midwestern fishes on multivariate environmental gradients, with emphasis on *Notropis lutrensis*. *American Midland Naturalist*, 113:225-237.

- MATTHEWS, W. J. 1986. Fish faunal structure in an Ozark stream: stability, persistence and a catastrophic flood. *Copeia*, 1986:388-397.
- MATTHEWS, W. J. 1998. Patterns in freshwater fish ecology. Chapman and Hall, New York, NY.
- MATTHEWS, W. J., R. C. CASHNER, AND F. P. GELWICK. 1988. Stability and persistence of fish faunas and assemblages in three Midwestern streams. *Copeia*, 1988:945-955.
- MCDONALD, D. L., T. H. BONNER, E. L. OBORNY, JR., AND T. M. BRANDT. In review. Effects of fluctuating temperatures and gill parasites on reproduction of the fountain darter, *Etheostoma fonticola*. *Journal of Freshwater Ecology*
- MEFFE, G. K. 1984. Effects of abiotic disturbance on coexistence of predator-prey fish species. *Ecology*, 65:1525-1534.
- MEFFE, G. K., AND W. L. MINCKLEY. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. *American Midland Naturalist*, 117:177-191.
- MINCKLEY, W. L., AND J. E. DEACON, EDS. 1991. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.
- MINCKLEY, W. L., AND G. K. MEFFE. 1987. Differential selection by flooding in stream-fish communities of the arid American southwest, p. 93-104. In Matthews, W. J. and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.
- NOVINGER, D. C., AND F. J. RAHEL. 2003. Isolation management with artificial barriers as a conservation strategy for cutthroat trout in headwater streams. *Conservation Biology*, 17:772-781.
- POFF, N. L., AND J. D. ALLAN. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology*, 76:606-627.
- POFF, N. L., J. D. ALLAN, M. B. BAIN, J. R. KARR, K. L. PRESTEGAARD, B. D. RICHTER, R. E. SPARKS, AND J. C. STROMBERG. 1997. The natural flow regime. *BioScience*, 47:769-784.
- RHODES, K., AND C. HUBBS. 1992. Recovery of Pecos River fishes from a red tide fish kill. *Southwestern Naturalist*, 37:178-187.

- RICHTER, B. D., D. P. BRAUN, M. A. MENDELSON, AND L. L. MASTER. 1997. Threats to imperiled freshwater fauna. *Conservation Biology*, 11:1081-1093.
- ROBERTSON, M. S., AND K. O. WINEMILLER. 2003. Habitat associations of fishes in the Devils River, Texas. *Journal of Freshwater Ecology*, 18:115-127.
- SCHENCK, J. R., AND B. G. WHITESIDE. 1976. Distribution, habitat preference and population size estimate of *Etheostoma fonticola*. *Copeia*, 4:697-703.
- SCHULTZ, A. A., O. E. MAUGHAN, AND S. A. BONAR. 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.
- SEERGIST, D. W., AND R. GARD. 1972. Effects of floods on trout in Sagehen Creek, California. *Transactions of the American Fisheries Society*, 101:478-482.
- SHARP, J. M. JR., R. BOGHICI, AND M. M. ULIANA. 2003. Groundwater systems feeding the springs of west Texas, p. 1-11. In Garrett, G. P. and N. L. Allen, editors. Aquatic fauna of the Northern Chihuahuan Desert. Special Publications Number 46, Museum, Texas Tech University.
- SMITH, M. L., AND R. R. MILLER. 1986. The evolution of the Rio Grande basin as inferred from its fish fauna, p. 457-485. In Hocutt, C. H. and E. O. Wiley, editors. The zoogeography of North American freshwater fishes. John Wiley and Sons, Inc, New York.
- SUMNER, F. B., AND M. C. SARGENT. 1940. Some observations on the physiology of warm spring fishes. *Ecology*, 21:45-51.
- TAYLOR, C. M., AND P. W. LIENESCH. 1996. Regional parapatry of the congeneric cyprinids *Lythrurus snelsoni* and *L. umbratilis*: species replacement among a complex environmental gradient. *Copeia*, 1996:493-497.
- TAYLOR, C. M., AND M. L. WARREN, JR. 2001. Dynamics in species composition of stream fish assemblages: environmental variability and nested subsets. *Ecology*, 67:1167-1179.
- TAYLOR, C. M., M. R. WINSTON, AND W. J. MATTHEWS. 1996. Temporal variation in tributary and mainstem fish assemblages in a Great Plains stream system. *Copeia*, 1996:280-289.

- TER BRAAK, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67:1167-1179.
- THOMPSON, P. D., AND F. J. RAHEL. 1998. Evaluation of artificial barriers in small Rocky Mountain streams for preventing the upstream movement of Brook trout. *North American Journal of Fisheries Management*, 18:206-210.
- WARD, D. L., A. A. SCHULTZ, AND P. G. MATSON. 2003. Differences in swimming ability and behavior response to high water velocities among native and nonnative fishes. *Environmental Biology of Fishes*, 68:87-92.
- WEBSTER, G. L. 1950. Observations on the vegetation and summer flora of the Stockton Plateau in northeastern Terrell County, Texas. *Texas Journal of Science*, 2:234-242.
- WILLIAMS, C. S. 2003. Cyprinid assemblage structure along physical, longitudinal, and seasonal gradients and life history and reproductive ecology of the Sabine shiner. MS thesis, Texas State University–San Marcos, Texas.
- WILLIAMS, L. R., T. H. BONNER, J. D. HUDSON III, M. G. WILLIAMS, T. R. LEAVY, AND C. S. WILLIAMS. 2005. Interactive effects of environmental variability and military training on stream biota of three headwater drainages in western Louisiana. *Transactions of the American Fisheries Society*, 134:192-206.
- WILLIAMS, J. E., J. E. JOHNSON, D. A. HENDRICKSON, S. CONTRERAS-BALDERAS, J. D. WILLIAMS, M. NAVARRO-MENDOZA, D. E. MCALLISTER, AND J. E. DEACON. 1989. Fishes of North America endangered, threatened or of special concern. *Fisheries*, 14:2-20.
- URBANCZYK, K. 2003. Contemporary water supply in west Texas as an example for the Northern Chihuahuan Desert, p. 13-23. In Garrett, G. P. and N. L. Allen (eds). Aquatic fauna of the Northern Chihuahuan Desert. Special Publications Number 46, Museum, Texas Tech University.
- VALDES CANTU, N. E., AND K. O. WINEMILLER. 1997. Structure and habitat associations of Devils River fish assemblage. *Southwestern Naturalist*, 42:265-278.
- ZAR, J. H. 1999. Biostatistical analysis, 4th edition. Prentice-Hall Inc., Upper Saddle River, New Jersey.

VITA

Jacqueline Michelle Watson, the daughter of Linda Suchogorski and Willard Watson, was born on March 1, 1979 in Houston, Texas. In 1991, Jackie moved overseas and attended school in Manama, Bahrain; Dubai, United Arab Emirates and graduated from American Community School, Cobham, England in 1997. Jackie received a Bachelor of Science degree from Texas State University–San Marcos in 2001, and a secondary teaching certificate in 2002. In January 2003, she entered the Aquatic Biology graduate program at Texas State. During her time as a graduate student Jackie was employed by the university as an instructional assistant and a research assistant, had a summer internship with the Texas Commission on Environmental Quality and a summer technician position with Texas Parks and Wildlife Department.

Permanent Address: 4400 Campbell Rd
 Clinton, Washington 98236

This thesis was typed by Jacqueline Michelle Watson.