EFFECTS OF UPLAND TIMBER HARVEST AND ROAD CONSTRUCTION ON HEADWATER STREAM FISH ASSEMBLAGES IN A SOUTHEASTERN FOREST

THESIS

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EFFECTS OF UPLAND TIMBER HARVEST AND ROAD CONSTRUCTION ON
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SOUTHEASTERN FOREST

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ABSTRACT

EFFECTS OF UPLAND TIMBER HARVEST AND ROAD CONSTRUCTION ON HEADWATER STREAM FISH ASSEMBLAGES IN A SOUTHEASTERN FOREST

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August 2007

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Peason Ridge Training Area, a part of the U.S. Army at Fort Polk, Louisiana was largely cleared of timber to develop a new Digital Multipurpose Battle Area. The purpose of this study was to assess the responses of fish assemblages and stream habitats to timber removal in three headwater streams in the Kisatchie Bayou drainage. The timber was extracted following stringent management plans designed by the U.S. Army to minimize stream impacts. With one stream held as a control, timber harvest activities (i.e. clear cut, selective harvest, and road and stream crossing construction) affected about 60% of the total acreage in the other two watersheds. Among eight stream habitat parameters measured, only the proportions of gravel and cobble substrates decreased in response to construction activities. Likewise, the densities of only 3 of 26 fish species decreased in the impacted streams, although there were similar density declines for these three species in the control stream. Multivariate assessment of fish-habitat associations indicated few, if any, shifts in habitat associations related to timber removal. Lack of major changes within these fish assemblages and stream habitat characteristics were attributed to adequate planning prior to timber abstraction, and to a natural resiliency of southeastern fish assemblages to environmental perturbations.

I. INTRODUCTION

The southeastern United States is sometimes referred to as a piscine rainforest, or an ichthyological cornucopia, because of the richness of freshwater fish taxa in this region (Lee et al. 1980, McAllister et al. 1986, Warren and Pardew 1998). The taxonomic diversity of freshwater fishes in Louisiana alone is extraordinary, with at least 148 species listed (Douglas 1974). However, declining numbers of native fishes in this region can be attributed to ongoing habitat degradation. Currently, 28% of the native freshwater fishes in the southern U.S. are considered to be vulnerable, threatened, endangered, or even extinct (Lydeard and Mayden 1994, Warren et al. 2000).

The biotic integrity in aquatic communities is predominantly reliant upon the maintenance of a suite of chemical, physical, and biotic factors (Karr 1981, Matthews and Robison 1998), as well as regional disturbance regimes (Reice et al. 1990). Maintenance of the chemical and physical factors are, in turn, strongly influenced by climate and drainage-basin characteristics such as geology, topography, and hydrology (Allan and Johnson 1997, Scott et al. 2002). These aquatic systems also are impacted by anthropogenic factors such as land use, agricultural, timber harvest, and water management practices (Schlosser 1991).

Habitat alteration is a major concern, since stream habitat is correlated with fish species diversity and overall heterogeneity of aquatic communities (Gorman and Karr 1978). Fish assemblages are altered by both high-intensity and low intensity disturbances (Ross and Baker 1983, Weaver and Garman 1994). Previous studies indicate that fish assemblages can be negatively impacted by timber removal and associated construction activities (i.e., road construction and stream crossings). Such activities can disrupt the essential lotic processes of forested upland streams by altering the chemical and physical parameters required by aquatic communities (Rutherford et al. 1992, Angermeier et al. 2004).

Parameters reported to have been altered by timber harvest activities in the watersheds of upland streams include; increased water temperatures (McLean 1992, Davies and Nelson 1994), reduced dissolved oxygen (Ensign and Mallin 2001), increased sediment loading (Lockaby et al. 1997, Williams et al. 2007), reduced depths (McLean 1992, Hartman et al. 1994), and increased intensity of algal blooms (Ensign and Mallin 2001). Woody debris input is also usually altered (Dolloff and Warren 2003, Gregory et al. 2003). This can happen through a reduction in naturally fallen timber which, in turn, reduces sediment retention (Campbell and Doeg 1989), and also an increase in the amount of smaller woody debris, which can lead to undesirable changes as well (Monzyk 1994, Hart 2002).

In addition to direct effects of timber loss, roads constructed for equipment and timber transport can increase erosion and sediment loading into streams. Concrete or metal culverts can also fragment habitat continuity by trapping large woody debris and by accelerating in-channel current velocities (Wellman et al. 2000, Angermeier et al. 2004, Gibson et al. 2005). Ecosystem processes such as fish and wildlife migration, sediment transport, natural hydrology, the movement of woody debris, and the formation of undercut banks are all important in maintaining stable aquatic ecosystems.

The impacts of timber removal on aquatic biota include:

- *Reduced coarse particulate organic material (CPOM)* - This negatively impacts filter-feeding macroinvertebrate taxa (Campbell and Doeg 1989, Rabeni and Smale 1995).
- *Increased turbidity* - This blocks light and reduces in-stream primary productivity (Wood and Armitage 1997, Kedzierski and Smock 2001, Sutherland et al. 2002).
- *Impaired reproduction* – This is especially true for lithophilic spawners, due to changes in instream gravel and cobble substrates. This either reduces the amount of spawning substrate, or restricts availability of oxygen to newly deposited eggs or benthic larvae (Binkley and Brown 1993).
- *Increased insolation* - Fish and macroinvertebrate taxa are also affected when insolation to a stream is increased following the removal of the riparian canopy. This raises water temperatures and reduces dissolved oxygen (Coon 1987, Matthews 1987).
- *Increased vulnerability to predation* - The loss of woody debris as refugia (Drury and Kelso 2000) increases vulnerability of some species to predation.
- *Habitat fragmentation* –As habitat fragmentation increases, diversity and genetic variability are reduced in the fragments because of reduced gene flow between isolated populations (Angermeier et al. 1997, Warren et al. 1997).

The general purpose of this study was to assess impacts of clear-cut timber harvesting on stream habitat characteristics and fish assemblage structure within headwater streams of a southeastern forest. This assessment spans three years of pre-construction and during-construction activities. Ideally, this study would incorporate post-construction monitoring of stream habitat and fish assemblages; however, funding for post-construction monitoring was not made available. Specific objectives of the study were to assess the effects of timber removal on:

1. physical habitat characteristics [i.e., stream depth, current velocity, substrate, large woody debris (LWD), undercut banks (UCB)],
2. water quality indicators (i.e., temperature, dissolved oxygen, turbidity, conductivity, and pH),
3. indicators of the biotic integrity of fish assemblages (relative abundance and population density), and
4. indicators of fish-habitat association during pre-construction and construction phases on three streams.

II. MATERIALS AND METHODS

Study Area

The study area lies within the Gulf coastal plain province, one of five physiographic provinces in the western Mississippi drainage and within the lower Red River drainage basin, one of eighteen drainage basins comprising the western Mississippi Basin (Cross et al. 1986). Headwater streams in the coastal plain converge to form Kisatchie Bayou, which is classified as a Natural and Scenic River, and is also a tributary of the Red River. Several of the headwater streams originate on Peason Ridge (Vernon, Sabine and Natchitoches parishes), which is part of a noncontiguous U.S. Army training area located north of Fort Polk and consists of 13,360 hectares of U.S. Army lands and 190 hectares of USDA Forest Service lands. Peason Ridge is designated as a Wildlife Management Area (WMA) as well as a training area for the U.S. Army, managed for multi-use purposes in conjunction with the U.S. Army and the Louisiana Department of Wildlife and Fisheries. The U.S. Army has implemented force transformation and mission capability enhancements at Fort Polk with respect to facilities, constructing a range complex to facilitate combined arms training as a part of the Digital Multipurpose Battle Area Course (DMPBAC). Construction activities include: access to, and actual timber clear cutting and thinning for new firing ranges and new road construction and improvements of existing roadways, including stream crossings, and modernization of existing firing ranges and battle grounds including mock village training areas. The construction area lies within the upper elevations of the ridge and potentially affects the drainages of several headwater streams and ultimately Kisatchie Bayou.

Topography and flora of Peason Ridge Training Area (PRTA) consists of moderate to high rolling hills scattered with creeks and stands of upland pine forests interspersed with various hardwoods (Louisiana Department of Wildlife and Fisheries 2006). The pine forests within this region are secondary and in some cases, tertiary growth, while the rest of the timber predominantly comprises fire climax communities (Williams et al. 2007).

The study site consisted of Odom, Tiger, and Little Sandy Creeks, all low order streams flowing northeasterly, originating in Natchitoches Parish (Appendix 1.1). These three creeks capture overland runoff and seepage from the northern scarp of Peason Ridge. Unlike the streams that make up the headwaters of the Calcasieu and Sabine drainages within PRTA, these tributaries are characterized by a higher gradient and are predominately shallow, moderately-flowing runs with sandy substrate (Williams et al. 2003). Fish composition includes species from the families: Petromyzontidae, Ictaluridae, Cyprinidae, Catostomidae, Esocidae, Fundulidae, Poeciliidae, Centrarchidae, Aphredoderidae and Percidae (Hancock 1951, Williams et al. 2003).

Two of these streams, Odom Creek and Tiger Creek, are located in the area of timber clearing and thinning, and construction of new roads and stream crossings. The third stream, Little Sandy Creek, which is located to the north of the construction area, was not impacted. This creek was used as the control reference stream. Tiger Creek is a short tributary that runs into Odom Creek which, in turn, flows into Little Sandy Creek, outside of PRTA study area (Appendix 1.2).

Timber clearing began on March 1, 2004 and ended on April 29, 2005. Thinning began on March 1, 2004 and continued until October 24, 2005.

Sampling Methods and Analyses

Mesohabitats (e.g., runs, riffles, pools, and backwaters) were sampled seasonally from a 100 to 200 m stretch of each stream from January 2003 through August 2005. On one occasion in the fall of 2004, Little Sandy Creek was closed because of training exercises.

At each site, seines, electro-shocker, and kick nets were used to collect fish species from all habitat types. Electro-shocking was accomplished by single-pass depletion techniques using a Smith-Root Model 12-B POW backpack electro-shocker (Vancouver, WA) and seines, using pre-positioned block nets for escape prevention. Stunned fish were then collected with dip nets. All fish collected at a specific mesohabitat were placed in a bucket designated for that site.

Collected fish were identified to species, counted, measured to total length (up to 30 per species), and then released, except for a few fish that were kept for voucher specimens. The latter were anesthetized using a lethal dose of tricaine methanesulfonate (trade name MS-222) in a concentration of 80 mg/l and preserved in 10% buffered formalin.

Physical habitat characteristics recorded for each mesohabitat type included thalweg length (m), width (m), at least three depth and current velocity measurements (Marsh-McBirney Model 2000 Flo-Mate, Frederick, Maryland), and percent total mesohabitat area covered by large woody debris (LWD). LWD included root wads, trunk fragments, limbs, and other intact organic pieces of related timber. The area covered by LWD was determined by (1) multiplying length by the width for each LWD, (2) summing these products across the mesohabitat, and (3) dividing the sum by the total mesohabitat area X 100%. Study streams lacked gauging stations to monitor flow regimes; instead, temporal patterns in flow were estimated from local precipitation records obtained from National Climatic Data Center of the National Oceanic and Atmospheric Administration (NOAA) for Leesville, LA. Degree of incision of the channel was determined by measuring the combined length of bank on both sides that was undercut, and then dividing by 2X thalweg length X 100%. Substrate was categorized as clay (<0.06 mm); sand (0.06 mm-2.00 mm); gravel (2 mm-64 mm); or cobble (64 mm-250 mm). Bedrock was defined as solid slab of compacted material > 4 m in length. Bedrock was usually hard-pan clay as dictated by regional geology.

Water quality parameters recorded for each mesohabitat type were collected using a YSI Series 6, Model 650 multiprobe meter (Yellow Springs, Ohio) and included temperature (°C), dissolved oxygen (mg/L), conductivity (μ*S*/cm), pH, and turbidity (NTU).

To assess spatial and temporal patterns in the fish assemblage and analyze variation between sampling sites and across years, relative abundance, density, taxa richness (*S*), diversity (*H*), and evenness (*E)* were analyzed by creek, site, seasons and years. Species densities were calculated to make inferences on CPUE and graphed by mesohabitat within creeks to show overall trends (stability, increase or decease) in population numbers before and during construction. Species turnover (β-diversity) was observed by using a one way analysis of similarity (ANOSIM) within streams and between phases of construction (Primer 6, Clarke and Gorley 2001). Simpson's Diversity Index, where $D=\sum(n/N)^2$ was used to compare changes of diversity between streams. For evenness, Shannon's Evenness Index, $E_H = H/H_{max},$ where $H_{max} = lnS$ was utilized to analyze changes within streams (Krebs 1989). Analysis of variance (ANOVA) was applied to differentiate species diversity, richness and evenness between sites and across years. Large woody debris (LWD) and undercut bank (UCB) were compared by streams and over years.

Multivariate analyses were used to assess correlations between in habitat variables among creeks (Principal Component Analysis; PCA) and between fish assemblages and habitat variables (Canonical correspondence Analysis; CCA), using CANOCO (Version 4.5; ter Braak and Smilauer 2002). Sampling scores for PC axis I, II, and III were compared among years using analysis of variance, to test for differences in habitat characteristics through time. To attenuate effects of predominant taxa in CCA, abundances were $\log_{10}$ (N+1) transformed with rare taxa down-weighted. Variables showing diel fluctuations (e.g., temperature, dissolved oxygen, conductivity, and pH) were deleted from multivariate analyses. Significance for all three was assessed with a Monte Carlo randomization method using 1,000 permutations for each (ter Braak and Smilauer 2002).

III. RESULTS

Little Sandy Creek, Tiger Creek and Odom Creek are spring-fed headwater streams with mean widths (±SD) ranging from 2.6 (±0.1) to 4.0 (±0.2) m, mean depths ranging 0.23 (±0.04) to 0.27 (±0.02) m, and mean current velocity ranging from 0.15 (±0.05) to 0.13 (±0.04) m/s (Appendix 1.3). Substrate was primarily sand (up to 100% in Odom Creek), followed by cobble, gravel, and bedrock. Main channel was well-defined by high (>2 m) banks and consisted of <13% undercut banks and small amounts of large woody debris (<10%). Water quality measurements taken at time of fish collections indicated that streams were well oxygenated 8.5 (±0.6) mg/L, had low conductivity (<100 uS/cm), generally slightly acidic (range: 6.2 to 7.3), and mid-day temperatures ranging from a mean of 8.6°C during the Winter to 31.3°C during the summer (Appendix 1.4).

The first three PCA axes explained 52% of the total variation in abiotic factors measured from each mesohabitat at each creek on each date. Principal component axis I explained 27% of the total variation and described a coarse substrate to fine substrate gradient (Appendix 1.5). Principal component axis II explained 13% of the total variation and described an additional substrate gradient. Principal component axis III explained 12% of the total variation and described undercut bank, large woody debris, and current velocity gradient.

Mesohabitats with highest negative loadings on PC axis I were riffles with shallow substrates, swift current velocities, and gravel or cobble substrates. Mesohabitats with highest positive loadings on PC axis I were pools and deep runs with greater mean depths, slower current velocities, and predominately sand substrates. Mesohabitats with highest positive loadings on PC axis II were backwater areas with predominately silt substrate or riffles with bedrock substrate. Mesohabitats with highest negative loadings on PC axis III were pool and deep runs with higher percentages of large woody debris. Mesohabitats with highest positive loadings on PC axis III were shallow and swift flowing runs and riffles with higher percentages of undercut banks. Based on graphical representation of the PCA plots, multivariate breadth and variability in abiotic factors generally were similar among creeks along PC axis I, differed along PC axis II because of bedrock riffle habitats at Little Sandy Creek, and differed along axis III with Tiger Creek and Little Sandy Creek showing greater variability in the amount of undercut banks and large woody debris.

Multivariate breadth and variability in abiotic factors did not differ among years (i.e., phases of construction) on PC axis I ($F_{2,57}$= 0.73; P= 0.48), PC axis II ($F_{2,57}$= 0.03; P= 0.97), or PC axis III ($F_{2,57}$= 0.53; P= 0.59) for Little Sandy Creek. Tiger Creek was PC axis I ($F_{2,86}$= 0.05; P= 0.96), PC axis II ($F_{2,86}$= 0.74; P= 0.48), and PC axis III ($F_{2,86}$= 1.43; P= 0.24). Odom Creek was PC axis I ($F_{2,37}$= 1.72; P= 0.19), PC axis II ($F_{2,37}$= 0.02; P= 0.98), and PC axis III ($F_{2,37}$= 0.03; P= 0.97). Little Sandy Creek, the control stream, generally had higher variability along PC axis III, whereas riffle habitats were lost, or more specifically covered with sand, in Odom Creek, hence the shift towards positive loadings in 2005.

Using univariate analyses to test specifically for changes in the amount of undercut banks and large woody debris, percentage of undercut banks did not differ ($F_{2,28}$

= 3.6, *P* = 0.0411) and percentage of large woody debris did not differ ($F_{2,27}$ = 8.9, *P* = 0.0125) between phases of construction. Instead, amount of undercut banks generally was inversely related with precipitation events, becoming less after large precipitation events (Fall 2004) in both the control and impacted streams (Appendix 1.6). Although not statistically tested using univariate procedures, water quality parameters and substrate types did not vary substantially between pre- and during construction phases (Appendix 1.4).

A total of 3,335 fish, consisting of 24 species and 9 families was collected among 11 quarterly sampling events from January 2003 to August 2005 (Appendix 1.7). Most abundant families were Cyprinidae (43% in relative abundance), followed by Fundulidae (26%), Ictaluridae (12%), Percidae (7%), Centrarchidae (6%) and Petromyzontidae (5%). Most abundant species were *Fundulus olivaceus* (26%), *Luxilus chrysocephalus* (22%), *Noturus phaeus* (10%), *Lythrurus umbratilis* (6%), *Etheostoma artesiae* (6%), *Notropis atrocaudalis* (5%), and *Ichtyomyzon gagei* (5%).

Nineteen species were common among all three creeks; two species were unique to only one creek and five unique to two creeks. Among sampling events, mean diversity was highest for Little Sandy Creek (Shannon Index of Diversity = 2.12), followed by Tiger Creek (1.90) and Odom Creek (1.86).

Fish assemblages did not differ between pre-construction and during construction phases in the impacted streams but did differ in the control stream. Pre-construction fish assemblage was 35% similar (Global R = 0.07; *P* = 0.02) to during construction phase in Little Sandy Creek, 38% similar (Global R = -0.006; *P* = 0.57) to during construction phase in Tiger Creek, 44% similar (Global R = 0.008; *P* = 0.36) to during construction phase in Odom Creek. Although fish assemblages were similar between phases of construction within the impacted streams, a few notable changes were observed in species densities, all of which are species of conservation concern.

Notropis sabinae densities (number per 100 m^2) decreased by 93% in Little Sandy Creek and by 41% in Odom Creek. *Etheostoma artesiae* densities decreased by 30% in Little Sandy Creek, by 36% in Tiger Creek, and by 38% in Odom Creek. *Notropis atrocaudalis* densities decreased by 70% in Little Sandy Creek. *Noturus phaeus* densities decreased by 8% in Tiger Creek.

Differences in habitat associations were noted for several fishes in Tiger Creek and Odom Creek between pre- and during construction phases. The first two axes of the CCA model with species abundance split between phases of construction explained 69% of the species-environment relation and described a current velocity and depth gradient (CCA axis I) and substrate gradient (CCA axis II).

Sample scores that were positive on CCA axis I generally had higher current velocities, shallow depths and sand, gravel, or cobble substrates whereas sample scores that were negative on CCA axis I generally had lower current velocities, greater depths and sand or silt substrates. Sample scores that were positive on CCA axis II generally had gravel and cobble substrates or silt substrates whereas sample scores that were negative on CCA axis II generally had sand substrates (Appendix 1.8).

Across phases of construction, *Ichthyomyzon gagei*, *Notropis sabinae*, *Noturus phaeus*, and *Etheostoma artesiae* were positively associated with CCA axis I. *Luxilus chrysocephalus*, *Notropis atrocaudalis*, *Lythrurus umbratilis*, *Semotilus atromaculatus*, *Fundulus olivaceous*, and *Lepomis cyanellus* were negatively associated with CCA axis I.

Between phases of construction, *Notropis sabinae* and *Cyprinella venusta* shifted towards swifter current velocities whereas *Luxilus chrysocephalus*, *Notropis atrocaudalis*, *Lythrurus umbratilis*, and *Fundulus olivaceous* shifted towards slower current velocities. However, stream discharge (as indicated by local precipitation records) was higher in the during construction phase, which provide habitats with swifter current velocities and greater depths and likely explains shifts in habitat associations rather than construction effects.

IV. DISCUSSION

Despite substantial alteration of the upland vegetation community and the addition of numerous roads and stream crossings, stream habitats and fish assemblages were minimally impacted in Tiger Creek and Odom Creek. Stream habitat characteristics, as assessed here by multivariate and univariate methods, were similar between pre- and during construction phases and displayed similar temporal variability as the control stream (Little Sandy Creek), except in Odom Creek where gravel and cobble substrates were buried by sand substrate.

Fish assemblages generally remained intact in the impacted creeks except for the decline of gravel and cobble substrate specialists *E. artesiae*; (this study, Chipps et al. 1994, Williams et al. 2004) in Odom Creek and Tiger Creek, a cyprinid often associated with shallow and slow flowing runs and riffles *N. sabinae*; (Williams and Bonner 2005) in Odom Creek, and a species often associated with undercut banks *N. phaeus*; (Chan and Parsons 2000) in Tiger Creek. However, only density decline of *E. artesiae* in Odom Creek can be attributed to immediate impacts of stream habitat alteration (i.e., loss of gravel and cobble substrate) during construction phase; *E. artesiae* density decline in Tiger Creek was observed without noticeable changes in the amount of gravel and cobble substrates as did *N. phaeus* density in Tiger Creek without noticeable changes in undercut bank habitats. *Notropis sabinae* densities decreased not only in Odom Creek but also in

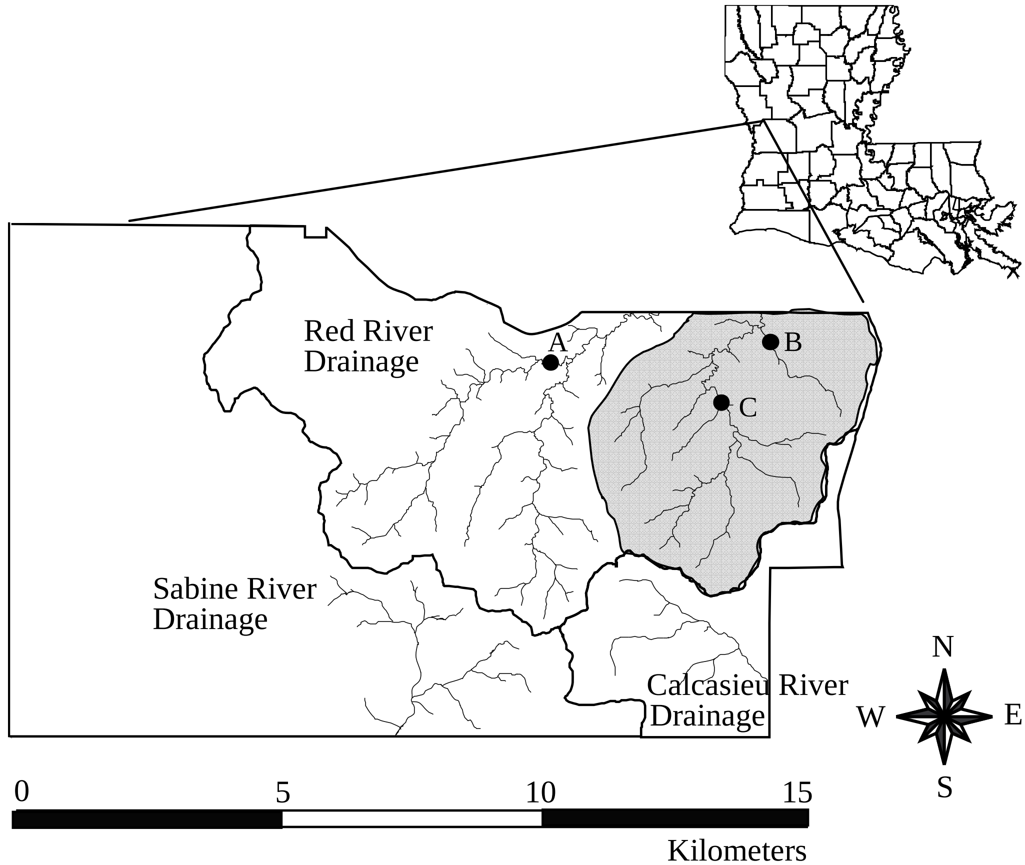
Little Sandy Creek during construction phase along with another cyprinid *N. atrocaudalis*. With density declines of *N. sabinae* in both the control and impacted creeks, impacts of the construction cannot be excluded from effecting *N. sabinae* abundance; instead, it is plausible that construction impacts extend downstream past the confluence of Odom and Little Sandy Creek thereby altering upstream *N. sabinae* movement (Williams and Bonner 2005) and upstream abundance collectively in both creeks.

Timber harvest activities generally cause substantial changes to stream habitats and fish assemblages (Rutherford et al. 1992, Angermeier et al. 2004). In the two creeks assessed in this study however, substantial alteration was not evident. Lack of substantial stream and fish assemblage alterations were attributed, in part, to extensive planning (i.e., minimize impact to riparian habitats, road and culvert design). Creeks subject to timber harvest as well as other streams within PRTA were assessed prior to harvest activities. Assemblage composition, historical fish information, and habitat associations were quantified by Williams et al. (2004). Life history information was determined for fishes found within the area (Williams 2003; L. R. Williams and 5 co-authors. 2003. A survey of fishes and macroinvertebrates inhabiting streams of Peason Ridge Wildlife Management Area. Ft. Polk, US Army, Louisiana. Submitted to US Army; Williams and Bonner 2006). Swimming speeds of fishes in the region were quantified by Leavy (2004), and the effects of culvert design on stream fish movement was assessed by Grubh (2006). In addition, long-term effects of timber harvest on stream habitat characteristics and fish assemblages were assessed in a nearby drainage that sustained similar impact as Peason Ridge WMA (Williams et al. 2007). Collectively, these studies provided compelling information to guide timber harvest activities on PRTA such as size of culverts, sedimentation fences, and limited destruction of riparian habitats.

Lack of substantial stream and fish assemblage alterations also were attributed, in part, to the innate characteristics of southeastern fishes to show high resiliency and quick recovery following natural or anthropogenic disturbances. Though fish assemblage structure is patchy and variable through time (Taylor and Warren 2001), resident fishes in low-order, headwater streams in southeastern forests tend to display high habitat plasticity, early maturing, and extended spawning seasons, all of which contribute to high resiliency under natural disturbance regimes (Reice et al., 1990; Winemiller and Rose 1992) and anthropogenic disturbances (Williams et al. 2003; Williams et al. 2007). Likewise, these fish assemblage characteristics also provide quick recovery of taxa and assemblages following massive disturbances (i.e., complete defaunation of stream reaches) by natural (i.e., flood; Matthews 1986) or manipulative means (i.e., controlled studies; Meffe and Sheldon 1990, Peterson and Bailey 1993). Consequently, natural and anthropogenic disturbances can have minimal impact on stream fish assemblages assuming stream habitats are not permanently altered, and streams are not fragmented by debris dams or road crossings (Metsker 1970, Warren and Pardew 1998, Schaefer et al. 2002).

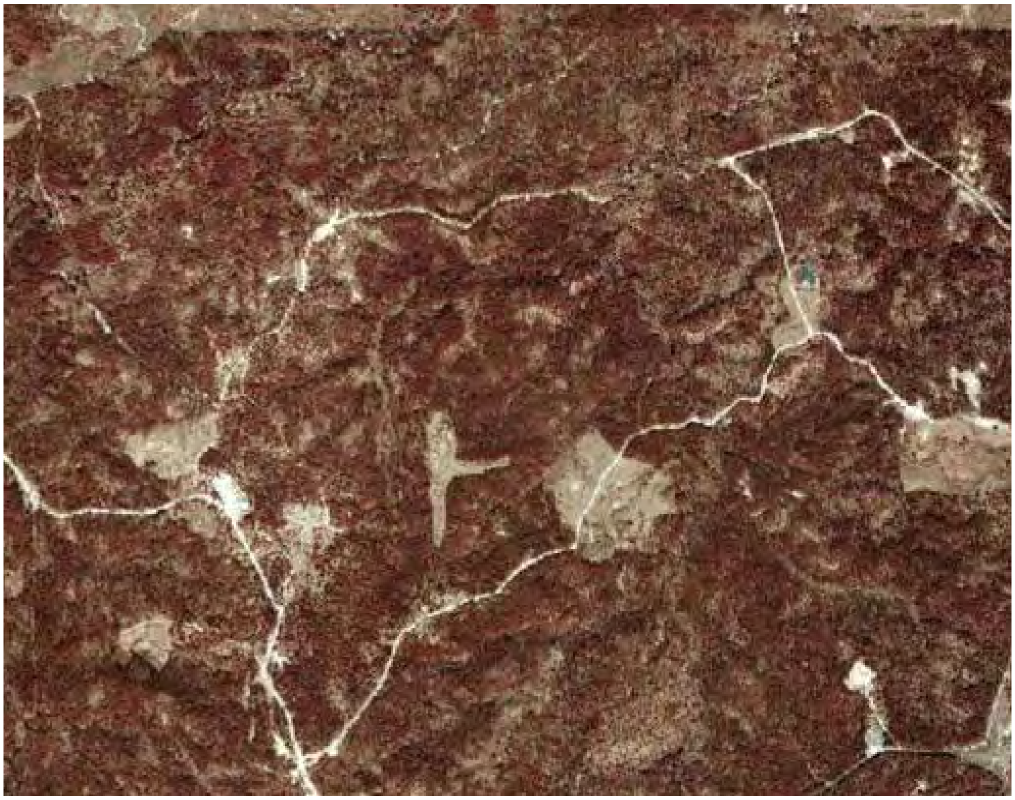
Southeastern low-order streams and along with their biotic components (i.e., aquatic insects, mussels, crustaceans, and fishes) are threatened and will continue to be threatened by timber harvesting , road construction, recreational activities, urban sprawl, low-head dams, reservoirs, and other anthropogenic activities (Lydeard and Mayden 1994, Leavy 2004, Williams et al. 2004). However, results of this study suggest that *a* *priori* understanding of stream and assemblage structuring mechanisms and proper planning to avoid disrupting described and latent structuring mechanisms can minimize anthropogenic effects on the stream community. Though feasible, protection, management, and wise use of low-order streams will not be realized until society commits to this endeavor and not just to game fishes or single species management for high profile species of conservation concern.

APPENDICES



*modified from Grubh, A.R., 2006

APPENDIX 1.1 Map of study area within the Peason Ridge Wildlife Management Area at Fort Polk, Louisiana. Sampling sites located on the headwaters within the Red River drainage are – A is Little Sandy Creek, B is Tiger Creek and C is Odom Creek. Little Sandy Creek was the reference stream receiving no impacts. Shaded area indicates impacted section.



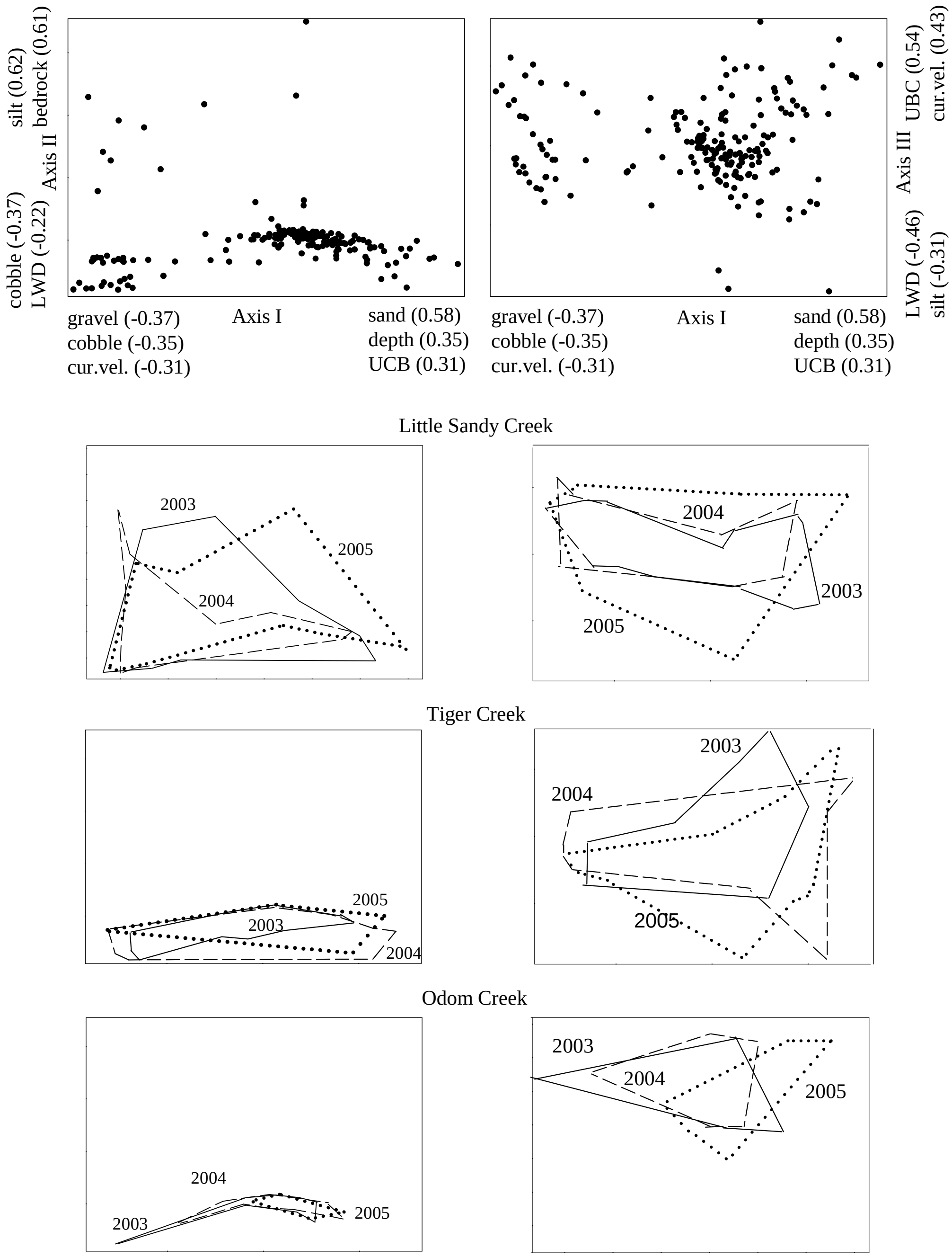
APPENDIX 1.2 US Army aerial before construction photo and Google Earth during construction screen shot showing creeks, clear cuts and stream crossings (US Army and Google Earth 2006).

APPENDIX 1.3 Sampling site description of study area with associated impacts during the year of timber harvest disturbance (2004) at Peason Ridge, Louisiana. Stream characteristics were collected during summer 2005. Modified from Grubh 2006.

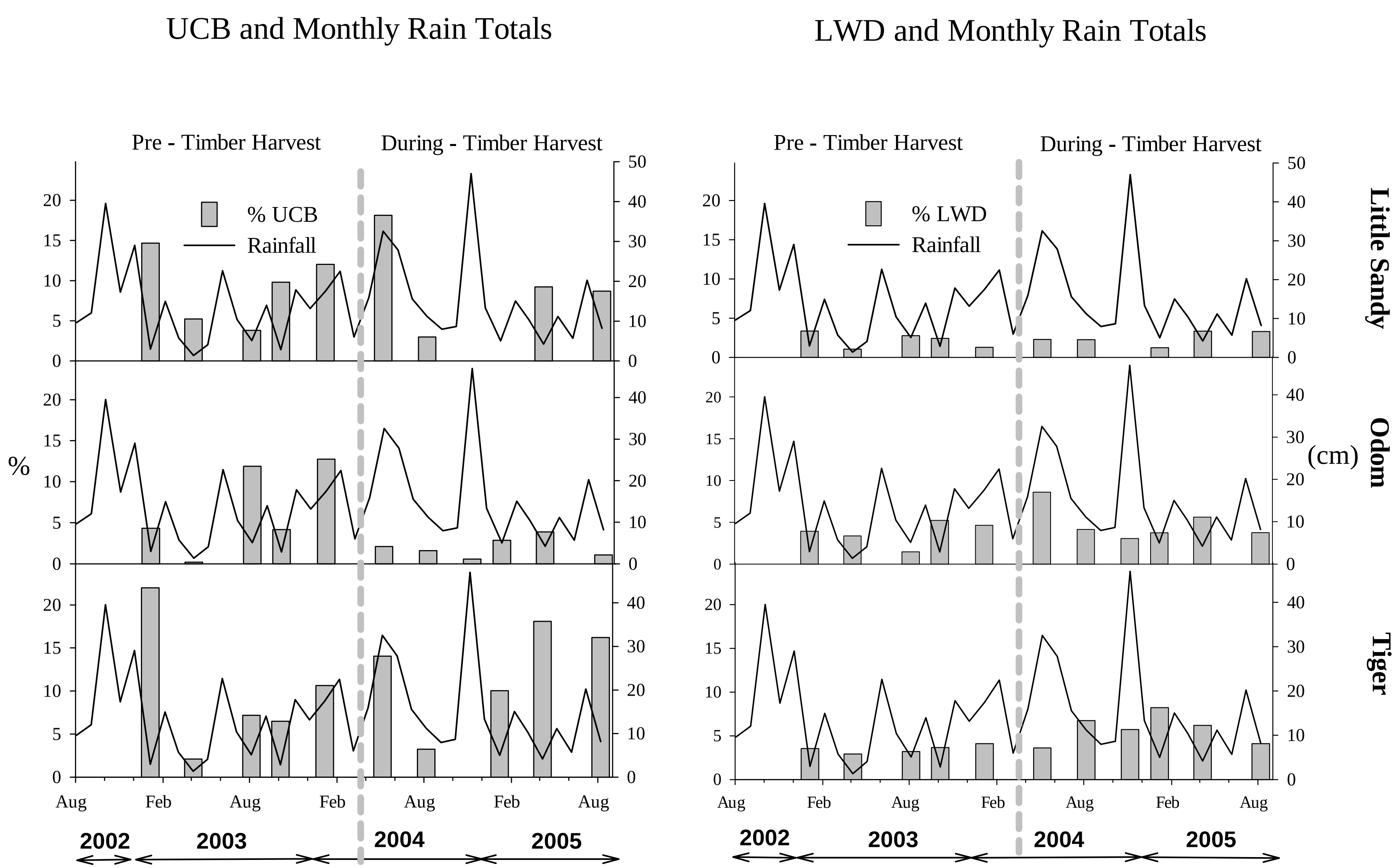
	Little Sandy	Odom	Tiger
Stream characteristics			
Floodplain width (m)	12	16	9
Bankful width (m)	10	9	5
Max. depth (m)	3.9	2.9	4.1
Mean length (m) (±SE)	30.3 (±3.9)	51.4 (±9.4)	19.5 (± 2.1)
Mean width (m) (±SE)	4.0 (±0.2)	4.1 (±0.3)	2.6 (±0.1)
Mean depth (m) (±SE)	2.7 (±0.02)	2.3 (±0.04)	2.5 (±0.02)
Percent undercut bank	7.0 (±1.1)	11.22 (±7.6)	8.3 (±3.0)
Percent large woody debris	3.6 (±2.2)	6.08 (±1.3)	7.5 (±1.9)
Disturbance extent of the streams			
Total area (hectares)	1015.9	1377.6	224.2
Clear-cut area (hectares)	*	266.8	4.8
Thinned area (hectares)	*	505.0	129.4
New roads constructed (hectares)	*	34.1	4.1
New road linear	*	10347.0	1067.0
New road area (m^2)	*	63075.3	6504.4
New road crossings constructed	*	8	2
Percent disturbed	*	58.5	61.7
Total riparian (hectares)	475.1	637.6	57.4
Riparain removed (hectares)	*	36.2	1.6
Percent riparian removed	*	5.7	2.8

APPENDIX 1.4 Mean (±SD) water quality and substrate data, collected from Red River drainage streams throughout study time. Modified from Grubh (2006).

	Little Sandy Creek			Odom Creek			Tiger Creek		
	2003	2004	2005	2003	2004	2005	2003	2004	2005
Conductivity (*µS/cm*)	116.5 (14.7)	32.2 (14.4)	67.3 (18.9)	90.0 (6.8)	38.3 (3.8)	48.0 (12.1)	107.3 (24.3)	59.5 (10.7)	50.3 (11.8)
DO (*mg/L*)	9.2 (1.0)	4.6 (2.8)	8.8 (0.3)	8.2 (0.6)	8.3 (0.6)	9.1 (0.4)	7.9 (0.5)	7.8 (0.2)	8.7 (0.6)
pH	7.2	7.6	6.3	7.0	6.2	6.3	7.4	7.6	6.7
Temperature (*ºC*)	17.7 (3.3)	26.5 (2.3)	22.1 (2.7)	18.5 (4.7)	25.2 (3.5)	21.9 (3.0)	17.2 (3.1)	18.4 (1.8)	20.6 (2.2)
Turbidity (*NTU*)	11.7 (6.0)	51.0 (7.5)	12.9 (4.9)	8.5 (4.7)	66.1 (12.5)	14.1 (6.0)	22.0 (8.4)	32.0 (3.8)	56.0 (4.0)
Clay %	*	8.6 (7.6)	*	*	*	*	*	*	*
Silt %	0.4 (0.4)	7.5 (7.3)	*	*	*	*	*	*	1.7 (1.7)
Sand %	69.4 (7.4)	40.3 (3.1)	67.9 (3.1)	96.6 (3.1)	96.9 (3.1)	100 (0.0)	84.8 (8.6)	88.2 (7.7)	82.0 (6.4)
Gravel %	1.3 (1.3)	3.6 (2.9)	5.2 (4.1)	*	*	*	8.1 (3.9)	5.6 (3.2)	15.1 (8.0)
Cobble %	18.2 (2.9)	13.2 (7.2)	16.1 (2.2)	3.4 (3.1)	3.1 (3.1)	*	7.1 (5.2)	6.3 (5.5)	1.2 (0.9)
Bedrock %	10.8 (7.9)	2.9 (2.8)	10.8 (5.7)	*	*	*	*	*	*
Undercut Bank %	6.6 (2.2)	6.2 (3.8)	8.3 (1.7)	6.1 (3.0)	7.6 (6.3)	20.0 (7.1)	6.8 (2.8)	6.4 (1.7)	11.8 (2.9)
Woody Debris %	6.1 (3.6)	2.5 (1.1)	2.2 (0.5)	5.2 (1.6)	5.6 (2.2)	7.5 (2.6)	5.4 (0.9)	9.1 (2.0)	8.0 (1.8)



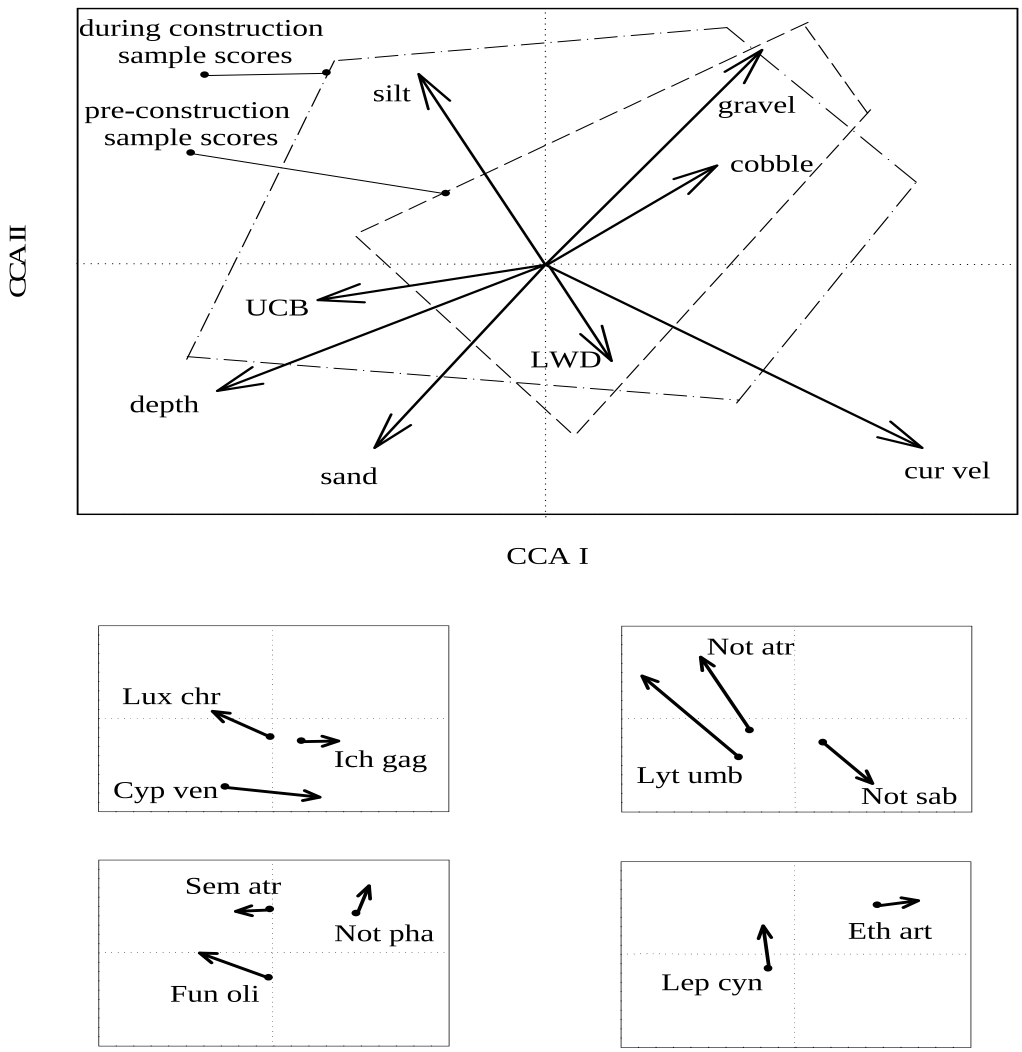
APPENDIX 1.5 Ordination plots of site scores for PC Axis I and II and PC Axis I and III showing environmental variables.



APPENDIX 1.6 Monthly rain (cm) amounts and occurrence of UCB and LWD for pre and during construction times. Rain amounts compiled from National Climatic Data Center, NOAA.

APPENDIX 1.7 Species relative abundance, richness, evenness and diversity for all creeks.

	Little Sandy Cr.			Odom Cr.			Tiger Cr.		
	2003	2004	2005	2003	2004	2005	2003	2004	2005
Icthyomyzon gagei	1	2	2	10	15	7	4	4	6
Ameiurus melas	13	.	.	.	.	.	.	.	.
Ameiurus natalis	<1	.	<1	<1	.	2	<1	.	<1
Noturus phaeus	6	17	15	10	19	15	9	9	6
Erimyzon oblongus	1	<1	<1	<1	.	.	1	1	1
Moxostoma poecilurum	.	.	.	.	.	.	.	<1	.
Cyprinella venusta	1	.	2	11	16	9	2	1	<1
Luxilus chrysocephalus	8	10	11	28	16	30	30	32	29
Lythrurus fumeus	.	.	1	.	.	.	<1	.	.
Lythrurus umbratilis	19	10	12	2	<1	.	7	7	7
Notropis atrocaudalis	13	11	4	1	1	6	3	3	5
Notropis sabinae	3	4	<1	12	5	2	.	.	.
Semotilus atromaculatus	2	4	2	2	1	3	4	5	2
Fundulus olivaceus	22	22	32	13	20	22	25	30	32
Gambusia affinis	<1	3	.	<1	.	.	.	.	.
Aphredoderus sayanus	1	1	1	.	.	.	<1	1	<1
Etheostoma artesia	11	10	8	7	2	2	4	1	2
Etheostoma chlorosomum	1	1	<1	<1	.	.	2	<1	1
Percina sciera	<1	<1	.	<1	.	.	<1	.	.
Lepomis cyanellus	2	2	3	1	2	2	3	3	3
Lepomis marginatus	4	1	.	<1	.	<1	2	1	<1
Lepomis megalotis	3	<1	3	1	.	.	<1	1	2
Lopomis miniatus	.	<1	<1	.	<1	.	2	1	<1
Lepomis sp.	1	<1	<1	<1	.	.	1	.	2
Micropterus punctulatus	<1	.	3	<1	.	<1	1	1	1
N=	589	211	520	517	209	297	431	425	364
Richness		14.4			10.27			12.91	
Shannon's Evenness		0.8			0.81			0.75	
Simpson's Diversity		0.84			0.81			0.79	



APPENDIX 1.8. Ordination (CCA) of habitat parameters, samples, and fishes in Tiger Creek and Odom Creek. Top figure with pre-construction and during construction samples scores outlined by different lines. Sub-plots illustrating fish multivariate habitat trajectories between pre-construction and during construction phases. Length of arrow indicates magnitude of habitat association shifts. Species <30 individuals in the two creeks were deleted from the CCA model. Species names are abbreviated with the first three letters of the specific epithet.

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