A COMPARATIVE ANALYSIS OF PLANT SPECIES DISTRIBUTION AND GROWTH RESPONSE TO EDAPHIC FEATURES BETWEEN THE SAN SABA RIVER AND A TRIBUTARY

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ABSTRACT

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Riparian corridors are often a mosaic of vegetative communities that serve as interfaces between terrestrial and aquatic systems and, consequently, span multiple environmental gradients. As such, an interesting question is whether the interconnection of streams and tributaries within a drainage basin facilitates homogeneous community structure and development, or if these systems host distinctly different floras as a result of differing physiognomy and disturbance cycles. In relation to the size of the state, relatively few comprehensive qualitative or quantitative surveys of natural plant

resources within managed areas of Texas have been conducted. As a result, quantitative data on vegetation are insufficient to support fine scale plant community classification for most of the natural regions in Texas. The objectives of this research were to 1) conduct a comprehensive floristic survey of the study site to identify, collect, and preserve specimens of each plant species located on-site and 2) conduct a comparative analysis to evaluate patterns of plant species richness and distribution in relation to edaphic characteristics between three riparian communities with different hydrologic regimes. Results show that, although multiple factors influence a particular ecological dynamic, only certain factors have a greater degree of importance in the development of plant communities. The most important factor in plant species distribution and richness at the study site appears to be moisture availability, with secondary effects of nutrient availability from flood deposits, as well as physical impacts from flood disturbance.

CHAPTER I

INTRODUCTION

Riparian corridors have long been recognized for their immense contribution to local and regional biodiversity, as well as their functional role in complex environmental processes. These corridors are often a mosaic of vegetative communities that serve as interfaces between terrestrial and aquatic systems and consequently span multiple environmental gradients (Naiman et al., 1993). It has even been suggested that riparian corridor communities may be useful indicators of the ecological health of both the upland and aquatic environment (Holland et al., 1991).

It is commonly understood that stream systems and their associated riparian corridor communities are reliable vectors for the transport and dispersal of plant species across local and regional landscapes (Goodson et al., 2001). As such, an interesting concept is whether the interconnection of streams and tributaries within a drainage basin facilitates sympatric community structure and development, or if these systems host distinctly different floras as a result of differing channel morphology, hydraulic regime, substrate composition, and intensity of disturbance, among other factors (Nilsson et al., 1994). Numerous models have been proposed to account for local and regional differences in river systems. Huston (1980, 1994) has indicated that species richness and distribution are largely a result of ecological disturbance paired with environmental gradients of productivity due to resource availability. Theoretically, one would expect to

see an negative, positive, or unimodal relationship between species richness and biomass as you move along a moisture availability/resource gradient, depending upon which part of the gradient is examined and the nature of the disturbance regime for the gradient (Tilman, 1984; Waide et al., 1999).

In order to understand the mechanisms controlling species richness and distribution we need to evaluate the parameters that directly impact plant growth (Pausas and Austin, 2001). Because plant community distribution, diversity, and total biomass can be highly dependent on the overall productivity, level of disturbance, and physiography of a particular area, by assessing the change in plant community development across a defined gradient one can begin to differentiate the dependence of growth characteristics on particular environmental factors (Huston, 1979).

According to Diamond et al. (1987), variation in climate and geology throughout Texas results in a wide variety of landforms, soils, and vegetation. The State of Texas can be divided into 11 natural regions, as described by the LBJ School of Public Affairs (1978), based upon distinguishing physiographic and biological features. Within these natural regions, 78 late seral stage plant communities have been described, referred to as "series" and characterized by their relative dominance of species or genera (Diamond et al., 1987). In relation to total land area, relatively few comprehensive qualitative or quantitative surveys of natural plant resources within managed areas of Texas exist. As a result, there are insufficient quantitative data on vegetation composition to properly provide fine scale plant community classification for most of the natural regions in Texas.

The study site is located within the Llano Uplift natural region, which has been considered by some authors (e.g., Gould, 1975; Griffith et al., 2004) a sub-region of the

larger Edwards Plateau natural region. The Llano Uplift, also known as the Central Mineral Region, is located near the center of the state and is almost completely surrounded by the Edwards Plateau. Elevations range from approximately 251 meters above mean sea level (amsl) to 686 meters amsl and rainfall ranges from approximately 71 to 81 centimeters annually (LBJ School of Public Affairs, 1978). As opposed to the Cretaceous limestones of the surrounding Edwards Plateau, the primary underlying geologic formations of the Llano Uplift are Precambrian igneous and metamorphic rocks, many of which are granitic (Sandlin, 1980). As a result of the mineralogy of these formations and atmospheric weathering, soils within this region are often much deeper than those of the neighboring Edwards Plateau. Additionally, granitic coarse-grained sandy soils tend to predominate in the Llano Uplift, as opposed to finer-grained clays and clay loams (SSDS, 1982).

Little floristic research and quantitative data collection have been conducted within the Llano Uplift natural region. With livestock and cropland agricultural practices constituting the primary industry in rural regions of central Texas, much of the vegetative landscape of this region has been altered by grazing, fire suppression, development, and crop conversion, leaving few natural and undisturbed vegetative communities for historical comparison. Although the riparian communities at the research site have likely been impacted over time by these same forces, historical aerial photography indicates that these communities have seen little to no unnatural disturbance, aside from recent and minor livestock grazing, since approximately 1948. Comprising mature, unimproved forest and woodland communities, the study site is a valuable resource for ecological

study, which will contribute to a better understanding of the role of environmental variables on riparian plant distribution and growth response in central Texas.

The objectives of this research are to 1) conduct a comprehensive floristic survey of the study site to identify, collect, and preserve specimens of each plant species located on-site and 2) conduct a comparative analysis to evaluate patterns of plant species richness and distribution in relation to edaphic characteristics between two riparian communities with distinctly different hydrologic regimes. The resulting goals are to better understand differing species richness and community structure patterns between two distinct riparian zones by establishing baseline floristic survey information and determining floristic spatial occurrence and abundance in relation to edaphic features within the riparian corridors.

CHAPTER II

MATERIALS AND METHODS

Study Area

The study area occurs within the northeast portion of the Llano Uplift natural region (Figure 1) and comprises approximately one and one-half kilometer of San Saba River frontage approximately six and one-half kilometers northeast of the town of San Saba, San Saba County, Texas (Figure 2).

Historical land use within San Saba County consists of traditional livestock grazing, including cattle, sheep, and goats within drier, non-irrigated uplands, while agricultural crops such as wheat, oat, and pecan predominate in irrigated fields or bottomlands. As a result, many natural grassland and riparian communities have been significantly altered or removed to accommodate more efficient agricultural practices, often introducing non-native plant species and reducing natural diversity.

Figure 1. Natural regions of Texas.

The study site consists of two discontinuous blocks of mature riparian forest corridors with distinctly different degrees of canopy and sub-stratum development, as well as differing species composition, topography, hydrology, and flood disturbance regimes. One forest corridor occurs along a perennial waterway, the San Saba River, while the other occurs along an intermittent tributary to the San Saba River. In total, these two corridors encompass approximately 14.56 hectares. Historical aerial photographs of the study area dating back to 1948 indicate that the riparian community along the San Saba River once occupied a slightly greater extent into the adjacent agricultural field.

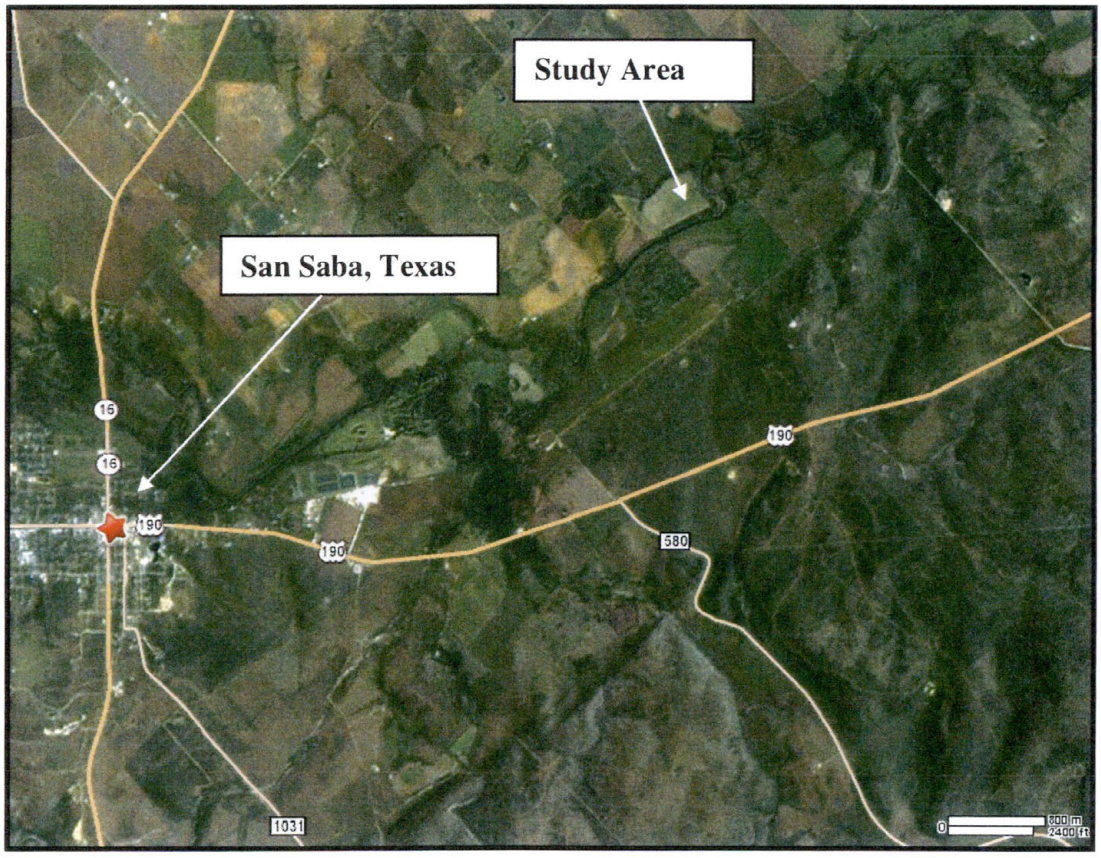


Figure 2. Study area vicinity map.

The two discontinuous blocks of mature riparian forest corridors were differentiated into three vegetation sampling communities (Figure 3). Riparian community C-1 trends southwest/northeast along the San Saba River and is restricted to a narrow band along a steep, southeast-facing embankment. The topography of C-1 is rather abrupt and narrow, with the horizontal distance from the river margin to the top of the bankfull, or incised river channel, (extent of the riparian community) rarely exceeding approximately 50 meters. The steep incision of this portion of stream bank and lack of rafted debris indicates a less frequent flood cycle within this riparian community.

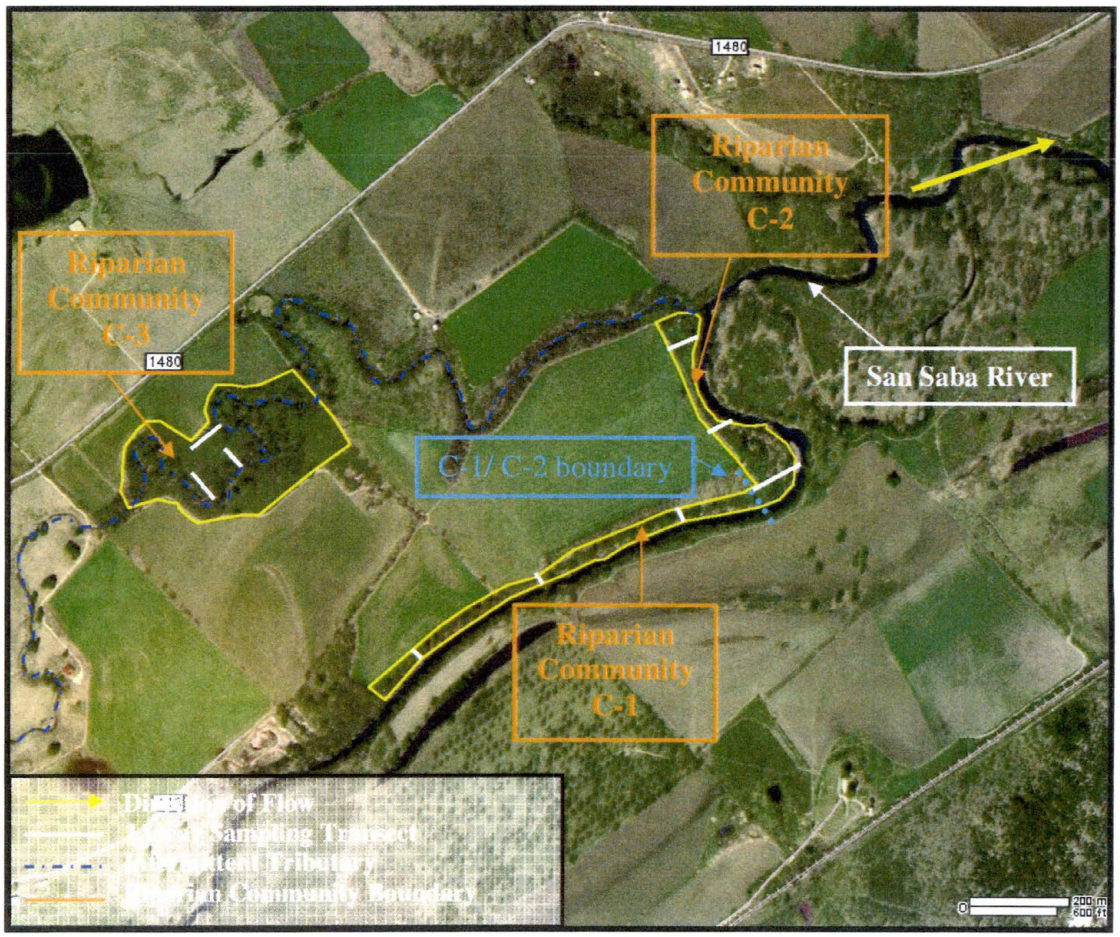


Figure 3. Aerial photograph of study area illustrating the three different riparian community boundaries and vegetation sampling transect locations.

Riparian community C-2 trends northwest/southeast along the San Saba River at the easternmost portion of the study site. The topography of C-2 is typically a long, gradual plain trending to the northeast with the occasional tall vertical bank (Figure 4). As evident by streambed scour and rafted debris, which delineate the high water mark, this area is frequently flooded. A distinct, linear upland boundary of communities C-1 and C-2 along the adjacent agricultural field perhaps suggests that these communities once exhibited a greater upland spatial extent.

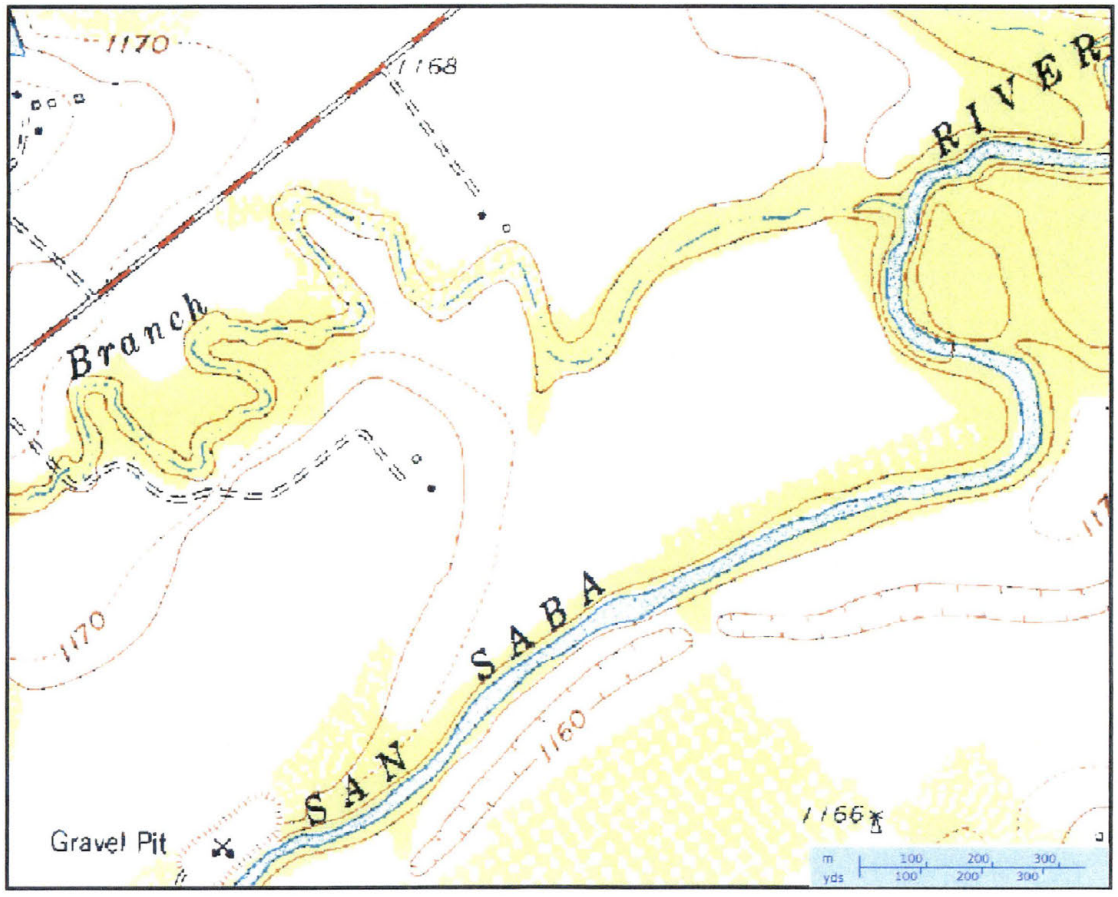


Figure 4. Topographic map of the study area along the San Saba River and a nearby intermittent tributary.

The third community (C-3) is located along an intermittent tributary to the San Saba River approximately 800 meters north/northwest of the main channel within an upland environment. The difference in elevation between this community and the San Saba River is approximately 10 to 15 meters. The topography is relatively flat and the intermittent stream has formed a deeply incised channel. Rafted debris within the surrounding vegetation suggests that the flood frequency is low, but potentially very intense.

The study area is characterized by moderately deep, fine and coarse-grained alluvial soils. Two distinct soil series occur within the study site; the Frio silty clay loam series (Fr) and Frio soils series (Fs) (SSDS, 1982). The Frio silty clay loam series is described as a well-drained clay loam soil along the San Saba River and its tributaries with high available water capacity, moderate alkalinity, and occasional flooding. This soil series has been mapped by the Soil Conservation Service (now Natural Resources Conservation Service) within the southern half of community C-2 and throughout community C-1. The Frio soils series is described as a well-drained clay loam along the lower bottom lands of the San Saba River and small streams with high available water capacity, moderate alkalinity, and frequent flooding. This soil series has been mapped within the northern half of community C-2 and throughout community C-3. However, visual observations of eroded stream banks, rafted debris, soil sediment, and vegetative patterns suggest the NRCS flooding assessment is inaccurate and should be revised. It appears as though frequent flooding occurs in the southern half of community C-2 and parts of C-1 while occasional flooding occurs in community C-3 and rarely occurs in the northern portion of C-2.

Floristic Survey

A complete floristic inventory of vascular plants was conducted within the riparian communities identified on the study site. The floristic survey was conducted from September of 2006 to May of 2008 and consisted of a general field survey throughout the site with use of a variety of local and regional botanical guides and associated literature. Vascular plants were collected approximately once per month during the cool season of October through February and collected approximately every two weeks during the warmer, growing season from March through September. Plants were collected, identified, and prepared in accordance with standard herbarium practices and procedures, as described by Diggs et al. (1999). Identification and nomenclature of all plant species follows *Shinners and Mahler's Illustrated Flora of North Central Texas* (Diggs et al., 1999), unless otherwise noted. Supplementary sources for plant identification were used, as needed. Representative voucher specimens of all taxa collected within the study area are deposited in the Texas State University Herbarium (SWT), San Marcos, Texas.

Vegetative Composition

The vegetative composition of the study site was determined by systematic vegetation sampling of twenty-one 10 x 10 m (nested) plots spaced at approximately 20 m intervals along linear transects trending perpendicular to the stream margin. Only access to the north and west side of the San Saba River was available for the proposed research. As a result, to avoid differences in aspect all transects and nested plots within the intermittent tributary (C-3) were located on the north and west side of the intermittent

stream channel. Three transects were located within each riparian zone (C-1 through C-3) and were evenly distributed along the length of the stream course for the respective zone (Figures 5 and 6).

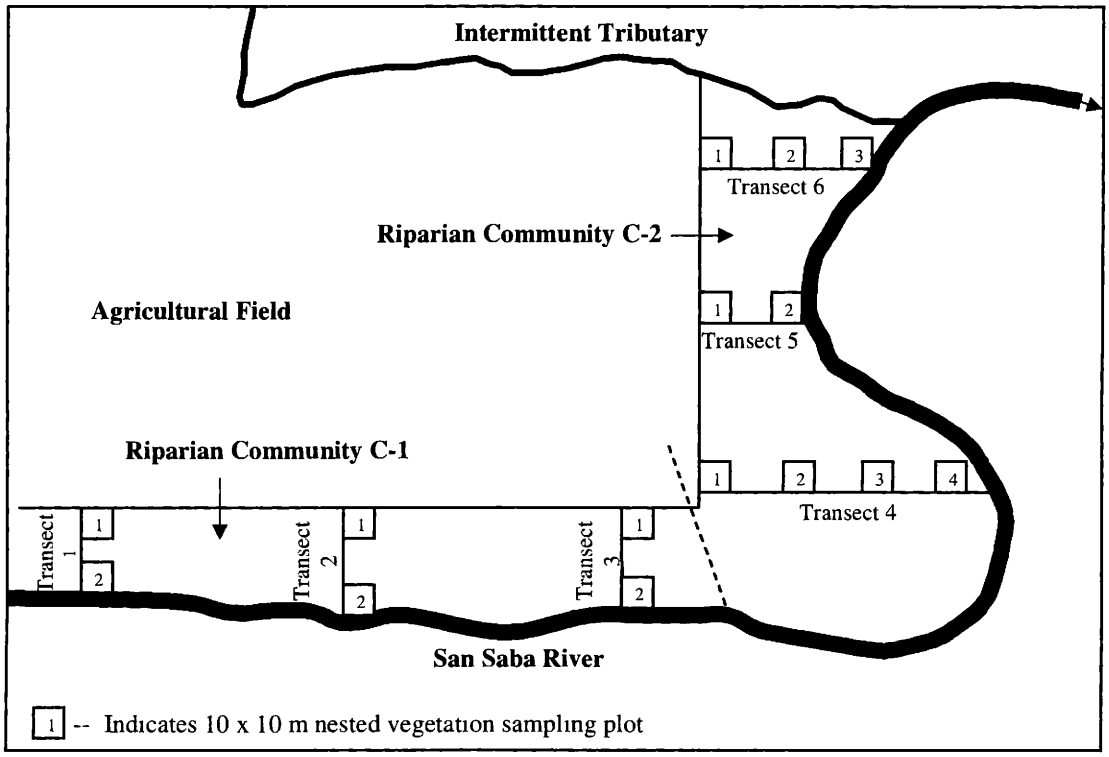


Figure 5. Vegetation transect and sampling plot layout in communities C-1 and C-2.

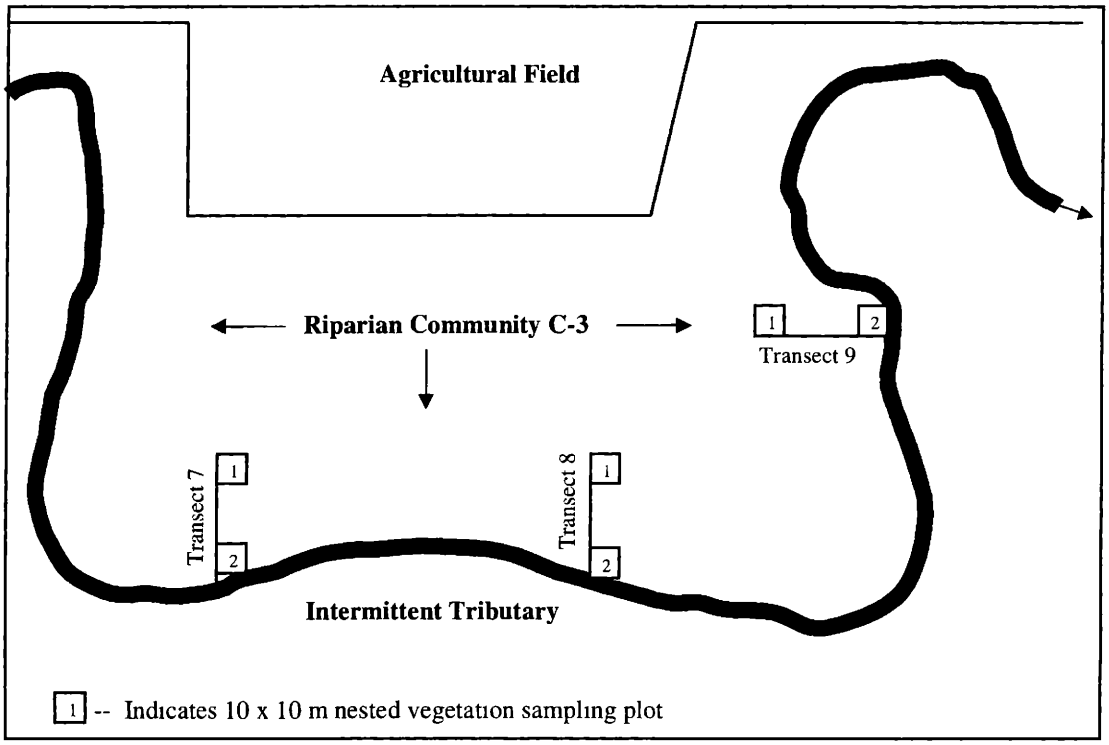


Figure 6. Vegetation transect and sampling plot layout in community C-3.

Transect length varied depending on the width of the riparian community and the subsequent placement of equidistant nested plots. Thus, the number of nested plots varied between any two transects. Each 100 m^2 primary plot was divided into a centered 5 x 5 m subplot with four 1 m^2 corner plots (northeast, southeast, southwest, and northwest), and a 1 m^2 center plot (Figure 7).

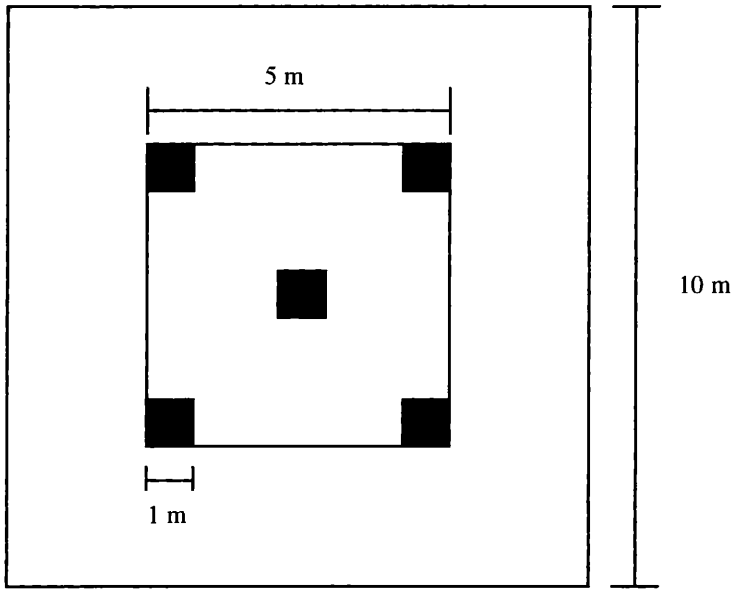


Figure 7. Nested plot design.

All plants were identified to species within the 1, 25, and 100 m^2 plots and maximum plant height, percent canopy cover, and percent ground cover by species were estimated for each of the 1 m^2 plots. Percent canopy cover for the entire 10 x 10 m area was estimated using a spherical densiometer and the average of five canopy cover readings from each 1 m^2 plot was reported. Percent down/woody debris was estimated for the entire 10 x 10 m area using cover-class estimates similar to those used for vegetation. The number of stems and heights of all woody plants were recorded for the 1, 25, and 100 m^2 areas. Additionally, species richness was calculated for each sampling plot and extrapolated to reflect the overall species richness of each plant community. Mean percent canopy cover, mean percent ground cover, mean percent woody debris cover, mean percent soil moisture, mean percent downed woody debris, mean maximum plant height, and mean species richness were determined by calculating the mean of each respective category within the five 1 m^2 plots within each nested sampling plot (N=5 for

the calculated means for each sampling plot). Due to variable numbers of sampling plots along each sample transect, the $1m^2$ sample sizes for each sample area (i.e., C-1, C-2, C-3) were N=30, N=45, and N=30, respectively. The location of each vegetation sampling plot was then mapped via GPS coordinate data collection from the center of each 100 m^2 plot (Table 1).

Table 1. GPS coordinates of the center of each sampling plot

Sample Location	Latitude N	Longitude W
T-1/P-1 (1)	31°13′ 09 85″	98°39′ 34 51″
T-1/P-2 (2)	31°13′ 09 43″	98°39′ 33.95″
T-2/P-1 (3)	31°13′ 16 41″	98°39′ 22.82″
T-2/P-2 (4)	31°13′ 15 93″	98°39′ 22.43″
T-3/P-1 (5)	31°13′ 21 60″	98°39′ 09 90″
T-3/P-2 (6)	31°13′ 20 73″	98°39′ 09 53″
T-4/P-1 (7)	31°13′ 25 69″	98°39′ 00.78″
T-4/P-2 (8)	31°13′ 26 28″	98°39′ 59 14″
T-4/P-3 (9)	31°13′ 26 90″	98°39′ 58.15″
T-4/P-4 (10)	31°13′ 27 54″	98°39′ 57 04″
T-5/P-1 (11)	31°13′ 28 89″	98°39′ 03 91″
T-5/P-2 (12)	31°13′ 29 50″	98°39′ 02 52″
T-6/P-1 (13)	31°13′ 36 11″	98°39′ 08 74″
T-6/P-2 (14)	31°13′ 36 58″	98°39′ 07 61″
T-6/P-3 (15)	31°13′ 37 08″	98°39′ 06 19″
T-7/P-1 (16)	31°13′ 25 29″	98°39′ 53 88″
T-7/P-2 (17)	31°13′ 24 55″	98°39′ 53 14″
T-8/P-1 (18)	31°13′ 26 71″	98°39′ 50 87″
T-8/P-2 (19)	31°13′ 25 94″	98°39′ 59 94″
T-9/P-1 (20)	31°13′ 28.38″	98°39′ 51 24″
T-9/P-2 (21)	31°13′ 29.39″	98°39′ 49 76″

A tree survey was conducted along each linear sampling transect to further define the tree species composition and distribution in relation to the stream margin and, presumably, available resources. Tree survey corridors were centered on each sampling transect and extended 15 meters on each side for a total survey corridor width of 30 meters. The survey corridors were then divided into five-meter zones, beginning at the upland vegetative community boundary and ending at the stream margin, to evaluate the occurrence of tree stratum environmental gradients. All trees with a diameter at breast height (DBH) of 7.6 centimeters or greater were identified to species and measured for DBH. The total basal area of each survey corridor was tabulated, and converted from cm^2 to m^2. The total basal area for each corridor was then converted to hectare by determining the total area of the survey corridor and dividing total basal area by the total area. The basal area for all of the three survey corridors within a particular sample area (C-1, C-2, and C-3) was then determined and the mean basal area for each community is provided in this report. Thus, for each community N=3. The same method was used to estimate mean tree density within each community.

The relative elevation of each linear sampling transect in relation to the stream margin was also measured and relative elevation profiles were created for each transect. The elevation profiles were created by using a Spectra Precision LL300 electronic laser level to record the relative elevation of the ground surface at three meter intervals along each linear transect, beginning at the upland vegetative community boundary and ending at the stream margin.

Soil Analysis

One composite soil sample was collected from each nested plot within the study site to compare the growth and distribution of plants in relation to local edaphic characteristics. The composite samples were collected by combining five soil cores taken at the corners and center of each 5 x 5 m plot. These samples were collected from a depth of 0-15 cm, with samples being collected once during the spring of 2008.

Soil texture is often considered one of the most important characteristics of soil due to its influence on important environmental properties such as cation exchange capacity, nutrient retention, water holding capacity, resistance to erosion, oxygen content, potential for microbial growth, and support for large vegetative structures (Grime, 2002). All soil samples were thoroughly mixed for homogeneity and the soil texture was characterized according to their particle size class using the Soil Conservation Service (now U.S. Department of Agriculture) Soil Classification System (1993). Soil texture was determined by conducting a particle-size analysis (PSA) according to standard Soil Science Society of America and American Society of Agronomy methodology (Gee and Or, 1996).

Particle-size analysis is a measurement of the size distribution of the individual particles in a sample of soil. Dry sieving methods measure the amount of soil retained on a calibrated sieve, which corresponds to a specified soil particle size. Multiple sieves are used to assess the percent contribution of a particular size class in relation to the entire sample. Dry sieving is typically reserved for coarse-grained soil particles exceeding 0.05 mm (50 μm) in diameter. Soil particles smaller than 0.05 mm in diameter undergo chemical and mechanical methods of soil aggregate dispersion, which allow for

observation of the rate of particle separation and sedimentation within a column of water known as a hydrometer. The combined results of these two processes provide an indication of the soil structure and textural classification (USDA, 2004).

Each composite soil sample was also analyzed for total carbon and nitrogen composition, percent moisture, and pH using methods outlined within the USDA Soil Survey Laboratory Methods Manual (2004). Percent soil moisture was also determined in the field by using a time domain reflectometry soil moisture meter. Percent soil moisture readings were collected from each 1 m^2 plot during spring and fall of 2008. Total carbon and nitrogen composition was determined using a CE Elantech Flash 2000 NC Analyzer and the carbon to nitrogen ratio for each sample was determined based upon analytical total carbon and total nitrogen values. Inferences about nitrogen mineralization rates for each soil type were then made based upon the carbon and nitrogen composition.

Data Analysis

Data were analyzed for statistical patterns and/or variability using JMP software. Basic regression equations were used to examine the relationship between plant species richness and distribution patterns in relation to edaphic characteristics. Analysis of variance was used to analyze vegetative patterns among the three riparian vegetative communities located within the study site. Due to variable numbers of sampling plots along each sample transect, a randomized re-sampling procedure was used to adjust for species richness among the three vegetation sampling areas. Specifically, Community C-2 had nine sampling plots, whereas communities C-1 and C-3 had six sampling plots,

respectively. The randomized re-sampling procedure randomly selected six of the nine sampling plots, from which total species richness was determined. This process was repeated 100 times, and the mean species richness, standard deviation, and confidence intervals were then determined. The mean species richness was from the randomized re-sampling procedure was considered the area-adjusted estimate of species richness for Community C-2. Area-adjusted determinations of total species richness were then used in statistical analysis, where appropriate.

CHAPTER III

RESULTS AND DISCUSSION

Floristic Survey

The current study resulted in the collection and identification of 142 specific and infraspecific vascular taxa in 127 genera from 55 families. A catalogue of vascular plant species is provided as Appendix I. The species are grouped as Angiosperms, Gymnosperms, and Ferns or Fern Allies. Angiosperms are further subdivided into Monocots and Dicots. Taxa are alphabetically arranged within each group according to families, genera, species, and lesser taxa. Vegetative growth forms and the native/non-native or endemic status of each species are also provided, along with the corresponding collection numbers.

The most represented family is the Asteraceae with 20 species, which account for 14.1 percent of all species identified in the study site (Table 2). The second most represented family is the Poaceae with 15 species, which account for 10.6 percent of all species identified in the study site. The families Brassicaceae (9 spp.), Fabaceae (9 spp.), and Solanaceae (7 spp.) are also well represented throughout the study site. The most represented genus is *Medicago*, with three species, while all remaining genera had two or fewer species present.

Table 2. The five most represented plant families observed within the vegetation sampling plots

Family	Genera	Species	Native	Exotic
	----------*Number*----------			
Asteraceae	18	20	17	3
Poaceae	13	15	10	5
Brassicaceae	9	9	3	6
Fabaceae	7	9	6	3
Solanaceae	5	7	7	0
Total	52	60	43	17

Of the 142 species collected, 113 are native to Texas, while 29 have been introduced (Table 3). Of the 29 introduced species, six belong to the Brassicaceae and five belong to the Poaceae, together constituting 37.9 percent of all introduced species in the study area. However, none of these exotic and native species are listed as noxious weeds in Texas by the U. S. Department of Agriculture's Texas Noxious Weeds list. The vascular flora of the study site consists of 109 annual, biennial, and perennial herbs; four woody vines; 14 shrubs, 17 trees; one hemi-parasite; and one epiphyte.

Table 3. Hierarchical classification of vascular plants at the study site

Division	Families	Genera	Species	Native	Exotic	Composition by Species
	----------*Number*----------					Percent
Magnoliphyta	53	125	140	111	29	98 6
Magnoliopsida	46	104	117	94	23	82 4
Liliopsida	7	21	23	17	6	16.2
Pinophyta	1	1	1	1	0	0 7
Pteridophyta	1	1	1	1	0	0 7
Total	55	127	142	113	29	100 0

According to sensitive-status species information provided by the U.S. Fish and Wildlife Service and the Texas Parks and Wildlife Department's Natural Diversity Database, no protected plant species are reported to occur in San Saba County. However, numerous plants endemic to Texas occur throughout the state and three of the identified species in the study area are Texas endemics; rock coreopsis (*Coreopsis wrightii*), Texas bluebonnet (*Lupinus texensis*), and sweet mountain grape (*Vitis monticola*).

Vegetative Composition

The riparian edge along the San Saba River was divided into two different study areas (communities), identified as C-1 and C-2. Based on quantitative estimates of tree density and canopy cover, community C-1 would be loosely associated with the Pecan-Sugarberry Series described by Diamond (1993). With an mean tree canopy cover of 78.7 percent, a mean tree density of 268.3 trees per hectare, and a mean tree basal area of 26.2 m^2/ha, this community conforms to a forest development (Diamond et al., 1987). This community exhibits a relatively dense canopy closure attributed to a greater

frequency of oaks including bur oak (*Quercus macrocarpa*) and plateau live oak (*Quercus fusiformis*), Texas sugarberry (*Celtis laevigata*), sycamore (*Platanus occidentalis*), mulberry (*Morus* spp.), and others. This community is also characterized by a moderately dense understory community with a greater abundance of understory shrub and tree species than the other two communities. Summary data for each of these communities are provided in Table 4.

Table 4. Vegetation community data summary (see sampling plot layout, figures 5 and 6)

Characteristic	Riparian Community		
	C-1	C-2	C-3
Number of Transects per Community	3	3	3
Number of 10x10 m Sampling Plots per Community	6	9	6
Number of 1x1 m Sampling Plots per Community	30	45	30
Total Species Richness	50	49	42
Total Species Richness (area adjusted)	-	46	-
Mean/SD of Percent Canopy Cover (N=30, 45, 30)	78.7/23 3	62 4/28 9	65.6/29 5
Mean/SD of Percent Vegetative Ground Cover (N=30, 45, 30)	70 9/29 5	77 3/26 8	64 8/22 4
Mean Tree Density (trees/ha [>7 6 cm dbh]) (N=3, 3, 3)	268 3	101 2	174 9
Mean Tree Basal Area (m^2/ha) (N=3, 3, 3)	26 2	16 6	15 9
Total Tree Species Richness (N=6, 9, 6)	11	9	5
Total Shrub Species Richness (N=6, 9, 6)	4	2	2
Total Vine Species Richness (N=6, 9, 6)	2	3	1
Total Herb Species Richness (N=6, 9, 6)	33	36	33
Mean Maximum Herb Plant Height measured within each 1x1 m plot (cm) (N=30, 45, 30)	58	60 8	40 1
Mean Maximum Woody Plant Height measured within each 1x1 m plot (cm) (N=30, 45, 30)	53 5	74 1	77 6
Mean Number of Woody Stems within each 1x1 m plot (N=30, 45, 30)	0 3	0 1	0 2
Mean Percent Downed Woody Debris measured within each 1x1 m plot (N=30, 45, 30)	5 7	4 2	5
Mean Percent Soil Moisture measured within each 1x1 meter plot (N=30, 45, 30)	15 7	32 1	16 9

The San Saba River changes direction from east/west to north/south at the northeastern edge of C-1. The change in direction marks a moderately abrupt change in plant community composition and structure, species richness, and physiographic structure. With a mean tree canopy cover of 62.4 percent, a mean density of trees with 7.6 cm DBH or greater of 101.2 trees per hectare, and a mean tree basal area of 16.6 m^2/ha, this area, identified as community C-2, also conforms to a forest development associated with the Pecan-Sugarberry Series. However, this community exhibits reduced canopy closure attributed to a reduced frequency of oaks. This community is characterized by numerous mature pecan trees (*Carya illinoinensis*) interspersed with occasional Texas sugarberry, bur oak, and a relatively increasingly open understory dominated by perennial grasses and forbs. Herbaceous species richness is relatively high, while woody shrub and tree species richness is moderate to low.

The area identified as community C-3 is moderately similar in composition and structure to the others; however there is a much greater abundance of live oak, cedar elm (*Ulmus crassifolia*), and mesquite (*Prosopis glandulosa*), while pecans are absent. With a mean tree canopy cover of 65.6 percent, a mean tree density of 174.9 trees per hectare, and a mean tree basal area of 15.9 m^2/ha this community also conforms to a forest development. The understory is increasingly open, relative to C-1 and C-2, but exhibits similar species richness.

Graphs illustrating tree density, species richness, and total basal area along each sampling transect are provided in Figures 8 through 10.

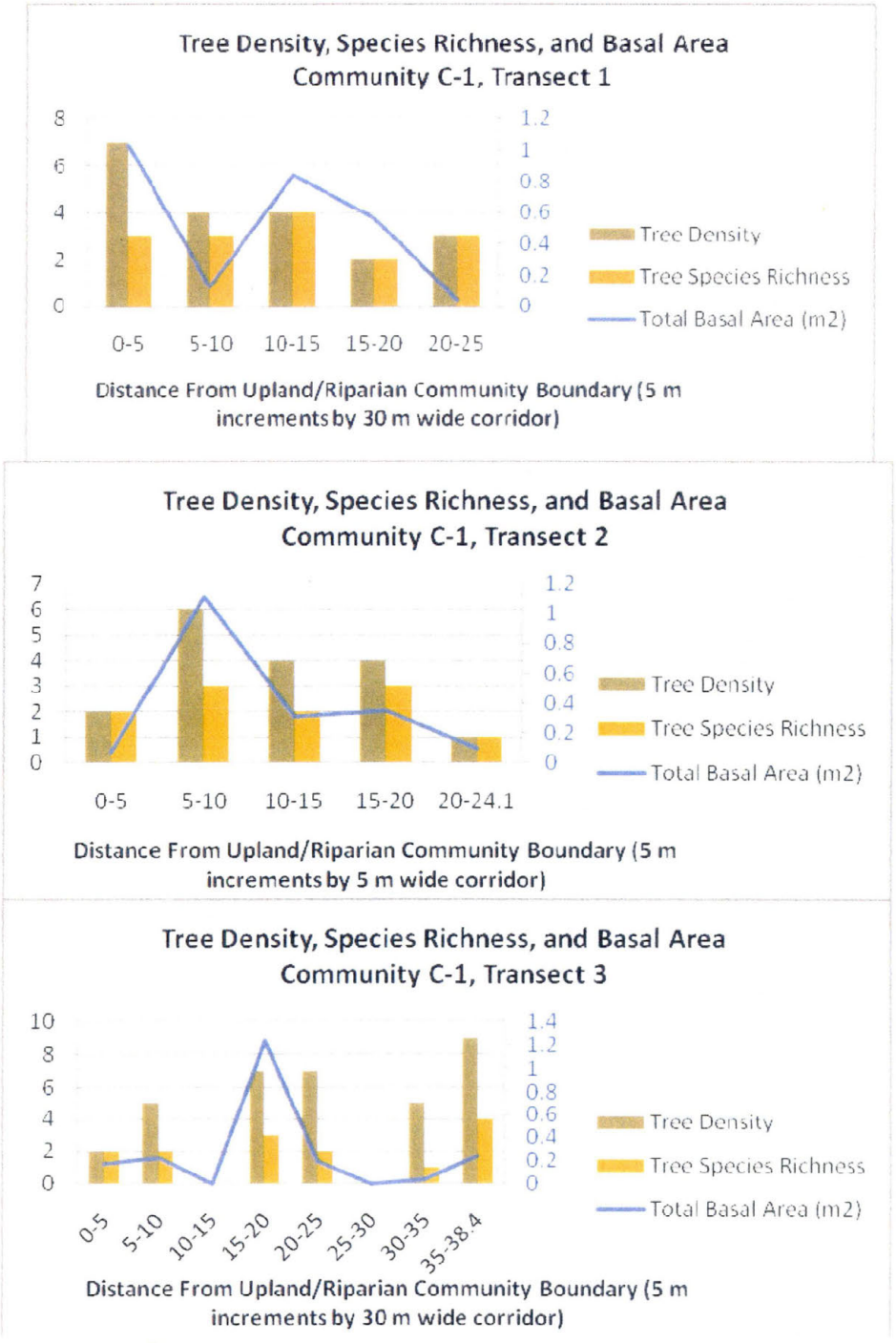


Figure 8. Distribution of tree density, tree species richness, and total basal area measured within a 30 meter-wide corridor, and at 5-meter increment zones, along sampling transects 1, 2, and 3 in community C-1.

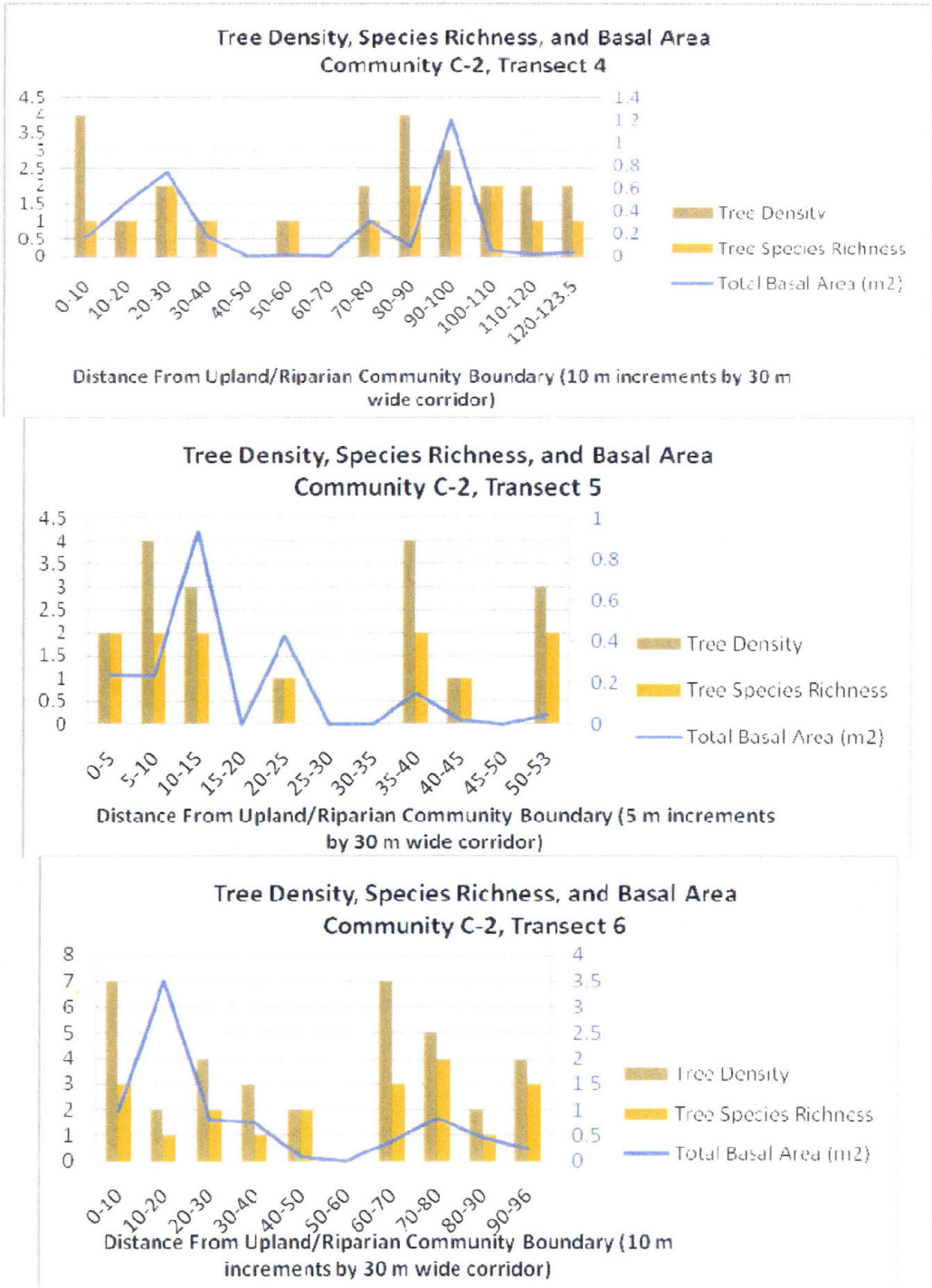


Figure 9. Distribution of tree density, tree species richness, and total basal area measured within a 30 meter-wide corridor, and at 5 and 10-meter increment zones, along sampling transects 4, 5, and 6 in community C-2.

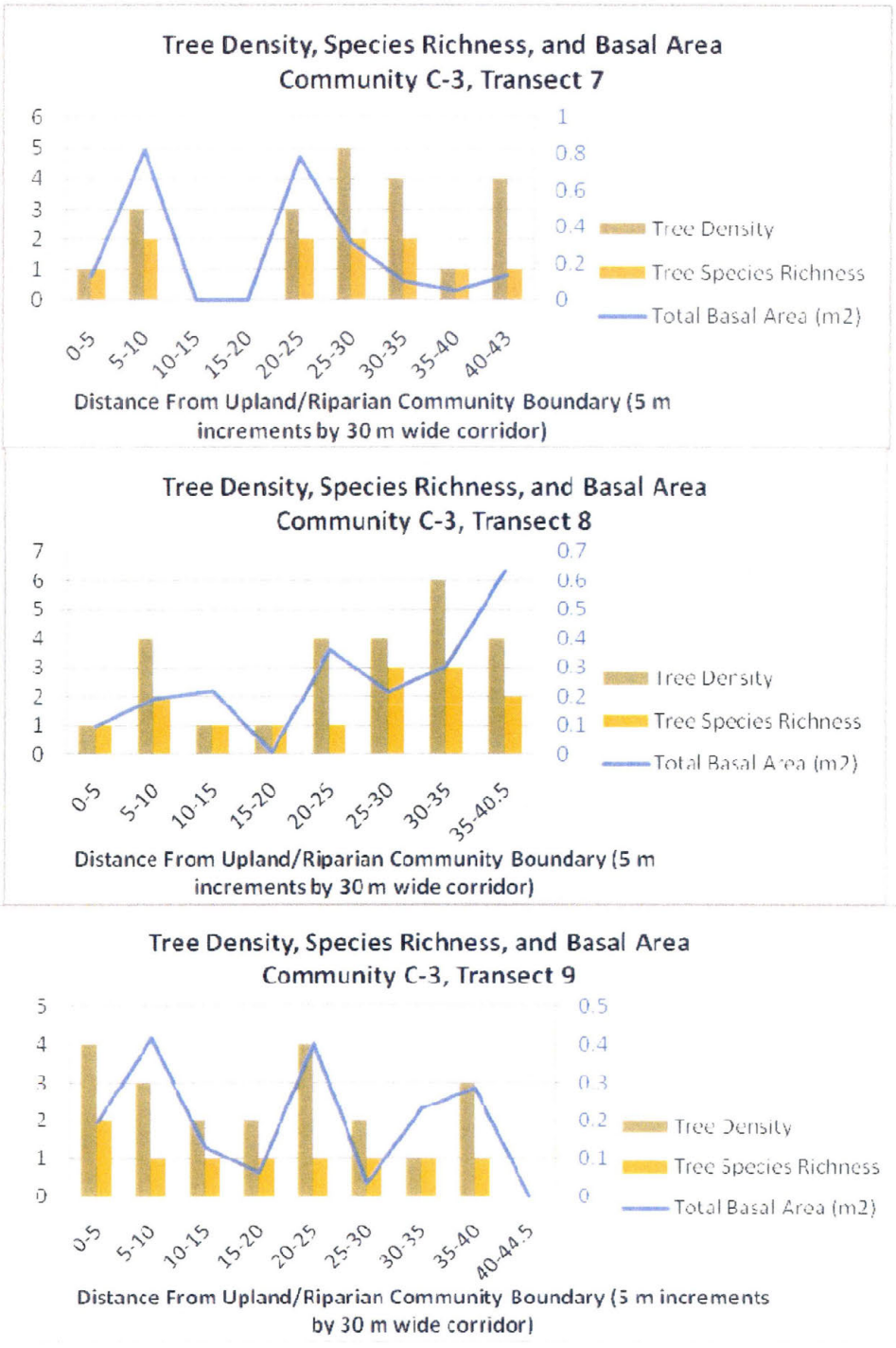
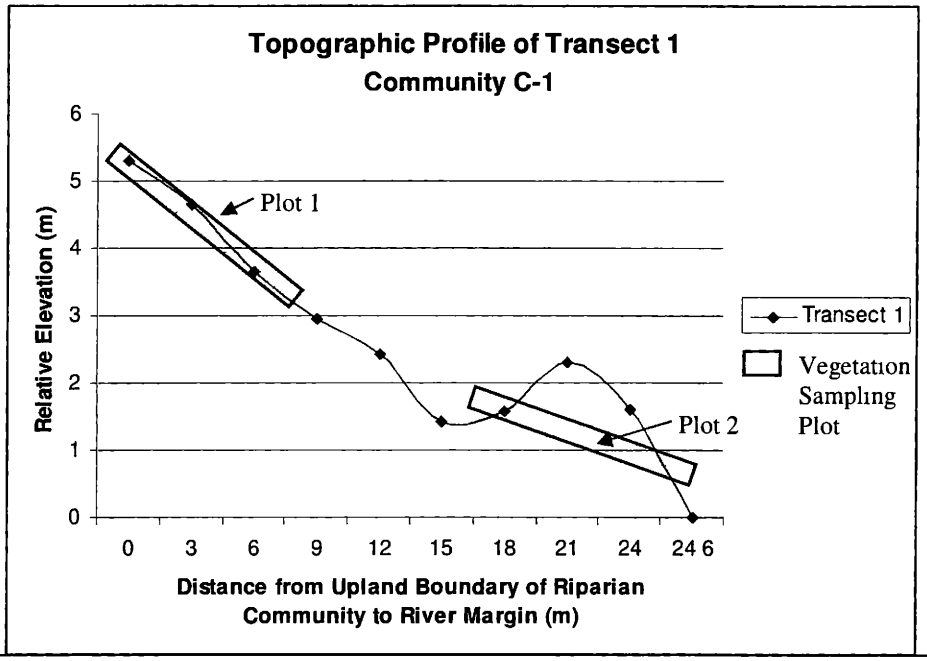


Figure 10. Distribution of tree density, tree species richness, and total basal area measured within a 30 meter-wide corridor, and at 5-meter increment zones, along sampling transects 7, 8, and 9 in community C-3.

Soil Analysis

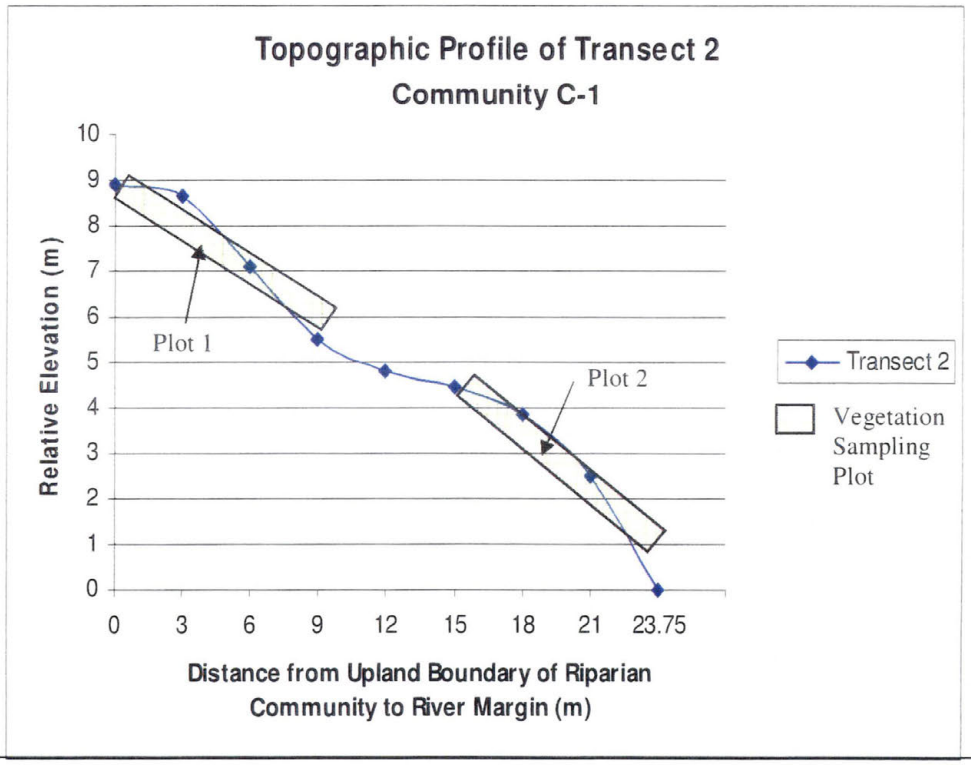
Twenty-one particle-size analyses were conducted resulting in clay, silty clay, sandy clay, clay loam, silty clay loam, sandy clay loam, and sandy loam soils within the study site (Table 5). Clay and clay loams predominated on the southeast facing stream banks within the C-1 and C-3 communities, while silty clays, sandy clays, and sandy loams predominated on the more frequently flooded northeast facing banks within the C-2 and C-3 communities. A general particle size depositional pattern was observed within the relatively broad and flat floodplain of Transect-4, trending from silty clay in the uplands to clay loam, sandy clay loam, and sandy clay towards the stream margin.

The southeast facing stream banks within the C-1 and C-3 communities are relatively steep and abrupt, with a noticeably lower, and seemingly less intense, flood stage as observed by the average high water mark. The reduced flood intensity is due to a deeper, steeply incised stream channel with high banks. The reduced frequency and intensity of floods in these areas likely contribute to less deposition of coarse-grained alluvial materials in the upland environments. As a result, clay and clay loam soils are more frequently observed in the study area and the locations from which these soil samples were taken are likely more consistent in soil texture over time. Topographic profiles illustrating the relative elevation of each linear sampling transect, as well as an associated table of vegetative and soil summary data, are provided in Figures 11 through 19.



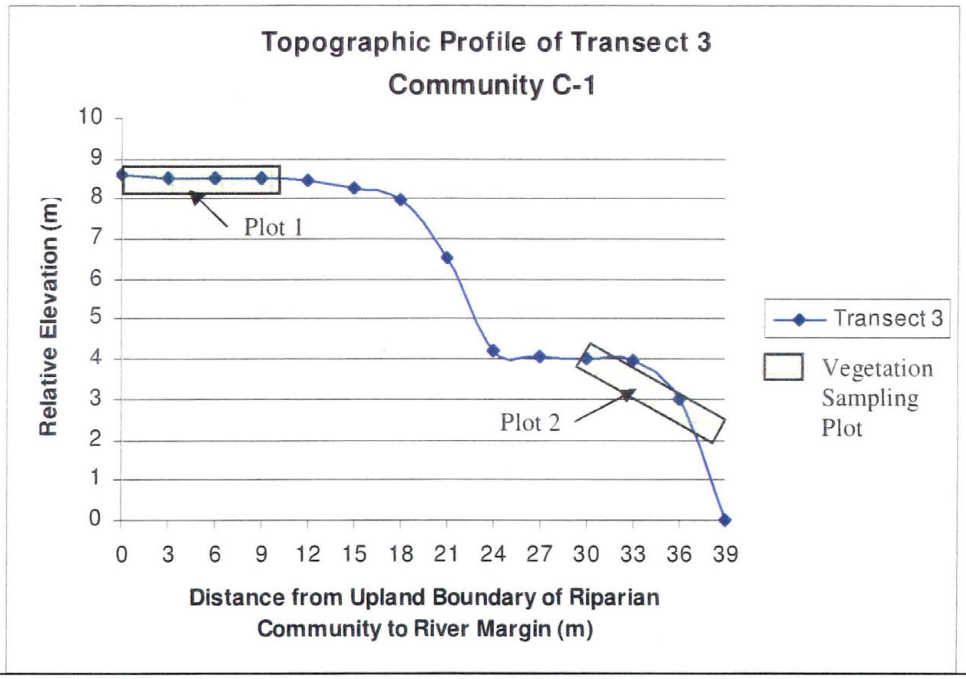
Vegetation and soil summary data for each 10x10 m sampling plot		
	Plot 1	Plot 2
Total species richness for overall 10x10 m plot	16	25
Total species richness/mean # of species in 1x1 m plots (N=5)	9/5 2	12/5 8
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	4/2 4	6/3 6
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	1/0 8	1/0.8
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	0/0	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	3/2.2	4/1 4
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	10/2 2	5/1
Mean % tree canopy cover in 1x1 m plots (N=5)	84 9	84 5
Mean % herbaceous ground cover in 1x1 m plots (N=5)	35	67 8
Mean % woody debris ground cover in 1x1 m plots (N=5)	13 4	6 9
Basal area from tree transect survey associated with each plot (m^2/ha)	38 4	19 9
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	93 5	83.9
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=11, N=5)	28 7	25 9
Soil classification (texture) (aggregate from five 1x1 m plots)	clay loam	clay loam
% total soil nitrogen (aggregate from five 1x1 m plots)	0 27	0 2
% total soil carbon (aggregate from five 1x1 m plots)	7 63	7 44
C.N ratio (aggregate from five 1x1 m plots)	28 25	37 2
Soil pH (aggregate from five 1x1 m plots)	7 3	7 19
Mean % soil moisture (N=10) (data collected spring and summer)	16.02	18 5

Figure 11. Relative elevation profile of Transect-1 and vegetation and soil summary data for each sampling plot.



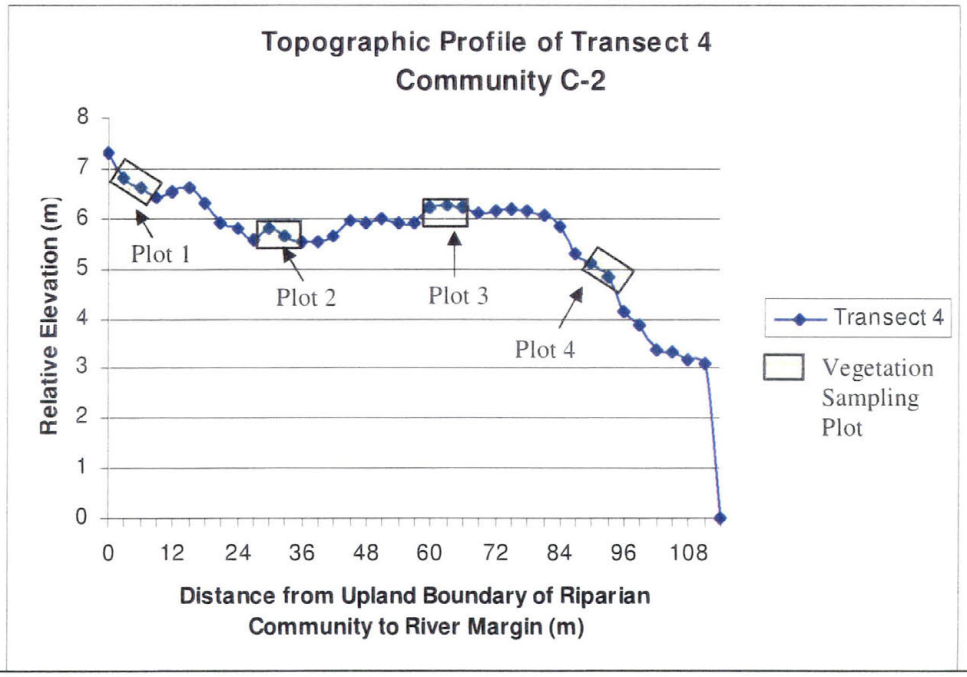
Vegetation and soil summary data for each 10x10 m sampling plot		
	Plot 1	Plot 2
Total species richness for overall 10x10 m plot	21	21
Total species richness/mean # of species in 1x1 m plots (N=5)	11/5.8	12/4
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	9/4.4	6/2.8
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	0/0	0/0
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	0/0	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	5/0.6	2/0.8
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	3/0.6	8/1.6
Mean % tree canopy cover in 1x1 m plots (N=5)	66.2	83.1
Mean % herbaceous ground cover in 1x1 m plots (N=5)	59.2	98.2
Mean % woody debris ground cover in 1x1 m plots (N=5)	7.9	0.4
Basal area from tree transect survey associated with each plot (m^2/ha)	39.4	16.6
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	112	39.8
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=8, N=5)	28.9	33.5
Soil classification (texture) (aggregate from five 1x1 m plots)	clay loam	clay loam
% total soil nitrogen (aggregate from five 1x1 m plots)	0.18	0.17
% total soil carbon (aggregate from five 1x1 m plots)	6.28	6.98
C:N ratio (aggregate from five 1x1 m plots)	34.8	41.05
Soil pH (aggregate from five 1x1 m plots)	7.3	7.48
Mean % soil moisture (N=10) (data collected spring and summer)	15.27	14.65

Figure 12. Relative elevation profile of Transect-2 and vegetation and soil summary data for each sampling plot.



Vegetation and soil summary data for each 10x10 m sampling plot		
	Plot 1	Plot 2
Total species richness for overall 10x10 m plot	11	25
Total species richness/mean # of species in 1x1 m plots (N=5)	11/5.8	14/5
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	5/2.4	14/3
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	2/1.2	0/0
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	0/0	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	5/2.4	1/0.2
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	22/4.4	1/0.2
Mean % tree canopy cover in 1x1 m plots (N=5)	96.6	57.7
Mean % herbaceous ground cover in 1x1 m plots (N=5)	64.2	92.4
Mean % woody debris ground cover in 1x1 m plots (N=5)	4.17	1.6
Basal area from tree transect survey associated with each plot (m^2/ha)	12.9	10.4
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	37.2	34.8
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=7, N=14)	24.5	14.2
Soil classification (texture) (aggregate from five 1x1 m plots)	clay loam	clay loam
% total soil nitrogen (aggregate from five 1x1 m plots)	0.26	0.16
% total soil carbon (aggregate from five 1x1 m plots)	7.32	6.94
C:N ratio (aggregate from five 1x1 m plots)	28.15	43.37
Soil pH (aggregate from five 1x1 m plots)	7.29	7.19
Mean % soil moisture (N=10) (data collected spring and summer)	17.26	12.36

Figure 13. Relative elevation profile of Transect-3 and vegetation and soil summary data for each sampling plot.

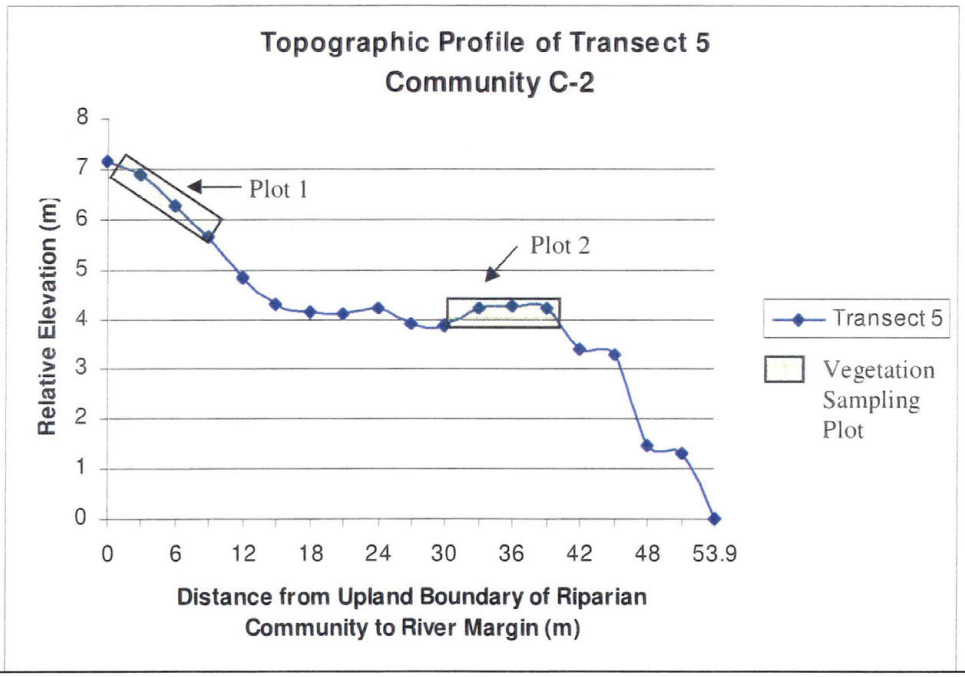


Vegetation and soil summary data for each 10x10 m sampling plot				
	Plot 1	Plot 2	Plot 3	Plot 4
Total species richness for overall 10x10 m plot	13	13	8	12
Total species richness/mean # of species in 1x1 m plots (N=5)	9/3.2	9/4.6	7/3.2	8/3.2
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	9/2.2	9/2.6	6/2.4	6/2.4
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	0/0	0/0	0/0	1/0.2
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	0/0	0/0	0/0	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	0/0	0/0	1/0.4	1/0.2
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	0/0	1/0.2	2/0.4	1/0.2
Mean % tree canopy cover in 1x1 m plots (N=5)	53.4	29.4	83.9	79.9
Mean % herbaceous ground cover in 1x1 m plots (N=5)	95.8	99	38.4	31.8
Mean % woody debris ground cover in 1x1 m plots (N=5)	0	0	15.8	8.33
Basal area from tree transect survey associated with each plot (m^2/ha)	5.7	5.9	0	40.1
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	26.6	47.8	0	102.7

Figure 14. Relative elevation profile of Transect-4 and vegetation and soil summary data for each sampling plot.

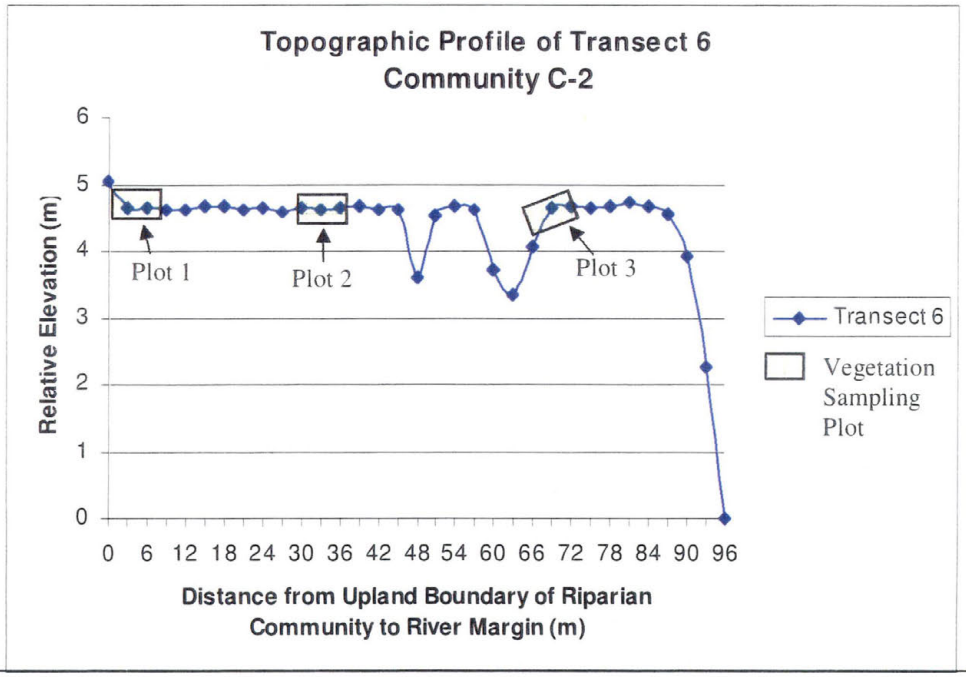
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=5, N=2, N=0, N=4)	18 4	23 9	0	46 1
Soil classification (texture) (aggregate from five 1x1 m plots)	silty clay	clay loam	sandy clay loam	sandy loam
% total soil nitrogen (aggregate from five 1x1 m plots)	0 32	0 21	0 23	0 26
% total soil carbon (aggregate from five 1x1 m plots)	8 12	7 09	7 91	8 71
C:N ratio (aggregate from five 1x1 m plots)	25 37	33 76	34 39	33 5
Soil pH (aggregate from five 1x1 m plots)	7 06	7 35	7 4	7 35
Mean % soil moisture (N=10) (data collected spring and summer)	26 7	29 14	16 4	18 9

Figure 14. Continued.



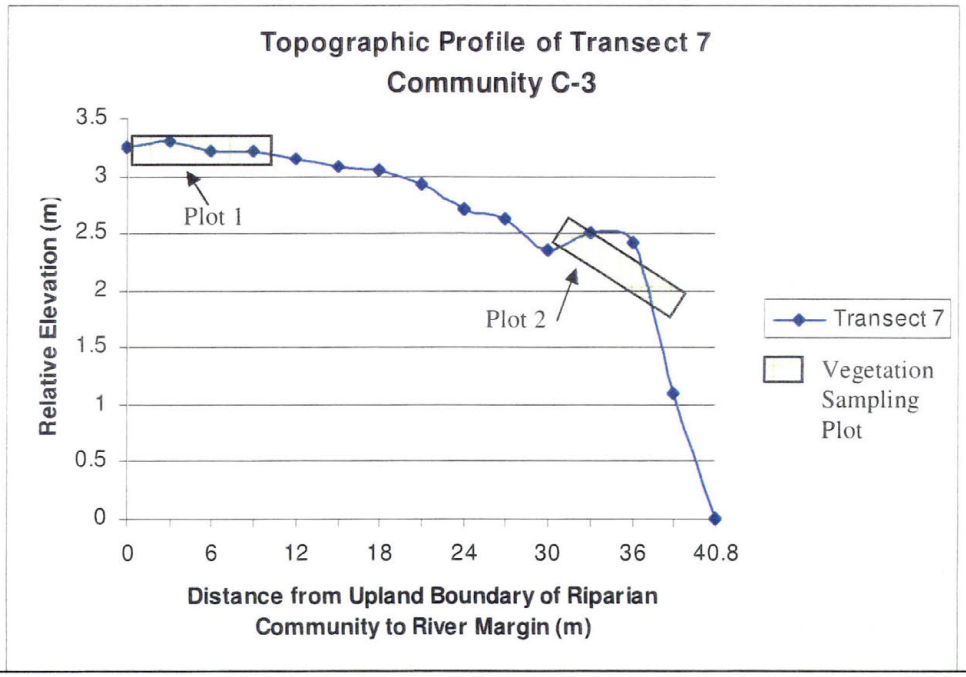
Vegetation and soil summary data for each 10x10 m sampling plot		
	Plot 1	Plot 2
Total species richness for overall 10x10 m plot	23	17
Total species richness/mean # of species in 1x1 m plots (N=5)	10/4.8	13/5.2
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	6/3.4	10/4.6
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	1/0.2	0/0
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	0/0	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	2/1.2	3/0.6
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	6/1.2	4/0.8
Mean % tree canopy cover in 1x1 m plots (N=5)	71.1	76.8
Mean % herbaceous ground cover in 1x1 m plots (N=5)	75.8	89
Mean % woody debris ground cover in 1x1 m plots (N=5)	3.8	1.5
Basal area from tree transect survey associated with each plot (m^2/ha)	15.8	4.9
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	48.9	25.1
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=6, N=5)	29.3	17.1
Soil classification (texture) (aggregate from five 1x1 m plots)	silty clay loam	clay loam
% total soil nitrogen (aggregate from five 1x1 m plots)	0.27	0.24
% total soil carbon (aggregate from five 1x1 m plots)	7.65	8.04
C:N ratio (aggregate from five 1x1 m plots)	28.33	33.5
Soil pH (aggregate from five 1x1 m plots)	7.32	7.34
Mean % soil moisture (N=10) (data collected spring and summer)	21	21.3

Figure 15. Relative elevation profile of Transect-5 and vegetation and soil summary data for each sampling plot.



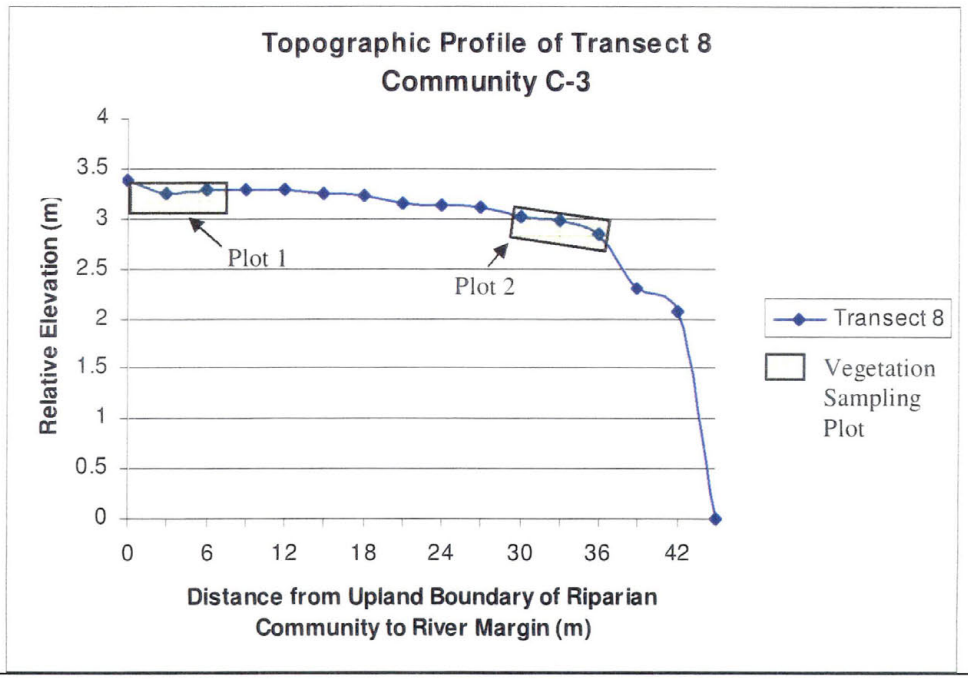
Vegetation and soil summary data for each 10x10 m sampling plot			
	Plot 1	Plot 2	Plot 2
Total species richness for overall 10x10 m plot	18	16	22
Total species richness/mean # of species in 1x1 m plots (N=5)	13/5.8	14/7.8	12/5.2
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	11/5	10/5.2	10/4.8
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	1/0.2	0/0	1/0.2
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	0/0	0/0	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	1/0.6	4/2.6	1/0.2
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	5/1	17/3.4	2/0.4
Mean % tree canopy cover in 1x1 m plots (N=5)	37.4	92.2	85.1
Mean % herbaceous ground cover in 1x1 m plots (N=5)	88	92	87
Mean % woody debris ground cover in 1x1 m plots (N=5)	1.6	2.7	4
Basal area from tree transect survey associated with each plot (m^2/ha)	32.7	24.9	12.8
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	74.9	61.2	35.9
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=7, N=3, N=7)	47.1	56.3	25.3
Soil classification (texture) (aggregate from five 1x1 m plots)	silty clay	silty clay	silty clay
% total soil nitrogen (aggregate from five 1x1 m plots)	0.41	0.22	0.27
% total soil carbon (aggregate from five 1x1 m plots)	9.32	6.2	6.96
C:N ratio (aggregate from five 1x1 m plots)	22.73	28.18	25.88
Soil pH (aggregate from five 1x1 m plots)	7.29	7.45	7.43
Mean % soil moisture (N=10) (data collected spring and summer)	34.32	32.05	22.78

Figure 16. Relative elevation profile of Transect-6 and vegetation and soil summary data for each sampling plot.



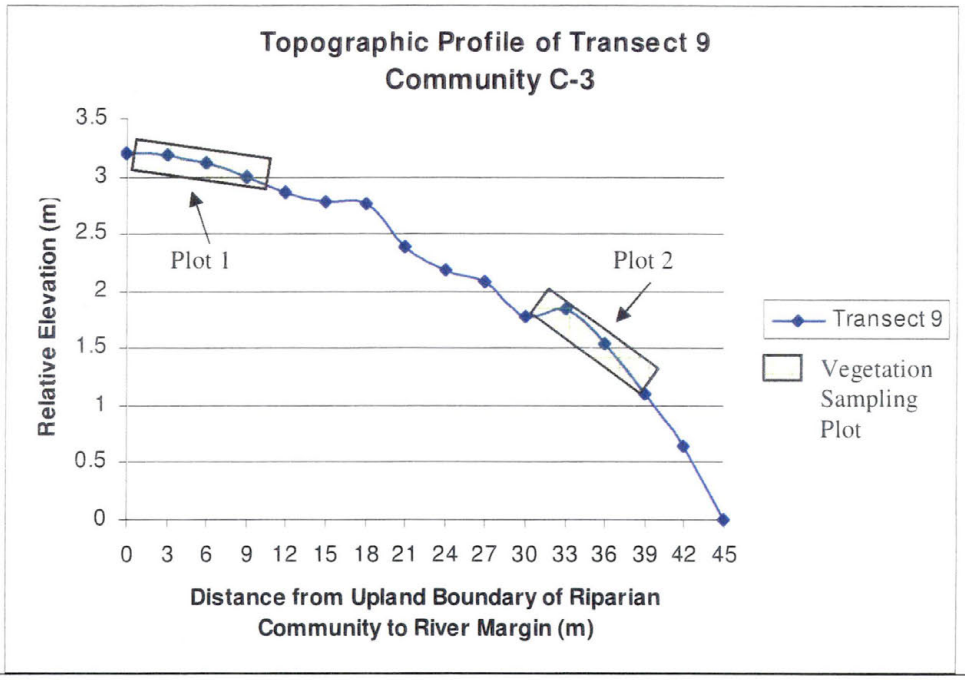
Vegetation and soil summary data for each 10x10 m sampling plot		
	Plot 1	Plot 2
Total species richness for overall 10x10 m plot	15	25
Total species richness/mean # of species in 1x1 m plots (N=5)	8/4.4	14/6.2
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	8/4.4	11/5.6
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	0/0	1/0.2
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	1/0.2	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	0/0	2/0.4
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	2/0.4	1/0.2
Mean % tree canopy cover in 1x1 m plots (N=5)	79.1	89
Mean % herbaceous ground cover in 1x1 m plots (N=5)	54	90
Mean % woody debris ground cover in 1x1 m plots (N=5)	2.9	4.8
Basal area from tree transect survey associated with each plot (m^2/ha)	31.7	6.8
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	91.3	25.9
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=4, N=5)	48.1	19.5
Soil classification (texture) (aggregate from five 1x1 m plots)	clay loam	clay
% total soil nitrogen (aggregate from five 1x1 m plots)	0.16	0.12
% total soil carbon (aggregate from five 1x1 m plots)	3.38	2.95
C:N ratio (aggregate from five 1x1 m plots)	21.25	24.58
Soil pH (aggregate from five 1x1 m plots)	6.8	7.37
Mean % soil moisture (N=10) (data collected spring and summer)	16.72	24.64

Figure 17. Relative elevation profile of Transect-7 and vegetation and soil summary data for each sampling plot.



Vegetation and soil summary data for each 10x10 m sampling plot		
	Plot 1	Plot 2
Total species richness for overall 10x10 m plot	24	16
Total species richness/mean # of species in 1x1 m plots (N=5)	11/5.4	12/5.6
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	10/5.2	9/3.8
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	0/0	0/0
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	0/0	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	1/0.2	3/1.8
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	27/5.4	30/6
Mean % tree canopy cover in 1x1 m plots (N=5)	25.4	94.8
Mean % herbaceous ground cover in 1x1 m plots (N=5)	85	46
Mean % woody debris ground cover in 1x1 m plots (N=5)	7.6	6.4
Basal area from tree transect survey associated with each plot (m^2/ha)	9.6	34.7
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	35.3	78.5
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=5, N=10)	25.2	29.9
Soil classification (texture) (aggregate from five 1x1 m plots)	clay loam	clay
% total soil nitrogen (aggregate from five 1x1 m plots)	0.36	0.17
% total soil carbon (aggregate from five 1x1 m plots)	6.84	4.23
C:N ratio (aggregate from five 1x1 m plots)	19	24.88
Soil pH (aggregate from five 1x1 m plots)	7.26	7.08
Mean % soil moisture (N=10) (data collected spring and summer)	13.17	22.75

Figure 18. Relative elevation profile of Transect-8 and vegetation and soil summary data for each sampling plot.



Vegetation and soil summary data for each 10x10 m sampling plot		
	Plot 1	Plot 2
Total species richness for overall 10x10 m plot	17	21
Total species richness/mean # of species in 1x1 m plots (N=5)	11/4.8	8/4.6
Total # of herb species/mean # of herb species in 1x1 m plots (N=5)	10/4.6	8/4.6
Total # of vine species/mean # of vine species in 1x1 m plots (N=5)	0/0	0/0
Total # of shrub species/mean # of shrub species in 1x1 m plots (N=5)	1/0.2	0/0
Total # of tree species/mean # of tree species in 1x1 m plots (N=5)	0/0	0/0
Total # of woody stems/mean # of woody stems in 1x1 m plots (N=5)	1/0.2	0/0
Mean % tree canopy cover in 1x1 m plots (N=5)	54.8	82.7
Mean % herbaceous ground cover in 1x1 m plots (N=5)	68	61.2
Mean % woody debris ground cover in 1x1 m plots (N=5)	6	1.95
Basal area from tree transect survey associated with each plot (m^2/ha)	20.3	10.6
Maximum woody diameter from tree transect survey associated with each plot (cm at breast height)	45.4	54.4
Mean woody diameter from tree transect survey associated with each plot (cm at breast height) (N=7, N=4)	31.6	38.1
Soil classification (texture) (aggregate from five 1x1 m plots)	silty clay	sandy loam
% total soil nitrogen (aggregate from five 1x1 m plots)	0.38	0.28
% total soil carbon (aggregate from five 1x1 m plots)	9.81	7.61
C:N ratio (aggregate from five 1x1 m plots)	25.81	27.17
Soil pH (aggregate from five 1x1 m plots)	7.17	7.29
Mean % soil moisture (N=10) (data collected spring and summer)	16.57	7.68

Figure 19. Relative elevation profile of Transect-9 and vegetation and soil summary data for each sampling plot.

Portions of the northeast facing stream banks within the C-2 and C-3 communities are much lower in elevation with a broader and flatter profile than C-1. Flood frequency and intensity in these regions appears to be much higher as observed by obvious vegetation changes, large amounts of rafted organic debris, and the average high water mark. The increased frequency and intensity of flood deposits in these areas appears to contribute to a greater stratification of coarse-grained alluvial materials, resulting in siltier and sandier soils and a much more apparent transition of soil textures from the uplands to the stream margins. These soils also likely exhibit a less consistent soil texture over time, as they are frequently modified by flood deposits.

Soil pH ranged from 6.8 to 7.48, with lower pH soils frequently occurring in the upland communities of C-3 and higher pH soils occurring within the more frequently flooded areas of the C-2 community (Table 5).

Table 5. Soil particle size analysis results (percent composition by dry weight)

	Sample Location	pH	% Gravel	% Sand	% Silt	% Clay	Soil Classification
Community C-1	T-1/P-1 (1)	7 30	0 02	31 73	30 73	37 52	Clay Loam
	T-1/P-2 (2)	7 19	0.16	26 22	34 6	39 02	Clay Loam
	T-2/P-1 (3)	7 30	0 08	39 38	26 02	34 52	Clay Loam
	T-2/P-2 (4)	7 48	0 21	36 12	27 09	36 58	Clay Loam
	T-3/P-1 (5)	7 29	0 03	37 27	28 15	34 55	Clay Loam
	T-3/P-2 (6)	7 19	0 06	45 62	24 31	30 01	Clay Loam
Community C-2	T-4/P-1 (7)	7 06	0 03	9 74	45 25	44 98	Silty Clay
	T-4/P-2 (8)	7 35	0	33 92	31 5	34 58	Clay Loam
	T-4/P-3 (9)	7 40	0.04	43 48	21 44	35 04	Sandy Clay Loam
	T-4/P-4 (10)	7 33	0 24	57 65	4 31	37 8	Sandy Clay
	T-5/P-1 (11)	7 32	0 01	14 37	45 7	39 92	Silty Clay Loam
	T-5/P-2 (12)	7 34	0.13	31 48	31 79	36 6	Clay Loam
	T-6/P-1 (13)	7 29	0	8 63	41 3	50 07	Silty Clay
	T-6/P-2 (14)	7 45	0	5 06	46 99	47 95	Silty Clay
	T-6/P-3 (15)	7 43	0	7 07	51 76	41 17	Silty Clay
Community C-3	T-7/P-1 (16)	6 8	0 02	24 65	37 77	37 56	Clay Loam
	T-7/P-2 (17)	7 37	0 66	33 18	23 56	42 6	Clay
	T-8/P-1 (18)	7 26	0	22 59	40 72	36 69	Clay Loam
	T-8/P-2 (19)	7 08	0 18	17 94	39 74	42 14	Clay
	T-9/P-1 (20)	7 17	0 07	14 99	44 49	40 45	Silty Clay
	T-9/P-2 (21)	7 29	6 21	63 72	18 5	11 57	Sandy Loam

The total carbon and total nitrogen composition of a soil provides a depiction of the potential nitrogen availability of the soil, likelihood for nitrogen immobilization by soil microbes, and allows inferences to be made regarding nitrogen mineralization rates within the soil (Barbour et al., 1999). The percent total carbon content of soils within the study site ranged from 2.95, within community C-3, to 9.81, also within community C-3.

The percent total nitrogen ranged from 0.12, within community C-3, to 0.41, within community C-2 (Table 6).

Table 6. Percent soil total carbon and total nitrogen in each sampling plot

	Sample Location	% Total Carbon	% Total Nitrogen	C N
Community C-1	T-1/P-1 (1)	7 63	0 27	28 25
	T-1/P-2 (2)	7 44	0 2	37 2
	T-2/P-1 (3)	6 28	0 18	34 8
	T-2/P-2 (4)	6 98	0 17	41 05
	T-3/P-1 (5)	7 32	0 26	28 15
	T-3/P-2 (6)	6.94	0 16	43 37
Community C-2	T-4/P-1 (7)	8 12	0 32	25 37
	T-4/P-2 (8)	7 09	0 21	33 76
	T-4/P-3 (9)	7 91	0 23	34 39
	T-4/P-4 (10)	8 71	0 26	33 5
	T-5/P-1 (11)	7 65	0 27	28 33
	T-5/P-2 (12)	8 04	0 24	33 5
	T-6/P-1 (13)	9 32	0 41	22 73
	T-6/P-2 (14)	6 2	0 22	28 18
	T-6/P-3 (15)	6 99	0 27	25.88
Community C-3	T-7/P-1 (16)	3 38	0 16	21 25
	T-7/P-2 (17)	2 95	0 12	24 58
	T-8/P-1 (18)	6 84	0 36	19
	T-8/P-2 (19)	4 23	0 17	24 88
	T-9/P-1 (20)	9 81	0 38	25 81
	T-9/P-2 (21)	7 61	0 28	27 17

Soils with a higher percent total carbon were observed to occur more often within the C-1 and C-2 communities, with the highest value observed in the C-3 community (Figures 20 through 23). The lowest percent total carbon soils were observed within the

C-3 community (Figure 22). The percent total nitrogen of the soil followed a similar pattern; however, nitrogen concentrations were less consistent among the C-1 and C-2 communities, exhibiting slightly less nitrogen within the C-1 community soil. The ratio of percent total carbon to percent total nitrogen (C:N), therefore, exhibited a similar pattern, with the highest C:N occurring in the C-1 community and the lowest in the C-3 community (Figure 23).

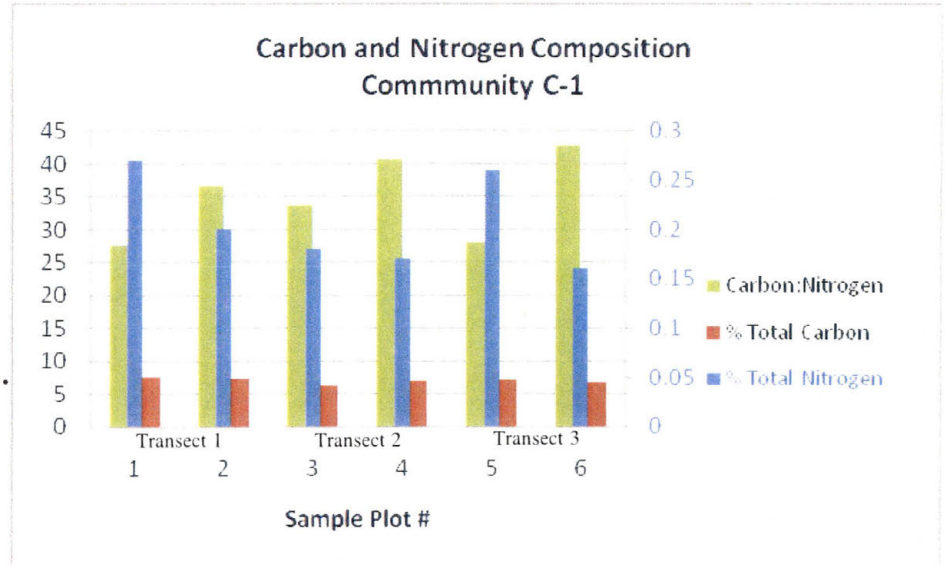


Figure 20. Comparison of percent total carbon, percent total nitrogen, and carbon:nitrogen within each nested plot in community C-1.

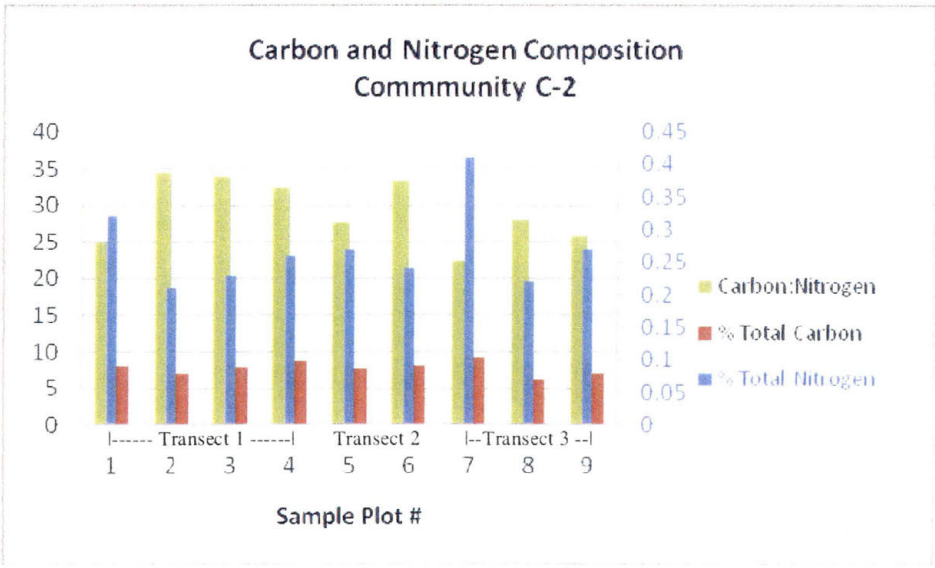


Figure 21. Comparison of percent total carbon, percent total nitrogen, and carbon:nitrogen within each nested plot in community C-2.

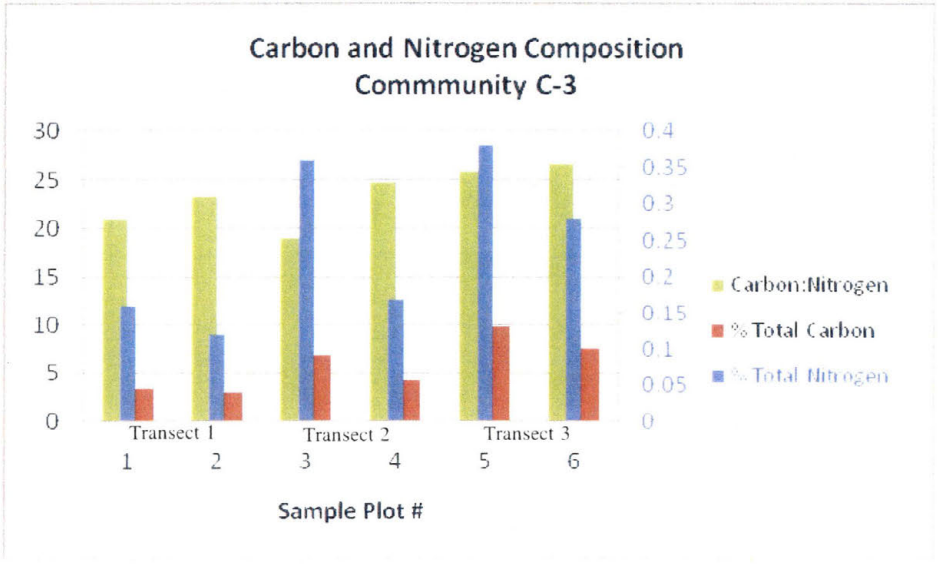


Figure 22. Comparison of percent total carbon, percent total nitrogen, and carbon:nitrogen within each nested plot in community C-3.

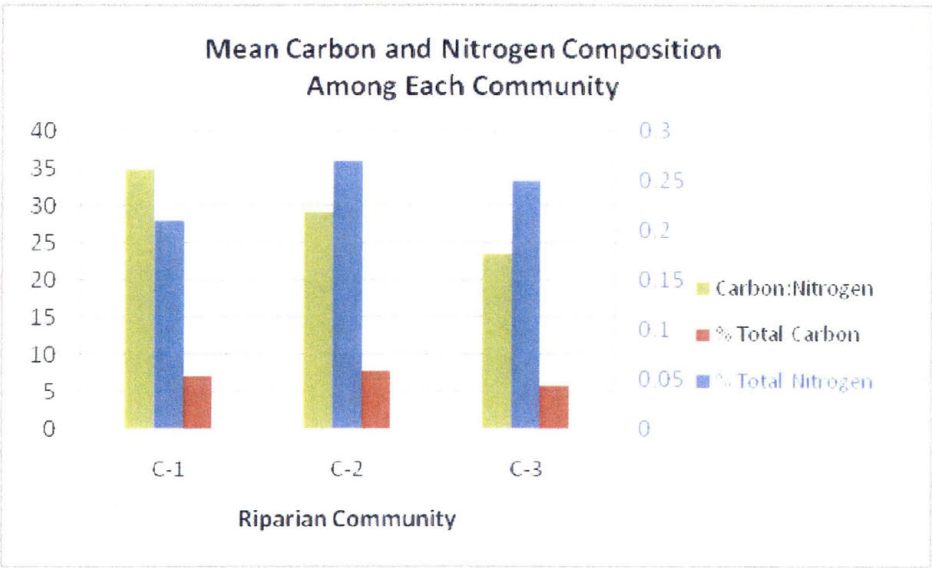


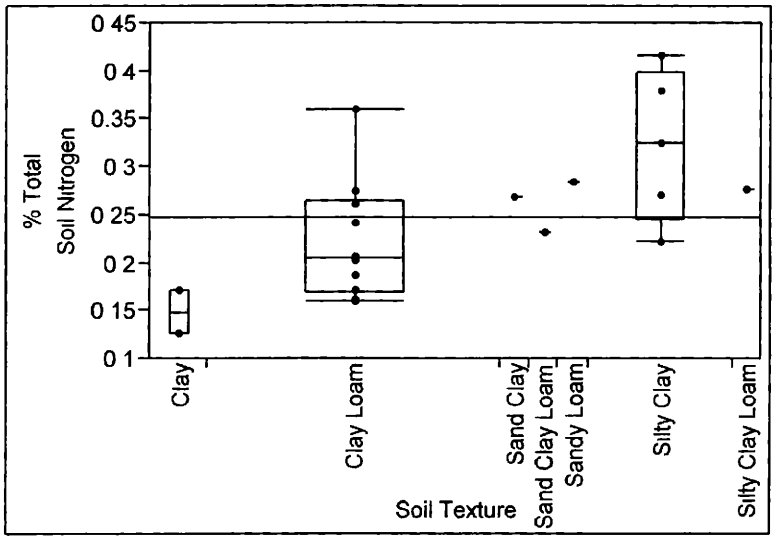
Figure 23. Comparison of mean percent total carbon, percent total nitrogen, and carbon:nitrogen values among each riparian community.

Statistical Analysis

Bivariate correlation and linear regression were used to test for differences in vegetative distribution, species richness, and soil chemistry patterns among the three defined riparian communities.

An ANOVA of percent total nitrogen in the soil in relation to soil texture indicated that silty clay soil and soil with a greater sand component exhibited greater total nitrogen composition ($f=2.15$, $df=(6,14)$, p-value=0.11, r-squared=0.47). Conversely, clay and clay loam soils were characterized by the lowest total nitrogen composition (Figure 24). Within the study area, clay and clay loam soils predominate in the upland environments outside of the immediate area of flood influence, while silty and sandy soils predominate along the stream margin and the more frequently flooded inner bank. The low nitrogen content in clay soil may be attributable to reduced or less frequent

deposition of water and sediment from flood events, which may provide additional dissolved nutrients or organic material.

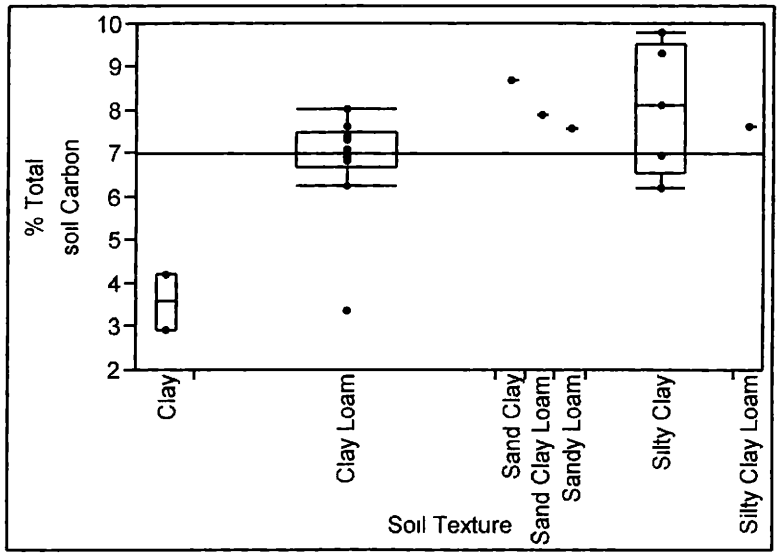


Source	DF	Mean Square	F Ratio	Prob > F
Soil Texture	6	0.001	2 15	0 11
Error	14	0 004		
C Total	20			

Figure 24. ANOVA of percent total nitrogen by soil texture, with quantile boxplots.

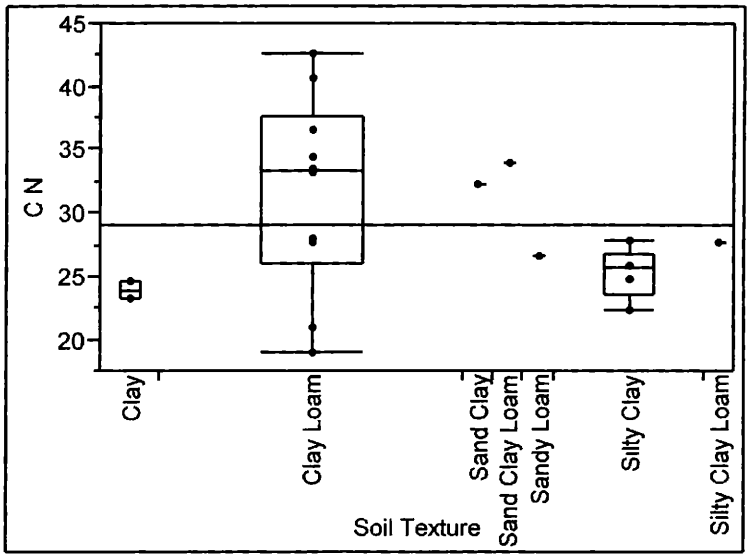
A stronger pattern than with nitrogen was observed between percent total carbon in the soil in relation to soil texture (f=3.17, df=(6,14), p-value=0.03, r-squared=0.57; Figure 25); however, a comparison of C:N to soil texture indicates lower C:N in silty soil and a relatively high C:N in clay loam soil (Figure 26). The percent total nitrogen and carbon in the upland, clay loam soil is relatively low, yet the C:N is relatively high, which could be exacerbating the conditions within an already nitrogen-deficient soil, thereby increasing the effects of nitrogen immobilization. Observation of these upland environments also indicates a higher frequency of mature tree species such as live oak and cedar elm, which could be contributing increased amounts of high C:N leaf litter

(mean upland tree density of 174.9 trees per hectare and mean basal area of 15.9 m^2/ha compared to a mean lowland/stream margin tree density of 184.8 trees per hectare and mean basal area of 21.4 m^2/ha).



Source	DF	Mean Square	F Ratio	Prob > F
Soil Texture	6	0 31	3 17	0 03
Error	14	0 003		
C Total	20			

Figure 25. ANOVA of percent total carbon by soil texture, with quantile boxplots.



Source	DF	Mean Square	F Ratio	Prob > F
Soil Texture	6	38 62	0 95	0.48
Error	14	40 27		
C Total	20			

Figure 26. ANOVA of C:N by soil texture, with quantile boxplots.

Additionally, there is a weak negative trend between the number of trees present within a sample plot and the percent total nitrogen (t=3.25, df=20, p-value=0.09, r-squared=0.15) and a non-significant positive trend between the number of trees and the percent canopy cover (t=3.7, df=20, p-value=0.87, r-squared=0.14; Figure 27). A weak negative trend was observed between the percent mean canopy cover and percent mean vegetative ground cover (t=4.14, df=20, p-value=0.06, r-squared=0.18; Figure 27). A greater density of trees within a given area may contribute to increased competition for sunlight in the understory environment and reduce the primary production of the understory communities.An increase in the number of trees would also likely contribute to a greater demand for nutrient resources in the soil, further depleting the total amount of nitrogen in the soil.

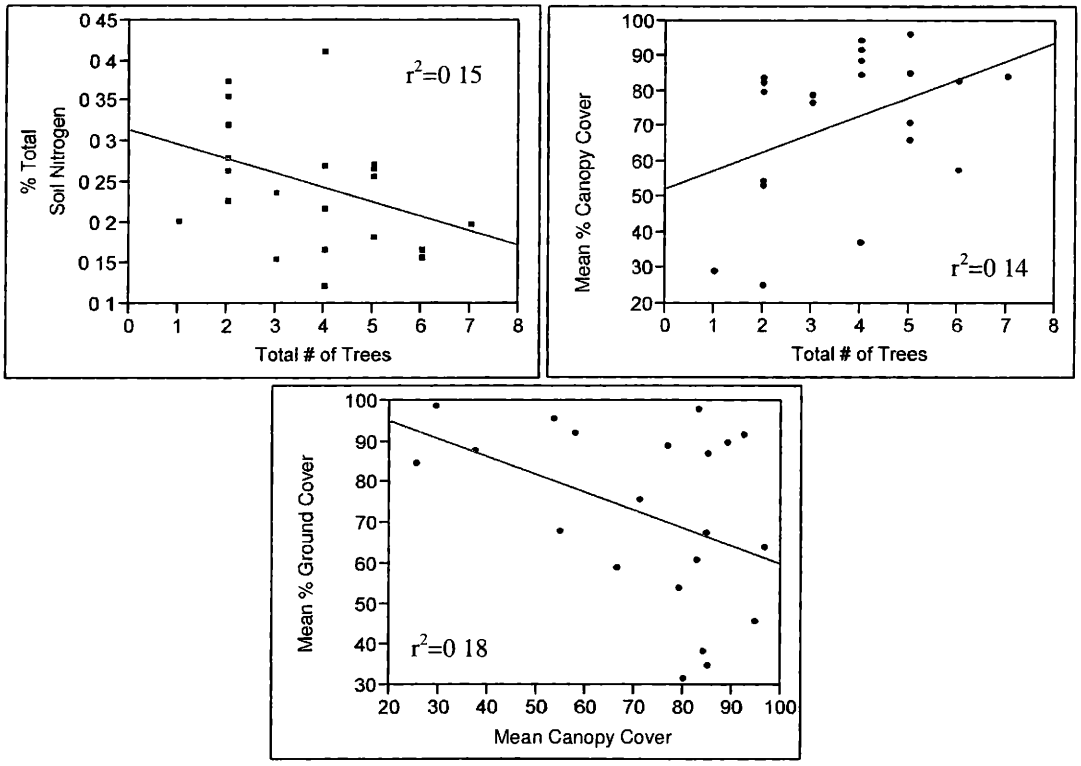


Figure 27. Bivariate regression of the total number of individual trees in relation to percent total soil nitrogen and mean percent tree canopy cover; mean percent tree canopy cover in relation to mean percent herbaceous ground cover.

There was no significant relationship between C:N and the total sampling plot plant species richness (total plot richness) (t=0.04, df=20, p-value=0.84, r-squared=0.002). An analysis of C:N in relation to shrub species richness, vine species richness, herbaceous species richness, the percent composition of woody debris, and the percent composition of bare ground all demonstrated no significant relationship with r-squared values ≤ 0.05 and p-values ≥ 0.32. However, there is a weak positive relationship between C:N and tree species richness (t=3.73, df=20, p-value=0.07, r-squared=0.16; Figure 28). An analysis of the mean percent cover by legume species, particularly honey mesquite, in relation to total soil nitrogen, soil carbon, and C:N all

yielded no significant relationship. However, the results of this analysis are likely affected by the overall lack of legume species within the study area and the vegetation sampling plots.

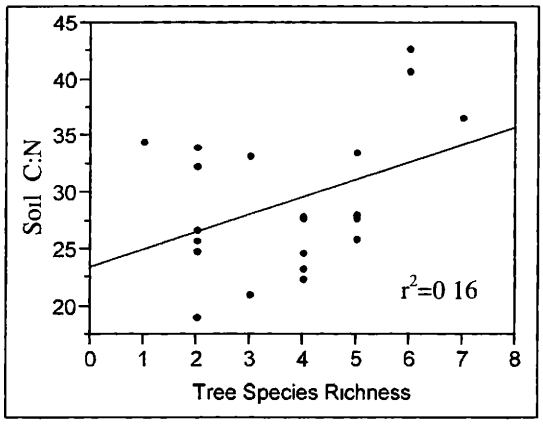


Figure 28. Bivariate regression of tree species richness per 10x10 meter plot in relation to the total soil C:N.

No significant relationship was observed between the mean percent ground cover and C:N (p-value=0.69, r-squared=0.01) or between the mean percent leaf litter and C:N (p-value=0.34, r-squared=0.04), indicating that the C:N in areas with increased tree canopy closure is not being strongly affected by an increased contribution of high C:N leaf litter. No significant relationship was observed between soil pH and total plot richness (p-value=0.71, r-squared=0.01); however, a weak positive relationship was observed between C:N and pH (t=2.59, df=20, p-value=0.12, r-squared=0.12; Figure 29).

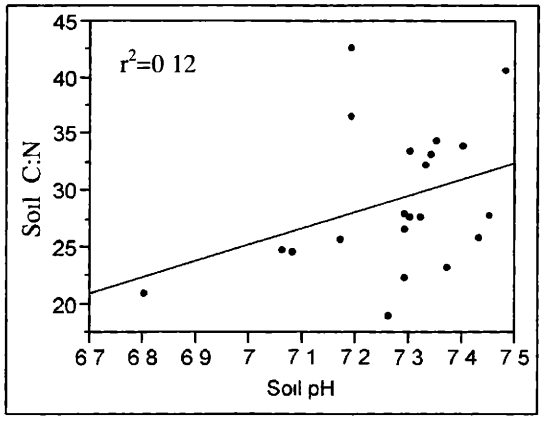
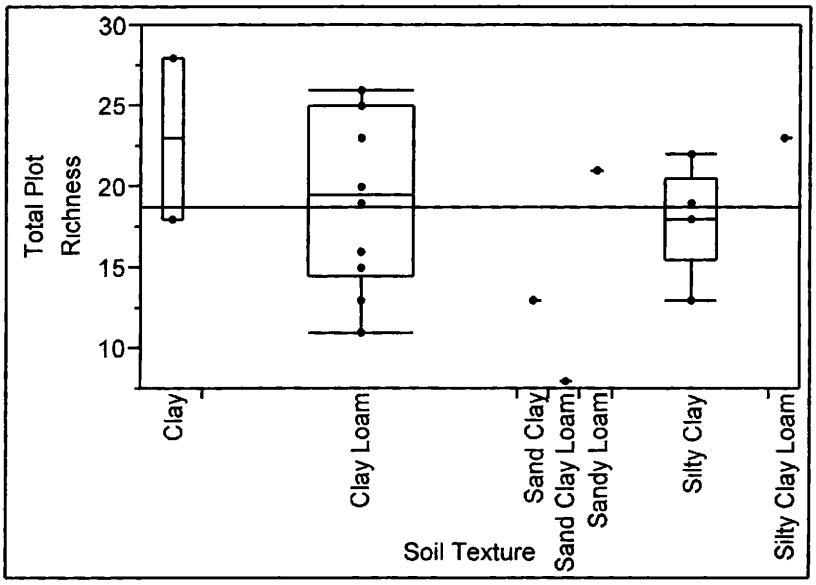


Figure 29. Bivariate regression of soil pH in relation to the total soil C:N.

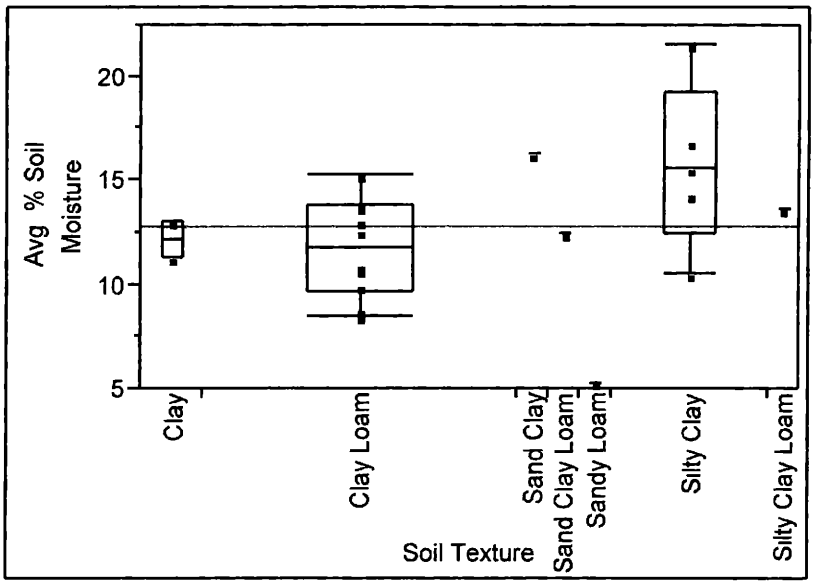
Furthermore, the lack of significant relationships among these factors suggest either the percent total nitrogen and carbon in the soil are not the driving factors in determining richness within the study area or perhaps the differences in C:N among the sites are so minimal that other factors are more directly driving the vegetative composition and structure of the area. It can then be assumed that C:N, pH, and total plot richness are not dependent upon, or predictive of, one another.

Although not statistically significant, an ANOVA of total plot richness in relation to soil texture showed highest total plot species richness in clay and clay loam soils, while sandy clay and sandy clay loam soils had the lowest total plot richness (f=1.4, df=20, p-value=0.27, r-squared=0.37; Figure 30). A comparison of the mean percent soil moisture and soil texture indicates a nearly inverse pattern to that of total plot richness (f=2.56, df=20, p-value=0.06, r-squared=0.52; Figure 31), perhaps illustrating the dominant effects of moisture availability on plant growth within the study area.



Source	DF	Mean Square	F Ratio	Prob > F
Soil Texture	6	35.61	1 4	0.27
Error	14	25 29		
C Total	20			

Figure 30. ANOVA of total plot richness by soil texture, with quantile boxplots.



Source	DF	Mean Square	F Ratio	Prob > F
Soil Texture	6	20 91	2.56	0 06
Error	14	8.15		
C Total	20			

Figure 31. ANOVA of mean percent soil moisture by soil texture, with quantile boxplots.

As more moisture is available, growing conditions improve and a few aggressive plant species are able to competitively exclude other plants, thereby dominating the area and reducing total plot richness. Examples of the more aggressive (dominant) plant species in the study area include frostweed (*Verbesina virginiana*), straggler daisy (*Calyptocarpus vialis*), Virginia wildlrye (*Elymus virginicus*), Canada wildrye (*Elymus canadensis*) and Japanese brome. For example, these five species exhibit a cumulative mean ground cover of 47.9 percent in community C-1, 26.8 percent in community C-2, and 36.3 percent in community C-3. This is further supported by a weak, negative linear relationship between percent moisture and total plot richness (t=0.64, df=20, p-value=<0.001, r-squared=0.03), where total plot richness decreases linearly as percent moisture increases (Figure 32). A maximum growth response trend could be an

alternative explanation for this occurrence, in which the total number of plant species initially increases as soil moisture increase, then peaks and begins to decrease due to competitive exclusion and the eventual dominance of specialist species in increasingly moist environments.

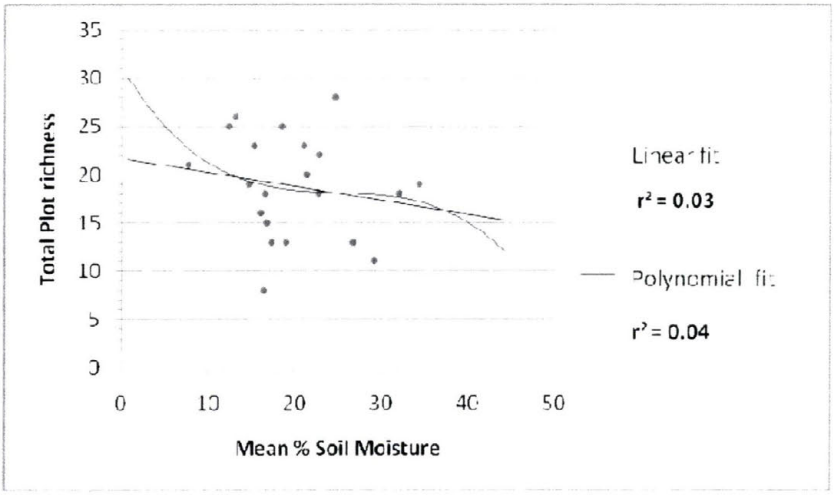


Figure 32. Bivariate regression of total plot richness by mean percent soil moisture.

There was a negative linear relationship between grass species richness and mean percent soil moisture (t=6.37, df=20, p-value=0.02, r-squared=0.21; Figure 33). No simple linear relationship was observed between mean percent soil moisture and mean maximum plant height within each sampling plot (t=3.66, df=20, p-value=0.001, r-squared=<0.001; Figure 33), but there was a positive linear relationship between the mean percent soil moisture and mean percent herbaceous ground cover (t=3.71, df=20, p-value=0.005, r-squared=0.16; Figure 33). However, these patterns could also be explained by an asymptotic growth response trend, in which the maximum plant height or ground cover increases until plants reach a plateau where plants no longer benefit from

increasing soil moisture. In this scenario, maximum plant height or cover will either stabilize and remain flat or it will decrease as plants are adversely affected by excessive soil moisture conditions. No other significant relationships were observed between plant growth and percent soil moisture.

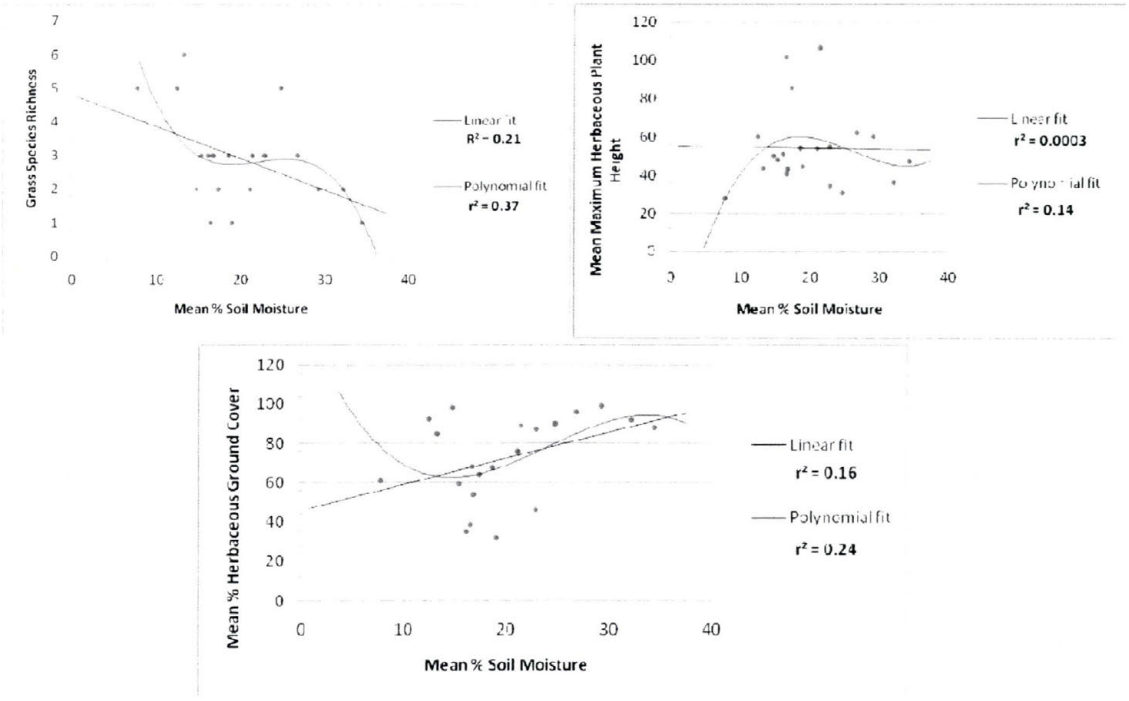


Figure 33. Bivariate regression of grass species richness by mean percent soil moisture, mean maximum plant height by mean percent soil moisture, and mean percent herbaceous ground cover by mean percent soil moisture.

Further complicating this relationship between moisture availability, soil texture, and richness is the proximity of each sampling plot to the lower elevation stream margins and, ultimately, the water table. Although many of the coarse-grained soils such as sandy loam and sandy clay have a naturally reduced ability to hold and store water, thereby contributing to their propensity for lower water content within the study area, they are

typically the product of flood water deposition. As a result, these soils are commonly located adjacent to primary stream margins and are naturally closer to sub-grade water sources, which can be more easily reached by plant root systems. This proximity to water would likely be more advantageous to shrub and herbaceous species with short taproot or fibrous root systems that would not typically be able to access deeper water sources from higher upland elevations. This proximity to water would also undoubtedly benefit tree species that often produce much longer tap roots. However, many tree species' tap roots can extend ten meters or more below the ground surface allowing them to access deeper water sources from higher upland elevations. Additionally, those soils that contain greater amounts of coarse-grained flood deposits (sandy loam and sandy clay) also have a greater percent total nitrogen and carbon, perhaps as a result of the depositional flood forces providing additional dissolved nutrients and organic matter.

Net primary production is presumably also increased in these moisture-rich environments further facilitating a positive feedback with lower C:N leaves being deposited on the surface. These increases in both water and nutrients likely contribute to better growing conditions and increased plant competition. Even though these areas typically experience more frequent and intense disturbance from flood events, the improved growing conditions likely allow a few fast-growing plant species, such as cottonwood (*Populus deltoides*), sycamore, black willow (*Salix nigra*), American elm (*Ulmus americana*), and Chinaberry (*Melia azedarach*), the ability to quickly recover, further contributing to the competitive exclusion of smaller plants. However, these frequent disturbance cycles would limit the development of large woody perennial species such as trees because they would be less capable of recovering from frequent

flood damage. Consistent with this interpretation, a greater density of small trees with low basal area was observed adjacent to the stream margin as opposed to the upland riparian boundary.

Finally, a comparison of percent tree canopy cover in relation to soil percent total nitrogen indicated a negative linear relationship (t=6.59, df=20, p-value=0.01, r-squared=0.25) where the percent total nitrogen decreased with increased canopy cover (Figure 34).

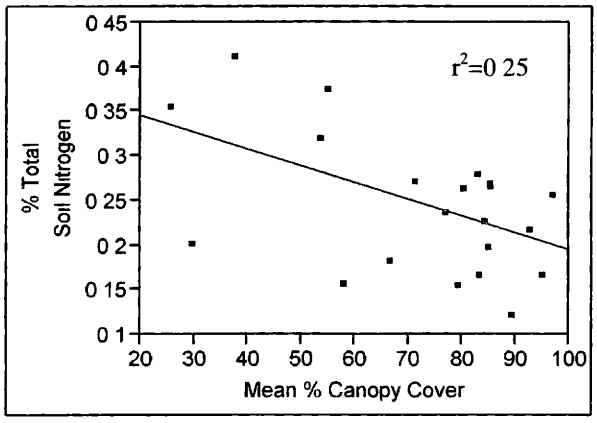


Figure 34. Bivariate regression of percent total soil nitrogen by mean percent tree canopy cover.

A similar pattern was observed in the percent total carbon (t=2.76, df=20, p-value=0.11, r-squared=0.12), but there was no significant relationship between C:N and percent canopy cover (t=0.28, df=20, p-value=0.59, r-squared=0.01; Figure 35). This result is somewhat counter-intuitive, because higher soil nitrogen content should lead to larger trees and greater canopy cover. However, a reduction in total nitrogen in response to increased canopy cover could be attributed to several factors. First, as canopy cover

increases the percent vegetative ground cover decreases (t=4.14, df=20, p-value=0.05, r-squared=0.18; see Figure 27). This reduction in herbaceous vegetation could contribute to less overall nitrogen in the soil following senescence, death, and decomposition if those herbaceous species had high overall nitrogen contents and low C:N. Second, the larger tree species that contribute to the increased canopy cover, such as burr oak, American elm, and pecan, would likely have higher C:N in their leaves. Increased carbon-rich leaf litter, particularly from semi-evergreen species such as live oak and cedar elm, may be contributing to greater soil C:N as canopy cover increases, which then increases nitrogen immobilization by soil microbes. This increased C:N in the leaves of evergreen species is due to increased amounts of carbon allocated to leaf production, in which the carbon adds rigidity and durability to the leaf for a longer period of photosynthetic productivity and resistance to environmental stresses such as heat, drought, wind, or herbivory. Third, increased canopy may be contributing relatively increased amounts of nitrogen through leaf litter, but this increase may simultaneously increase soil microbial activity, leading to nutrient immobilization that may be limiting nutrient conversion and uptake. Garten (1993) describes nitrogen as a critical limiting element to forest productivity on a mixed hardwood forest community, Walker Branch Watershed, and studies have shown that net nitrification is limited by availability of soil ammonium, which is partly controlled by heterotrophic demand for soil nitrogen. As a result, even though a system is accumulating nitrogen, nitrate immobilization by heterotrophic microbes may be limiting plant growth.

Another consideration is whether plants can affectively alter the C:N of a system by depleting or reducing the nitrogen availability within the soil through uptake demand.

In systems where nitrogen is the limiting element, larger trees such as pecan, sycamore, and American elm would require larger amounts of soil nitrogen to sustain their growth, thereby utilizing much of the available nitrogen in the soil. In essence, these forested communities could be taking up available nitrogen faster than they, or other plants, are returning nitrogen to the system through leaf litter or root mortality.

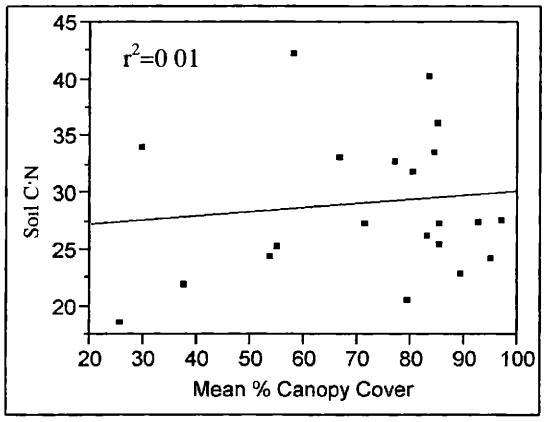


Figure 35. Bivariate regression of soil C:N by mean percent tree canopy cover.

CHAPTER IV

SUMMARY

A study by Margules et al. (1987) showed that complex patterns of species richness in relation to environmental gradients emerge when multiple environmental variables are evaluated simultaneously. Although multiple factors influence a particular ecological dynamic, it is reasonable to suggest that specific factors within a given ecosystem may have a greater degree of importance in the development of plant communities, many of which may change temporally or spatially, such as moisture availability, nutrient availability, and disturbance (Mittlebach et al., 2001). Huston and Smith (1987) showed that a single mechanism of interaction such as competition for light resources could result in a wide variety of successional patterns. However, Garten (1978) suggests the measurement of soil nutrient concentrations often inadequately delimits ecological niches because nutrient composition of the substrate sometimes fails to reflect the manner in which plant species utilize nutrient resources due to physiological mechanisms that differentially absorb or exclude elements.

Pastor and Post (1986) view geomorphology, soil texture, and climate as constraints within which feedbacks between vegetation and light or nitrogen availabilities operate. Those geologic and climatic factors constrain the feedback scenarios by affecting plant and microbial physiology, thereby affecting species composition. Therefore, interactions between demographic plant processes, microbial processes,

climatic factors, and geologic factors should explain much of the observed variation in ecosystem carbon and nitrogen storage and cycling. Yet these interactions are often difficult to distinguish. A study conducted by Gauch and Whittaker (1972) was unable to recognize patterns of species richness along environmental gradients, while a study by Grime (1973) was able to demonstrate a strong relationship between species richness and soil pH (Austin and Smith, 1989). However, plants incur physiological tradeoffs for the ability to survive and reproduce under environmental conditions considered intolerable to other plant species. If water and light availability are two resources that often limit plant growth (Smith and Huston, 1989) and these two resources vary greatly on spatial and temporal scales, the consequences of constraints on the simultaneous use of light and water by individual plants can be expected to explain a large proportion of the variation in plant community structure over a range of those scales.

Garten et al. (1999) describes several limitations to the study of soil nutrient composition and resource gradients. Among them, the range of environmental differences along a gradient may be too narrow for making confident predictions through extrapolation. Farley and Fitter (1999) also indicate that environmental heterogeneity would only affect plant growth if it occurs at scales that are relevant to, and detectable by, plants. The smallest scale of significant nutrient heterogeneity measured by Roberston et al. (1993) was 7 m, which was considered perceptible to the roots of trees and shrubs, but insignificant to smaller herbaceous plants. The temporal characteristics of nutrient heterogeneity are also important, whereas heterogeneity that occurs at small scales or for short periods of time may not elicit a morphological or compositional response from plants (Farley and Fitter, 1999; Robinson, 1996). Woodlands have also been described as

large nutrient sinks, in which their mycorrhizal networks may be effectively closing the mineral nutrient cycle (Grime, 1991), and in a particular study, Goss et al. (1995) found that soil nitrogen was six times lower in a woodland site than a newly abandoned field. Farley and Fitter (1999) ultimately concluded that the nutrient-rich patches in their study were short-lived, and plants must be able to respond quickly if they are to exploit the nutrients available during this period.

An initial visual observation of the study area suggests a moderate compositional change in vegetation between the three defined communities, with C-1 exhibiting the greatest species richness (50 species); C-2 exhibiting an intermediate species richness (49 species; 46 species – area adjusted [SD=2.6, 95% CI=2.1, lower CI=43.5, upper CI=47.7]); and C-3 exhibiting the lowest species richness (42 species). While C-1 is characterized by a relatively dense tree canopy structure and understory community (78.7 percent mean canopy cover and 70.9 percent mean vegetative ground cover), C-2 is characterized by a relatively open canopy structure with an open understory of dense grasses and forbs (62.4 percent mean canopy cover and 77.3 percent mean vegetative ground cover). Community C-3 is characterized by a moderately dense canopy structure with an open understory of grasses and small forbs (65.6 percent mean canopy cover and 64.8 percent mean vegetative ground cover).

Changes in soil texture are attributable to the proximity of sampling plots to perennial stream flow and subsequent alluvial deposition over time. Heavier clay soils tend to predominate in the outer bank and upland environments, while loamy and sandy soils predominate in backwater flooded environments and closer to the stream margin. Total nitrogen and total carbon content is higher in C-1 and C-2, likely due to

depositional flood forces, which deposit rafted organic debris and dissolved nutrients as well as alluvial sediments. Net primary production is also increased in these moisture-rich environments due to a greater abundance of available resources, further facilitating a positive feedback by creating more plants that contain higher nitrogen content and lower C:N leaves, which are ultimately deposited in the surface litter. Litter decomposition rates would be expected to be accelerated by enhanced microbial growth and activity due to the organic chemical quality of the litter and exogenous nutrient deposition, further fueling the NPP positive feedback cycle (McClaugherty, Pastor, and Aber, 1985).

It appears as though what is really driving the nitrogen and, to some degree carbon, composition in the soil is the deposition of flood water sediments and the resultant increase in NPP. Increased canopy cover appears to have a secondary effect on nitrogen and carbon by facilitating the NPP/C:N feedback cycle, which is perhaps an overall effect that is reduced in areas adjacent to the river due to a more frequent and accessible supply of moisture and deposited nutrients, leading to lower C:N. The wooded upland environments experience reduced flood deposition, as well as reduced nitrogen, perhaps from these secondary effects and reduced overall NPP. Although the upland clay soils have the physical potential to hold more moisture than other areas, they are further away from the stream margin and the water table. The reduced water and nutrient availability paired with reduced flood disturbance together produce rather poor to moderate growing conditions and lower overall NPP, with higher C:N in the leaves and soil. According to the Dynamic Equilibrium theory, these conditions should lead to increased plant species richness when compared to similar locations within the study area that have improved growing condition (Huston, 1994). Likewise, locations with sandy or

silty soils are characterized by greater total nitrogen and carbon due to their proximity to flood deposits. Although sandy and silty soils have less physical potential to hold and store water, they tend to occur closer to the water table (river margin) and, paired with the elevated nitrogen content, produce better growing conditions. As a result, these areas tend to be characterized by reduced total plot richness.

Flood disturbance is perhaps having a secondary effect on richness by occasionally removing some plants and preventing slower growing or less resilient species from becoming established. However, due to the improved growing conditions afforded by the deposition of nutrient rich sediments, most fast-growing plant species have the ability to quickly recover, further contributing to the competitive exclusion of less competitive plants until the next flood event.

Therefore, the most important factor in plant species richness and composition within the study area appears to be moisture availability, which is somewhat expected in the moderately xeric, moisture-limited environment of the study area. As described by Farley and Fitter (1999), the morphological or compositional effects of soil micronutrient variability are so minor between the communities, that moisture availability seems to play a more observable/dominant/apparent role in the community compositional dynamics. For example, reduced moisture availability is likely the primary force in reducing growing conditions in the C-3 community. The limited amount of alluvial deposits in the soil further suggests that this community receives very little floodwater nutrient or sediment deposition. Growing conditions are then further reduced by limited outside nutrient deposition and reduced NPP, resulting in lower species richness (Figure 36).

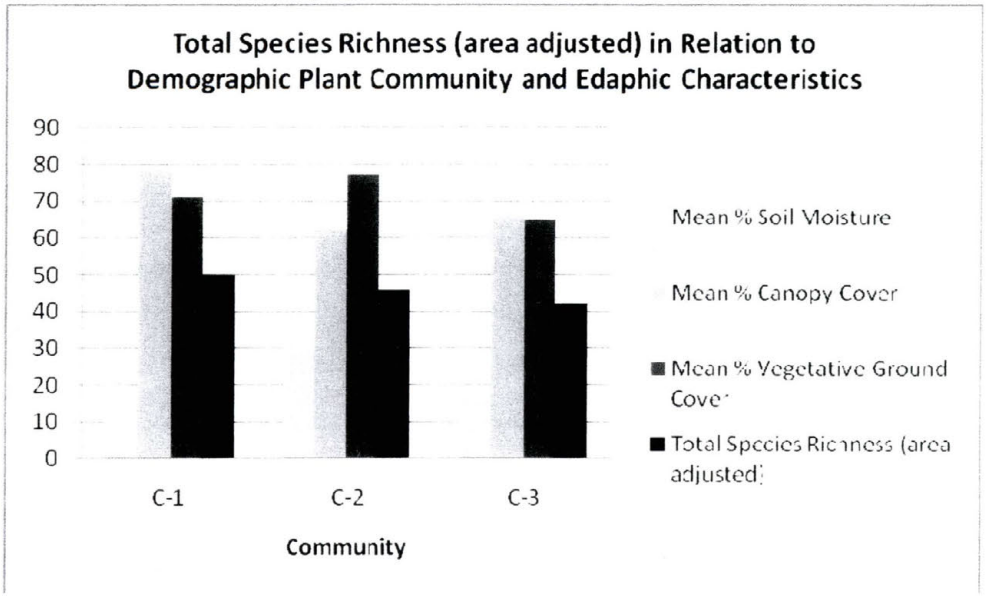


Figure 36. Graph of total species richness (area adjusted) in relation to the mean percent soil moisture, mean percent canopy cover, and mean percent vegetative ground cover among the three riparian communities within the study area.

As stated earlier, an interesting concept is whether the interconnection of streams and tributaries within a drainage basin facilitates sympatric community structure and development, or if these systems host distinctly different floras as a result of differing channel morphology, hydraulic regime, substrate composition, and intensity of disturbance, among other factors (Nilsson et al., 1994). Individual species occurrence seems relatively uniform among the three communities, with only minor exceptions such as pecan trees, beebrush (a shrub species), and a few herbaceous species. Wind is likely capable of transporting small seeds the short distance between the perennial and intermittent corridors, and small mammals and avian species likely utilize all three habitats with only minor variation. As a result, seed dispersion limitations are not expected to play a primary role in community composition within the study area. The seed bank is anticipated to remain relatively consistent from year to year, which further

suggests community composition is primarily derived from germination success based upon moisture and nutrient availability and modified by disturbance events, competition, and survival. According to (Smith and Huston, 1989), disturbances can have very different affects at different points along a resource gradient due to a variety of fundamental strategies (functional type) for resources utilized by plants. Although plants grow best with abundant light, water, and nutrient resources, plants are rarely most abundant in natural communities under their physiological optimum due to competition from other plant species and the rate at which they recover from a disturbance event.

Finally, this study may have some implications for ecological, or habitat, restoration. As a growing issue in natural resources management, ecological restoration is often centered on riparian systems, which can be highly disturbed as a result of agriculture, urbanization, and poor watershed management. It has been surmised that it would be foolish to consider only one factor when trying to understand the reason for a particular ecological assemblage (Kendeigh, 1954). However, by better understanding the limiting resources on plant development within an ecosystem we can better evaluate the needs for native plant community reconstruction and successful restoration. Although it may be cost prohibitive to engage in this level of environmental analysis on small scale restoration efforts, continued research may enable practitioners to more efficiently isolate the limiting resources within an environment and steer their efforts in a successful direction. Even more, by studying the environmental constraints on plant community composition in multiple ecosystems with similar plant assemblages, it could be possible to predict the ultimate success of individual plant species, with a statistical degree of confidence, based upon select localized parameters such as soil texture, C:N, nitrogen

mineralization rates, or a unique combination of these. Through the development of a predictive model focused solely on predicting the suitability and success of particular plant species or communities within a given streamshed or geomorphological environment, perhaps these efforts could even go as far as to predict the optimum vegetation planting density and compositional structure to ensure rapid habitat assimilation and climax development of these revegetated communities.

APPENDIX I

Appendix 1: Catalogue of Vascular Flora

Division	Family	Species	Voucher	Native/Non-Native	Growth Form
Magnoliophyta (dicots)					
	Apiaceae	*Chaerophyllum tainturieri* Hook	Henson 30	Native	A, H
		Conium maculatum L	Henson 275	Non-Native	B, H
		Coriandrum sativum L	Henson 135	Non-Native	A, H
	Aquifoliaceae	*Ilex decidua* Walter	Henson 136	Native	P, S
	Asclepiadaceae	*Matelea biflora* (Raf) Woodson	Henson 237	Native	P, H
	Asteraceae	*Achillea millefolium* L	Henson 163	Native	P, H
		Ambrosia psilostachya DC	Henson 277	Native	P, H
		Aster ericoides L	Henson 282	Native	P, H
		Aster praealtus Poir	Henson 267	Native	P, H
		Calyptocarpus vialis Less	Henson 45	Native	P, H
		Centaurea melitensis L	Henson 131	Non-Native	A, H
		Cirsium texanum Buckley	Henson 227	Native	B, P, H
		Coreopsis wrightii (A Gray) H M Parker	Henson 248	Native	A, H
		Erigeron philadelphicus L	Henson 46	Native	P, H
		Eupatorium altissimum L	Henson 255	Native	P, H
		Gutierrezia texana (DC) Torr & A Gray	Henson 283	Native	A, H
		Helenium amarum (Raf) H Rock	Henson 210	Native	A, H
		Parthenium hysterophorus L	Henson 240	Native	A, H
		Ratibia columnifera (Nutt) Wooten & Standl	Henson 238	Native	P, H
		Silybum marianum (L) Gaertn	Henson 202	Non-Native	A, P, H
		Solidago gigantea L	Henson 275	Native	P, H
		Sonchus oleraceus L	Henson 254	Non-Native	A, H
		Verbesina encelioides (Cav)& Hook ex A Gray	Henson 256	Native	A, H
		Verbesina virginica L	Henson 257	Native	P, H
		Viguiera dentata (Cav) Spreng	Henson 276	Native	P, H
	Berberidaceae	*Berberis trifoliolata* Moric	Henson 47	Native	P, S
	Boraginaceae	*Buglossoides arvensis* (L) I M Johnst	Henson 29	Non-Native	A, H
	Brassicaceae	*Capsella bursa-pastoris* (L) Medik	Henson 26	Non-Native	A, H
		Descurainia pinnata (Walter) Britton	Henson 42	Native	A, H
		Erucastrum gallicum (Willd) O E Schulz	Henson 132	Non-Native	A, H
		Erysimum repandum L	Henson 51	Non-Native	A, H
		Lepidium austrinum Small	Henson 124	Native	A, H
		Myagrum perfoliatum L	Henson 36	Non-Native	A, H
		Rapistrum rugosum (L) All	Henson 28	Non-Native	A, H
		Rorippa sessiliflora (Nutt) Hitchc	Henson 266	Native	A, H
		Sisymbrium irio L	Henson 41	Non-Native	A, H
	Cactaceae	*Opuntia engelmannii* var *lindheimeri* (Engelm) Parfitt & Pinkava	Henson 283	Native	P, S
		Opuntia leptocaulis DC	Henson 284	Native	P, S
	Caprifoliaceae	*Sambucus nigra* (L) var *canadensis* (L) Bolli	Henson 250	Native	P, S
	Caryophyllaceae	*Stellaria media* (L) Vill	Henson 27	Non-Native	A, H
	Chenopodiaceae	*Chenopodium ambrosioides* L	Henson 269	Non-Native	A, P, H
		Chenopodium simplex (Torr) Raf	Henson 249	Native	A, H
	Cornaceae	*Cornus drummondii* C A Mey	Henson 199	Native	P, S

Division	Family	Species	Voucher	Native/Non-Native	Growth Form
	Euphorbiaceae	*Euphorbia dentata* Michx.	Henson 260	Native	A, H
		Ricinus communis L.	Henson 278	Non-Native	A, H
		Tragia betonicifolia Nutt.	Henson 133	Native	P, H
	Fabaceae	*Amorpha fruticosa* L.	Henson 200	Native	P, S
		Lupinus texensis Hook.	Henson 74	Native*	A, H
		Medicago arabica (L.) Huds.	Henson 123	Non-Native	A, H
		Medicago minima (L.) L.	Henson 70	Non-Native	A, H
		Medicago polymorpha L.	Henson 50	Non-Native	A, H
		Mimosa aculeaticarpa Ortega var. *biuncifera* (Benth.) Barneby	Henson 230	Native	P, S
		Prosopis glandulosa Torr.	Henson 287	Native	P, T
		Sesbania herbacea (Mill.) McVaugh	Henson 271	Native	A, H
		Sophora affinis (Ortega) Lag. ex DC.	Henson 128	Native	P, T
	Fagaceae	*Quercus fusiformis* Small	Henson 40	Native	P, T
		Quercus macrocarpa Michx.	Henson 121	Native	P, T
	Fumariaceae	*Corydalis curvisiliqua* Engelm.	Henson 39	Native	A, H
	Geraniaceae	*Erodium cicutarium* L.	Henson 37	Non-Native	A, B, H
		Erodium texanum A. Gray	Henson 52	Native	A, B, H
		Geranium texanum (Trel.) A. Heller	Henson 79	Native	A, H
	Hydrophyllaceae	*Phacelia congesta* Hook.	Henson 198	Native	A, B, H
		Phacelia patuliflora Engelm. & A. Gray	Henson 122	Native	A, H
	Juglandaceae	*Carya illinoinensis* (Wangenh.) K. Koch	Henson 127	native	P, T
	Lamiaceae	*Lamium amplexicaule* L.	Henson 35	Non-Native	A, H
		Marrubium vulgare L.	Henson 129	Non-Native	P, H
		Salvia farinacea Benth.	Henson 211	Native	P, H
		Salvia reflexa Hornem.	Henson 239	Native	A, H
	Lythraceae	*Ammannia coccinea* Rottb.	Henson 273	Native	A, H
	Malvaceae	*Abutilon fruticosum* Guill. & Perr.	Henson 262	Native	P, H
		Callirhoe leiocarpa R. F. Martin	Henson 286	Native	A, H
		Hibiscus moscheutos L. susbp. *lasiocarpos* (Cav.) Blanch.	Henson 268	Native	P, H
		Sphaeralcea coccinea (Nutt.) Rydb.	Henson 226	Native	P, H
	Moraceae	*Maclura pomifera* (Raf.) C.K. Schneid.	Henson 130	Native	P, T
		Morus alba L.	Henson 73	Non-Native	P, T
	Oleaceae	*Forestieria pubescens* var. *pubescens* Nutt.	Henson 32	Native	P, S
		Menodora heterophylla Moric. ex DC.	Henson 56	Native	P, H
	Onagraceae	*Gaura suffulta* Engelm. ex A. Gray	Henson 138	Native	A, H
	Oxalidaceae	*Oxalis corniculata* L.	Henson 55	Native	P, H
	Papaveraceae	*Argemone albiflora* Hornem.	Henson 118	Native	A, B, H
	Pedaliaceae	*Proboscidea louisianica* (Mill.) Thell.	Henson 280	Native	A, H
	Phytolaccaceae	*Phytolacca americana* L.	Henson 279	Native	A, H
		Rivina humilis L.	Henson 252	Native	P, H
	Plantaginaceae	*Plantago rhodosperma* Decne.	Henson 126	Native	A, H
	Platanaceae	*Platanus occidentalis* L.	Henson 119	Native	P, T
	Polygonaceae	*Polygonum punctatum* Elliott	Henson 274	Native	A, P, H
	Ranunculaceae	*Anemone berlandieri* Pritz.	Henson 53	Native	P,H
		Clematis pitcheri Torr. & A. Gray	Henson 77	Native	P, V
		Delphinium carolinianum var. *carolinianum* Walter	Henson 196	Native	P, H

Division	Family	Species	Voucher	Native/Non-Native	Growth Form
	Rhamnaceae	*Condalia hookeri* M C Johnst	Henson 117	Native	P, S
	Rosaceae	*Crataegus mollis* Scheele	Henson 71	Native	P, T
		Prunus mexicana S Watson	Henson 33	Native	P, T
		Rubus riograndis L H Bailey	Henson 120	Native	P, S
	Rubiaceae	*Galium aparine* L	Henson 38	Native	A, H
	Rutaceae	*Ptelea trifoliata* L	Henson 195	Native	P, S
	Sapindaceae	*Sapindus saponaria* L var *drummondii* (Hook & Arn) L D Benson	Henson 236	Native	P, T
		Ungnadia speciosa Endl	Henson 78	Native	P, T
	Sapotaceae	*Sideroxylon lanuginosum* Michx subsp *oblongifolium* (Nutt) T D Penn	Henson 258	Native	P, T
	Scrophulariaceae	*Veronica peregrina* var *xalapensis* L	Henson 209	Native	A, H
	Solanaceae	*Capsicum annuum* var *glabriusculum* (Dunal) Heiser & Pickersgill	Henson 265	Native	P, S
		Margaranthus solanaceus Schltdl	Henson 264	Native	A, H
		Nicotiana repanda Willd	Henson 270	Native	A, H
		Physalis pubescens L var *integrifolia* (Dunal) Waterf	Henson 263	Native	A, H
		Physalis virginiana Mill	Henson 243	Native	P, H
		Solanum elaeagnifolium Cav	Henson 140	Native	P, H
		Solanum triquetrum Cav	Henson 139	Native	P, H
	Ulmaceae	*Celtis laevigata* Willd	Henson 69	Native	P, T
		Ulmus americana L	Henson 34	Native	P, T
		Ulmus crassifolia Nutt	Henson 253	Native	P, T
	Urticaceae	*Parietaria pensylvanica* var *obtusa* (Rhybd ex Small) Shinners	Henson 141	Native	A, H
		Urtica chamaedryoides Pursh	Henson 68	Native	A, H
	Valerianaceae	*Valerianella woodsiana* (Torr & A Gray) Walp	Henson 125	Native	A, H
	Verbenaceae	*Aloysia gratissima* (Gillies & Hook) Tronc	Henson 201	Native	P, S
		Glandularia pumila (Rhydb)	Henson 31	Native	A, H
		Verbena brasiliensis Velloso	Henson 246	Non-Native	P, H
	Viscaceae	*Phoradendron tomentosum* (DC) Engelm ex A Gray	Henson 48	Native	P, He
	Vitaceae	*Parthenocissus quinquefolia* (L) Planch	Henson 241	Native	P, V
		Vitis monticola Buckley	Henson 197	Native	P, V
Magnoliophyta (monocots)			Henson		
	Bromeliaceae	*Tillandsia recurvata* (L) L	Henson 282	Native	P, E
	Commelinaceae	*Commelina communis* L	Henson 245	Non-Native	A, H
	Cyperaceae	*Carex cephalophora* Muhl ex Willd	Henson 137	Native	P, H
		Cyperus odoratus L	Henson 272	Native	A, P, H
		Eleocharis microcarpa Torr	Henson 75	Native	A, H
	Liliaceae	*Allium drummondii* Regel	Henson 142	Native	P, H
	Poaceae	*Bromus catharticus* Vahl	Henson 49	Non-Native	A, H
		Bromus japonicus Thunb ex Murray	Henson 72	Non-Native	A, H
		Coelorachis cylindrica (Michx) Nash	Henson 205	Native	P, H
		Elymus canadensis L	Henson 44	Native	P, H
		Elymus virginicus L	Henson 233	Native	P, H
		Festuca versuta Beal	Henson 54		P, H
		Hordeum vulgare L	Henson 204	Non-Native	A, H
		Lolium perenne L subsp *multiflorum* (Lam) Husn	Henson 235	Non-Native	A, P, H
		Melica nitens (Scribn) Nutt ex Piper	Henson 207	Native	P, H
		Nassella leucotricha (Trin & Rupr) Barkworth	Henson 208	Native	P, H

Division	Family	Species	Voucher	Native/Non-Native	Growth Form
		Panicum sphaerocarpon Elliott	Henson 206	Native	P, H
		Paspalum laeve var *laeve* Michx	Henson 228	Native	P, H
		Setaria scheelei (Steud) Hitchc	Henson 251	Native	P, H
		Sorghum halepense (L) Pers	Henson 242	Non-Native	P, H
	Smilacaceae	*Smilax bona-nox* L	Henson 284	Native	P, V
Pinophyta			Henson		
	Cupressaceae	*Juniperus ashei* J Buchholz	Henson 285	Native	P, T
Pteridophyta			Henson		
	Marsileaceae	*Marsilea vestita* Hook & Grev subsp *tenuifolia* (Engelm ex A Braun) D M Johnson	Henson 281	Native	H

A - annual
B - biennial
E - epiphyte
H - herb
He - hemiparasite
P - perennial
S - shrub
T - tree
V - vine
*Denotes Texas endemic

LITERATURE CITED

Austin, M, and Smith, T. 1989. A new model for the continuum concept. *Vegetatio*, Vol. 83, No. 1/2:35-47

Barbour, M.G., Burk, J.H., Pitts, W.D., Gilliam, F.S., Schwartz, M.W. 1999. *Terrestrial plant ecology*, Third Edition. Benjamin/Cummings, Menlo Park, California

Diamond, D., Riskind, D., and Orzell, S. 1987. A framework for plant community classification and conservation in Texas, *The Texas Journal of Science*, Vol. 39, No. 3: 203-221

Diamond, D. 1993. Plant Communities of Texas. Texas Natural Heritage Program, Texas Parks and Wildlife Department, Austin

Diggs, G., Lipscomb, B., and O'Kennon, R. 1999. *Shinner's and Mahler's illustrated flora of north central Texas*, First Edition. Botanical Research Institute of Texas, Fort Worth, Texas

Farley, R. and Fitter, A. 1999. Temporal and spatial variation in soil resources in a deciduous woodland. *Journal of Ecology*, Vol. 87: 688-696

Garten, C. 1978. Multivariate perspectives on the ecology of plant mineral element composition, *The American Naturalist*, Vol. 112, No. 985: 533-544

Garten, C. 1993. Variation in foliar 15N abundance and the availability of soil nitrogen on Walker Branch Watershed, *Ecology*, Vol. 74, No. 7: 2098-2113

Garten, C., Post, W., Hanson, P., and Cooper, L. 1999. Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian Mountains, *Biogeochemistry*, Vol. 45, No. 2: 115-145

Gauch, H, and Whittaker, R. 1972. Coenocline simulation. *Ecology*, 53: 446-51

Gee, G. W. and Or, D. 1996. *Methods of soil analysis, part three: chemical methods*, Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin

Gould, F. 1975. *Texas plants – a checklist and ecological summary*, Third Edition. Texas Agricultural Experiment Station, Texas A&M University, College Station, Texas

Griffith, G., Bryce, S., Omernik, J., Comstock, J., Rogers, A., Harrison, B., Hatch, S., and Bezanson, D. 2004. Ecoregions of Texas (color poster map, descriptive text, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:2,500,000)

Grime, J. 1973. Control of species density in herbaceous vegetation. *Journal of Environmental Management*, 1: 151-167

Grime, J. 1991. The role of plasticity in exploiting environmental heterogeneity, *Exploration of Environmental Heterogeneity by Plants* (eds M.M. Caldwell and R. Peracy), pp. 2-19, Academic Press, London, UK

Grime, J. 2002. *Plant strategies, vegetation processes, and ecosystem properties*, Second Edition. John Wiley and Sons, Chichester, UK

Gross, K., Pregitzer, K. and Burton, A. 1995. Spatial variation in nitrogen availability in three successional plant communities, *Journal of Ecology*, Vol. 83: 357-368

Goodson, J., Gurnell, A., Angold, P., and Morrissey, I. 2001. Riparian seed banks: structure, process, and implications for riparian management, *Progress in Physical Geography*, Vol. 24, No. 3: 301-32

Holland, M., Risser, P., and Naiman, R. 1991. *Ecotones: the role of landscape boundaries in the management and restoration of changing environments*, Chapman & Hall, New York, New York

Huston, M. 1979. A general hypothesis of species diversity. *American Naturalist*, Vol. 113, No. 1: 81-101

Huston, M. 1980. Soil nutrients and tree species richness in Costa Rican forests, *Journal of Biogeography*, Vol. 7, No. 2: 147-157

Huston, M. and Smith, T. 1987. Plant succession: life history and competition. *American Naturalist*, 130: 160-198

Huston, M. 1994. *Biological diversity: the coexistence of species on changing landscapes*, Cambridge University Press, New York, New York

Kendeigh, S. C. 1954. History and evaluation of various concepts of plant and animal communities in North America. *Ecology*, Vol. 35, No. 2: 152-17

Lyndon B. Johnson School of Public Affairs. 1978. The Natural Heritage Policy Project, *Preserving Texas' Natural Heritage*, The University of Texas at Austin, Policy Research Project Report, No. 31

Margules, C., Nicholls, A, and Austin, M. 1987. Diversity of *Eucalyptus* species predicted by a multi-variable environmental gradient. *Oecologia*, 71: 229-332

McClaugherty, C, Pastor, J, and Aber, J. 1985. Forest litter decomposition in relation to soil nitrogen dynamics and litter quality. *Ecology*, Vol. 66, No. 1: 266-275

Mittelbach, G., Steiner, C., Scheiner, S., Gross, K., Reynolds, H., Waide, R., Willig, M., Dodson, S., and Gough, L. 2001. What is the observed relationship between species richness and productivity? *Ecology*, Vol. 82, No. 9: 2381-2396

Naiman, R., Decamps, H., and Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity, *Ecological Applications*, Vol. 3, No. 2: 209-212

Nilsson, C., Ekblad, A., Dynesius, M., Backe, S., Gardfjell, M., Carlberg, B., Hellqvist, S., and Jansson, R. 1994. A comparison of species richness and traits of riparian plants between a main river channel and its tributaries. *Journal of Ecology*, 82: 281-295

Pastor, J, and Post, W. 1986. Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. *Biogeochemistry*, Vol. 2: 3-27

Pausas, J. and Austin, M. 2001. Patterns of plant species richness in relation to different environments: an appraisal, *Journal of Vegetation Science*, Vol. 12, No. 2: 153-166

Robertson, G., Crum, J., and Ellis, B. 1993. The spatial variability of soil resources following long-term disturbance. *Oecologia*, Vol. 96: 451-456

Robinson, D. 1996. Resource capture by localized root proliferation: why do plants bother? *Annals of Botany*, Vol. 77: 179-185

Sandlin, G. 1980. Geology of the Llano Region. West Texas Geological Society Guidebook to the Annual Fieldtrip, Publication 80-73, Midland, Texas

Smith, T. and Huston, M. 1989. A theory of the spatial and temporal dynamics of plant communities. *Vegetatio*, Vol. 83, No. 1/2: 49-69

Soil Survey Division Staff. 1982. *Soil Survey for San Saba County, Texas*. United States Department of Agriculture, Soil Conservation Service, U.S. Government Printing Office, Washington, D.C.

Soil Survey Division Staff. 1993. *Soil Survey Manual.* Soil Conservation Service. United States Department of Agriculture Handbook 18, U.S. Government Printing Office, Washington, D.C.

Tilman, D. 1984. Plant dominance along an experimental nutrient gradient. *Ecology*, 65, No. 5: 1445-1453

United States Department of Agriculture, 2004. Soil Survey Laboratory Methods Manual: Soil Survey Investigations Report, No. 42, Version 4.0, U.S. Government Printing Office, Washington, D.C.

Waide, R., Willig, M., Steiner, C., Mittelbach, G., Gough, L., Dodson, S., Juday, G., and Parmenter, R. 1999. The relationship between productivity and species richness. *Annual Review of Ecology and Systematics*, 30: 257-300

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