Brazos River Faunal Community and Relation to 'River Styles' River Assessment Scheme with a

Comparison of Conventional Field Sampling Methods versus DIDSON Instrumentation

(Cost/Benefit Estimate)

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Abstract

The geomorphology of a stream is important in describing the habitat of biota such as fish and invertebrates because channel morphology provides the framework in which these organisms live (Gordon et al. 2004). The Texas Instream Flow Program is developing techniques for geomorphic segmentation of rivers in Texas at various scales (Coffman et al. 2011). Previous applications of those techniques have segmented the Brazos River into coarse scale units of River Styles (or "geomorphic process zones") and geomorphic units (Phillips, 2007, Coffman et al., 2011). These units range in size from many kilometers to several channel widths along the length of a river. A finer scale mapping unit, called a hydrologic unit (or "Hydraulic Habitat Unit"), on the order of several to less than one channel top width in dimension is also envisioned. This project was undertaken in order to investigate the potential biological significance of hydraulic habitat units. A 2.27-km meander bend of the Brazos River 11 km downstream of Highway 60 near Snook, Texas, was selected as a study site. Güneralp and Hales (2013) assessed the physical and hydraulic features of this site, making it possible to divide the site into hydraulic habitat units. This report documents fish and macroinvertebrate data collected at the site and analyses completed to determine the relationship between biota and these units. The project also investigated the use of Dual frequency Identification SONar (DIDSON) equipment for biological data collection. We calculated seining and electroshocking catch per unit effort (CPUE), alpha and beta Shannon biodiversity for fish samples, and ran multivariate analyses of fish and macroinvertebrate assemblage structures and their associations with hydraulic and geomorphic habitat features, hydrologic parameters, and physicochemical conditions across all sample sites. DIDSON recordings were processed to count fish in three total-length size classes (< 10 cm, 10-30 cm, > 30 cm) both mannually and

automatically by using two post-processing programs. Across the study reach, assemblages of

fish were relatively homogenous and dominated by two Cyprinid species (*Cyprinella lutrensis*,

Red Shiner and *Pimephales vigilax*, Bullhead Minnow) in shallow habitats, and by Centrarchid

sunfishes (Lepomis sunfishes and *Micropterus salmoides*, Largemouth Bass) and Ictalurid

catfishes (*Ictalurus furcatus*, Blue Catfish and *Ictalurus punctatus*, Channel Catfish) in pools and

glides. Among river sections, the apex of the meander bend contained greater geomorphic

and hydraulic complexity and more diverse fish and macroinvertebrate assemblages. For both

seined fish and benthic macroinvertebrates, multivariate analysis showed that assemblage

composition was correlated with all five environmental components used to characterize

habitats at each sampling site (hydraulic habitat types, structural habitat features, sediment

size composition, physicochemical variables, and hydrologic parameters). Although

covariation was common across these different components, individual components as well as

particular combinations explained most of the variation in species distribution among samples

(63% for fish, 85% for macroinvertebrates). Numerically dominant species in the Brazos River

are habitat generalists and tolerant of stressful conditions (high temperature, low dissolved

oxygen). However, the morphological and hydrologic complexity associated with the apex of

the meander bend, contained the most diverse assemblages of fish and macroinvertebrates.

DIDSON recordings documented and confirmed (a) simultaneous fish association in complex

habitats and (b) behaviors among various fish sizes and species that otherwise could only be

inferred from extrapolated data across separate species and body sizes and multiple gears at

different times and locations. We conclude that geomorphic features identified by Güneralp

and Hales in the concurrent project (pool depth and mid-channel and point bars) that controled

hydrologic parameters are key to understanding the relationship between river habitat

complexity and distribution of biotic diversity. Therefore, future studies should strive to

produce models that link variation in flow regimes (and water extraction) to hydraulic

processes for formation and maintenance of dynamic river habitats and thus, more accurately

describe consequences for distribution and abundance of biota in river communities.

Chapter 1 Faunal Community and Relation to 'River Styles' River Assessment Scheme; Conventional Field Sampling Methods versus DIDSON

Introduction

The study of stream geomorophology and aquatic ecology in river systems has been extensively discussed (Wadeson and Rowntree, 1998, Newson, 2000, Clifford et al., 2006, Thorp et al., 2006). River systems are complex ecosystems that change frequently by season, flooding, and human use. Hydrologic stream ecology combines velocity, depth, and substrate to define suitable habitats for benthic invertebrates and fish. Stream ecologists have used several key terms to define stream habitat: flow types, biotypes, and patch dynamics. Flow type is the visual surface appearance of water that is believed to reflect the hydrologic conditions of the water column. Using this concept Wadeson and Rowntree (1998) defined hydrologic biotypes by referring abiotic flow factors to spatially describe distinct flow environments that are characterized by hydraulic attributes that supply the abiotic environment inhabited by species and assemblages. By combining flow type with geomorphological characteristics, Wadeson and Rowntree (1998) standardized 11 hydraulic biotypes; backwater, slackwater, glide, pool, chute, run, riffle, rapid, cascade, waterfall, and boil. Pickett and Thompson (1978) described patch dynamics as internal dynamics that are generated by patterns of disturbance and succession. The disturbance regime establishes patch size, density, and temporal frequency, while the internal structure determines the species composition, population density and dispersal, and geometry. Townsend (1989) related patch dynamics to stream ecology by stating that it can provide a general model for understanding river community and structure dynamics because every stream to some extent

is patchy and each patch has its own kind of disturbances, colonization, colonist sources, and species interaction.

Studying hydrologic stream ecology, also known as 'habitat hydraulics' or 'eco-hydraulics', is a daunting task and combining hydrology and ecology studies can become challenging. Newson and Newson (2000) discussed the difficulties and challenges of combining geomorphological and ecological river characteristics to define physical habitat and species assemblages. Historically environmental stream assessment has been a function of measured physicochemical water quality but didn't include physical habitat or biological impacts. To determine 'stream health', a measure of the quality of physical habitat structure and hydrological indices, successful and accurate assessment of both hydrology and ecology is necessary to conserve and define essential habitat in streams (Gordon, 2004).

A common problem for ecologists in describing river fish assemblages is the need to use multiple gear types to accurately assess fish biomass and density. It is possible to optimize a data collection method for a single species within a particular range of body size or life-stage for the purpose of estimating its abundance in any specific habitat (e.g., adult Blue Catfish by gill netting in deep pools), but multiple gear types are required to estimate a species' abundance across all life stages and habitats present in the field for a given project. Moreover, the efficiency of even a single gear type can vary across different habitats, as well as across fish species and body-sizes. Therefore, to estimate fish abundance, comparative gear efficiency must be calculated for the range of variation in species and habitats for each project. In other words, for each fish species and size category, one must be able to calculate estimates of abundance (number per area or volume) from data for catch per unit of effort (CPUE) for one

combination of habitat and sampling gear. Then abundance estimates are converted into a probability of CPUE within an equivalent area or volume of a different habitat sampled using a different gear type. This requires replication of each sampling method across each habitat type at a rate such that an acceptable precision for abundance estimates is achieved (e.g., 20% of the mean value).

Agencies use CPUE in management practices, but it is generally not a 'good rule of thumb' to combine CPUE calculations from different gear types due to different catchability of species by each gear (Quist et al., 2009). Recently the American Fisheries Society provided standard methods and gear guidelines for sampling North American freshwater fishes for various habitats in an effort to standardize data collection to make comparisons between agencies, time, and seasons (Bonar et al., 2009). For example, a combination of eight different gears are recommended for warmwater fishes in rivers (Guy et al., 2009), because each gear targets certain species and sizes, and can potentially miss others.

Hydroacoustic tools are useful and practical in fishery ecology and hydrology research to estimate acoustic biomass and size distribution of fish in different habitats in shallow waters because they can collect more inclusive data on fishery ecology (Boswell et al., 2007). Light wave lengths detected by humans do not penetrate water more than a few meters below the surface and it is even more difficult to see in waters containing suspended particles. Sound wave lengths are longer and can penetrate deeper into water (Simmonds and MacLennan, 2005). DIDSON (Dual frequency IDentification SONar) is now available that makes it possible to identify and count fish, as well as concurrently map their location and structural habitat features, and to observe behavior using a single apparatus in areas with complex habitat

combinations, high turbidity or low visibility (nighttime). The DIDSON uses high frequency sound with multiple, narrow, two-way beam-widths and remote focus capability that reduces acoustic cross talk to generate sharp images (Belcher et al., 2001, Belcher et al., 2002). DIDSON runs at two frequencies, high frequency or identification mode (1.8MHz and 96 two-way beamwidth at 0.3° horizontal x 10.8° vertical) and low frequency or detection mode (1.0 MHz and 48 two-way beamwidth at 0.4° horizontal x 10.8° vertical). The high frequency mode provides a higher resolution and images objects at distances up to 12 m, whereas the low frequency mode images objects at distances up to 40 m but at decreased quality of resolution.

DIDSON has been used in research for anadromous fisheries and habitat imaging in turbid and cloudy waters, and is a harmless method of estimating fish abundance, outline and shape, and features of an object target (Simmonds and MacLennan, 2005, Caimi et al., 2008). DIDSON proved to be a capable and robust tool in capturing images of movement in confined spaces such as walls, gratings, support cables or pilings, and identifying Chinook smolts, *Oncorhynchus tshawytscha*, adult Rainbow Trout, *Oncorhynchus mykiss*, and juvenile Pacific Lamprey, *Lampetra tridentate*, in hydropower facilities (Moursund et al., 2003). It also detected migrating salmon at distances up to 18 m from the transducer in very turbid waters of the Copper River in Alaska (Maxwell and Gove, 2004). Conventional trapping methods are not successful in capturing all fish. DIDSON captured images of migrating fish in a fishway that documented trap avoidance or exit without being caught (Baumgartner et al., 2006).

For our project, in support of the proposed use by Texas Water Development Board (TWDB) of the River Styles Methodology, we conducted a pilot study in a 2.27-km meander bend of the lower Brazos River located south of the Highway 21 gauge in Bryan, TX and 11-km

downstream of the Highway 60 bridge in Snook, TX.. In order to survey the faunal community, we sampled beyond fishes, including mussels and benthic macroinvertebrates, and characterized associations among biota and multiple characteristics of habitat across our sampling sites. Conventional field sampling of community composition and quantitative estimates of species abundance across habitats in the Brazos River includes multiple types of gears and deployment methods because fish must be captured in order to identify and count individuals within a quantified area or volume of habitat. The purpose of including supplemental fish sampling with DIDSON was to produce a pilot study to assess the similarities and differences in fish assemblages across designated habitats by contrasting data collected using DIDSON to that for conventional sampling (e.g., gill netting, seining, and electroshocking). Our objective was to ascertain if a more comprehensive assessment of the relationship between physical habitats and fish assemblages could be acquired by adding DIDSON videography to river sampling protocols. Following research findings by Güneralp and Hales (2013) in a companion project to ours that included construction of a hydrologic model, we used data for low discharge (Q1) conditions, to define our habitat types (run/riffle, glide, pool, backwater, and bar) for samples of fauna across all hydraulic habitat types. In addition to the above described habitat types, we defined microhabitats. Repeated samples were planned for at least two levels of discharge conditions and multiple seasons, but weather conditions and river stage precluded our access to the study site (see additional comments in discussion). To describe biotic variation across these habitats we analyzed fish data for multiple types of gears, including DIDSON recordings, boat electroshocking, seining, and gill netting, and associated data for habitat characteristics at each site. A similar approach was

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used for macroinvertebrates using kick netting and benthic grab samples. We compared fish

biodiversity indices for habitats located between across-stream transects, microhabitats within

transects, as well as indices of species' relative abundances associated with those habitats.

We used multivariate analysis to identify associations among hydraulic habitat types for fish

species and macroinvertebrate taxa. DIDSON video recordings captured images of fish

behavior and habitat use. We counted the average number of fish of three size classes in the

images. We provide recommendations for use of DIDSON in sampling river systems similar to

our study site and discuss benefits and limitations for both DIDSON and conventional sampling

methods.

Methods

The study reach is a meandering bend, 2.27 km long with an average width of 61.4 m. It

is located on the lower Brazos River near College Station, Texas in Brazos County 11-km south

of Highway 60 bridge (30°32'26.71"N, 96°23'6.92"W), where 11 transects (T) were located by

Güneralp and Hales (2013) and others of TAMU GEOG, and D. Flores and others of the TWDB

(Fig. 1). The Brazos River is the largest low lying river in Texas, length > 1900 km. It is located

in the coastal plains of Texas and is described as having meandering channels of mainly sand

and mud sediment with areas of bedrock and floodplains (Phillips, 2006).   Conventional

methods of fish sampling included gill netting, seining, and electroshocking and Sound Metrics

DIDSON V5.23 was used for sonar imaging.
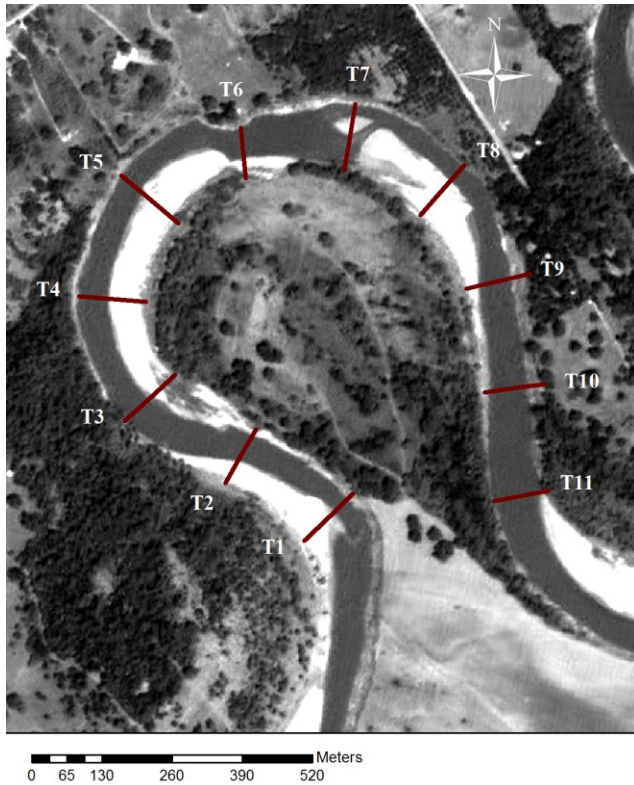
Figure 1.1 Brazos River study reach, 30°32'26.71"N, 96°23'6.92"W. Advanced Land Observation Satellite (ALOS) Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) image, acquired on August 17, 2010. (Source: Japan Aerospace Exploration Agency (JAXA)

For all the years of study, we collected samples in low flow conditions, therefore, we used the model-generated maps of velocity and depth for conditions of low discharge (Q1) that were derived from TWDB report by Güneralp and Hales(2013). Across sampling locations, we compared the relative abundances of fish and macroinvertebrates to stream hydrologic parameters generated by the model. Using model data for low discharge, our own visual descriptions of surface flow in the field, and referencing previous research on hydraulic biotypes (Wadeson and Rowntree, 1998, Harvey et al., 2008) we defined our hydraulic fish habitats as run/riffle, glide, pool (shallow or deep), backwater, bars (mid-channel and lateral). When comparing the water flow (velocity) and depth as high, moderate, and low, in our

discussions, we based our terminology off the numeric scales provided on Q1 maps referenced and included within this report. We categorized run/riffles as hydrologic units with visible surface ripples, high flow and depth < 1m, while glides were areas where there was smooth uniform surface flow (Wadeson and Rowntree 1998), moderate velocity, and 1-3 m deep. We defined hydrologic units with little to no flow as backwater and pool. Pools are connected to the main channel and categorized as deep if depth was >3 m and shallow if depth was 1-3 m, whereas backwater is separated from the main channel by some type of physical boundary (e.g. wood debris or mud bars). In addition, we classified microhabitats within transects as mid-channel and shoreline in T3 – T4 and T11, and as a transition area between run/riffle and backwater on T7 transect line. To describe the sampling locations within the study reach we used the following symbology: transect line number-hyphen-transect number for areas sampled between transects, e.g., T3-T4; locations on a transect as T and number of transect, e.g., T7; site directly upstream or downstream of a transect as beginning of and/or the end of a transect, e.g., end of T6 and beginning of T7. We provided GPS coordinates to Güneralp and Hales (2013) for each of our sample areas and they provided estimated values for hydrologic parameters .

Dr. Güneralp also provided sediment compositional analysis and water physicochemical data (temperature, conductivity, and DO) from the 2010 field campaign. Briefly, sediment samples were taken from left bank, right bank, and centerline along each transect. The Sediment Lab at Texas A&M University processed the collected samples and performed pipette analysis for substrate sediment to determine grain size and the proportion of sand, silt, and clay in sediment. For detailed methodology on sediment procedures refer to Güneralp and

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Hales (2013). Sediment sample data was missing from T7, however, we collected sediment

with our benthic samples and used visual descriptions to determine estimates for sediment

type along that transect for use in fish habitat analysis. A YSI 5906 probe manufactured by SI

Environmental in Yellow Springs, Ohio, was used to collect water parameters at each left and

right bank and center of the transect in mid-channel. For point bar measurements samples

were taken 0.3 m from the shoreline and for cut bank measurements samples were taken 1.0 m

from the shoreline. If the sample site was deep enough, separate measurements in upper and

lower water column were recorded using a cut off of 0.75 m, and values were averaged. In 2012

we measured depth, conductivity, and temperature and added flow measurements using Flow-

Mate 2000 from Marsh-McBirney Inc. at our fish sample sites. Due to faulty equipment on

some sampling dates/locations we were unable to measure dissolved oxygen (DO), so values

for those samples were interpolated from data taken at similar habitats under similar

conditions. For our multivariate analyses, we concatenated the data matrices for hydraulic

parameters, sediment size composition, and physicochemical variables to our data matrices

for fish and macroinvertebrates, and habitat types.

Fish Sampling

Conventional Sampling

We sampled between transects T3-T4, T5-T6, T6-T7 (area at the end of T6 and along T7

transect line), T8-T9, and downstream of T11 because these sites contained the different

hydraulic fish habitat types, run/riffle, glide, point and mid channel bars, backwater, and pool.

We deployed experimental gill nets (150' long x 6' deep, five 5'-long panels, one each of mesh

sizes 1, 1.5, 2, 2.5, and 3" bar mesh) angled away from shore in deeper areas (6'-18') of the

Brazos River overnight and also for a few hours during daytime while we were sampling with

other methods. We used a bag seine (20'long x 5'deep, 4' x 4' bag) and straight seine (20' long,

5' deep) near shore and in backwaters of the study reach (Table 1). Fish were placed in 10%

formalin solution preserved for two days, washed in distilled water for 8 hours and transferred

to 70% ethanol. Preserved fish were later identified to species. In 2011 and 2012, we

electroshocked fish from a 15' John boat using a 1.5 KVA Electrofisher (Smith-Root Inc.) set at

250V AC. To estimate relative fish abundance we calculated CPUE for each sampling gear by

taking either the ratio of the number of fish caught per seined area (m^2), or the ratio of the

number of fish caught per panel hour for gill netting, or the ratio of number of fish shocked

and netted per minute of actual electroshocking trigger-on time. In 2012, water conductivity

was high and we were unable to stun enough fish to calculate accurate CPUE; however,

stunned fish from 2012 were included in the diversity indices. Preliminary multivariate

analyses indicated a difference in relative abundance among species for seine samples

between sampling years, but it was determined to be due primarily to more effective sampling

of fish abundance in smaller habitats during extreme drought conditions of 2011. Because all

sampling occurred during low discharge conditions, we combined seining catch data for all

three years to calculate diversity indices for sample sites in areas between transects and also

across the entire project reach.

Transects T3-T4, T5-T6, T6-T7, and T11 were sampled multiple times; therefore, we

were able to calculate both alpha and beta diversity for these transects. Two methods can be

used with diversity sampling, either a standardized effort or adjusted effort to reflect variation

in diversity (Magurran, 2004a). To accommodate constraints due to resources, time, person

hours, and funds, we chose a commonly used protocol to adjust our sampling effort to reflect

diversity. An additional advantage of this method is that increasing the number of identical

samples taken at each site for calculating beta diversity does not affect the community

turnover calculation (Magurran, 2004b). We did at least three seine hauls at sampled habitats.

If the seines did not produce different species it was assumed that all species were represented

in the random sample. However, if seine hauls caught different fish then multiple hauls were

done until no new species were netted. This sampling procedure was followed for gill netting

and for electrofishing. To calculate true alpha diversity for each transect and microhabitat, we

used the exponential of the Shannon's diversity index, e^H (Jost, 2007). We also calculated

evenness, E_H, by dividing Shannon's diversity index, H, by the natural log of the total number

of species, S, at the sample site. As e^H approaches unity (S, the number of species), and E_H

approaches 1, the site is considered more diverse due to greater evenness. Conversely as e^H

and E_H approach zero, the site is considered less diverse due to numerical dominance by one

species or taxonomic group. Our samples were assumed to be unequal sizes; therefore, to

calculate beta diversity, D_β, we used the Shannon entropy index-free description of diversity

for unequal weights (Eq. 1 a, b, c, following (Jost, 2007)) for the whole study reach and for

paired comparisons among our transects. As D_β approaches 1, the species distribution across

the landscape is considered more dissimilar and more diverse, with high species turnover (i.e.,

heterogeneous) compared to a D_β that is approaching zero, which is considered to be

dominated by one species or taxonomic community across the landscape (i.e., homogeneous).

We seined one backwater and one run/riffle chute site at T7 on August 19, 2010, but no

field notes were associated with these samples to assign them to a specific habitat type, thus

fish were not included in calculations of CPUE or e^H index for microhabitats. However, they

were included in the total CPUE for the transect and for calculations of D_β.

a)

$$D_\beta = {D_\gamma}\big/{D_\alpha}$$

b)

$$D_\gamma = exp\left[\sum_{i=1}^{S} -(w_1\, pi_1\, +\, w_2\, pi_2\, ...\,...\,)\ln(w_1\, pi_1 + w_2 pi_2\, ...\,...\,)\right]$$

c)

$$D_\propto = exp\left[-w_1\sum_{i=1}^{S}(pi_1 \ln pi_1) +\, -w_2\sum_{i=1}^{S}(pi_2 \ln pi_2) + ...\,...\right]$$

Equations 1 (a, b, c) Shannon's index free description of beta diversity for unequal weighted samples (Jost, 2007). D_β = beta diversity, D_γ = gamma diversity, D_α = alpha diversity, w = weight, p_i = proportion of ith species.

DIDSON Recording

For our first trial in 2010, we mounted the DIDSON onto a pan and tilt motor suspended

from a pole attached to the side of a 15′ John boat that carried three persons. Two deep-cycle

marine batteries provided power adapted for the pan and tilt motor, and computer. We

oriented the DIDSON at multiple angles (scans, tilt, and pan settings) to gain familiarity with

the settings and view screen images provided by the equipment. GPS coordinates were

separately recorded (hand held Garmin, eTrex) for each DIDSON video file, and data were

backed up onto separate computer hard drives while we were in the field. Recordings were

taken back to the lab for additional review and data collection, including species identification

(by shape and behavior) when possible, size (body length), and average counts of fish per 3-minute time interval, and location and type of habitat used by fish. After reviewing recorded images from the 2010 field season we decided to construct a tripod stand to stabilize the DIDSON in order to obtain higher quality images for data processing. With the assistance of Dr. Kevin Boswell (Florida International University, Department of Biological Sciences) and Custom Fabricators in Bryan Texas, we designed an aluminum tripod stand (Fig 2 A).

In 2011, DIDSON field recordings were made from a 15' John boat in deeper water, or along the shoreline. Power was converted from two marine batteries and ran through cables to run the DIDSON, the gear rotator mounted on the tripod apparatus, and the field computer (Fig. 2 C). Once the apparatus was deployed and facing targeted fish habitats to view in a chosen direction upstream, downstream, or cross channel (Table 2.1), the camera was positioned by moving it manually up and down the mounting pole, and then rotating it remotely from the computer for optimal data capture. We then backed away up to 10 m from the apparatus and waited up to 5 minutes before beginning to record. During that time, we viewed the computer screen to see when fish had returned to more undisturbed behaviors, and then made two separate 3-minute recordings at each site. Recorded images were saved, backed up and further processed in the laboratory before analysis.

Here, we present data from videos recorded in 2011 due to their better image quality and positioning of the DIDSON. To determine the most effective processing program for DIDSON recordings we compared two programs, Echoview 4.90 and Sound Metrics, and also experimented with manual counts. Since manual counting can be very time consuming and Sound Metrics video quality was less refined and thus the counting program was less accurate,

we only present data from automatic counting (fish tracking) using the Echoview program

analysis. Recorded images were imported and processed through a series of image filters to

reduce background noise. The light threshold was adjusted to a desired level and then

processed into a single target echogram. Echograms, which are pictorial representations of the

water column recorded by an echosounder (Echoview, 2010), were generated for each

recording, but only recordings that displayed minimal background movement (e.g., drifting

particles, swirling sand and mud) were effectively analyzed for automatic counting. For fish

tracking, we defined a fish by setting echo (target) parameters and then ran the program.

After tracking, the echogram was verified and edited as needed prior to exporting the data into

Microsoft Excel. Fish species in the study reach had overlapping length classes, so we

categorized recorded fish into three different size classes, <10 cm, 10-30 cm, and >30 cm, that

maximized the distinctions among species (e.g., large-bodied versus small-bodied adults) and

age/length group. A sample for analysis was calculated as the average number of counted fish

in each size group across the two 3-minute recordings. Average number of fish for each

sample location was then overlaid on hydrology model maps.

Benthic Sampling

We collected macroinvertebrates from subsamples of benthos, drift wood, seining, and

electroshocking. We used a D-frame net to collect the top layer (10 cm) of sediment in

transects T3 – T4, T6 –T7, T6, and T11, and then calculated percent abundance by taxon for

each habitat sample. Following Hauer et al. (1996), each benthic sample from transect

habitats was strained into a bucket through a mesh sieve (500µ), roughly sorted from debris,

and fixed in either 50% or 70% isopropanol. In the laboratory, we randomly subsampled each

individual macroinvertebrate sample by spreading it across a shallow enamel pan, and then dividing it into four equal quadrants; a subsample was collected using a ring (8cm diameter) randomly place in each quadrant, and counted to obtain a total of 100 individuals to be identified. If 100 individuals were not obtained in the first four quadrants, the quadrants were subdivided into another set of four equal quadrants for subsampling until 100 individuals were counted. We calculated percent abundance of each taxon for each habitat sampled within each transect area. Some transect areas had more than one sample; therefore, we added together counts for each identified taxon for that location and then calculated its percent abundance for the transect area. Drift wood macroinvertebrate samples were preserved in the field by placing the wood into 50% isopropanol, and then allowed to fix for several weeks. Volume of each wood piece was calculated by measuring liquid displacement. Macroinvertebrates were extracted by examining the remaining fixative solution under magnification of a dissecting scope (45x) and by picking apart wood until a subsample of 100 individuals was counted. Electroshocked invertebrates were preserved along with fish in 10% formalin and later counted and identified in the lab. Invertebrates were identified to the lowest taxonomic group possible, typically genera; except Diptera was identified only to subfamily.

Multivariate Analysis of Biotic Assemblages

Biological data matrices for two separate analyses of fish were the CPUE values for species (columns of the matrix) in each sample location (rows of the matrix) collected by seining, and for species in each sample collected by electroshocking. For macroinvertebrates, data were the counts of the identified individuals of each taxon (columns of the matrix) in each sample (row). Data for taxa were $\log_{10}$ transformed and centered (subtracting column means

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of each taxon from each individual value) before analysis, thus each taxon was weighted by its variance in the covariance matrix for the analysis. The dependent variables (columns in the data matrix) were the individual taxa in separate analyses for each of our two biotic assemblages. The independent variables (columns in the data matrix) were explanatory environmental variables in the data matrices for each sample location (same rows of the matrix as for dependent variables) for the multivariate modeling components grouped as follows: physicochemical water quality parameters (temperature, DO, and conductivity), mean values for each of five relevant hydraulic factors (depth, velocity, shear stress, Froude number and helix strength)—averaged across point values for each discrete sampling located on maps of the study reach prepared by I. Güneralp and Hales (2013), the proportion of sediment in each of four size class (coarse, sand, silt, clay), and categorical variables (0/1) for each of our habitat types (pool, glide, run/riffle, transition, backwater) and structural features (wood, rubble, vegetation, bare). We used forward selection and backward elimination procedures with Monte Carlo Randomization algorithms in the software package CANOCO (ver. 4.5; Lepš and Šmilauer 2003) to identify the set of independent variables that would have minimum redundancy, yet maximize the total explained variance in the dependent variables of the biological dataset. The results of the analyses were visualized as plots scaled to visually emphasize differences among taxa in each biotic assemblage while depicting correlations among ordination scores for our dependent variables (either fish or macroinvertebrates) and our independent variables (environmental habitat components). Lepš and Šmilauer (2003) provides additional details regarding these methods.

We first ran exploratory indirect gradient analyses—Principal Components Analysis (PCA) and Detrended Correspondence Analysis (DCA) — using the CANOCO software package (vers. 4.5, Microcomputer Power, Ithaca NY; Lepš and Šmilauer 2003). The results indicated that datasets for both fish and macroinvertebrates contained intermediate-length gradients of variation (i.e., less than three standard deviations of change; Jongman et al. 1997). Thus, a linear direct gradient analysis — Redundancy Analysis (RDA) — was appropriate for building a linear multivariate model to quantify correlations among environmental habitat variables, and to link them to correlations among ordination scores for each of our biological taxa. To focus the analysis on the more common species (and avoid spurious correlations due to small sample size of individual taxa), we limited our analysis matrices for dependent biotic variables to taxa that occurred in at least three samples (fish), or comprised > 1% of the total abundance (macroinvertebrates) across all samples (17 fish species and 16 macroinvertebrate taxa).

To evaluate the relative contribution of each set of environmental components to the multivariate (RDA) model, we used partial correlation to decompose the explained variation among samples for each of our biotic groups (fish and macroinvertebrates) into that due uniquely to each component group of explanatory variables (e.g., hydraulic factors or habitat type), and that which could be shared among (attributable to) more than just one component group of variables due to their inter-variable correlations.

We used multivariate analysis biplots to visualize the fit of relationships among ordination scores for the biological taxa to the best linear combination of the independent variables on each canonical (explanatory) axis. However, the response of taxa to individual explanatory variables is less obvious when variables are weakly correlated to one another—

therefore displayed better on multiple canonical axes, or when similar habitat values (e.g., depth) occur across different habitat categories (pools, glides, riffle/runs). To visualize the relation between each taxon and relevant individual explanatory variables in the multivariate analysis, we analyzed response curves of all taxa (including those not included in the multivariate direct gradient analysis) by fitting a generalized additive model (GAM) using Akaike Information Criterion (AIC) to choose the best fit model (McCullagh and Nelder, 1989). The model fitted a Poisson response distribution of the taxon for the chosen predictor variable (e.g., velocity, or proportion of sand in the sediment) using a semi-parametric, cubic-spline smoother, set to a maximum of 3 degrees of freedom for its complexity.

We evaluated correlations between categorical designations for our five habitat types (pool, glide, run/riffle, transition, and backwater) and the values for hydrologic variables measured in the field (depth and velocity) and provided by Güneralp and Hales (2013) for maps at Q1, low discharge (shear stress, Froude number, and helix strength). We also evaluated an alternative hypothesis for the explained variation in hydrologic parameters based on our other environmental variables. Our two matrces for the alternative hypotheses were for environmental data measured in the field (temperature, conductivity, DO, presence/absence of structure identified as wood, rubble, vegetation or bare substrate) and data provided by Güneralp and Hales (2013) for sediment composition (proportions for total coarse, sand, silt and clay). We displayed these relationships in ordination plots depicting the direct correlation among habitat variables and hydrologic parameters, and plots for the post-hoc correlations of the alternative (environmental) variables with the axes of the constrained ordination.
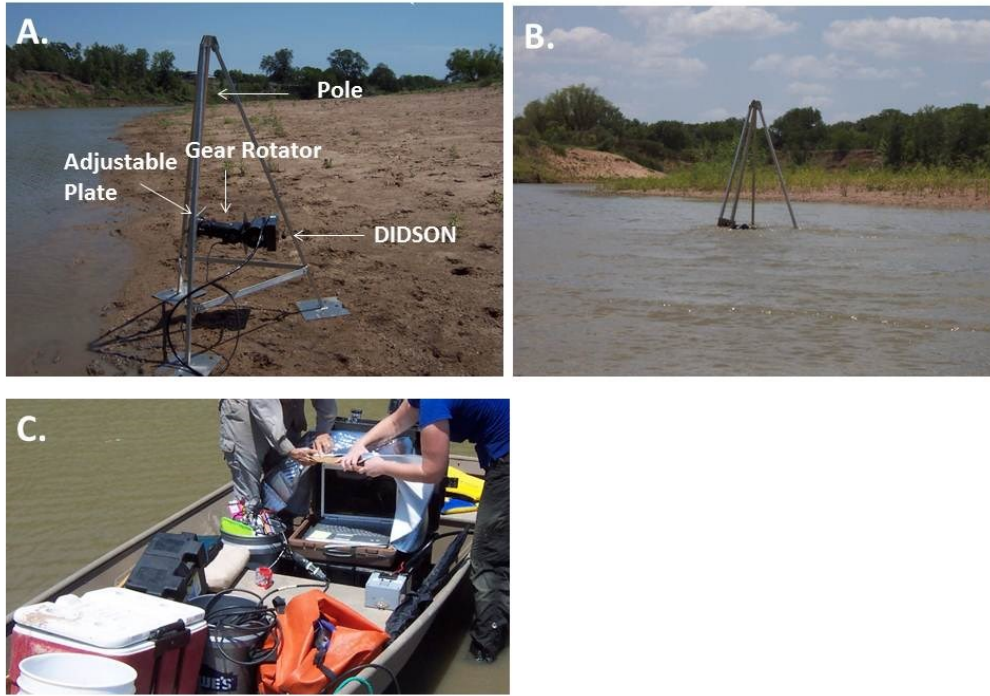
Figure 1.2 DIDSON tripod stand (A) deployment (B) and field recording configurations (C).

Table 1.1 DIDSON placement and orientation in recorded sites between transects.

Date	Transect	Depth	Orientation
	T3-T4	1.5	Across channel shot, mid-channel facing cut bank and wood pile by bank
	T3-T4	1.5	Across channel shot, mid-channel facing cut bank and wood pile by bank
	T3-T4	1.5	Across channel shot, mid-channel facing cut bank and wood pile by bank
	T3-T4	1.6	Across channel shot, mid-channel facing submerged log facing point bar
6 15 2011	T3-T4	1.6	Across channel shot, mid-channel facing submerged log facing point bar
	T5 - T6	6	Across channel shot in pool with rip-rap, in middle of pool facing left/cut bank, rip
	T5 - T6	6	Across channel shot in pool with rip-rap, in middle of pool facing left/cut bank, rip
	T5 - T6	3	Across channel shot in pool opposite of rip-rap, facing right bank
	T5 - T6	3	Across channel shot in pool opposite of rip-rap, facing right bank
	T 11	≤ 1	Across channel shot by cut bank facing wood pile
	T 11	≤ 1	Across channel shot by cut bank facing wood pile
	T 11	≤ 1	Across channel shot at mid-channel facing log
	T 11	≤ 1	Across channel shot at mid-channel facing log
6 16 2011	T7-T8	1.5	Upstream channel shot below riffle DIDSON facing towards brush
	T7-T8	1.5	Upstream channel shot below riffle DIDSON facing towards brush
	T7	1	At riffle across riffle bottom
	T7	1	At riffle across riffle bottom
	T3-T4	1	Vertical deployment from boat, by wood pile at same location on 6 15 2011
	T3-T4	1	Vertical deployment from boat, by wood pile at same location on 6 15 2011
	T3-T4	1	Vertical deployment from boat, by wood pile at same location on 6 15 2011
	T3-T4	1	Vertical deployment from boat, by wood pile at same location on 6 15 2011
6 18 2011	T3-T4	1	Vertical deployment from boat, by wood pile at same location on 6 15 2011
	T5-T6	3	Vertical deployment from boat, by rip rap at same location on 6 15 2011
	T5-T6	3	Vertical deployment from boat, by rip rap at same location on 6 15 2011
	T5-T6	3	Vertical deployment from boat, by rip rap at same location on 6 15 2011
	T5-T6	3	Vertical deployment from boat, by rip rap at same location on 6 15 2011

Results

      Bottom sediment mainly consisted of particles <2 mm (i.e. sand, silt, and clay) with

coarser grains on the left bank or transects that correspond to where there was a point bar,

low-sloped cutbank, or a transition to a point bar. Exceptions to this pattern included the right

bank at T3, T4, and T5 (grain size > 2mm diameter); T5 and T6 at left bank (close to 30% of

each sand, silt, and clay); and T1 and T2 center line where there was an increase of coarse

sediment (Table 1.2). For complete analysis refer to Güneralp and Hales (2013).

      Hydraulic biotypes from the beginning of the study reach to T5 and from T9 to the end

of the reach mainly comprised glide and run/riffle. Overall T1-T6 and downstream of T9 were

homogeneous with somewhat high velocity (0.417 – 0.541 m/s,), and depth between 1.11 and

2.9 m at mid channel, which decreased in value towards the left and right banks. However, T4-

T5 and T1-T2 had slightly lower velocity (0.338 – 0.416 m/s). Glides located in T2-T5 and from

T8 to the end of the reach occurred on the left bank and mid channel while the glides in the

beginning of the reach to T2 were on the right bank. T5 to T6 had a deep pool (depth 5.37-6.30

m, flow ~0-0.126 m/s) with a concrete bank structure on the left bank and backwater adjacent

to the downstream side of the point bar on the right bank. The deep pool extended halfway

between T6 and T7 where it then became a shallow pool.   Alongside the mid channel bar at

the downstream end of T6 and the channel chute at T7 transect line, flow increased creating

run/riffle habitat. The run/riffle surrounded the mid channel bar that became a temporary

island during low flow conditions. On the right bank of the river channel to the right of the mid

channel bar, was a small section of backwater. We labeled the section of the point bar

connecting the backwater to the channel chute as the transition area. Flow increased from the

backwater (0.205~0.00 m/s) to the chute (0.741-1.55 m/s). The run/riffle conditions along the

bank slope continued to the middle of T8 and T9 (Figs 1.4-1.6 and 1.8). In 2011, we labeled the

area on the right bank of the mid-channel bar/temporary island as flooded island vegetation.

The hydrologic model did not extend into T11 however, but in 2012 we measured flow at our

sampled areas. Flow for the T11 backwater on the left bank was 0.02 m/s and on the right bank

with wood debris was -0.03 m/s. Measured velocity in the T6-T7 backwater was 0.08 m/s in the

spring and -0.03 m/s in the summer of 2012 (our data for velocity is not shown on the map).

Conductivity and temperatures were higher in the summer compared to the spring

sample dates. Throughout the study reach in 2010, conductivity and temperature remained

relatively constant (respectively, 1500-1530 µS and 33-35°C) while DO varied slightly; T6-T7,

and T7-T8 had the lowest DO (respectively, 6.4 mg/L and 6.53 mg/L), with higher values at T8

(7.51 mg/L), T3-T4 (7.76 mg/L), and T9-T10 (7.77 mg/L). T11 and T4-T5 had the highest values

(respectively, 8.14 mg/L and 8/16 mg/L; data not shown in tables).

Table 1.2 Güneralp and Hales (2013) sediment analysis for size distribution along the study reach at transects from T1-T11.

Transect		Water Depth (meter)	Total Coarse >2 mm	Total Sand 0.05–2.00 mm	Very coarse Sand 1.00–2.00 mm	Coarse Sand 0.5–1.00 mm	Medium Sand 0.25–0.50 mm	Fine Sand 0.10–0.25 mm	Very fine Sand 0.05–0.10 mm	Total Silt 0.002-0.05 mm	Total Clay <0.002 mm
			(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
T1	Left bank[a]	0.92	13.91	77.74	2.67	16.44	30.56	24.28	3.79	5.17	3.19
	Center	3.03	28.39	62.08	9.95	8.45	10.17	27.50	6.02	4.65	4.87
	Right bank[a]	1.43	7.90	65.11	0.37	0.64	1.75	36.29	26.06	17.04	9.95
T2	Left bank	0.92	0.23	80.31	0.00	0.00	0.30	61.06	18.96	10.58	8.88
	Center	2.02	10.15	66.31	0.81	2.70	29.56	19.23	14.02	14.83	8.72
	Right bank	2.57	2.75	62.14	0.29	0.58	2.43	31.02	27.81	21.49	13.61
T3	Left bank	1.18	2.57	68.98	0.00	0.00	2.44	48.81	17.73	13.93	14.52
	Center	0.92	0.15	98.35	0.30	3.99	49.12	44.53	0.40	1.10	0.40
	Right bank	0.11	45.71	45.33	6.08	10.91	20.09	5.70	2.55	5.27	3.69
T4	Left bank	2.12	32.73	52.94	4.71	9.96	22.60	11.91	3.77	8.74	5.58
	Center	1.39	0.63	95.89	1.59	11.23	39.55	41.93	1.59	2.38	1.09
	Right bank	0.33	54.88	14.71	0.05	0.09	0.32	4.60	9.66	16.02	14.39
T5	Left bank	0.97	3.36	30.44	0.68	0.77	0.87	14.01	14.11	30.25	35.95
	Center	1.63	0.43	84.84	0.70	3.98	18.12	50.88	11.15	9.26	5.48
	Right bank	0.34	85.13	13.53	1.15	1.71	4.55	5.25	0.88	0.77	0.57
T6	Left bank	2.33	0.00	29.60	0.00	0.10	0.20	6.10	23.20	39.70	30.70
	Center	5.91	1.04	85.90	3.17	35.63	39.68	3.86	3.56	6.93	6.14
	Right bank	0.42	0.04	49.58	0.00	0.10	0.30	23.49	25.69	26.99	23.39
T7	Left bank	–	–	–	–	–	–	–	–	–	–
	Center	–	–	–	–	–	–	–	–	–	–
	Right bank	–	–	–	–	–	–	–	–	–	–
T8	Left bank	2.00	11.45	50.21	1.33	1.59	2.48	27.98	16.82	22.23	16.12
	Center	2.10	0.00	85.10	0.00	1.50	7.10	62.20	14.30	6.60	8.30
	Right bank	1.16	0.13	80.79	0.10	1.50	14.18	48.24	16.78	9.79	9.29
T9	Left bank	1.47	1.36	61.55	1.18	2.96	1.87	24.66	30.88	21.90	15.19
	Center	–	–	–	–	–	–	–	–	–	–
	Right bank	0.31	0.00	80.80	0.00	0.70	10.60	48.90	20.60	10.70	8.50
T10	Left bank	2.10	0.04	49.78	0.00	0.10	0.40	9.40	39.88	30.09	20.09
	Center	1.13	0.23	91.99	0.10	3.39	47.69	35.82	4.99	4.39	3.39
	Right bank	0.10	0.00	93.10	0.00	0.10	7.50	80.70	4.80	3.50	3.40
T11	Left bank	0.57	37.88	54.04	6.40	10.81	19.88	4.78	12.18	5.03	3.04
	Center	–	–	–	–	–	–	–	–	–	–
	Right bank	0.31	0.01	80.19	0.00	0.10	0.20	35.50	44.39	10.20	9.60

Conventional Sampling

We collected a total of 23 genera and 32 species of fish by seining. The most abundant species caught across all transects was *Cyprinella lutrensis* Red Shiner and *Pimephales vigilax* Bullhead minnow. 'Other Seined Species' (Table 1.3) were defined as species other than *C. lutrensis* or *P. vigilax*, and varied among transects and habitat types (Tables 1.4-1.7). In general, total CPUE increased from upstream to downstream for seined samples along the shore

around the meander bend from the end of T6 to beginning of T7 (Fig. 1.4). Seined fish in

samples at sites that were in or adjacent to areas with mid to high velocity, and coarser

sediment and sand, mainly consisted of *C. lutrensis*, but in sites that had lower velocity, CPUE

for *P. vigilax* and other species proportionally increased as *C. lutrensis* decreased. This was

especially evident in the microhabitats at the downstream end of T6 to beginning of T7

shoreline area. *C. lutrensis* made up 94% of the catch at the run/riffle chute (CPUE 3.079

catch/m² out of a total CPUE of 3.288 catch/m²). Relative density of *P. vigilax* and other species

increased in the transition, temporary island shoreline, and backwater. *P. vigilax* CPUE

increased from 0.072 catch/m² in the run/riffle to 2.551 catch/m² in the transition area, and it

became the dominant species in the backwater (*P. vigilax* 1.655 catch/m²). Other species

seined did not make up a majority of the catch; however, their relative density increased in

backwaters with lower velocity and finer sediment (Fig. 1.4, Table 1.3).

Overall alpha diversity, e^H, for seined fish indicated that individual seined sites were not

very diverse due to low evenness (E_H; high dominance). The most abundant species were *C.

lutrensis* or *P. vigilax* at all sampled sites; however, sampled sites did display slight differences

in alpha diversity, species richness (S) and evenness (E_H). T3-T4 run/riffle shoreline and T7

chute run/riffle had low alpha diversity and evenness, (respectively, $e^H < 2$, $E_H < 0.35$). T3-T4

mid-channel glide, T6-T7 transition, island vegetation, and backwater, T5-T6 shallow pool, and

T11 shoreline run/riffle and backwater had greater alpha diversity in their respective seine hauls

($2 < e^H < 3$), but overall low diversity as compared to species richness (site unity; 6<S<12).

Evenness at these sites, however, was low to moderate ($0.35 < E_H < 0.5$), indicating that alpha

diversity among individual seine hauls within most transect areas was greater than alpha

diversity among whole transects for both T3-T4 run/riffle shoreline and T7 chute run/riffle habitat (Table 1.6). Although we combined spring and summer collections for data analysis, we only collected *M. chrysops* in the spring samples.

Beta diversity (D_β) ranges from 0 to 1, and seine samples indicated that the study reach was very homogenous (D_β = 0.114). Pairwise analysis between transects supported this result, however, it did show slight differences between some transects.   Comparisons of D_β between the area downstream of T11 and the T3-T4 area to D_β calculated between the T6-T7 area and T5-T6 were slightly more dissimilar (respectively D_β = 0.146, D_β = 0.142). T3-T4 and T5-T6 were most dissimilar (D_β = 0.215) to each other amongst all pairs of transect areas (Fig. 1.3).

We electroshocked in 2011 to focus on capturing larger fish that were not Cyprinids. A few small Cyprinids were collected during shocking in most habitats, which indicated not only their presence, but that if larger fish also had been present, they would have been stunned— because of their larger surface area, larger fish are more readily stunned than smaller fish. We electroshocked a total of 10 genera and 18 species in four samples located in T1 –T4, T5 – T6, T6 – T7, and downstream of T11 (Table 1.7). No fish were produced by shocking in the habitat downstream of T6 (Fig. 1.5).   The most commonly captured fish were Ictalurid catfishes and Lepomis sunfishes. Therefore, when we calculated CPUE, catch/min, we organized the results into three categories: Ictalurids, Lepomis sunfishes, and Other Species (those not included in the other two categories; Table 1.7)

Other fish shocked included juvenile *M. salmoides, C. lutrensis*, *D. cepedianum, L. oculatus,* and *C. carpio.* The deep pool at T5 – T6 with slow flow and fine sediment had the highest total CPUE (2.520 catch/min); *Lepomis spp.* (1.490 catch/min), other species (0.570

catch/min), and Ictalurids (0.460 catch/min) among all transects and microhabitats. Total

CPUE was second highest at T6 – T7 (1.25 catch/min); this habitat had relatively fast and

shallow water with a combination of fine and coarse sediment. The area downstream of T11

and from T1 toT4 had the lowest CPUEs (respectively, 0.07 catch/min and T1-T4 = 0.850

catch/min). At T1 – T4 only *P. olivaris* and *I. furcatus* were shocked (Table 1.7).

Alpha diversity for electroshocked fish showed that the sites were both diverse and

even. T1-T4 and T11 were most diverse, reaching or very near unity (i.e., when $e^H = S$; Table

1.7), while T5-T6 and T6-T7 had diversity index values near unity and high evenness. This was in

contrast to beta diversity calculations, which indicated the study reach landscape was highly

homogenous (D_β = 0.012), but there were some slight differences between transects (Fig. 1.3

B); T1-T4, T5-T6, and T6-T7 were similar to each other while T11 was the most dissimilar.

In 2010, gill nets captured fish in the run/riffle and glide at T4-T5, the deep and shallow

pools at T5-T6 , and in the main channel along T7 (Fig. 1.6, Table 1.3). Species in these habitats

included *Lepisosteus osseus, Lepisosteus oculatus, Atractosteus spatula,* and *Alosa chrysochloris*.

In 2011, *Lepisosteus osseus, Dorosoma cepedianum,* and *Carpidoes carpio* were caught in T5-T6

pool (Fig. 1.6, Table 1.3).

Table 1.3 Summary table for CPUE for 2010, 2011, and 2012 seines (catch/m^2), gill net (catch/panel hour), and electroshocking (catch/min) at sampled habitats. Electroshocked fish were combined by transect and not separated by microhabitat for 2011 electroshocking.

Transect	Habitat and Hydraulic Units	Seine				Gill Net	Electroshocking			
		C. lutrensis	*P. vigilax*	Other	Total		*Lepomis spp.*	Ictaluridae	Other	Total
T3-T4	Mid-channel, glide, wood debris	0.20	0.02	0.01	0.23	0.00	0.00	0.85	0.00	0.85
T3-T4	Point/sand bar, run/riffle	3.85	0.44	0.34	4.63	-				
T4-T5	Run/riffle, glide with backwater	0.12	0.06	0.04	0.22	0.25	-	-	-	-
T5-T6	Backwater, shallow pool, shoreline vegetation	0.29	0.04	0.01	0.34	-	-	-	-	-
T5-T6	Concrete bank stucture, deep and shallow pool	-	-	-	-	0.07	-	-	-	-
T5_T6	Concrete bank structure, middle of deep pool	-	-	-	-	0.09	1.49	0.46	0.57	2.52
T6	Shoreline, glide	-	-	-	-	-	0.00	0.00	0.00	0.00
T6-T7	Run/riffle at edge of point/sand bar and lateral/mid-channel bar	3.08	0.07	0.14	3.29	0.03	0.16	0.39	0.70	1.25
T6-T7	Transition, run/riffle, between point/sand bar and lateral/mid-channel bar	2.84	2.55	0.68	5.86	-				
T6-T7	Backwater between water edge and lateral/mid-channel bar	0.65	1.66	0.36	2.66	0.00				
T6-T7	Temporary island run/riffle between two lateral/mid channel bars	9.92	8.75	0.58	19.25	-				
T8	Submerged wood debris, run/riffle, glide	-	-	-	-	0.00	-	-	-	-
T9-T10	Backwater adjacent to mid-channel, glide, mid-channel bar	0.15	0.25	0.08	0.47	-	-	-	-	-
T11	Run/riffle between point/sand bar and lateral/mid-channel bar	1.04	2.07	0.21	3.33	-	0.04	0.01	0.02	0.07
T11	Backwater between water edge and lateral/mid channel bar, wood debris	1.44	2.75	0.50	4.69	-				

Table 1.4 Fish species and abundances (n_i) captured by seining in transects and habitats, and indices for species richness (S), Shannon diversity (H), alpha diversity (e^H), and evenness (E_H).

Transect	Habitat	Species	n_i	S	H	e^H	E_H
T3-T4	Mid-channel Glide	Cyprinella lutrensis	96	8	1.001	2.721	0.481
		Pimephales vigilax	12				
		Dorosoma cepedianum	11				
		Morone chrysops	1				
		Notropis buchanani	8				
		Carpiodes carpio	2				
		Lempomis cyanellus	1				
		Lepisosteus osseus	1				
	Run/riffle Point bar	Cyprinella lutrensis	500	7	0.675	1.964	0.347
		Pimephales vigilax	56				
		Carpiodes carpio	2				
		Gambusia affinis	1				
		Notropris buchanani	23				
		Notropis shumardi	3				
		Dorosoma cepedianum	21				
T5-T6	Shallow pool Backwater Point bar	Cyprinella lutrensis	132	9	0.826	2.285	0.376
		Pimephales vigilax	19				
		Dorosoma cepedianum	6				
		Agonostomus monticola	1				
		Lepomis cyanellus	1				
		Lepomis megalotis	1				
		Percina caronaria	1				
		Notropis buchanani	6				
		Ictalurus punctatus	1				

Table 1.5 Fish species and abundances (n_i) captured by seining in T6-T7 microhabitats, and indices for species richness (S), Shannon diversity (H), alpha diversity (e^H), and evenness (E_H).

Habitat	Species	n_i	S	H	e^H	E_H
Run/riffle Chute, point bar	*Cyprinella lutrensis*	564	12	0.401	1.493	0.161
	Ictalurus punctatus	6				
	Pimephales vigilax	13				
	Carpiodes carpio	1				
	Mugil cephalus	2				
	Percina sciera	3				
	Macrhybopsis hyostoma	7				
	Morone chrysops	5				
	Dorosoma cepedianum	1				
	Lepomis spp.	1				
	Notropus buchanani	3				
	Lepomis megalotis	1				
Transition Point bar upstream from chute run/ riffle	*Cyprinella lutrensis*	223	10	1.059	2.884	0.460
	Pimephales vigilax	198				
	Carpiodes carpio	20				
	Ictalurus punctatus	7				
	Lepomis cyanellus	2				
	Gambusia affinis	5				
	Mugil cephalus	1				
	Micropterus salmoides	3				
	Lepisosteus osseus	1				
	Dorosoma cepedianum	1				
Temporary Island vegetation Run/riffle	*Cyprinella lutrensis*	119	6	0.826	2.285	0.461
	Pimephales vigilax	105				
	Mugil cephalus	1				
	Ictalurus punctatus	3				
	Percina sciera	1				
	Macrhybopsis hyostoma	1				
Backwater Cutbank	*Cyprinella lutrensis*	163	14	1.096	2.991	0.415
	Pimephales vigilax	417				
	Carpiodes carpio	24				
	Ictalurus punctatus	1				
	Poxomis annularis	5				
	Lepomis cyanellus	3				
	Lepomis microlophus	1				
	Lepomis miniatus	1				
	Lepomis macrochirus	2				
	Gambusia affinis	11				
	Micropterus salmoides	2				
	Morone chrysops	7				
	Dorosoma cepedianum	15				
	Notropis buchanani	1				

Table 1.6 Fish species and abundances (n_i) captured by seining inT11 microhabitats and indices for species richness (S), Shannon diversity (H), alpha diversity (e^H), and evenness (E_H).

Habitat	Species	n_i	S	H	e^H	E_H
	Cyprinella lutrensis	784	12	1.051	2.862	0.423
	Pimephales vigilax	768				
	Agonostomus monticola	1				
	Gambusia affinis	58				
Shoreline	*Etheostoma chlorosmum*	5				
point bar,	*Notropris buchanani*	14				
run/riffle	*Dorosoma cepedianum*	29				
	Ictalurus punctatus	4				
	Lepomis megalotis	4				
	Microperus salmoides	1				
	Carpiodes carpio	20				
	Fry	1				
	Cyprinella lutrensis	381	17	1.044	2.842	0.369
	Pimephales vigilax	719				
	Carpiodes carpio	18				
	Ictalurus punctatus	10				
	Microperus salmoides	2				
	Noturus gyrinus	1				
	Pomoxis annularis	1				
	Dorosoma cepedianum	4				
Backwater	*Lepomis cyanellus*	4				
	Lepomis marginatus	1				
	Lepomis miniatus	2				
	Gambusia affinis	60				
	Hybognathus nuchalis	2				
	Lepisosteus osseus	1				
	Hypobsis annis	1				
	Percina sciera	2				
	Morone chrysops	2				

Table 1.7 Fish species and abundances (n_i) captured by electroshocking in transect areas, and indices for species richness (S), Shannon diversity (H), alpha diversity (e^H), and evenness (E_H).

Transect	Species	n_i	S	H	e^H	E_H
T1-T4	*Pylodictis olivaris*	6	2	0.693	2.000	1.000
	Ictalurus furcatus	6				
T5-T6	*Pylodictis olivaris*	8	13	2.235	9.346	0.871
	Micropterus salmoides	6				
	Lepomis gulosus	2				
	Lepomis cyanellus	5				
	Lepomis macrochirus	2				
	Lepomis spp.	1				
	Lepomis megalotis	10				
	Lepomis marginatus	1				
	Lepomis humilis	3				
	Lepomis miniatus	2				
	Pimephales vigilax	2				
	Cyprinella lutrensis	1				
	Carpiodes carpio	1				
T6-T7	*Lepisosteus oculatus*	1	13	1.995	7.352	0.778
	Dorosoma cepedianum	4				
	Ictalurus punctatus	9				
	Mugil cephalus	1				
	Pylodictis olivaris	2				
	Carpidoes carpio	9				
	Lepomis megalotis	1				
	Micropterus salmoides	2				
	Lepomis miniatus	1				
	Lepomis humilis	2				
	Cyprinella lutrensis	3				
	Pimephales vigilax	1				
	Lepomis macrochirus	1				
T11	*Pylodictis olivaris*	1	4	1.277	3.586	0.921
	Cyprinella lutrensis	2				
	Lepomis macrochirus	1				
	Lepomis megalotis	3				
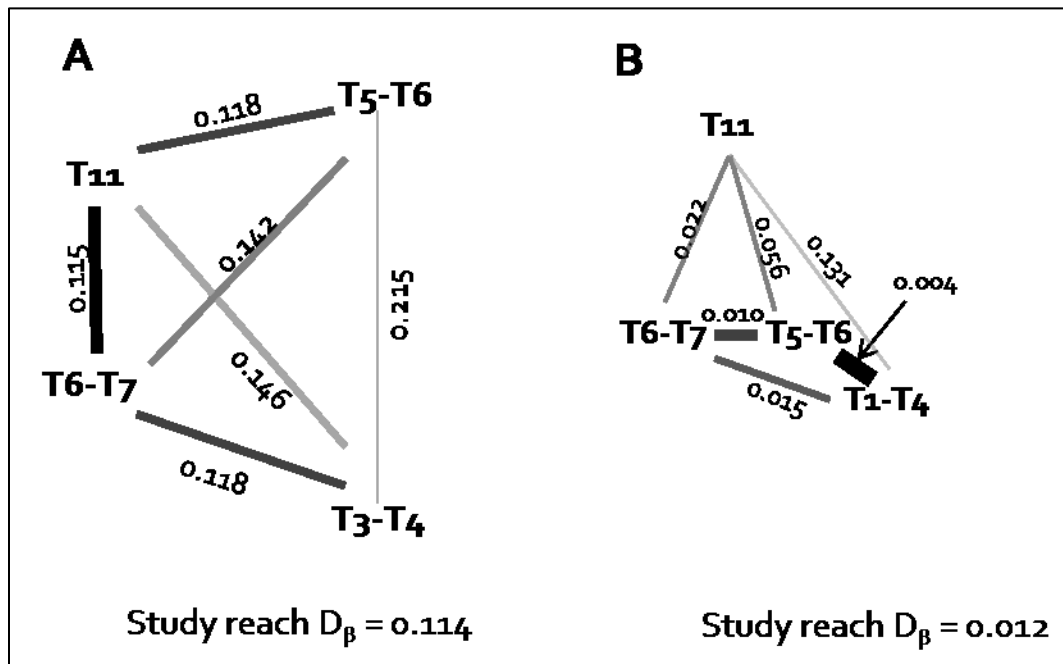
Figure 1.3 Pairwise D_β between transects and study reach for seining (A) and electroshocking (B). Darker, shorter, thicker lines indicate high similarity between transects while lighter, longer, thinner liners indicate more dissimilar transects.
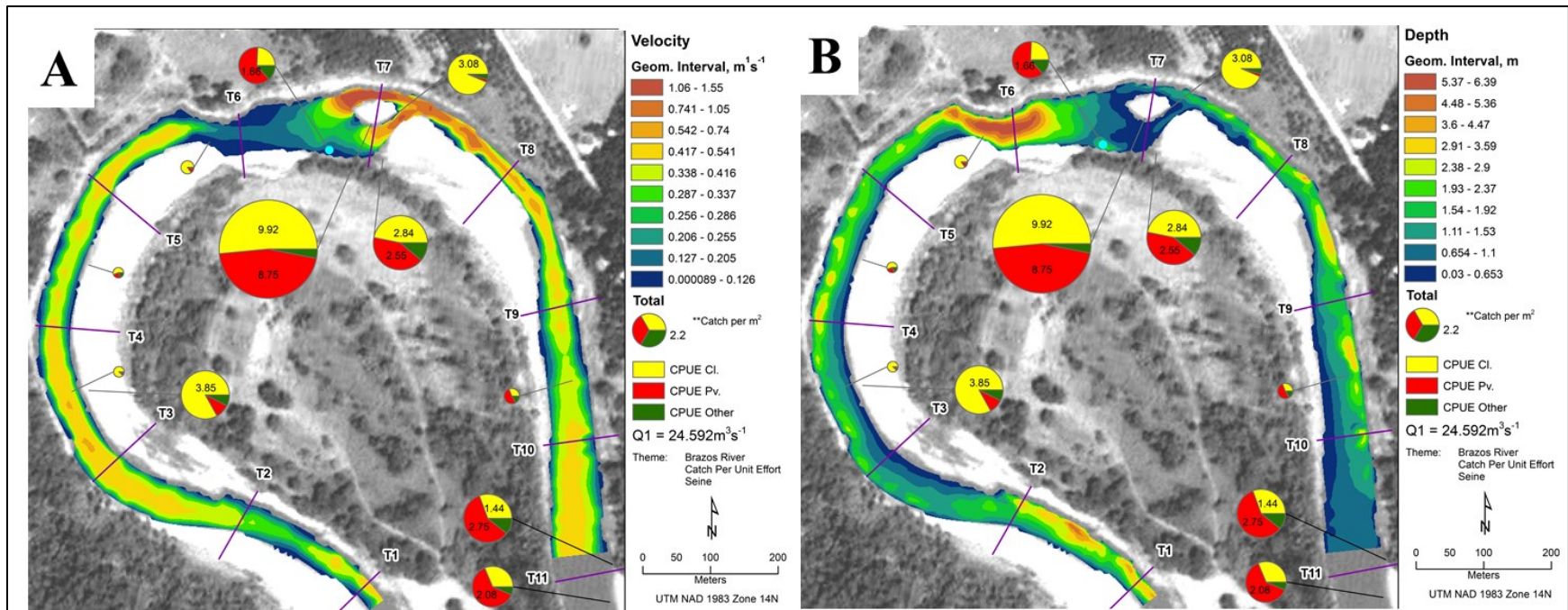
Figure 1.4 Seining CPUE overlaid in low flow conditions of velocity (A) and depth (B) maps of the study reach for *C. lutrensis* (Cl, yellow), *P. vigilax*, (Pv, red), and species seined other than *C. lutrensis* and *P. vigilax* (other, green).
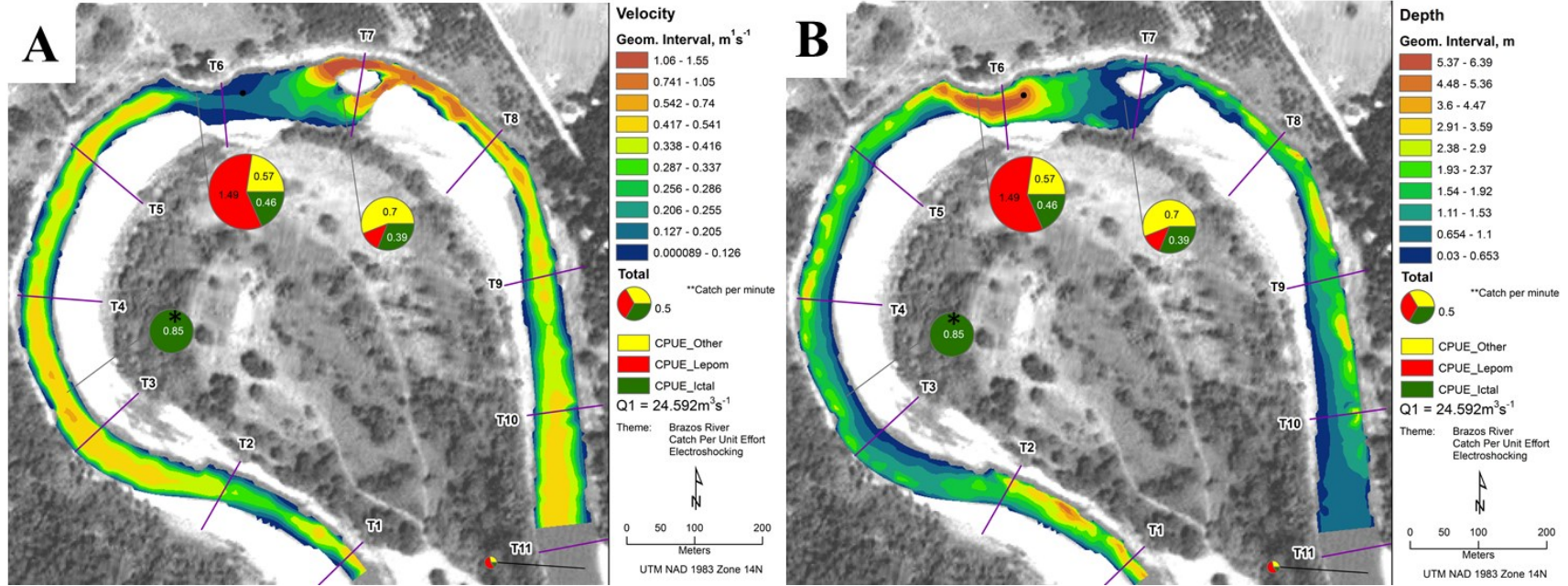
Figure 1.5 Electroshocking CPUE overlaid on velocity (A) and depth (B) maps of the study reach for family Icataluridae (Ictal, green), genus *Lepomis spp*. (Lepom, red), and other species of fish other than in the family Icataluridae and genus *Lepomis spp* (other, yellow). Black circle by T6 designates a site where no fish were successfully stunned. CPUE for species shocked between T1-T4 is displayed as a data point between transect 3 and 4 (*).
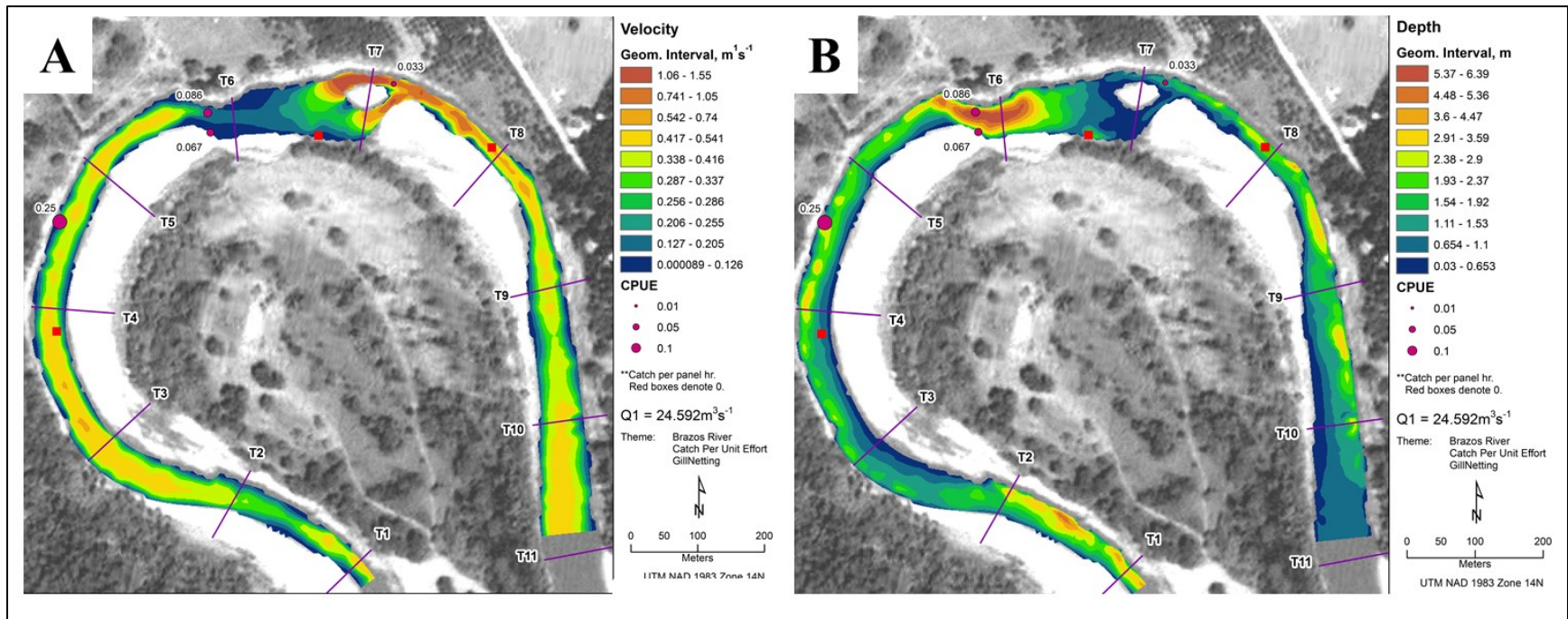
Figure 1.6. Gill netting CPUE at sample sties overlaid on velocity (A) and depth (B) maps of the study reach. Red squares designate sampled sites where no fish were netted while purple circles indicate successful catches in nets.

DIDSON Results

We made a total of 33 DIDSON recordings in 2010 and 2011 at different habitats, including 10 in T3 – T4, eight in T5 – T6, four at transect line T7, and four in T11 (Table 1.8). Video recordings captured current movement, sand plumes, and fish activity in sand plumes and among woody debris and backwaters.   It also captured images of woody structures and debris submerged under water (Fig. 1.7). The use of the tripod stand substantially increased video quality. Stabilizing the DIDSON greatly reduced background movement, which was later filtered out (using Echoview software) in order to distinguish fish. Here, we only present data from 2011 Echoview because it produced more accurate fish counts. Of the seven analyzed Echoview recordings, we present data from five due to the time restriction on the program's temporary license and need for familiarization with the software program. We also identified two Blue catfish, *Ictalurus furcatus*, a gar, and what appeared to be either a River Carpsucker *Cyprinus carpio* or Smallmouth Buffalo *Ictiobus bubalus*.

Both large and small fish were visualized with DIDSON. DIDSON recordings captured fish <1 cm TL and as large as 70.87 cm TL. Based on fish shape, swimming behaviors, and data from our electroshocking, gill netting and seining samples, the larger fish most likely were either Ictalurids, Lepisosteids or *Micropterus* bass; fish >10 cm TL were probably Cyprinids, *G. affinis*, and juvenile fish, or a mixed assemblage; fish 10 – 30 cm most likely were juvenile catfishes, *Micropterus* bass or *Lepomis* sunfishes. The submerged brush in T7-T8 showed the highest average number of small fish (<10 cm, 478.5) within the run/riffle hydraulic biotype (Table 1.8, Fig. 1.7 C). The glide habitat in T3 –T4 video facing the cutbank had the highest number of fish >30 cm. T5-T6 deep pool with back water conditions had the highest average

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number of fish between 10 – 30 cm (Table 1.8, Fig. 1.8). T11 mid-channel recording of a

submerged log had the lowest number of fish in all class sizes. In the T11 cross channel

recording we were unable to detect fish most likely due to a suboptimal angle and placement

of the DIDSON on the tripod.
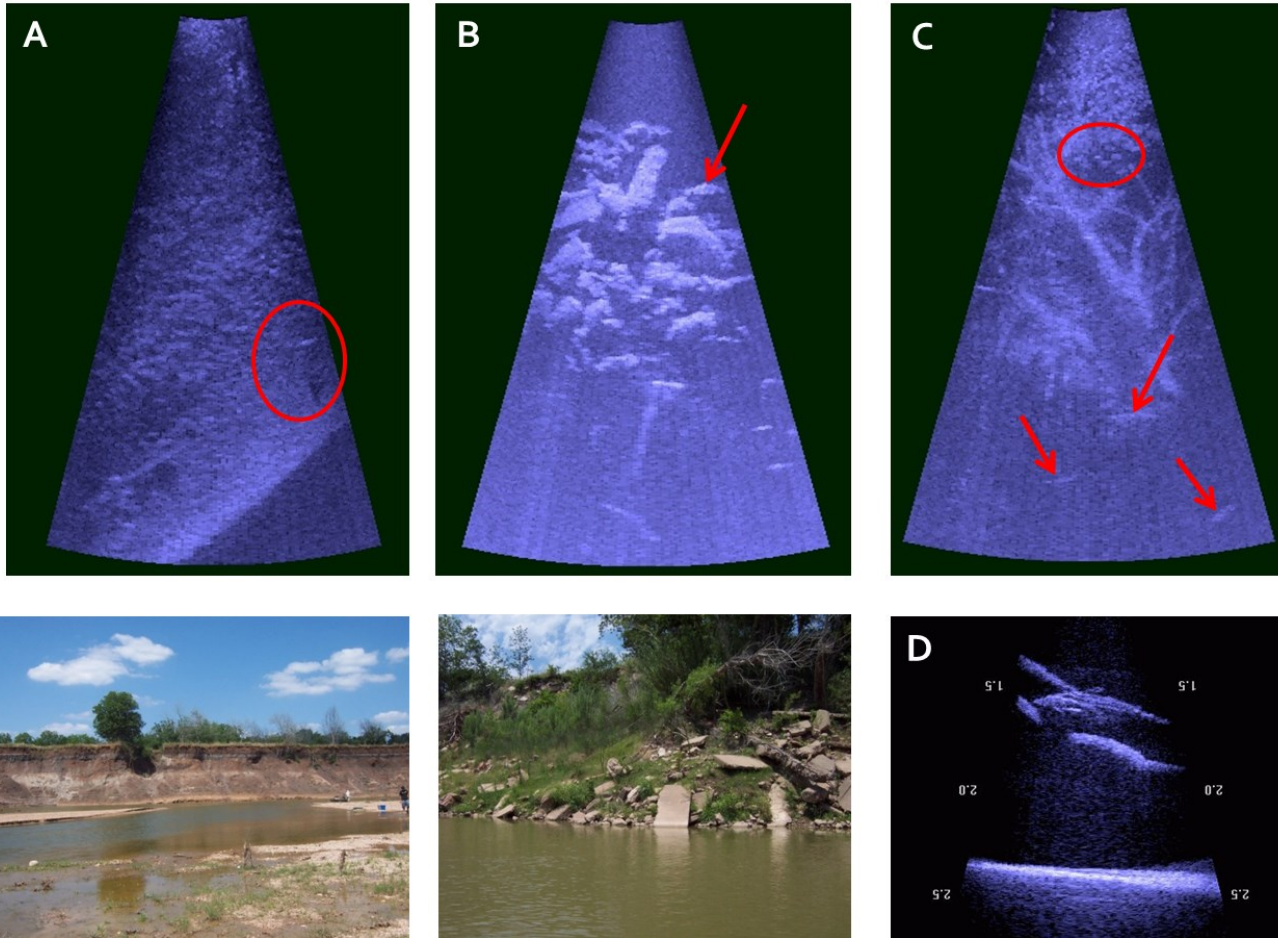
Figure 1.7 DIDSON still images (upper panels) with associated water surface habitats (lower panels) of T7 chute between mid-channel and point bars (panel A), T5-T6 concrete bank protection structure and deep pool (upper and lower panels B), T7 submerged tree (C), and *I. furcatus* swimming in place over a submerged log (D). Circles in DIDSON still images encircle a fish and its shadow (A) and a small school swimming in brush of log (C). Arrows indicate large fish in rubble (B) and mid sized fish (C) by submerged log.

Table 1.8 2011 DIDSON average fish counts per 3 minute recording in transect areas and sampled habitats for three size classes.

Transect	Hydraulic Unit Habitat	Size Class (cm)		
		<10	10-30	>30
T3-T4	Cross channel shot facing cutbank	185.33	9.67	6
T3-T4	Mid channel facing sumberged log	120.5	2.5	1.5
T5-T6	Deep pool	315	33	3.5
T5-T6	Concrete bank struture, deep pool	52.5	16	2
T7	Cross channel shot of cut through by temporary island	280.5	30	1.5
T7-T8	Upstream orientation facing submerged brush	478.5	19.5	2
T11	Mid channel facing sumberged log	48.5	0.5	0

Figure 1.1.8 Average fish counts from DIDSON recordings for three size classes, <10 cm, 10-30cm, and >30cm overlaid on velocity (A) and depth (B) maps of the study reach. Black triangles provide a visual representation of the estimated DIDSON recording area.
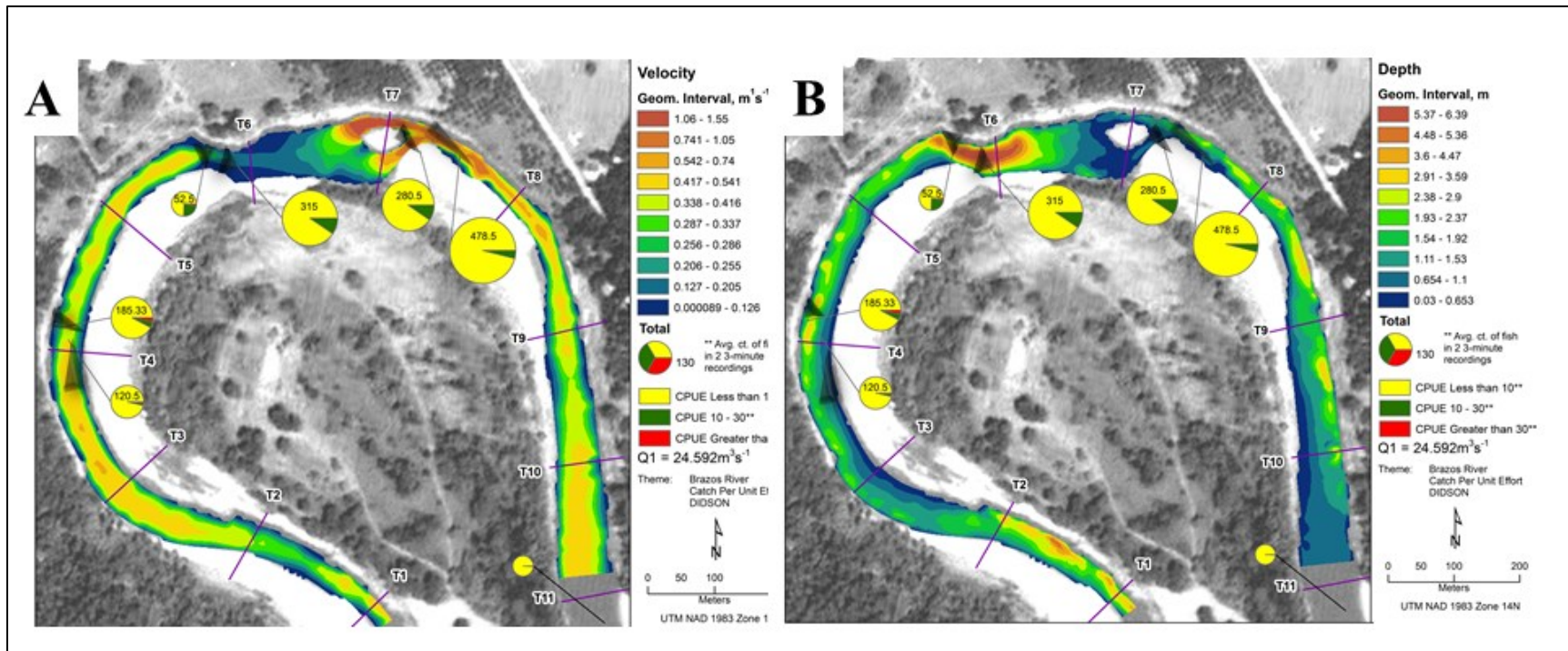
Benthic sampling results

We identified a subsample of 126 freshwater mussel shells collected on the shore of the whole study reach (Table 1.9). In 2010 the location of shells was not distinguished; in 2011 we recorded locations for collections and identified 27 at T7, 18 at T11, and 6 at T3 (Table 1.9). The most abundant species identified in our collections were *Lampsilis teres*, *Quadrula apiculata*, *Potamilus ohienesis*, and *Leptodea fragilis*. We tentatively identified two endangered species in our study site as Texas Fawnsfoot *Truncilla macrodon* and Smooth Pimpleback *Quadrula houstonensis*; however, the latter also could possibly be *Quadrula mortoni*. One live Texas Fawnsfoot was identified upstream near the boat launch site in July 2011 during our DIDSON demonstration (Clint Robertson, TPWD, personal communication). During our pilot study we encountered two live mussels in 2010, identified as *L. fragilis*, which returned to the point bar shoreline downstream of T11.

In kick net and benthic grab samples, seine hauls, drift wood, and electroshocking nets (Fig. 1.9-1.12, Tables 1.9 and 1.10), we collected seven orders of aquatic macroinvertebrates; Trichoptera, Ephemeroptera, Diptera, Odonata, Coleoptera, Hymenoptera, Hemiptera, and two families Hydrophilidae, and Corixidae. In samples from electroshocking, seining, and bank kick netting samples (Figs. 1.9-1.11, Table 1.10), three crustaceans were also identified; *Macrobrachium acanthurus*, *Palaemonetes spp.*, and order Amphipoda. T6-T7 supported higher species richness than other areas (11 species, Fig. 1.10 D backwater root bank; 12 species, Fig. 1.12 C run/riffle chute). We also collected bank samples from T6-T7 backwater and T6 backwater bank. In spring 2012, two samples were included from T5-T6 shoreline and mid-channel, one sample from T6-T7 mid-channel bar backwater and three from the riffle; and three samples were included from T11 habitats: shoreline, mid-channel, and backwater. A

grab sample taken from T3-T4 in 2012 mid-channel produced no aquatic invertebrates as

compared to more than 100 individuals in 2010 (Fig. 1.9 D).

In run/riffle across all years, the most abundant taxon identified in shoreline samples at

T5, T6-T7, and T11 was Trichoptera genus *Hydropysche* and in T3-T4 the predominant taxon

was order Diptera subfamily Chironominae (Fig. 1.9-1.12).   In the transition area in T6-T7 the

most abundant invertebrate was Trichoptera *Hydropysche*. In backwater samples across years,

T6-T7 and T11 the most abundant identified invertebrate order was Diptera subfamilies

Tanypodinae and Chironominae. However, in the summer 2011, T6-T7 backwater sample the

abundance of Trichoptera *Hydropysche* and Diptera Chironominae were similar (Fig. 1.10 B).

Samples collected from T6-T7 and T6 backwater root bank samples included orders:

Hemiptera, Trichocorixa, and Coleoptera, and Odonata (Fig. 1.10 E). Mid-channel benthic

invertebrate assemblages were more varied.   The most abundant taxon in T3-T4 was order

Diptera family Chironomus, in T5-T6 pool was order Ephemeroptera family Ephemera, and in

T11 was Trichoptera *Hydropysche* Order Zygoptera genus *Enallagma* was only collected from

drift wood sampled in 2010, where they were the most abundant taxon (38%) along with

Diptera Chironomini and the cased caddisfly larvae in order Trichoptera, family Leptoceridae,

genus *Nectopsyche* (Table 1.9 respectively 38%, 33%, and 12%). Invertebrates in the order

Ephemeroptera were not common in the benthic samples and were not abundant except for

burrowing mayflies family Ephemeridae in the 2012 spring sample from the mid-channel at T5

(Fig. 1.12 B).
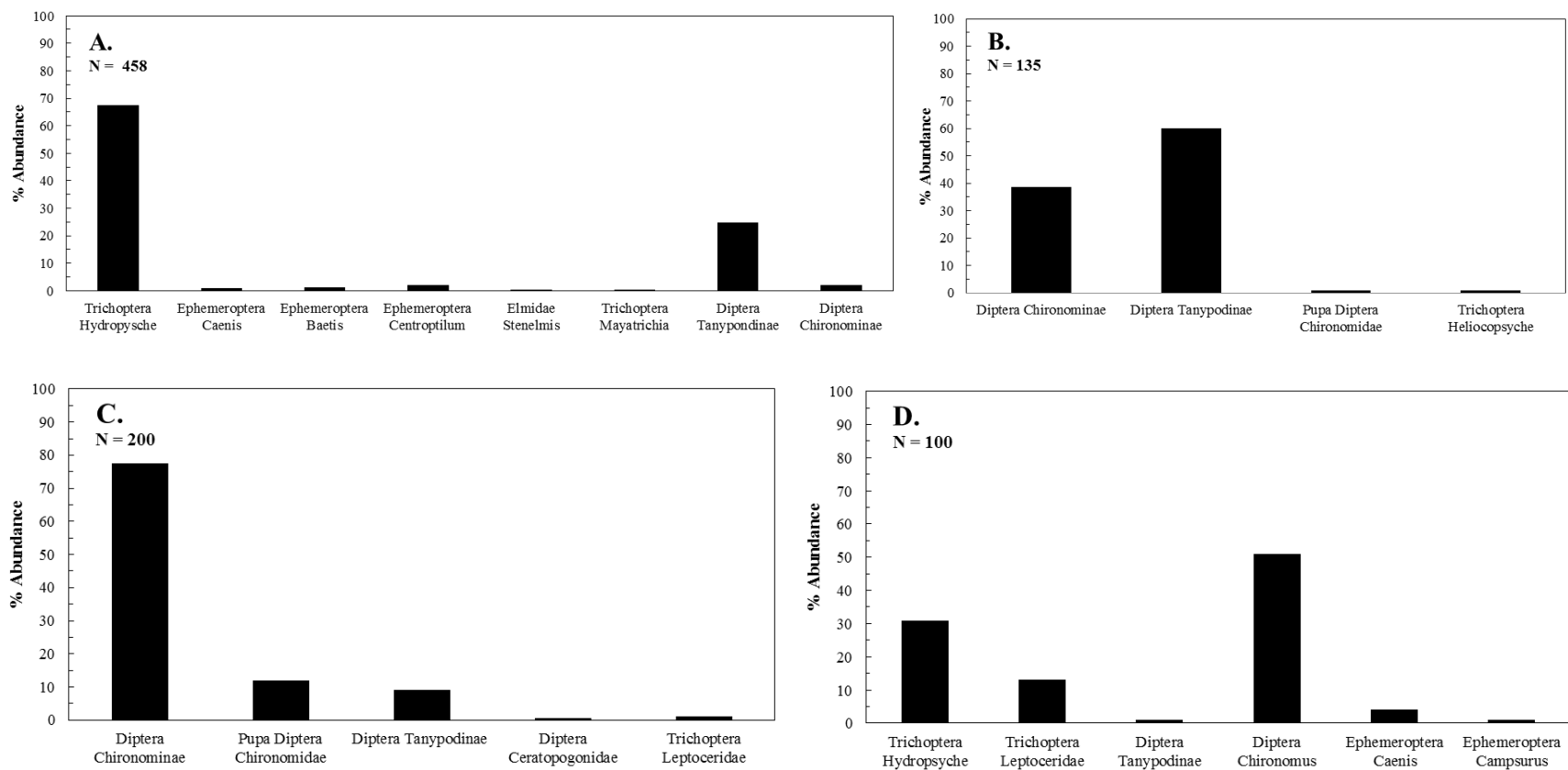
Figure 1.9 2010 Summer benthic macroinvertebrate samples. A) T7 riffle chute B) T6-T7 backwater C) T3-T4 shoreline D) T3-T4 mid-channel.
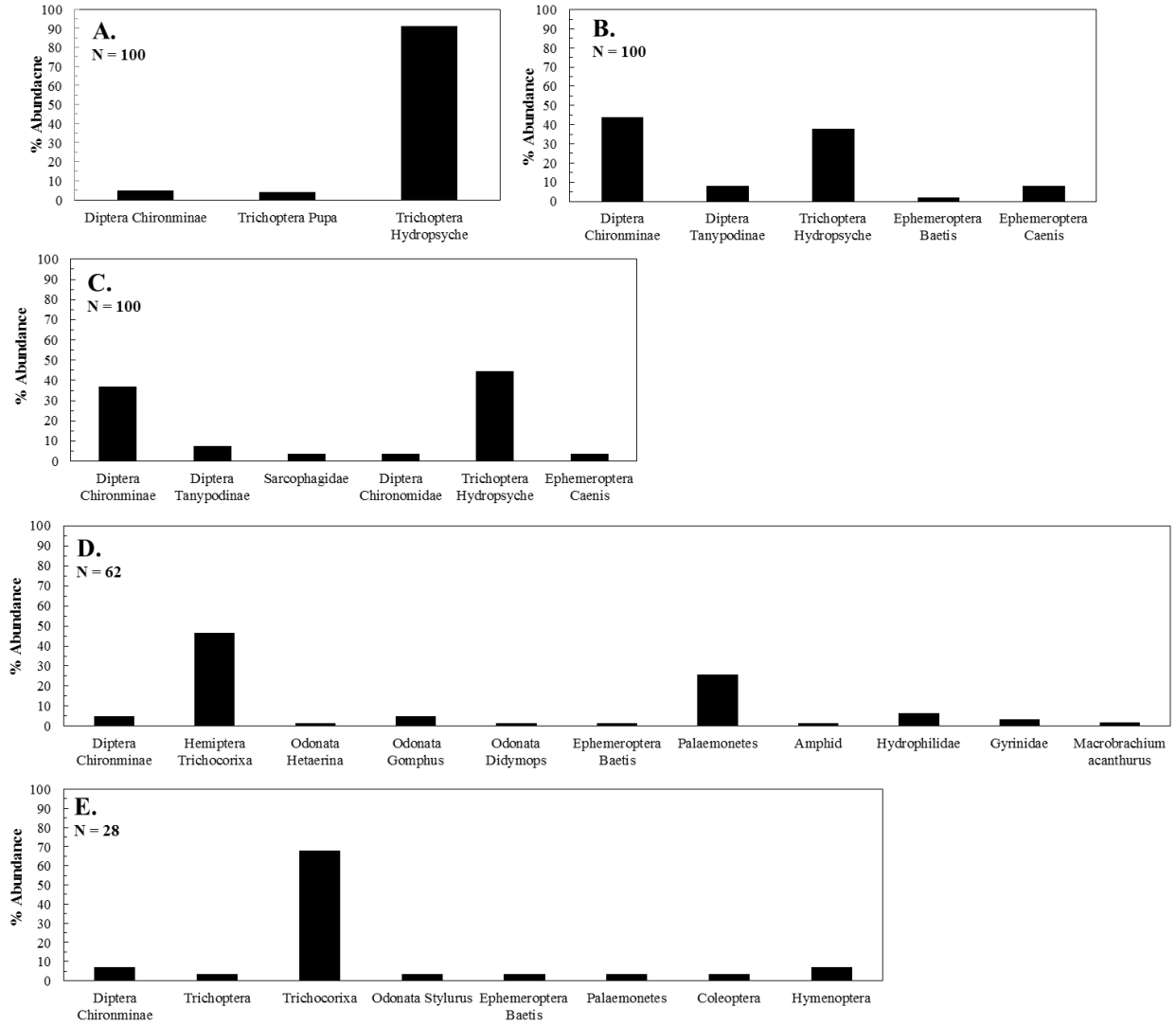
Figure 1.10 2011 Summer macroinvertebrate samples. A) T7 run/riffle chute B) T6-T7 backwater C) T6-T7 transition D) T6-T7 backwater root bank E) T6 root bank
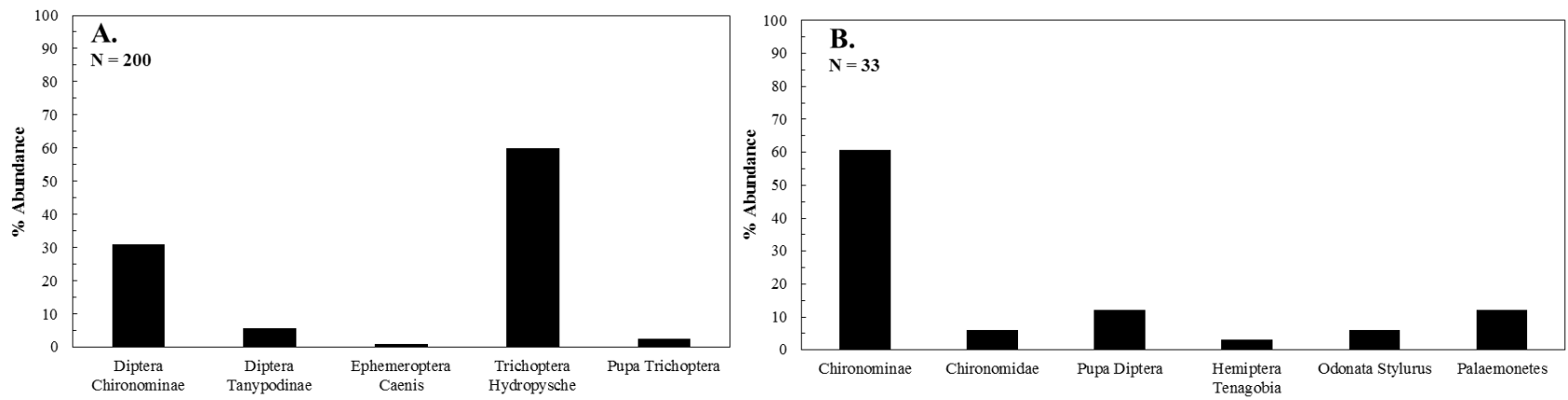
Figure 1.11 T-11 2011 Spring Macroinvertebrate Samples. A) Shoreline riffle B) Backwater
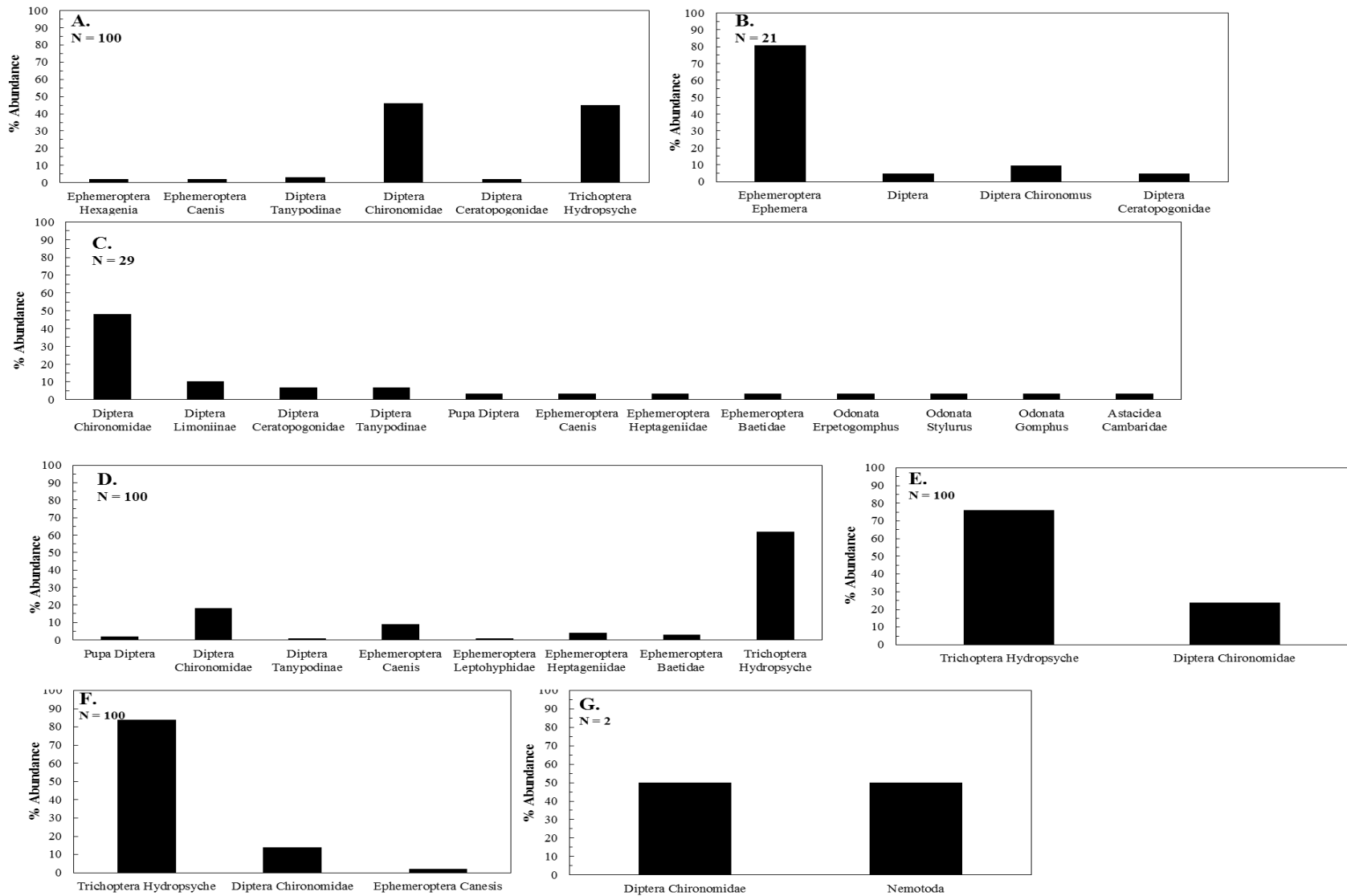
Figure 1.12 Spring 2012 Macroinvertebrate samples A) T5 Shoreline B) T5 Mid-channel C) T7 run/riffle chute D) T6-T7 Mid-channel bar backwater E) T11 Midchannel F) T11 Shoreline G) T11 Backwater

Table 1.9 2010 Macroinvertebrates identified from drift wood caught in gill nets set at T7 – T8.

	Order	Family	Genus	Number	% Abundance
	Trichoptera	Leptoceridae	*Nectopsyche*	12	12
	Ephemeroptera	Baetidae	*Centroptilum*	1	1
		Caenidae	*Caenis*	2	2
Sample 1		Tanypodinae		38	38
N = 100	Diptera	Ceratopogonidae		7	7
		Chironomini		33	33
	Odonata	Zygoptera	*Enallagma*	7	7
Sample 2	Diptera	Tanypodinae		10	62.5
N = 16		Chironomini		5	31.25
	Diptera			1	6.25

Table 1.10 Percent abundance of identified macroinvertebrates caught in seines and in T5 electroshocking (*)

Year	Transect	Habitat	Order	Family	Genera	% Abundance
		Backwater	Decapoda	Palaemonidae	*Palaemonetes*	95.5
2010	T11	N = 66		Gomphidae	*Gomphus*	3
			Odonata	Macromiidae	*Didymops*	1.5
	T6-T7	Backwater, N = 1		Macromiidae	*Didymops*	100
	T5	Rip Rap, deep pool*, N = 5	Decapoda	Palaemonidae	*Macrobrachium*	100
2011	T6	Backwater shoreline, N = 2	Decapoda	Palaemonidae	*Macrobrachium*	100
	T11	Backwater, N = 4	Decapoda	Palaemonidae	*Palaemonetes*	100

Table 1.11 Species list for mussels and clams collected along the shore of the reach in 2010, and in specific transect locations in 2011.

2010			2011		
Location	Genus Species	Number	Location	Genus Species	Number
T1-T11	*Amblema plicata*	7	T7 riffle	*Cyntonaias tampicoensis*	2
	Carbicula spp.	14		*Quadrula mortoni*	5
	Cyrtonaisas tampicoensis	12		*Potamilus ohiensis*	6
	Lampsilis teres	22		*Leptodea fragilis*	6
	Leptodea fragilis	15		*Lampsilis teres*	1
	Megalonaias nervosa	2		*Potamilus parparatus*	2
	Potamilus ohienesis	17		*Quadrula apiculata*	3
	Potamilus purpuratus	2		*Truncilla macrodon*	2
	Quadrula apiculata	18		**Total**	**27**
	Quadrula houstonensis	2	T11	*Cyntonaias tampicoensis*	2
	Quadrula mortoni	10		*Quadrula houstonensis*	3
	Strophitus undulatus	1		*Potamilus ohiensis*	1
	Truncilla donaciformis	1 or 2		*Leptodea fragilis*	3
	Truncilla marodon	1 or 2		*Potamilus parparatus*	2
	Total	**126**		*Truncilla macrodon*	4
				Amblema plicata	3
				Total	**18**
			T3	*Potamilus ohiensis*	3
				Leptodea fragilis	1
				Ameblema plicata	2
				Total	**6**

Multivariate Analysis of Fish Assemblages in Seine Collections

Our environmental variables explained 63% of the total variation among 17 fish species among 32 samples collected by seining (Table 1.12). The largest unique contributions to that explained variance were by physicochemical (11%) and hydrologic variables (10%); all variables together shared (equally explained) 25% of the variance (Table 1.12). Plots for RDA axes 1 and

2 depict 54% of the species variance (respectively, 43% and 11%) and 86% of the species-

environment (explanatory) correlation (respectively, 69% and 26%; Fig. 1.13).

Table 1.12 Components of variance (eigenvalues) in multivariate analyses for fish CPUE collected by seining and electroshocking, and for benthic and wood samples for macroinvertebrate abundance, explained by hydrologic parameters (depth, velocity, shear, Froude, Helix), physicochemical factors (T°C, DO mg/L, conductivity μS), habitat types (pool, glide, run/riffle, transition, backwater), structural features (wood, rubble, vegetation, bare) and sediment size classes (coarse, sand, silt, clay). * = component variation that includes variation shared with other variables.

Variance	Fish seined	Electrofishing	Macroinvertebrates
Total	1	1	1
Total explained	0.627	1	0.850
Shared explained	0.253	1	0.596
Total unexplained	0.373	0	0.150
Components			
Hydrologic	0.102	1.000*	0.137
Physicochemical	0.111	0.635*	0.301*
Habitat type	0.076	0.635*	0.043
Structure	0.032	0.357*	0.074
Sediment size	0.053	1.000*	0.211*

Species most strongly associated with higher velocity and Froude numbers occurred

primarily in transition habitat with vegetation (Fig. 1.13; upper right quadrants of both frames),

particularly *C. lutrensis* and Striped Mullet *Mugil cephalus*. Species most strongly associated

with higher conductivity, temperature and helix strength and finer substrates (silt and clay),

and were negatively associated with run/riffle habitat and high shear stress (Fig. 1.13; lower

right quadrants of both frames), particularly *P. vigilax*, Western Mosquitofish *Gambusia affinis*,

and Largemouth Bass *Micropterus salmoides* (most bass in seine samples were young of the

year and small adults (< 6" long). Species associated with pool and backwater habitats with

wood structure and sandy substrate (lower left quadrants of both frames of Fig. 1.13) included

Lepomis sunfishes and the Tadpole Madtom catfish, *Noturus gyrinus*, but in deeper habitats

with additional wood and rubble structure (Fig. 1.13; left two quadrants of both frames), seine collections included White Crappie *Pomoxis annularis*, White Bass *Morone chrysops* and Gizzard Shad *Dorosoma cepedianum*.

Notable responses of seined fish species to individual hydrologic parameters showed both similar and contrasting trends to those in the direct ordination analysis (RDA) that are constrained by correlations with other explanatory variables (Fig. 1.14). In particular, the strong and gradual rise in abundance of *C. lutrensis* with respect to both Froude number and velocity, and a peak within negative helix strength, was in contrast to Striped Mullet *M. cephalus*, which was rarely collected at low velocities, had a weak response to Froude number and no response to helix strength (left two frames of Fig. 1.14). Shoal Chub *Macrhybopsis hyostoma* was only collected at T7 (June 2011) in shoreline habitat near the temporary island and in the chute (Table 1.7), and like *C. lutrensis*, was abundant at negative values for helix strength (Fig. 1.14).

Figure 1.13 Ordination plots for results of a direct gradient analysis for seine samples in the study reach of fish species CPUE (upper frame) and correlated explanatory variables (lower frame) among samples in ordination space. Both plots are for the same resulting axes, but rescaled for clarity of labeling. Arrows for species (upper frame) are labeled with the first three letters of the genus and the first three letters of the specific epithet and indicate the direction of increasing value among samples. Arrows for explanatory variables (lower frame) indicate the direction of increasing value for continuous explanatory variables (hydrological, sediment size, water quality) among the same samples. Triangles are centroids for the distribution of categorical explanatory variables (habitat type and structural features) among samples.

Figure 1.14 Fish species CPUE response along gradients in hydraulic parameters at sites for seine samples in the study reach. Labels for species are the first three letters of the genus and the first three letters of the specific epithet.

Multivariate Analysis of Fish Assemblages in Electrofishing Collections

Because we had only four electrofishing samples and many more explanatory variables, our component groups of explanatory variables explained 100 % of the total variation among the 18 fish species in our collection (Table 1.12). Also, any pair of components also explained 100% of the variation, so covariables could not be used to remove shared variance. Therefore, variation explained by each component group of variables for electrofishing samples also includes the variation that is shared by (covaries with) other components. Hydrologic and sediment components were each able to separately explain 100% of the species variation, and the physicochemical and habitat components were each able to separately explain 64% of species variation; structural features explained 36% of the variation in species among the four electrofishing samples (Table 1.12).

Our RDA ordination plot reflects the multivariate correlations among CPUE for 18 fish species and all environmental variables in our electrofishing samples (Fig. 1.15). Plots for RDA axes 1 and 2 (Fig. 1.15) depict 88% of both the species variance and species-environment correlation (respectively, 55% and 33%). Blue Catfish *Ictalurus furcatus*, was associated with higher shear stress, higher Froude number and higher velocity conditions, and with glides with woody debris, which occurred mostly in T1-T3 and T-11 collections (Table 1.5), whereas Flathead Catfish *Pylodictus olivarus* was more associated with deeper pools, lower velocity, and sand substrate in those river sections (left quadrants of both frames in Fig. 1.15). Most other species were negatively correlated with the catch of Blue Catfish in our electrofishing samples—indicated by their arrow directed opposite to those for other species on RDA axis 1 (upper frame of Fig. 1.15).
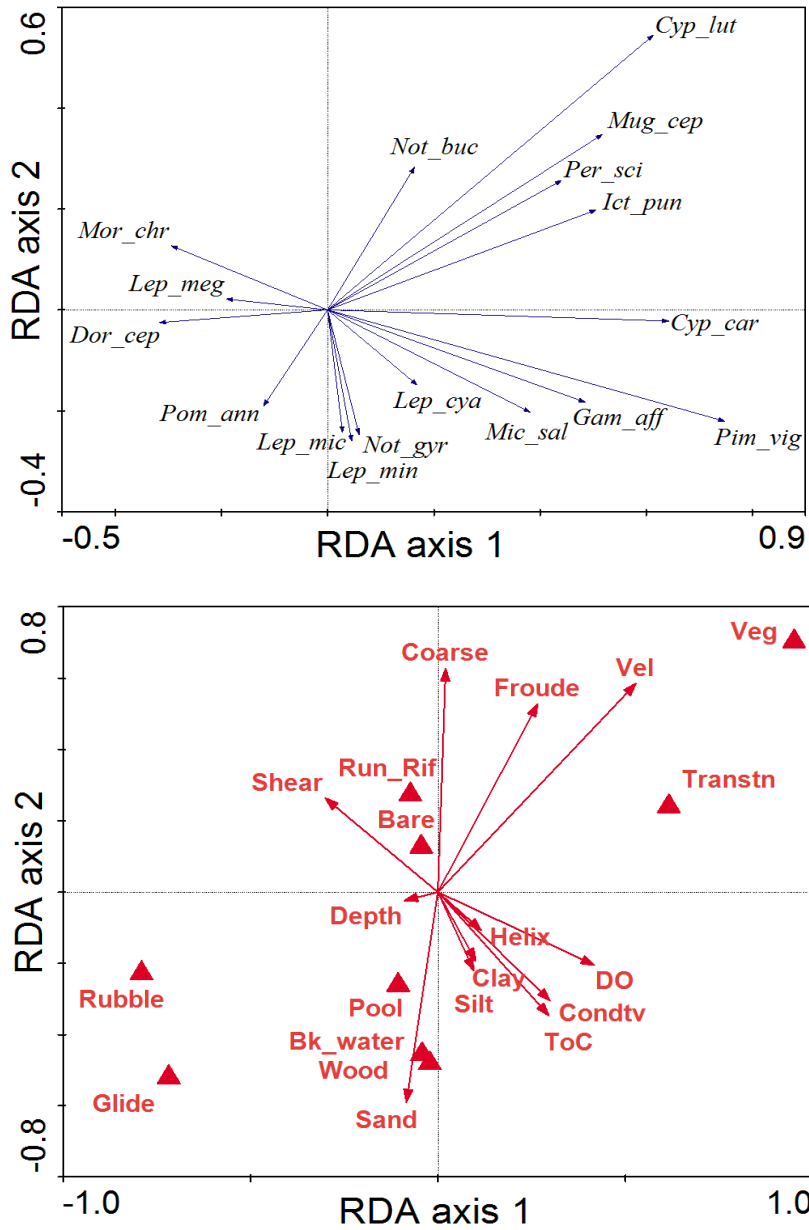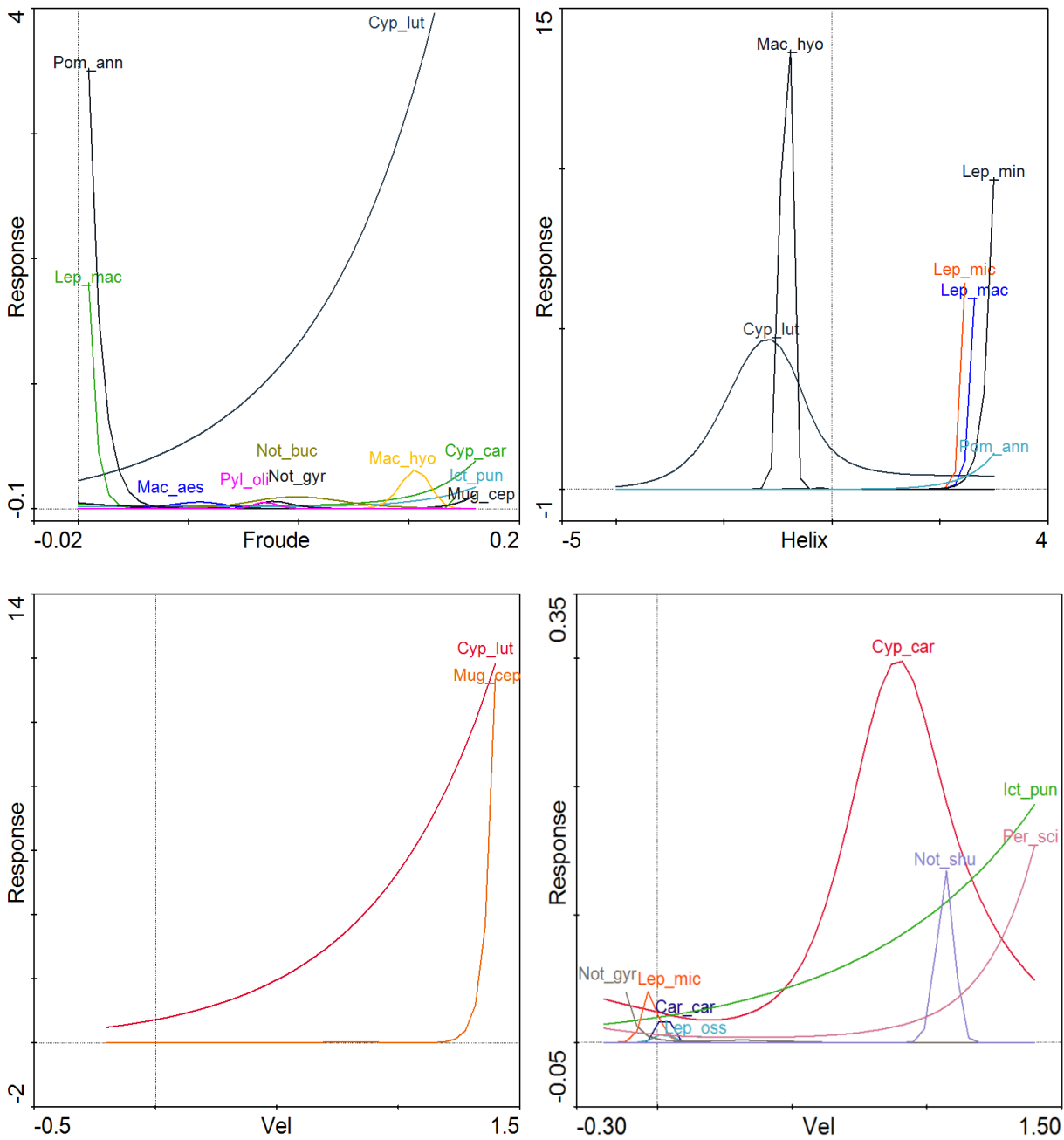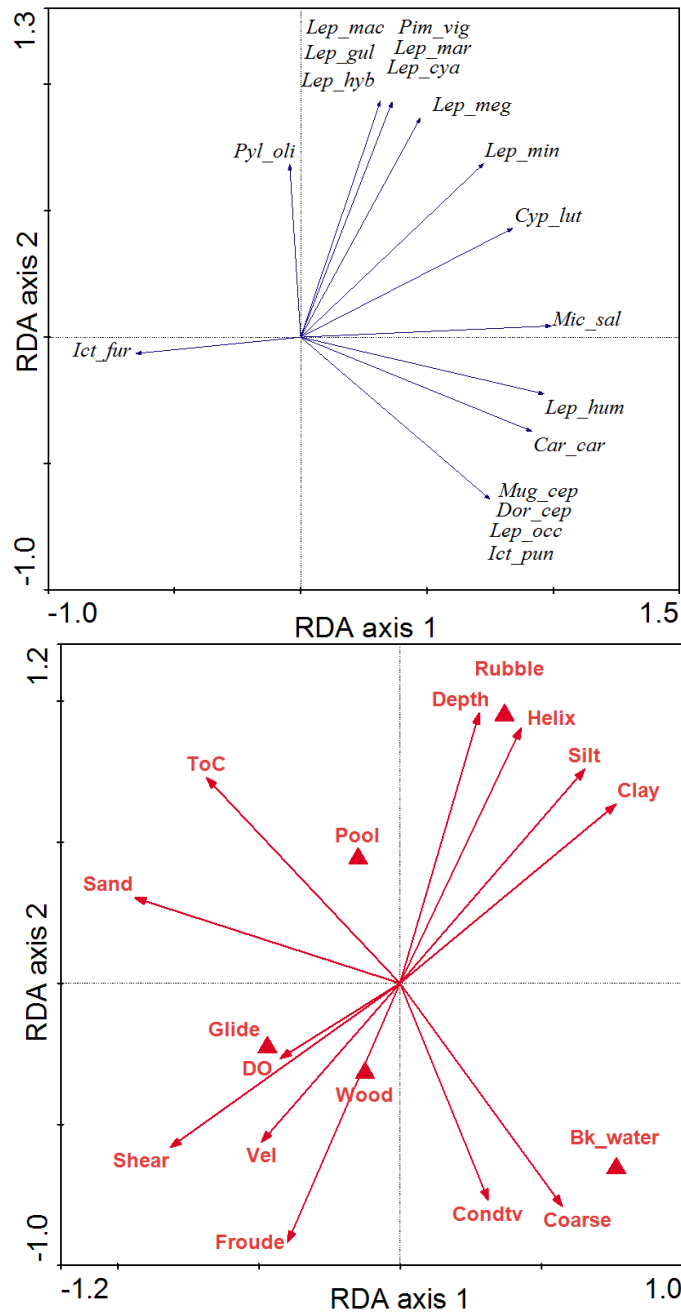
Fig. 1.15 Ordination plots for results of a direct gradient analysis for electrofishing samples in the study reach of fish species CPUE (upper frame) and correlated explanatory variables (lower frame) among samples in ordination space. Both plots are for the same resulting axes, but rescaled for clarity of labeling. Arrows for species (upper frame) are labeled with the first three letters of the genus and the first three letters of the specific epithet and indicate the direction of increasing value among samples. Arrows for explanatory variables (lower frame) indicate the direction of increasing value for continuous explanatory variables (hydrological, sediment size, water quality) among the same samples. Triangles are centroids for the distribution of categorical explanatory variables (habitat type and structural features) among samples.

Most of the Lepomis sunfishes were associated with rubble structure, greater helix strength, deeper pools, and clay and silt substrate that occurred in the T5-T6 area (Table 1.5; upper right quadrant of both frames in Fig. 1.15). Although not differentiated in the ordination analysis, more of the bigger Largemouth Bass were in electrofishing samples from the T5-T6 area, whereas smaller individuals were collected in the backwater in the T6-T7 area (Table 1.5). The T5-T6 electrofishing collections also included more River Carpsucker *Carpiodes carpio* and Orangespotted *Lepomis humilis* sunfish (right side of both frames in Fig. 1.15). Species most strongly associated with backwater habitat and presence of coarse substrate in the T6-T7 area collections included Striped Mullet, Gizzard Shad, Spotted Gar Lepisosteus oculatus, and Channel Catfish *Ictalurus punctatus* (lower right quadrant of both frames in Fig. 1.15; Table 1.5). The species response curves showed interesting contrasts as well as similarities with the RDA ordination plots. In particular, Largemouth Bass, Orangespotted Sunfish, River Carpsucker and Channel Catfish responded similarly to substrate size composition (Fig. 1.16) and similar to that depicted in the RDA plot (Fig. 1.15). In contrast, the bimodal response curve of Flathead Catfish for substrate composition is seen in all substrate size groups (Fig. 1.16), but is not depicted in the RDA plot of the first two axes (Fig. 1.15). Flathead Catfish did show a strong unimodal response to depth similar to that for Blue Catfish, whereas most Lepomis sunfishes, Gizzard Shad and River Carpsucker showed a bimodal response to depth (Top frame of Fig. 1.17). This reflects their relative abundances across habitat areas and transects that had different characteristic depths (Table 1.4). The response curve also clarified the similar responses by Channel Catfish and Blue Catfish to velocity (both positive, but of different magnitude) that is only evident on RDA axis 2 (Fig. 1.15)

63
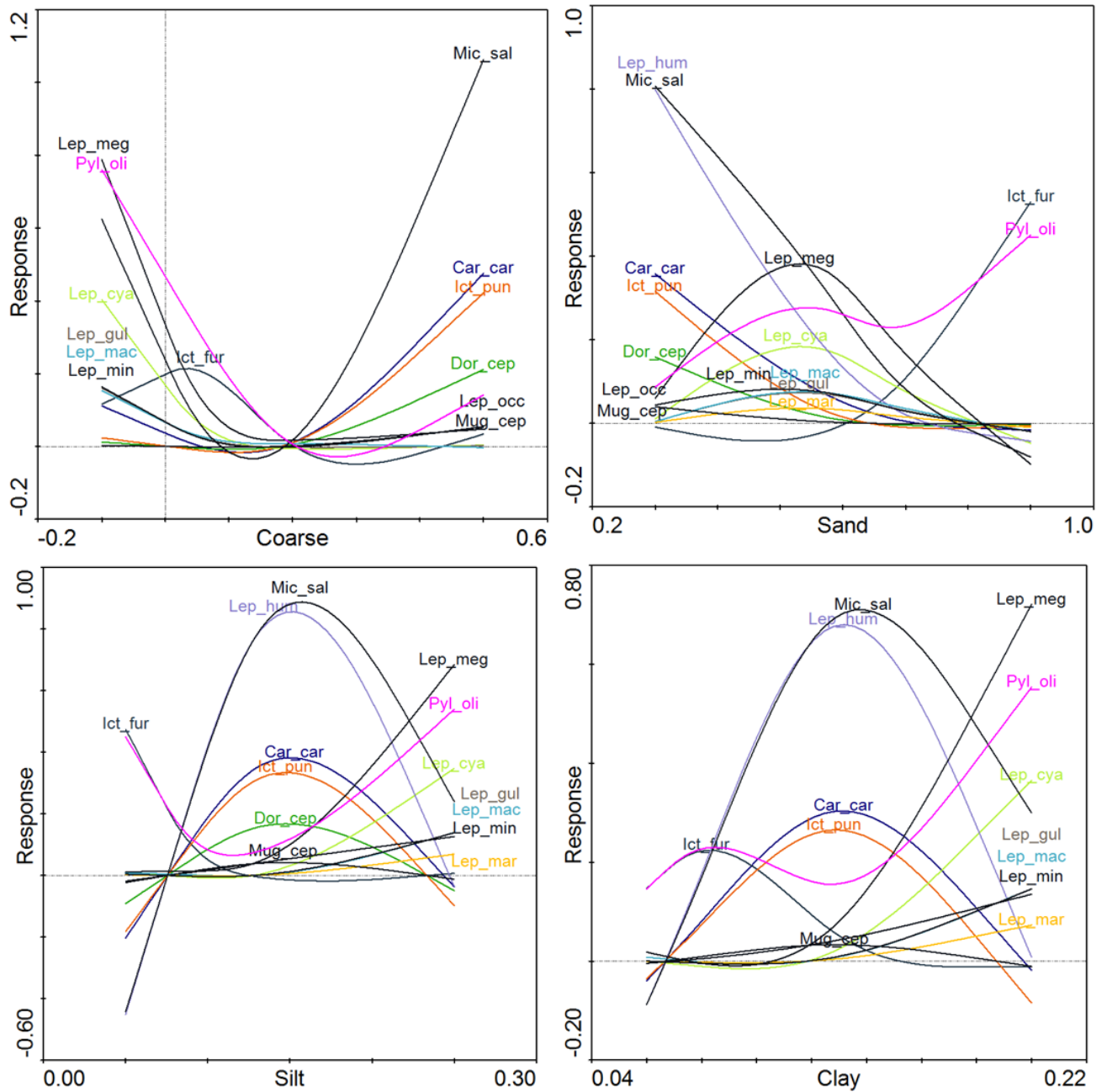
Figure 1.16 Fish species CPUE response along gradients in sediment particle size among electrofishing samples in the study reach. Species labels are the first three letters of the genus and the first three letters of the specific epithet.
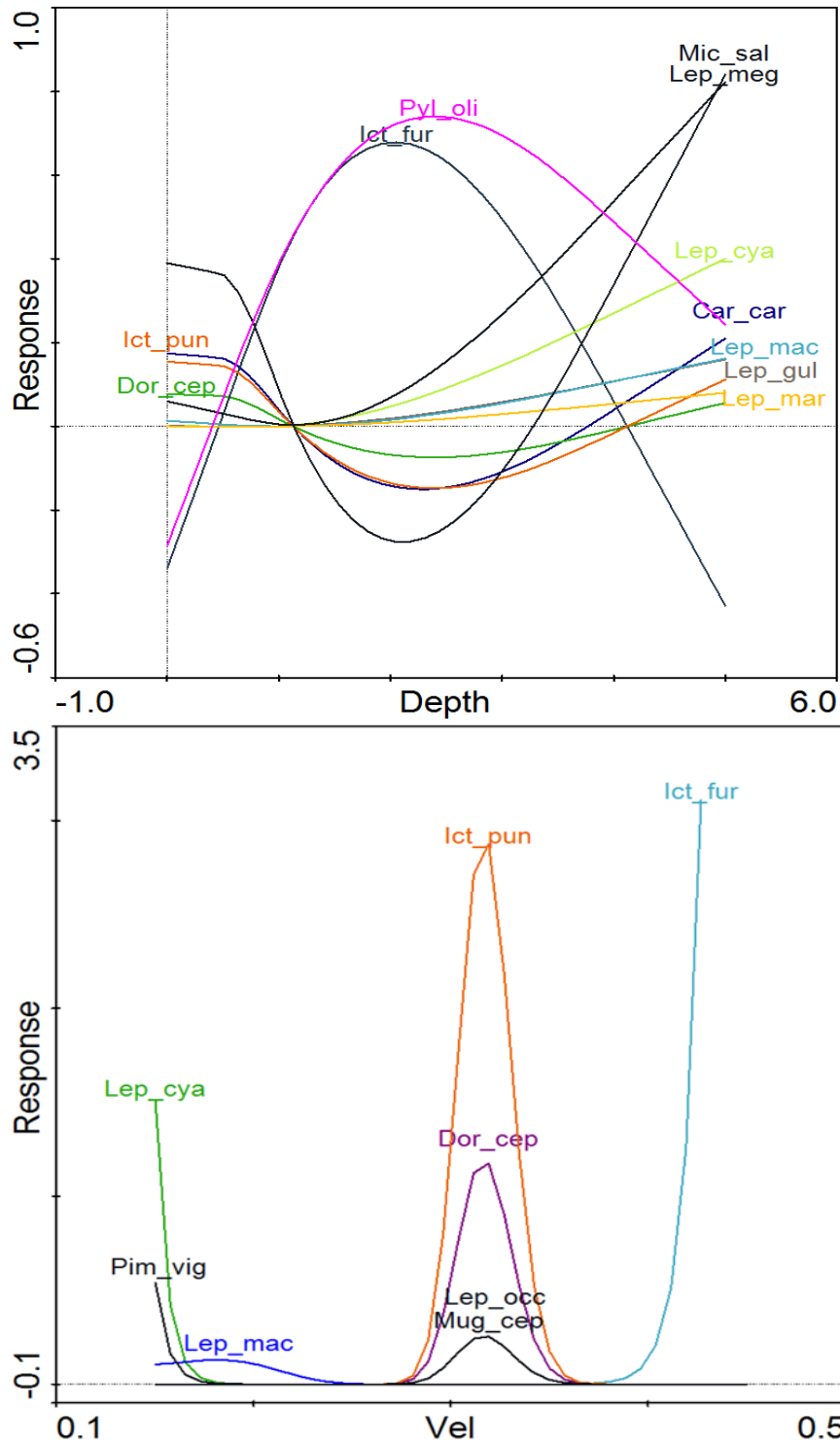
Figure 1.17 Fish species CPUE response along gradients in depth and velocity among electrofishing samples in the study reach. Labels for species are the first three letters of the genus and the first three letters of the specific epithet.

Multivariate Analysis of Macroinvertebrate Assemblages

All components of our explanatory variables together explained 85% of the total variation among 16 macroinvertebrate taxa across 19 samples (Table 1.12). The largest unique contributions to the explained variation were by hydrologic variables (14%) and habitat structure (7%), but overall, the greatest component of explained variation was related to physicochemical and sediment size variables (30% and 21% respectively), larger in part because these variables were totally correlated with many of the variables in other components, and thus their unique variation could not be partitioned (Table 1.12).

Plots for RDA axes 1 and 2 depict 44% of the macroinvertebrate taxon variance (respectively, 26% and 17%) and 51% of the species-environment correlation (respectively, 31% and 20%; Fig. 1.18). Caenis and Hydropsyche were strongly associated with larger values for Froude number, shear stress and velocity, in slightly deeper habitats with coarse substrate, including run/riffles and glides (lower left side of both frames in Fig. 1.18), whereas Tanypodinae, Baetis and Centroptilium were associated with lower values for these conditions and Tanypodinae and Centroptilium were more associated with transition habitat (lower left quadrant of both frames in Fig. 1.18). Macroinvertebrates more associated with pools that had more sand substrate and lower values for hydraulic variables included Chironimidae, Heptageniiadae and Chironomus (upper left quadrant in both frames of Fig. 1.18). Stylurus and Ephemeridae were associated with slower pool habitats with sand and greater helix strength, whereas, Pupae of Chironomids, Palaemonetes and Ceratopogonids were associated with backwater habitat with more silt and clay substrate and wood (upper right quadrant of both frames in Fig. 1.18). Chironominae and Leptoceridae were more associated with these habitats

in August 2010 when DO and conductivity were highest and where vegetation was present (lower right quadrants of both frames in Fig. 1.18).

The response curves for substrate composition depicted bimodal distributions for some taxa (e.g., Chironominidae, Heptageneids, Chironomus, Chironominae, and Leptoceridae) that indicated why their arrows in the ordination plot were located intermediately between centroids for similar substrate compositions in different habitat types (Fig. 1.18). The response curves for Froude number and helix strength also depict the negative correlation of macroinvertebrate taxa to these two variables, which is shown in the RDA plot as arrows pointing to opposite sides of the ordination (Fig. 1.19). Although Hydropsyche, Chironomus, Leptoceridae and Ceratopogonidae and Centroptilium were associated with higher Froude numbers (right side of top frame in Fig. 1.19), these taxa also were associated with negative values for helix strength (left side of bottom frame in Fig. 1.19). These hydraulic differences distinguish faster-flowing (run/riffle and glide) from slower-flowing (pool and backwater) habitats (Fig. 1.18).
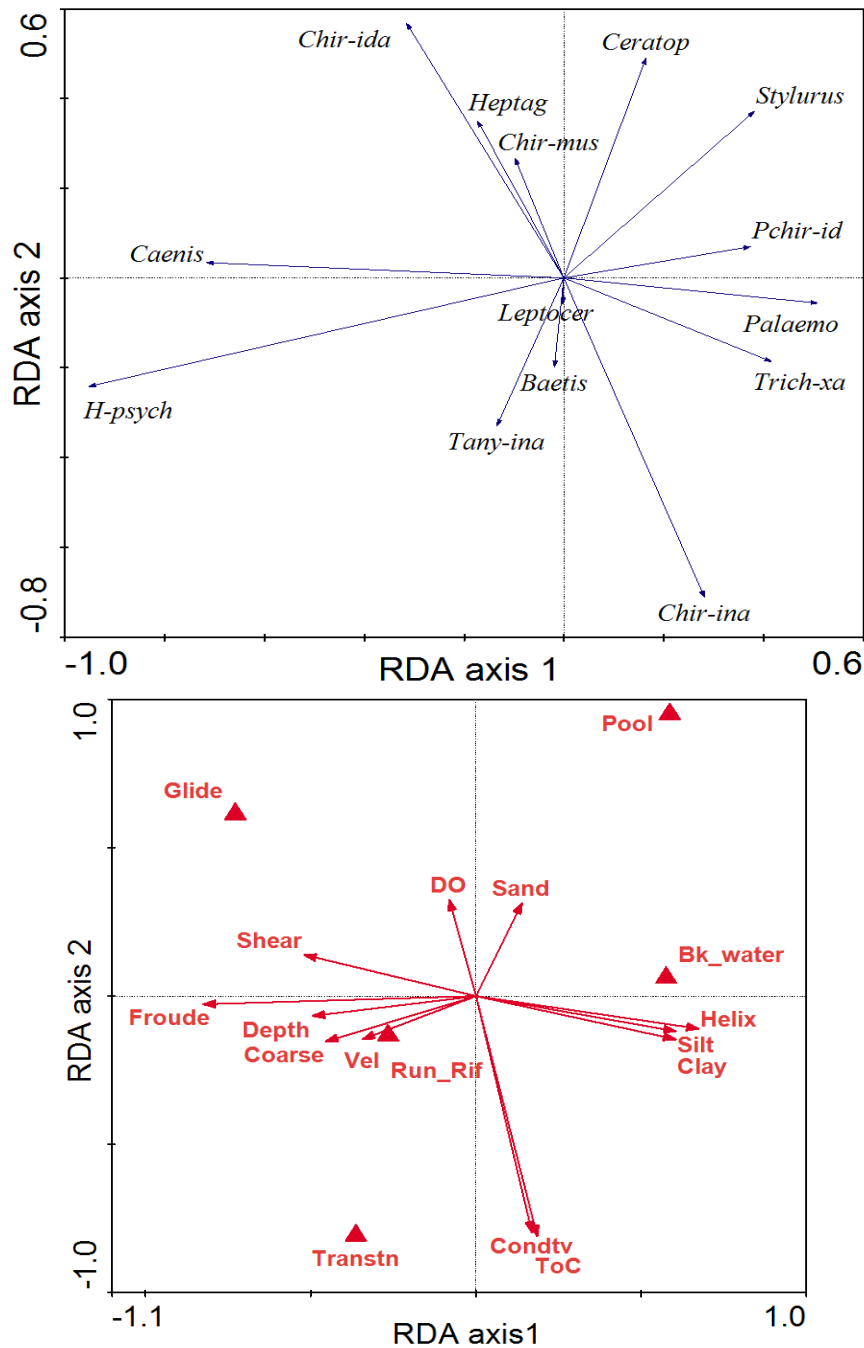
Figure 1.18 Ordination plots for results of a direct gradient analysis for benthic samples in the study reach of relative abundances of macroinvertebrate taxa (upper frame) and correlated explanatory variables (lower frame) among samples in ordination space. Both plots are for the same resulting axes, but rescaled for clarity of labeling. Arrows for taxa (upper frame) are labeled with abbreviations (order or genus) and indicate the direction of increasing value among samples. Arrows for explanatory variables (lower frame) indicate the direction of increasing value for continuous explanatory variables (hydraulic parameters, sediment size, water quality) among the same samples. Triangles are centroids for the distribution of categorical explanatory variables (habitat type and structural features) among samples.
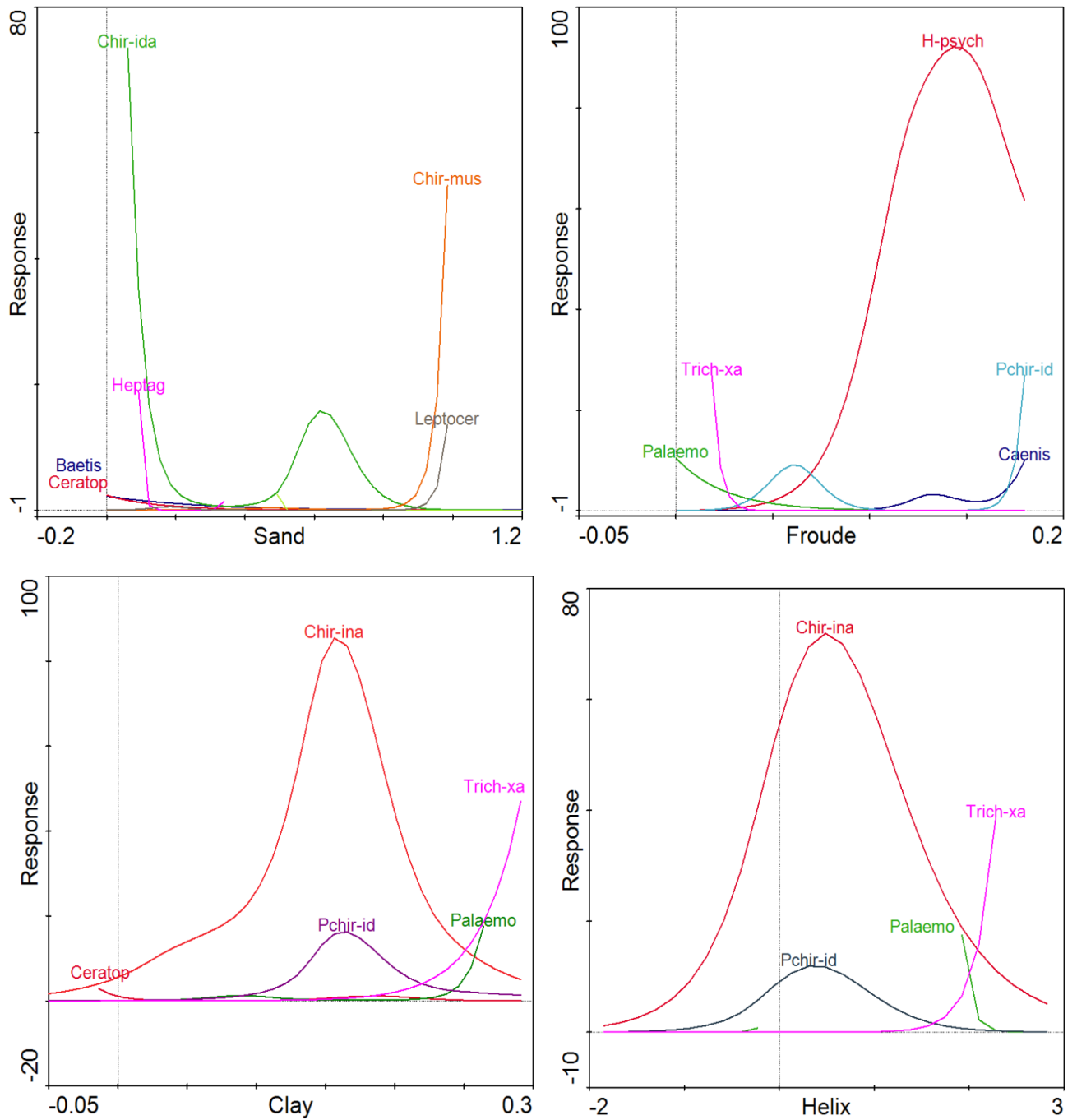
Figure 1.19 Response of relative abundances of macroinvertebrate taxa along gradients in sediment particle size (left panels) and hydrology parameters (right panels) among benthic samples in the study reach. Labels are abbreviations of order or genus.

Multivariate Analysis of Hydrologic Parameters, Habitat Types

Our defined habitat types explained 35% of the variation in measured and calculated

hydrologic parameters (Güneralp and Hales, 2013; modeling for Q1 discharge) among our

samples. The ordination plot (Fig. 1.20) depicts 95% of the explained variation on RDA axes 1

and 2 (respectively 85% and 10%). Our alternative (supplemental) environmental variables

explained 42% of the variation in the hydrologic parameters. The ordination plot depicts 97%

of the explained variation on RDA axes 1 and 2 (respectively 87% and10%). The post-hoc

correlations of our supplemental alternative environmental variables are depicted on the first

two RDA axes (Fig. 1.20). The first RDA axis depicts the negative relationship between shear

stress, velocity and Froude number associated with glide habitat (right side of Fig. 1.20) as

compared with greater helix strength in riffle/runs and backwaters (left side of Fig. 1.20). The

second RDA axis depicts the influence of depth that differentiates pool habitat from other

habitat types (top of Fig. 1.20) and its negative relationship to velocity and Froude number

(bottom of Fig. 1.20).
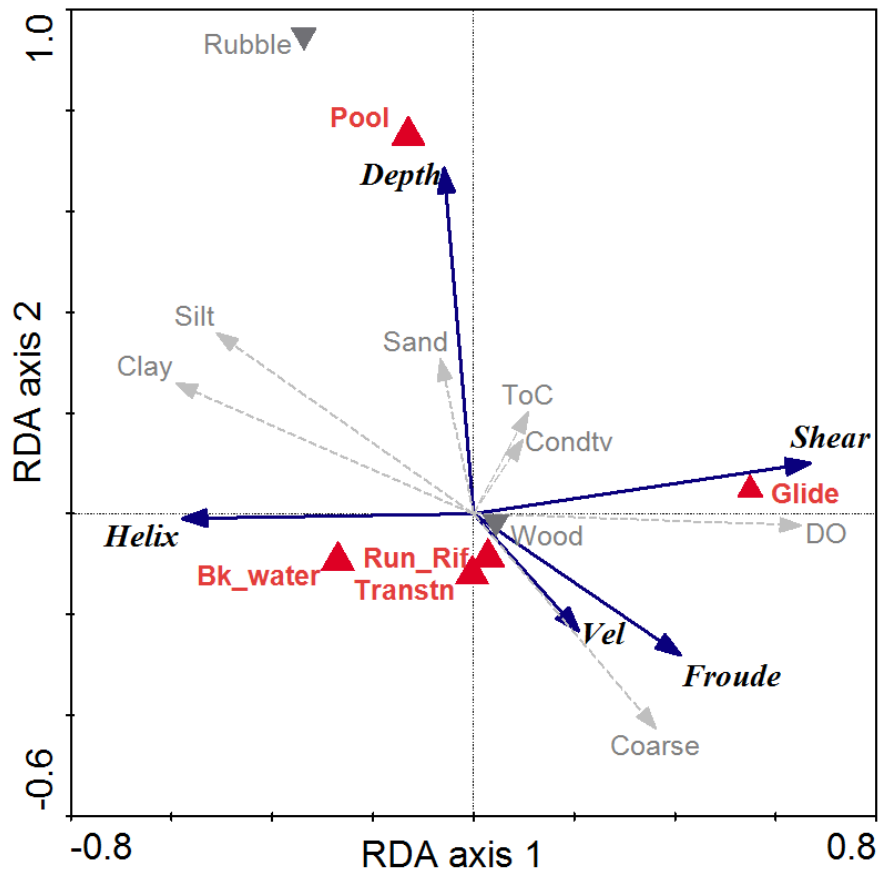
Figure 1.20 Ordination plot for results of correlation of habitat types (red uptriangles) and hydrologic parameters (dark blue solid arrows) on the first two canonical axes. Post-hoc correlations of supplementary environmental variables (grey dashed arrows) show their relations with variation in hydrologic parameters as constrained by their correlation with the explanatory habitat types.

Discussion

Fish species composition and fish length distributions in riverine systems differ among microhabitat types and seasons (Gorman and Karr, 1978, Grossman et al., 1987) so understanding habitat structure and seasonal variation are important in assessing fish communities. Our results show the variation of fish and macroinvertebrate assemblages in our spring-summer samples (2010-2012) at low discharge (Q1, as defined by Güneralp and Hales

2013) along an 11-km long meander bend of the Brazos River downstream of HWY 60. For three collection methods, total explained variation among samples (63% in seining collections, 85% in macroinvertebrate collections, and 100% for electroshocking) was primarily due to their shared component (respectively, 25%, 60% and 100%) indicating strong covariation among our explanatory variables. A multivariate analysis showed that our habitat types (related to depth, velocity and visual disturbance of the water's surface described as pool, glide, run/riffle, run/riffle-backwater transition, and backwater) were highly correlated with other environmental variables (up to 85% of the variation), but they captured only 35% of the variation in the hydrologic parameters among our sites (Fig. 1.20, i.e., depth, velocity, shear stress, Froude number, and helix strength). This demonstrates the difficulty in defining appropriately-unique habitat categories at a scale that is useful for establishing field sites for sampling biota. For seined fish and macroinvertebrate samples, hydrologic parameters showed uniquely-explained variation (Table 1.12, respectively, 10% and 14%, collectively for depth, velocity, shear stress, Froude number, and helix strength), as did structural habitat (respectively, 3% and 7%, collectively among woody, rubble, vegetation, bare), and our defined habitat types (respectively, 8% and 4%). Unique variation for two other components was detected only in fish seining samples; these were water quality (11% collectively among temperature, DO, conductivity) and substrate composition (5% collectively among coarse, sand, silt, and clay).

The geomorphology of a stream is important to describing fish habitat because channel morphology provides the framework in which organisms live (Gordon, 2004), and as shown by Güneralp and Hales (2013), pool and mid-channel bar morphological features can provide the

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control for some of the hydrodynamic parameters that also influence fish associations (e.g., velocity, shear stress, helix strength).   We measured several community indices of diversity (number of species, alpha diversity, evenness, beta diversity) for fish samples among sections of the meander bend, which contained different habitats, but relatively homogeneous diversity of fishes at the scale of the entire landscape of the meander. Indices showed there was greater local biodiversity in structurally heterogeneous sections of the bend that contained a variety of geomorphic habitat types, particularly habitats that were associated with greater values for velocity, Froude number and helix strength (e.g., run/riffle, transition, and backwater). Our pilot study of DIDSON videography to collect data for fish abundance and size classes filled in specific information gaps for large areas of the study reach, and showed that more information for fish density (abundance and biomass) could be gathered across larger areas using less field effort, than when using only conventional sampling methods. Counts for medium- and large-bodied fish could be assigned to species, genus or family based on fish shape, and behavior. As with most acoustic sampling methods, especially for smaller fish, some reference samples using conventional methods were needed to associate DIDSON fish images with their most likely taxonomic identity.

We made initial collections of mollusk shells along the banks and shallow shoreline in 2010 to assemble a reference voucher collection. However, low abundance of live mussels in our initial samples influenced us to focus our sampling on fish and macroinvertebrates, and at every opportunity to identify live mussels in the field when conducting our other sampling and return live mussels to the river unless needed as vouchers. Our original scope of work had planned for additional sampling in other seasons and at other discharge levels. Weather

conditions and water levels prevented access to the study site except during Q1 discharge in summer (August) 2010, spring and summer (May, June, and July) 2011, and summer (June) 2012. However, we do include in our discussions the extreme drought conditions in summer 2011 and differences in the biota sampled as compared to water levels and habitats sampled in spring and summer of other years. In addition we compare our results to those of Li and Gelwick (2005) who sampled similar habitat in the Brazos River downstream near Sealy TX. Below, we discuss our specific findings for fish-environment relationships and diversity of fish collected during our field campaigns using conventional sampling methods, and for macroinvertebrate-environment relationships for samples collected using conventional benthic methods. We include discussions of assemblage taxonomic composition and associations related to environmental variables commonly measured or identified in the field, and the additional information and insight provided by data for hydrologic variables.

Fish taxa collected in field campaigns

Beta diversity indices for each set of seine and electroshocking samples indicated that the fish assemblage across the landscape of the study reach was homogenous. At all sampled sites, the most abundant species seined was *C. lutrensis*; this was found by other researchers in the lower Brazos River (Zeug et al. 2005, Winemiller et al. 2000, Li and Gelwick 2005). Overall, total seine CPUE was low in mid-channel glides and pools most likely because deep pools generally support larger fish (Winemiller et al., 2000, Lamouroux and Souchon, 2002), whereas seining targets smaller fish. The two main fish groups we shocked were genus *Lepomis* and family Ictaluridae. There were no surprises in their location among the different hydraulic habitat types. The three species of catfish, *Pylodictis olivaris*, *Ictalurus furcatus*, and *Ictalurus*

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punctatus, were collected in glides, pools and the shoreline of the temporary island/mid-

channel bar in T6-T7 adjacent to the shallow pool; *I. furcatus* was only caught in the mid-

channel glides of the study reach in areas of moderate flow and 1-3 m depth, which are noted

as their characteristic habitat (Jenkins and Burkhead, 1994). We shocked *P. olivaris* in glides

and also in the deep pool that contained the concrete rubble and bank structure. *P. olivaris* are

commonly found in moderate to deep pools over hard or lightly-silted sediment which is the

hydraulic fish habitat in the T5-T6 deep pool. We collected juvenile *P. olivaris*, < 32 cm, in the

glide between transects T1 and T4 which is not surprising since juveniles are found in areas

with moderate velocity (Jenkins and Burkhead, 1994). *I. punctatus* can live in multiple habitat

types; though commonly associated with pools, they are also found in areas with moderate

current and can survive in turbid waters (Jenkins and Burkhead, 1994). We did not catch any

adult *I. puncatuts,* but we both shocked and seined juveniles in faster flowing sections

surrounding the mid-channel island at the end of T6 and beginning of T7. All species shocked

in genus Lepomis are commonly found in backwater and pools with sandy to silty sediment

sizes; conditions which these species tolerate (Jenkins and Burkhead, 1994, Hassan-Williams,

2013). The Centarchids (genus Lepomis and Micropterus) that we electroshocked were

collected in the deep pools and T6-T7 that had backwater microhabitat and a shallow pool.

These findings were also supported by habitat associations detected in the multivariate

analysis for electroshocked fish assemblages.

Gill nets were deployed in our study site where seining and electroshocking were

neither possible nor effective in deep water, but their catch rates were low (Fig. 1.6). The

predominant species caught in gill nets was *L. osseus*. It was difficult to readily locate secure

attachment sites for nets in the flowing current. Underwater obstructions and floating debris also snagged and tangled our nets. Placing the nets so as to effectively cover the bottom of the channel was difficult due to the complex bottom morphology and submerged woody debris. Thus, fish could avoid nets by swimming over or under them.

The second most abundant species we seined was *P. vigilax*, which typically inhabits standing water and shallow shoreline habitats (Merritt and Cummins, 1984, Jenkins and Burkhead, 1994). Its density increased in slower water in our study reach and it became the dominate species in T6-T7 backwater and both T11 sample sites, but not in T5-T6 backwater, and the shallow pool with concrete rubble bank structure. In backwaters, we primarily captured juvenile *Lepomis spp.*, *P. annularis,* and *M. salmoides, D. cepedium,* and *G. affinis* fish in seine samples, again typical of their habitat use (Pflieger, 1975, Jenkins and Burkhead, 1994, Warren, 2009). Individuals of *Notropis spp.*, *C. carpio* and *M. aestivalis* were generally collected by seining in habitat with moderate current and coarser sediment, again typical habitats for these species. Notably, Ghost Shiners *N. buchanani* are generally found in larger pools and backwaters of large rivers (Pflieger, 1975); but we collected Ghost Shiners in the same habitat as other *Notropis spp.*, but not backwater pools. We suspect that depth and velocity conditions for backwater in wider reaches of large rivers are more similar to those in our run/riffle and glide habitats, and Li and Gelwick (2005) found Ghost Shiners were abundant in river-margin habitats of a wider section of the Brazos River further downstream.

Our fish samples for seining, electroshocking, and DIDSON videography displayed slight differences among sites for species distribution (respectively, Figs. 1.4, 1.5, and 1.8), alpha biodiversity, evenness, and similarity (Tables 1.3-1.8). This was especially evident in T6-

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T7. At the end of T6 and beginning of T7, there were four distinct microhabitats that differed in sediment size composition (Table 1.2), presence of wood and vegetation (Table 1.3) and depth and current velocity (Figs. 1.4 and 1.5). We found that density of *C. lutrensis* was generally higher in run/riffle habitats (Table 1.3). Seine CPUE and alpha diversity index for T7 chute revealed that *C. lutrensis* was the dominant species in this habitat (Table 1.3 and 1.5). Multivariante analysis and species response curves also showed that *C. lutrensis* in our study was strongly associated with higher velocity habitats (Figs. 1.13 and 1.14), but this was not the case in electrofishing samples (Figs. 1.15 and 1.17). *C. lutrensis* s are tolerant of many conditions (including high temperatures and low DO; Matthews (1987), but has previously been reported to be more common in quiet pools and backwaters (Pflieger, 1975). We did seine *C. lutrensis* in calm backwater and pools, but CPUE was generally lower compared to run/riffle habitats. The dominant seined fish species in the run/riffle chute shifted from *C. lutrensis* to *P. vigilax* as samples at T6-T7 progressed upstream from the run/riffle towards the backwater (Fig. 1.4) and CPUE of other fish species increased. Seining biodiversity was relatively high in T6-T7 compared to other sites (Table 1.5). Yield from electroshocking in this section also supported the uniqueness of this area. T6-T7 electroshocking results had the second highest values for total CPUE (Table 1.3) and for alpha biodiversity (e^H, Table 1.7). Although T5-T6 had the highest electroshocking CPUE and alpha diversity, beta diversity showed that assemblages in these two transects were similar (Fig. 1.3). For seine samples, T11's backwater had the second highest total CPUE (Table 1.3, Fig. 1.4) and alpha diversity, and shoreline microhabitat was third highest (Table 1.6).   But beta diversity analysis again showed that T5-T6 and T-11 were more similar to each other than to other transects (Fig. 1.3). These results suggest that

T6-T7 habitats and large pools most likely are important to sustaining the fish biodiversity among communities within the meander bend.

Average DIDSON counts also were greater in T5-T6 and T7 transect (Table 1.8, Fig. 1.8). Counts increased for mid-size and large (10-30 cm and > 30 cm) fish in T5-T6 recording locations in the pool and T7 chute (Table 1.8, Fig. 1.8). Large-bodied fish imaged at the bank protection structure in T5-T6 (Fig. 1.8) were most likely adult *M. salmoides* and *P. olivaris*. Mid-sized fish in the pool were mostly *Lepomis spp.* and the larger fish, Ictaluridae family or *M. salmoides* based on capture of juvenile fish in other collections, and shape and swimming behaviors observed in recordings (Fig. 1.7). We visualized what was most likely a mid-size *P. olivaris* flathead catfish, swimming among smaller fish in the T6 – T7 riffle site. Larger fish in mid-channel shots that were observed around wood debris in fast current were most likely *I. furcatus* and *L. osseus* based on their swimming behavior in recordings and presence in electroshocking and gill net catches.

In 2010, a DIDSON video "captured" a large Blue Catfish (~50 cm TL; Fig. 1.7 D) in 2-m deep water under a tree log and either a Smallmouth Buffalo *Ictiobus bubalus* or River Carpsucker *C. carpio* near a large wood pile. It also captured a gar slowly swimming along sandy sediment in a backwater pool near T6, where small fish (most likely minnows based on size and behavior) were schooling. Observing fish behavior with DIDSON is possible and can be a powerful tool in understanding fish habitat use and ecological interactions (authors' personal observations; personal comments from local anglers near our study reach). Previous research with DIDSON has shown swimming behaviors and direction, feeding behaviors, and spawning at night for migrating fish (Maxwell and Gove, 2004, Tiffan et al., 2005, Baumgartner et al.,

2006). Echograms can be used to analyze tail beat patterns and bioenergetics for large fish (Mueller et al., 2010), and to quantify distribution of fish biomass (a capability included in processing software program not included in our study due to time constraints).

Macroinvertebrate taxa collected in field campaigns

The numerically dominant macroinvertebrate taxa collected in backwaters was Diptera, as compared to run/riffles and shorelines where *Hydropysche* dominated (Fig. 1.18). We did not collect enough individuals of Odonata and Ephermpotera to conclusively associate them with habitat type(s), but we did collect more individuals of these taxa in backwaters or glides (Fig. 1.9 D, 1.10 B, D, 1.11B, 1.12B and D). Texas underwent an extreme drought in 2011, when it experienced the highest temperatures on record since such records were taken (NOAA, 2011). The macroinvertebrate populations appeared to have decreased after the 2011 drought (2010 and 2011 in Figs. 1.9 and 1.12, compared to 2011 in Figs. 1.10 and 1.11). In 2010 and 2012, we commonly obtained more than enough individuals in our samples for a sub-sample of 100, but in 2011 obtaining a sample of 100 was challenging, especially in backwater habitats (Fig.1.10 D and E, and Fig. 1.11 B). Cowx et al. (1984) found similar changes in macroinvertebrate populations in Alfon Duas River in Wales during and after droughts that showed there were initial decreases in some populations followed by a change in the whole community structure in the following year. Similarly, in our collection for T7 riffle in 2012, we were unable to collect 100 individuals despite taking two benthic samples similar in size and substrate composition to those taken in other years (note: in 2010 we sorted samples and counted individuals in the field, but in following years we brought samples to the lab for both sorting and counting). We also noted a shift in assemblage structure of backwater, shoreline and mid-channel from 2010

to 2012 from family Diptera in 2010 (Fig. 1.9 B,C and D) to increases in Trichoptera (Fig. 1.10 B, D and E, Fig. 1.11, and 1.12 A,B,D,E, and F) and particularly Ephermeroptera in 2012 (Fig. 1.12B). This could also have been due to the sampling season and differential breeding cycles among taxa, since we did not collect any spring samples in T6-T7 and T3-T4 in 2010 and 2012.

As previously stated, we made representative collections of shells of dead mussels and clams along the shoreline of the study reach in 2010 to serve as our reference sample for identification and vouchers of occurrence (Table 1.9). The abundance of live mussels in initial collections indicated that considerable field effort would be needed to document live mussels, so we focused our efforts on macroinvertebrate collections, but also collected live mussels and shells at every opportunity during all other sampling activities. Unless needed to confirm identification, we returned live mussels to the site where they were collected. Otherwise, we could not determine specific habitat for mussels since they had either washed ashore or were carried by predators to shore and consumed (frequent evidence observed along the shoreline included foraging birds such as Great Blue Herons and Common and Snowy Egrets, and tracks of wading birds and Raccoons). The most common mussels/shells collected were in the genus *Quadrula* and the species *Potamilus ohienesis, Potamilus parparatus, and Leptodea fragilis*. We also identified shells of two individuals of Texas Fawnsfoot, *Truncilla macrodon*, which is a threatened species in Texas; in July of 2011 Clint Robertson (TPWD) identified a live specimen during our DIDSON demonstration. Currently Dr. Kevin Conway, Ichthyologist at Texas A&M University, Wildlife and Fisheries Sciences, is studying specificity of fish as hosts for glochidia of several local taxa of mussels in Texas rivers (K Conway, personal communication).

Conclusions

The Brazos River is dominated by tolerant generalist species (e.g., *C. lutrensis*, *P. vigilax*, and Channel Catfish; Li and Gelwick 2005, Matthews 1987, Winemiller et al. 2000), which in part explains the low overall evenness and low beta diversity calculated for collections in this study. Our study reach is within the lower section of river style 2 (meandering incised valley fill; upstream and downstream of SH 60 bridge; Latitude-Longitude 30.5643, -96.4304 to 30.4432, -96.2899; Phillips, 2007). We suggest that biodiversity in similar reaches can be preserved/enhanced if the Brazos River is allowed to maintain a flow regime (i.e., frequency, magnitude, and duration for both high channel forming flows and naturally seasonal intermediate highs and lower base-flows and naturally seasonal intermediate high and lower based-flows) so as to perpetuate and preserve river sections that contain multiple geomorphic habitats. The cross-bar channel (Coffman et al 2011) which had formed at T6-T7, is an example of a geomorphic unit that leads to a slightly shortened flow path and thus lower sinuosity and higher velocity that causes the bar sediments to be reworked and sorted forming riffle areas. However, rather than originating from an inundated swale in the point bar during a high flow event, Güneralp and Hales (2013) suggests that the cross-bar channel at T6-T7 is likely to have had an anthropogenic source related to placement of large boulders and rip-rap structures upstream along the bank opposite to the T6-T7 point bar. Based on our results, such geomorphic and hydraulic habitat diversity is especially important to maintaining the biological diversity that was associated with backwaters and run/riffles and mid-channel bars surrounded by areas with glide and pool habitat similar to that of the T5-T8 section of the meander bend in our study reach. This section appears to provide habitat for all life stages of

native aquatic biota, and strongly contributes to the biodiversity of native species in this reach of the Brazos River. Section T5-T8 spans the apex of the meander bend (Fig. 1.1). Meandering bends are known to support high biodiversity in fish and macroinvertebrates due to the diversity and spatial contiguity of hydraulic geomorphic habitat units (Frothingham et al., 2001, Garcia et al., 2012). There is a deep pool just upstream from transect line 6 and a shallow pool just downstream that lead into four microhabitats at the end of T6 and beginning of T7; backwater, transition, run/riffle, and mid-channel bar (Fig. 1.1).   This area generally had higher biodiversity and greater relative abundances of fish species for the each sampling gear (Figs. 1.4, 1.5, and 1.8) and higher macroinvertebrate species richness (Figs. 1.9, 1.10 and 1.12). Based on the analysis of our DIDSON videography sample the deep pool in T5-T6 on average had more fish >10 cm and a large number of smaller fish, < 10 cm (Table 1.8). This suggests that the apex of the meander bend supported higher biodiversity during low discharge than other regions of the study reach. T11 seining results also showed that the aforementioned habitats supported higher biodiversity similar to that for T6-T7. Due to high conductivity that led to unsuccessful electroshocking collections, problems with placement or stability of the DIDSON camera, and difficulties with hydrologic modeling of data for T11 (B. Hales, personal communication), we are unable to confirm that the downstream end of the meandering bend could support a similarly diverse community.

Although we were unable to make collections in our study reach at alternative discharge levels, Li and Gelwick (2005) discuss the collection and habitat use by fishes in a wider section of the Brazos River further downstream (near Sealy TX), during three levels of discharge (50th, 30th and 15th percentiles each in summer and winter seasons). Shallow-water

margins, backwaters, and scour pools, where adventitious streams joined with the main river, were important additions to explaining fish-habitat associations, in particular, spawning areas for gar and refuge habitats for smaller fishes during seasonally high flow events. Li and Gelwick (2005) speculated that the latter supported the low seasonal variation in assemblage structure (their multivariate analyses showed only 6.7% and 2.3% variation respectively, for shallow and deep habitats) in that reach. Moreover, Li and Gelwick (2005) recorded strong recruitment of juveniles into assemblage structure following seasonal high flows in spring-early summer. Interestingly, *C. lutrensis* and *P. vigilax* were the two dominant small-bodied fishes in those collections, as they were in our meander reach for this project. Many other species were common to both studies, such as *Notropis schumardi, N. buchanani, Macrhybopsis aestivalis, Mugil cephalus*, and *Dorosoma cepedianum* in shallow water, and *Lepisosteus osseus, L. oculatus, Carpiodes carpio, Ictalurus furcatus* and *I. punctatus* in deep water pools and glides. Also in common were, juvenile Ictalurid catfish, especially channel catfish *I. punctatus*, that were abundant in riffle habitat in the lower Brazos River (Li and Gelwick, 2005) as they were in our T6-T7 run/riffle chute samples. For gill net collections, high velocity was related to zero catches in both studies. However, the percentage of explained variation in seined fish in the lower reach of the Brazos River (Li and Gelwick, 2005) that was due to depth, flow and substrate size was approximately half of that calculated for the meander bend in our current project (32% in the 2005 project, as compared to 63% in our project in 2010-2012). In part this is likely due to the greater habitat heterogeneity downstream in the larger reach of the Brazos River across a greater range of shallow water habitat types (i.e., greater variation associated with depth and velocity). Also, greater total species richness and abundances downstream in

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the larger reach of the Brazos River would tend to reduce statistical detection of change among the less-abundant species in analyses.

Despite a pattern of little seasonal change in fish assemblage structure in the Brazos River (Li and Gelwick 2005, and this project), fishes could change their distribution under different flow conditions. Güneralp and Hales (2013) showed in their model for projected high discharges (Q2 and Q3) that areas of low velocity would decrease and mid-channel bars would become submerged as deep-water habitats increased (Figures 32 and 33 in Güneralp and Hales, 2013). This would create a more homogenous landscape in the meander bend, making the area similar to T1-T4 and T8-T10. If such conditions were to continue over longer time periods (i.e., multiple generations for these species), we project a change in species dominance in this reach would follow due to ecological adaptations among species and dynamics of populations over time in response to the new habitat regime. For example, the T7 run/riffle chute present during our sampling period (2010-2012) would be lost and become a habitat we identified as glide (not included in morphological units of Figure 22 in Güneralp and Hales 2013). The microhabitats we observed would also be lost and numerical dominance of *C. lutrensis* most likely would decrease and shift to dominance by *P. vigilax*, and 'other' fish species (e.g., sunfishes and juvenile bass, and catfish) since our results indicated that these species preferred a slower current.

Our information about aquatic communities is timely because of recent changes in climate conditions and demands on water for use by people (Roach, 2013). Different species and fish at different life stages utilize different habitats. Additionally, surrounding vegetation and landscape effect the morphology and stream environment. Thorp et al. (2006) proposed a

heuristic model called the Riverine Ecosystem Synthesis (RES) to investigate the biocomplexity of lotic systems by providing a framework to understand river regimes and ecological patterns. Thorp et al. (2006) combined information and data on eco-geomorphology and terrestrial landscape to provide a hierarchal data organization. Therefore, we encourage additional studies, or use of available datasets, to add information about landscape, land use, and side-channel vegetation that could enhance our current analyses. For example, by combining data for water withdrawls for irrigation and municipal use into the model of hydrologic and geomorphic habitats (Güneralp and Hales 2013), models for alternative flow regimes could be linked to projections of human water use to better understand consequences for river biota.

During our study, we encountered difficulties with boat shocking within the study reach. Boat shocking and seining are generally recommended over the use of gill nets for river sampling (Bonar et al., 2009). A study in the San Francisco River, Mexico, demonstrated that electroshocking was optimal for collecting fish community data and provided higher total abundance estimations and was 80% more effective (Mercado-Silva and Escandón-Sandoval, 2008). However, we were unable to electroshock in 2010 due to lack of accessibility and available boat size, but we were able to access the river to electroshock in 2011 and 2012 with a smaller boat and shocker configuration. With the smaller boat shocker system, however, the lower power of the smaller shocker and generator were not enough to successfully stun fish in deeper water, especially under conditions of high conductivity in 2012. Conductivity and sediment type both affect the success of electrofishing catch (Bohlin et al., 1989). In 2012 the water conductivity was 1128μS and 1500μS in 2010. An explanation for the high conductivity in that reach is that it is downstream of Texas Agricultural Experiment Station and other

agricultural fields where water for irrigation is pumped from the Brazos. (Ironically, it was due to the grading and gravel placed on the path created for the pump at this location that we were able to access to the river with our equipment.) When water is pumped from the river for irrigation, water levels decrease thus increasing the evaporation process that concentrates salt and other solutes, as well as fertilizers and other chemicals applied to cropland that return to rivers as soils are eroded (Clyde Munster, professor, Biological and Agricultural Engineering, Texas A&M University, personal communication). These events would lead to higher conductivity levels as compared to other non-agricultural areas along the Brazos River where there is no active irrigation. For example, Carmen Montaña, a recently graduated PhD student in Wildlife and Fisheries Sciences, Texas A&M University, also regularly sampled shallow water habitats of the Brazos River by seining and electrofishing upstream from the HWY 21 bridge. She shared the use of the smaller boat and electroshocker she usually uses for her collections, and while accompanying us, noted the higher conductivity and low effective catch rate for electroshocking samples in our reach (C. Montaña personal communication). Our electrofisher repeatedly short circuited in 2011 and 2012 at high voltage demands needed to increase the success rate of catching fish. Therefore, we have some concerns with the accuracy of the abundances and therefore with diversity calculations for electroshocking samples. At some sites, calculated alpha diversity (e^H) was high, but S for the catch was only two species (e.g. T1-T4 glide, Table 1.7). If one only evaluated alpha Shannon diversity, it would suggest that the electroshocking resulted in very diverse samples in those habitats, but beta weighted diversity calculation indicated that the biodiversity in that reach was very homogenous.

In 2011 relative abundance of biota was much higher than in the other two years of study. We believe this is also a result of the 2011 drought. *C. lutrensis* and *P. vigilax*, the most abundant species in our seine samples, drastically increased in relative density. For example, CPUE for *C. lutrensis* in T7 run/riffle chute in 2010 was 0.790 catch/m^2 and 1.703 catch/m^2 in 2012, but in 2011 CPUE was 14.762 catch/m^2 (Table 1.3). During droughts, low water levels make smaller habitat volume, so it is likely that the increase in abundance was due to fish being more confined, thus easier to seine, as well as to the numerical dominance under such conditions by these generalist and tolerant species (Matthews, 1987).

DIDSON Assessment

All gear has inherent bias that is known to cause inaccurate estimates of CPUE for conventional passive and active capture, and such bias requires the application of correction factors and standardization for results (Pierce et al., 1990, Hubert, 1996, Tyson et al., 2006). The purpose and benefits of gear standardization include the ability to collect data for comparisons over time, across large regions, and to encourage data sharing to assess species for conservation (Bonar et al., 2009). Bias associated with gill nets includes size selectivity due to mesh size and composition (Hubert, 1996). In general, our experimental gill nets proved to be unsuccessful in capturing desired fish (e.g., *M. salmoides* and catfish), and electroshocking success was unpredictable in the study reach. In addition, active sampling, electroshocking and seining, may not be an accurate representation of species composition and habitat use since it's a snapshot in time and electrical currents might not be strong enough to extract fish from deeper habitats and under log piles.

DIDSON provides a standardized method to sample more effectively across all habitats and thus, reduces gear selectivity and increases overall sampling data and capture efficiency by decreasing total field-hours to capture replicate data within sites and among more sites. It can also record for hours at a time, day and night, and in any season. We had to use three different gear types to capture all of these fish and each conventional gear type missed different species. But the DIDSON was able to capture images of both large and small fish, and importantly, in habitat where they occurred together. Echoview counted fish as small as 1 cm TL and as large as 70 cm TL. In a trial study of DIDSON in a vertical-slot fishway in an Australian river researchers used trap nets but were only successful at capturing smaller-bodied fish (Baumgartner et al., 2006). In comparison, DIDSON captured images of larger fish and showed that 80% of the fish went through the trap nets. The DIDSON also can capture images of river geomorphology. For example, in our study, it captured images of underwater structures including woody debris and rubble, and sand movement in vortices that was not well interpolated from hydraulic field data collection. However, such features were obvious explanations for problems in modeling of some reaches (I. Güneralp and B. Hales, personal communications).

As for any visual method for estimating fish species and abundances, DIDSON limits the user's ability to directly identify fish species, sex, and diet, for which conventional sampling allows fish to be physically captured. With practice to optimize deployment (e.g., stability and angle of camera trajectory), imaging fish for species identification increases in quality; but it is highly recommended to net fish while simultaneously recording in order to provide reference data on species' lengths and to aid in the discrimination among species. In cases where fish are

visually indistinguishable in a recording, the optimal species identification technique would be to use fish length as a determining factor. Bruwen et al. (2007) showed that DIDSON recordings of free swimming Steelhead Trout *Oncorhynchus mykiss* and Sockeye Salmon *Oncorhynchus nerka* at distances ≤ 12 m in high frequency mode could discriminate between these two species. However, if there are overlapping lengths for different species, depending on distinctness of their behavior and shape, one can only narrow down fish targets to one or two species or to genus. Table 21 provides a summary of the strengths and weaknesses of conventional and DIDSON sampling.

DIDSON bias is generally introduced in post processing, and deployment without proper training also increases bias. There is a steep learning curve for post processing and it takes an experienced individual to review and process recordings and echograms (similar to the experience needed when working with other hydroacoustic techniques and to working with GIS software (M. Kane-Sutton, personal observations). A lack of standardization has existed for protocol used in post processing of data, but recently this has been addressed (Boswell et al., 2008). As more researchers and agencies start to use DIDSON this problem will lessen.

Major difficulties with DIDSON were related to deployment and orientation. The art of fisheries acoustics is choosing the right sonar, operating parameters, signal processing and knowing limits of error estimation to ensure reliable results (Foote, 2009). Vertical and horizontal orientation play a significant role in determining reliable abundance estimations, and in different environments and some target species require differential placement of sonar equipment. We were able to identify two large species of fish in both vertical and horizontal deployment of the DIDSON, but we could not reliably identify species less than 40 cm total

length nor accurately distinguish species of large fish without the use of supplemental gear to verify likely species in the recorded images. Vertical (as compared to horizontal) orientation of hydro-acoustic equipment during recording can underestimate fish abundance up to 20-100% (Knudsen and Sægrov, 2002), but vertical orientation identifies shape, and thus species, more accurately. Therefore, it is beneficial to use both vertical and horizontal beaming of an area. Tilt angle of the transducer and variation in river-bed morphology should be taken into consideration when preparing for deployment (Becker et al 2011). Target strength (TS) is a function of shape and orientation as well as the material properties of the target. The swim bladder is the dominant reflecting organ and its orientation to the echoes influences length measurements because it reflects differently at slightly different ranges (Simmonds and MacLennan, 2005). The tilt angle of a split-beam echosounder influenced TS in migrating Atlantic cod, *Gadus morhua* (McQuinn and Winger, 2003). This should be considered in post processing because as tilt decreases, target size increases and when target abundance is high, the received signal is further modified (Simmonds and MacLennan, 2005). Mobile deployment for cross channel beaming made it impossible for automatic counting using software. Faulkner and Maxwell (2009) provided aiming protocols for DIDSON cross channel beaming and Boswell *et al.* (2008) developed a stable stationary platform for estuarine habitats. Stationary platforms that freely allow tilt and pan are recommended for recording.

Depending on orientation and depth of a river DIDSON can also measure depth. By attaching separate equipment to the DIDSON researchers can simultaneously record velocity and GPS location, which can be used to readily generate detailed maps of river habitat.

Based on our preliminary results for our pilot study, we believe the DIDSON is a powerful fish sampling tool for fish community research and will be useful in such aquatic habitats as large rivers, reservoirs, and hydroelectric facilities in Texas to collect data on fish behavior, abundance and biomass, and to describe habitat usage by fish of multiple sizes in turbid systems where visual counting is impossible, and in complex habitats (e.g., wood debris) due to conventional size bias of gear or conditions of high conductivity. But it is not appropriate for all fish research. DIDSON has limitations as noted above. Diet analysis provides useful information on habitat use and benthic community structure. As seen with our preliminary results, fish diets reflect habitat and food availability and species distribution depends not only on habitat, but on interactions with other species (predators, competitors, prey). If the interest of a research project is food web structure, species composition (especially of small fish) and sex ratios, then DIDSON is not appropriate. It is highly recommended to net fish on recording days to obtain reference size class data. However, DIDSON provides more inclusive data and is useful (such as at night) for surveys that are logistically difficult to accomplish (Williams et al., 2003, Tiffan et al., 2005, Rand and Logerwell, 2009). Due to a steep learning curve for post processing and skill required for DIDSON's proper deployment and orientation, we suggest a specific job description is needed for an individual who is (or would become) expert in DIDSON use and analysis, as would be needed for GIS modeling. This is common practice in research labs and agencies where DIDSON is used. Such an individual would reduce time, cost, energy, and bias in studies. More sampling dates are required to quantitatively assess the relative economic cost and effectiveness of DIDSON compared to conventional methods in our study reach. As we also note above, there are technical, biological, and ecological conditions that

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must be considered as well (such as direction of deployment to get accurate measurements of total length). Therefore, researchers need to take into consideration what questions they are trying to address prior to using DIDSON technology.

Table 1.13 Strength and Weaknesses comparison

Sampling Technique	Strengths	Weaknesses
DIDSON	Inclusive data	Expensive
	Fish behavior	Species identification
	Habitat mapping	Post processing steep learning curve
	Habitat utilization	Unable to count individual fish in schools
	Measure fish lengths	Must net while recording for reference data
	Estimate fish abundance	Post processing bias
	Less invasive way of capture	
	Capture images of fish at night and in cloudy and turbid waters	Can only target species within a certain size length
	Reduces gear selectivity bias	Need standardization developed for equipment placement
	Same piece of equipment can be used in multiple ecosystems (ice, rivers, lakes, ponds, marshes) and habitats within that ecosystem	
	Easy to deploy and requires little support (i.e. people)	
	Captures images of fish that conventional sampling missed	
Conventional	Identify species	Use multiple gear in environment with multiple habitats
	Can identify and collect fish <4 cm	Difficult standardizing gear for accurate density measurements
	Diet analysis	Gear selectivity bias
	Sex determination	Can be dangerous
	Target species	Gear can be high maintenance
	Aging	Requires more effort and support
		Can be time consuming

Chapter 2 **Cost Comparison for DIDSON versus Conventional Methods**

We calculated and compared the start-up costs for equipment to perform fish

community research using a DIDSON and conventional methods (Table 3.1) and salaries for

personnel (Table 3.2). We do not include additional costs for hydraulic field equipment and

person hours. The DIDSON gear rotator and bracket can be purchased from both Sound Metric

and Remote Ocean Systems (ROS). Sound Metrics estimate includes the connecting cable for

the rotator but ROS does not. The table provides an estimated total cost if the rotator and

equipment were purchased from ROS or from Sound Metrics. Pricing for gill and seine nets are

based off of Memphis Net and Twine Company online 2012 catalog

(http://www.memphisnet.net). Electroshocking equipment estimates were based off of Root-

Smith Inc. 2012 online catalog (http://www.smith-root.com). Salary estimates were based off

of current wages paid for this pilot study, $15/h for fulltime employee and $10/h for seasonal

employee. These estimates did not include benefits. Daily field costs (e.g. gasoline and boat

usage) would be the same for both sampling methods and are not provided. However,

DIDSON would require fewer field days and field person hours compared to only using

conventional methods to capture similar data for distribution and abundance of fish.

Additional costs are associated with each method. We recommend purchasing

Echoview software for post processing of data. Echograms viewed in Echoview were higher

quality, the software was more user-friendly, had better tech support, and allowed more

control over image threshold parameters. A rough estimate for Echoview is $2,000 but cost

can vary depending on the number of modules that are required. Currently, Echoview offers a

discount to agencies and universities using their program for fisheries research. Additional

fees for conventional methods would include repurchasing of gill and seine nets, and

electroshocking equipment (batteries, wands, maintenance, etc.). DIDSON does not normally

require a great deal of maintenance unlike conventional sampling and rarely malfunctions (K.

Boswell, Florida International University, personal communication).

DIDSON does require netting fish while recording to obtain a reference sample for

areas that have overlapping fish size classes. If researchers do not currently own nets or do

not have the option to borrow equipment, they would have to be purchased. We recommend

purchasing two seines and gill nets for lakes and reservoirs and shocking equipment (battery

and wand) for rivers (see Table 2.1 for prices on conventional equipment). Ocean Marine

Industries, Inc. provides the option of renting DIDSON. For our pilot study we rented DIDSON

for $650 per day (price may increase) plus shipping and insurance fees. If researchers and

government agencies want to use DIDSON for a five day working week the total cost would be

$3250. To gather sufficient information for data processing for one site, we recommend at

least one week of recording; therefore, it is advised to purchase DIDSON if agencies desire to

use the camera yearly at multiple research sites

Table 2.1 Initial DIDSON and conventional equipment costs. DIDSON total cost provided is an estimate for a rotator purchased from ROS or from Sound Metrics (SM).

DIDSON		Conventional		
Item	**Cost**	**Gear Type**	**Unit Price**	**Price for 2 nets**
DIDSON 300m sonar (Includes cable, transit case, Topside Box, Lens Fluid Replacement Kit, Software)	$74,900.00	Nets — Gill (150 ft)	$2.50-$5.00/yard	$114-315
Sound Metrics Rotator (Includes Sonar Mounting Bracket, Tool Kit,v2 ft. Cable Assembly, Transit Case)	$15,500	Seine (15 ft)	$3.80-$10.50/foot	$25 - $50
Rotator (ROS)	$12,560			**Price for 2 gear types**
Rotator Bracket Attachment (ROS)	$675.00	Shocking equipment — Batteries	$274-$384	$548 - $768
Field computer and Cables	$350.00	Backpacks	$4,995-$9,527	$9990 - $19,054
External Drive (16 GB)	$30.00	**Total**		$10,677 - $20,187
Computer Field Case*	$300.00	Boat*	$62,782-$78,091	
Tripod Stand**	$630.00	**Total**		$73,459 - $98,278
2 12V Batteries, wires, and supplies **	$290.93			
Misc. Hardware (Bolts, Screws, Tools)	$100.00			
Total	$89,835.93 (ROS) or $91,800.93 (SM)			

*This price could decrease depending on the size of purchased computer and the final field assembly.

**These items have already been purchased for the pilot study and do not need to be purchased again. However, different mounting stands may be required if the DIDSON is deployed in a different environment than the Brazos River study site.

Table 2.2 Employee cost comparison for DISON vs. conventional sampling

Sampling method	No. of employees	Duration	Hourly wage	Total
Conventional	1	12 months	$15	$28,800
	2	5 months	$10	$16,000
			Total	$44,800
DIDSON	1	12 months	$15	$28,800
	1	5 months	$10	$8,000
			Total	$36,800

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