

TREE COMMUNITY PATTERNS AND SOIL TEXTURE CHARACTERISTICS OF
A MEANDER BEND, LOWER TRINITY RIVER, SOUTHEAST TEXAS

A Thesis

by

SARAH ILDIKO NYIKOS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

December 2011

Major Subject: Geography

Tree Community Patterns and Soil Texture Characteristics of a Meander Bend, Lower

Trinity River, Southeast Texas

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Approved by:

Co-Chairs of Committee,	Andrew C. Millington Inci Güneralp
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ABSTRACT

Tree Community Patterns and Soil Texture Characteristics of a Meander Bend, Lower
Trinity River, Southeast Texas. (December 2011)

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Co-Chairs of Advisory Committee: Dr. Andrew C. Millington
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Meandering rivers and associated vegetation communities are highly dynamic systems that interact through various geomorphic and successional processes. However, much is still unknown about these interactions. Studies that focus on system integration rather than examining fluvial-related and vegetation dynamics individually will benefit science and the management of river systems. Tree communities in riparian areas, although consisting mainly of bottomland hardwood species, can be very diverse. Diversity has been linked to environmental influences such as meander migration, and changes in elevation and soil texture.

This study focused on a single meander bend of the lower Trinity River in southeast Texas. The purpose of this research was to examine interactions between soil texture variation and the establishment and succession of riparian tree communities, as such interactions contribute to the formation of complex riparian landscapes. A bend-scale approach was utilized to provide a detailed study of vegetation pattern and of soil texture resulting from sedimentation processes, to examine for any relationships between them. Aerial imagery was used to assist in interpreting patterns of vegetation succession.

The field portion of the study collected species and size class data on trees and soil samples for textural analysis. These data were analyzed separately to understand variations in tree communities and soils, but also together, to determine any relationships between soil texture and what tree communities are able to establish. Mean annual flow data from gauges upstream and downstream of the site were analyzed for changes in flow following dam construction upstream, as river regulation could potentially alter the vegetation establishment regime.

Results showed five distinct communities or zones of vegetation. Soils on the site were strongly skewed toward finer sands and high silt and clay content. Zone locations and community structure were not directly related to soil texture; however, given species had clear relationships of relative density or dominance with specific soil textures. No changes in flow were noted between pre- and post- dam construction periods, indicating that the riparian system at this site may operate under near-natural conditions.

Further studies in species-soil texture interactions, and for rare and invasive species in particular, may prove beneficial in improving understanding of the complex functioning of riparian systems and in providing valuable information for their management and restoration.

DEDICATION

This thesis is dedicated to my parents, Peter and Leila Nyikos, in gratitude for their unfailing moral support throughout this project.

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1. INTRODUCTION

The purpose of this research was to advance the understanding of the interactions between soil texture and riparian vegetation succession that result in the formation of complex riparian landscapes. Much research on river meandering to date has considered the vegetation merely as a static component of the landscape (Trimble 2004; Murray *et al.* 2008). However, rivers and riparian vegetation are highly dynamic and complex systems (Gurnell 1995; Naiman & Décamps 1997; Ward 1998; Huston 2004; Steiger *et al.* 2005), interacting with each other through various geomorphic and successional processes, such as sedimentation on point bars from flooding, and related establishment of vegetation (Corenblit *et al.* 2009). An improved understanding of these interactions is necessary, particularly for management or restoration of riparian areas (Gurnell 1995; Bendix & Hupp 2000; Huston 2004; Murray *et al.* 2008).

Understanding the interactions between meandering rivers and riparian vegetation has become increasingly important as a result of human impact on the environment, such as increased land use and urbanization, and flow regulation (Gurnell 1995; Dahm *et al.* 2005; Murray *et al.* 2008). The Trinity River basin includes several urban areas (most notably the Dallas-Fort Worth area, as well as Houston downstream of the study site), and has also undergone regulation of flow through the placement of dams (Dahm *et al.* 2005). The dam at Lake Livingston may be of particular importance to this study area, which is downstream of that dam. Regulation of flow has been found to

This thesis follows the style of the *Journal of Ecology*.

affect species diversity in riparian systems (Scott *et al.* 1997; Ward 1998). Studies that focus on system interactions rather than examining fluvial and vegetation dynamics individually are beneficial to society (Murray *et al.* 2008) and the management of river systems (Francis 2006; Steiger *et al.* 2005), in addition to their undeniable contributions to science through increasing awareness of linked processes. This study contributes to the growing body of scientific literature on biogeomorphology, and provides a specific and detailed case study of a single meander bend of the lower Trinity River.

This research sought to address the following question: Does vegetation pattern and establishment on this meander bend relate to soil texture characteristics? The following questions were considered as components of the overall question: What patterns of vegetation establishment are formed on this meander bend? What variation in soil texture can be seen across the bend? Are there any relationships between soil texture i.e., grain size, and species establishment and growth, which may result in the presence of certain tree communities?

In addition to expanding scientific research, this study could provide local landowners with information on fluvial dynamics-related vegetation growth patterns, and also species interactions they may see in the area, allowing them to make better informed decisions for management of their property. This study may also inform riparian ecosystems managers and restoration practitioners about potential species interactions, or vegetation patterns resulting from soil texture, and thus enable them to determine better practices for river restoration.

2. LITERATURE REVIEW

2.1. Riparian vegetation patterns and fluvial dynamics of meandering rivers

2.1.1. *The importance of integrated studies*

Until the last two decades, relatively little research focused on the integrated dynamics of rivers and riparian vegetation systems. Although significant advances have been made in this field, particularly in the last few years (e.g. Tal *et al.* 2004; Murray *et al.* 2008; Meitzen 2009), much about the interactions in riparian systems is still unknown (Bendix & Hupp 2000; Hupp 2000; Francis 2006; Murray *et al.* 2008; Meitzen 2009). Understanding the interactions between fluvial processes and riparian vegetation has become necessary with increasing human pressures on the environment, and also if the management of bottomland forests or restoration of degraded fluvial systems to more natural conditions are goals (Shankman 1993; Gurnell 1995; Hughes 1997; Naiman & Décamps 1997; Steiger *et al.* 2005; Murray *et al.* 2008). Past approaches often examined fluvial systems either solely from geomorphic and process-based perspectives, and ignored the impact of vegetation, or at best considered vegetation influence on erosion and bank stability as only passive or mechanically-based (Trimble 2004; Francis 2006). An integrated approach combining theories across disciplines is highly beneficial to understanding riparian system dynamics, as biogeographical, ecological or geomorphological approaches alone are not sufficient to explain the variability and complexity apparent in riparian systems (Kalliola *et al.* 1991; Gurnell 1995; Steiger *et al.* 2005; Stallins 2006; Renschler *et al.* 2007; Molau 2008; Murray *et al.* 2008).

Research on rivers can benefit from studies coupling the dynamics of riparian vegetation with fluvial processes, to better understand their interactions. Theoretical syntheses of integration need to be supported and refined through evidence collected in field-based studies (Steiger *et al.* 2005; Stallins 2006).

Fluvial processes and riparian vegetation dynamics occur across a wide range of spatial and temporal scales. In fluvial systems, magnitude and frequency of process events are important to consider (Wolman & Miller 1960; Lane & Richards 1997), whereas in vegetation dynamics it is important to study diversity of species, in addition to patterns of establishment (Kupfer & Malanson 1993; Robertson & Augspurger 1999; Robertson 2006; Perucca *et al.* 2006, 2007; Meitzen 2009). When studying the interactions of these components of a riparian system, it is crucial to consider and be able to link the patterns and processes across scales, as their effects can occur at more than one scale (Wolman & Gerson 1978; Hughes 1997; Lane & Richards 1997; Stallins 2006; Molau 2008; Meitzen 2009). Even identification of the appropriate scales of reference and the dominant processes acting at each of these scales may be difficult (Lane and Richards 1997).

2.1.2. Patterns of riparian vegetation resulting from fluvial dynamics

Interactions between fluvial processes and geomorphic features in a river system are ‘major determinants’ of biodiversity, influencing diversity both directly and indirectly (Shankman 1993; Ward 1998). Floods can affect tree establishment directly

through deposition of sediment, or indirectly via channel narrowing (Scott *et al.* 1997). Patterns of vegetation establishment are closely connected to river migration processes and the resulting creation of landforms, particularly newly-created bare areas resulting from deposition by flows (Kalliola *et al.* 1991; Kupfer & Malanson 1993; Shankman 1993; Gurnell 1995; Hughes 1997; Robertson & Augspurger 1999; Bendix & Hupp 2000; Hupp 2000; Francis 2006; Perucca *et al.* 2006; Robertson 2006; Meitzen 2009). In addition, patterns in riparian vegetation are often highly directional, can be predicted across scales, and are affected by environmental gradients such as elevation and soil texture (Kupfer & Malanson 1993; Shankman 1993; Gurnell 1995; Hughes 1997; Naiman & Décamps 1997; Robertson & Augspurger 1999; Francis 2006; Robertson 2006). Locations of individual species may also vary based on environmental gradients or hydrogeomorphological conditions associated with landforms (Bendix & Hupp 2000; Robertson 2001). Distinct patterns of vegetation are formed in different areas of the river and its floodplain, such as cutbank versus pointbar communities, newly-formed riparian edge communities versus those in interior areas, as well as differences in forest type between backwater areas, creeks, natural levees and terraces (Kalliola *et al.* 1991; Kupfer & Malanson 1993; Gurnell 1995; Hughes 1997; Meitzen 2009). These patterns of vegetation establishment are closely tied to meander migration in space and time, and are also often transitional in nature, changing from one community type to another as a result of channel migration (Kupfer & Malanson 1993). Patterns of vegetation can also affect the ultimate form of river channels by altering flow patterns, as demonstrated by recent flume studies conducted on braided rivers (e.g., Tal *et al.* 2004; Coulthard 2005;

Tal & Paola 2007). Vegetation can also influence channel form and processes through bank stabilization and alteration of in-channel hydraulics (Gurnell 1995; Naiman & Décamps 1997; Tal *et al.* 2004; Trimble 2004; Francis 2006; Perucca *et al.* 2007).

Vegetation can influence the rate and spatial distribution of sedimentation by controlling deposition, particularly of smaller grain sizes that would be found in suspension (Nanson & Beach 1977; Gurnell 1995; Hupp 2000).

The study by Kupfer & Malanson (1993) focused on the concept of edge, specifically the dynamics observed in riparian edge environments, which differ from other types of edge environments, or environments further inland. They hypothesized that an area that is *not* riparian edge may transition over time to riparian edge with the movement of a river channel and subsequent bank erosion. Spatial patterns in landscape evolution created by channel migration are significant in that they differ from succession at most sites. Most sites will be ‘continuing through recurrent disturbances’, but riparian edge sites develop on a ‘temporal trajectory’, with each site taken uniquely, and with sites continually being created or destroyed as the channel migrates (Kupfer & Malanson 1993). Cutbank edge communities in particular can be seen as a ‘natural experiment’ for understanding species succession in riparian areas, and can provide valuable insights into earlier successional models (Kupfer & Malanson 1993). This work is useful for the understanding of feedbacks among various processes in a landscape, and spatial diversity of vegetation distribution.

Robertson & Augspurger (1999) analyzed the relationship between fluvial geomorphic processes and spatial patterns of vegetation on the Bogue Chitto River in

Louisiana, a meandering river on the Coastal Plain. They hypothesized that these patterns could be predicted, and were heavily influenced by initial physical conditions associated with forest establishment, specifically elevation and channel morphology. Furthermore, these influences frequently occurred at highly-localized scales. Also, the distribution of canopy tree species and their recruits pointed to the conclusion that establishment patterns remained relatively consistent as the river migrated (Robertson & Augspurger 1999). An elevational gradient was found to be particularly closely associated with spatial variation in species distribution, even on a micro-scale; the authors had found similar evidence in other studies (Robertson & Augspurger 1999). They further suggested that this gradient might be connected specifically to shear stress on the point bar (Robertson & Augspurger 1999, 1060). Also, shear stress varied spatially in magnitude and effect, resulting in a related spatial variation in the vegetation (Robertson & Augspurger 1999, 1060-1061).

Robertson (2006) focused on the study of tree species distributions on point bars of meandering rivers, and how processes associated with meandering can to a large extent determine the patterns of vegetation establishment apparent in a riparian landscape. Ten rivers in the Southeast U.S. were compared to determine whether common patterns could be observed. Robertson hypothesized that common patterns would exist, and could furthermore be predicted with an adequate understanding of underlying fluvial processes and environmental, soil and elevational gradients.

2.1.3. Modeling of interactions

Recently, there has been a growing interest in the interactions of river morphodynamic processes and riparian vegetation dynamics. For instance, studies on braided rivers in the past decade have shown that feedbacks between vegetation and channel form exist, and are more complex than previously assumed (e.g. Murray & Paola 2003; Tal *et al.* 2004; Murray *et al.* 2008). Considerable advances have been made in modeling riparian interactions. For example, Perucca *et al.* (2006, 2007) examined the long-term coupled dynamics of meandering rivers and vegetation. Results from their simulations show that the spatial pattern of riparian vegetation succession along the river depends on river meandering processes, and that vegetation dynamics affect the evolution of meander patterns by altering bank erosion rates along the channel planform. These theoretical models are based on a simplified assumption of reality, i.e., they assume an initially homogenous vegetation density, and do not account for species' diversity or species-specific responses to certain variables, but instead treat the vegetation as a single unit. Nonetheless, they are very useful for developing new insights into the interactions between meandering and riparian vegetation processes. Such processes play an important role in the evolution of channel planform and vegetation pattern that cannot be adequately explained through models that consider solely vegetation dynamics (e.g. Kupfer & Malanson 1993) or fluvial processes (Murray *et al.* 2008). However, field observations on fluvial processes and riparian vegetation patterns that include species density and diversity components, both complement modeling

studies, and are critical in achieving a better understanding about these interactions and ultimately for refining theoretical insights.

2.2. Characteristics of bottomland hardwood tree communities: formation and diversity

Plants in riparian systems play a role in connecting hydrogeomorphic and biological dynamics, both at the ecosystem scale, and arguably also at the scale of the evolution of individual organisms (Corenblit *et al.* 2009). ‘Co-adjustments’ may occur between organisms and their physical environment, e.g. geomorphic processes and landforms, leading to the pattern and persistence of the ‘evolving assemblages’ characteristic of riparian systems (Kalliola *et al.* 1991; Corenblit *et al.* 2009).

Heterogeneous biotic community structure and the dynamic nature of river systems help maintain functional integrity of an ecosystem (Ward 1998). Forest succession is a ‘major determinant’ of biodiversity patterns in riparian systems (Ward 1998). Succession in riparian areas is mainly primary, as new sites for colonization by vegetation are created through river migration. Riparian vegetation occurs in distinct zones or bands throughout the floodplain system, resulting in a distribution of species along an elevational gradient that is both spatially and temporally ‘segregated’ (Scott *et al.* 1997; Mahoney & Rood 1998; Ward 1998, p. 273; Bendix & Hupp 2000; Hupp 2000). This in part results from flood disturbance (Kalliola *et al.* 1991; Shankman 1993; Gurnell 1995; Hughes 1997; Scott *et al.* 1997; Hupp 2000), and also depends on the timing of migration (Nanson &

Beach 1977; Scott *et al.* 1997). Changes in species composition, i.e., zonation of vegetation, tend to occur along a gradient of increased distance from the active river channel (e.g. Nanson & Beach 1977; Naiman & Décamps 1997; Robertson & Augspurger 1999). Species can also segregate at finer (microsite) scales, creating unique communities within different parts of the same river system, often in close proximity to one another (Kalliola *et al.* 1991; Ward 1998). Forests at many different stages of succession or age can be found in the same area in a riparian system, leading to high beta diversity (Scott *et al.* 1997; Ward 1998). Species richness of vegetation usually increases with greater flow; however, intermediate levels of disturbance resulting from flooding may inhibit competitive exclusion by other species or lead to greater species diversity (Ward 1998; Bendix & Hupp 2000). Variation in riparian forest composition may be maintained by periodic flooding, creating a *stable* system, rather than being a result of secondary succession recovery from large floods (Scott *et al.* 1997; Bendix & Hupp 2000). Anthropogenic regulation of flow via dams decreases downstream sediment loads and flow magnitude and frequency, leading to less sediment deposition downstream (e.g. Naiman & Décamps 1997; Scott *et al.* 1997). Additionally, flow regulation and channelization lead to the simplification or homogenization of riparian vegetation by inhibiting establishment and eliminating various successional stages, particularly early or pioneer stages (Shankman 1993; Scott *et al.* 1997; Ward 1998; Steiger *et al.* 2005). This leads to decreased biodiversity. Age structure of species may also be important to understand in identification of successional changes (Nanson & Beach 1977).

Early successional species such as Eastern cottonwood (*Populus deltoides*) establish on newly created and regularly-flooded sites (Shankman 1993; Hughes 1997; Scott *et al.* 1997; Mahoney & Rood 1998; Ward 1998; Cooper *et al.* 2003; Corenblit *et al.* 2009), and are characterized by rapid growth, intolerance of shade, tolerance of sediment accretion, and high seed production (Shankman 1993; Hughes 1997; Scott *et al.* 1997). Conversely, later species such as green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), boxelder (*Acer negundo*), hackberry (*Celtis occidentalis*), sweetgum (*Liquidambar styraciflua*) and willow oak (*Quercus phellos*) that establish approximately 10 years after the early species are typically found on elevated areas and interact with flow-related dynamics only during infrequent, high-magnitude floods (Shankman 1993; Gurnell 1995; Bendix & Hupp 2000; Corenblit *et al.* 2009). This temporal variation in establishment leads to the creation of a mosaic of habitats and stages of succession (Ward 1998; Hupp 2000), resulting, for example, in both even and uneven aged stands of trees, e.g., *P. deltoides* (Cooper *et al.* 2003). *P. deltoides* does not easily establish or survive at higher elevations, due to the lack of water availability and to drought stress, and seedlings of *P. deltoides* and other early colonizing species at lower elevations may have difficulty in establishing if high flows are frequent (Mahoney & Rood 1998; Bendix & Hupp 2000; Cooper *et al.* 2003). Large flows may cause delays in woody plant establishment in general, of one or more years, due to erosion or burial of newly-established seedlings (Kalliola *et al.* 1991; Hughes 1997; Naiman & Décamps 1997; Cooper *et al.* 2003; Francis 2006). Floods can also lead to vegetation mortality by breaking plants (Bendix & Hupp 2000; Francis 2006).

Persistent flows (i.e., long duration of flooding) will also prevent establishment (Hall & Smith 1955). Five to 10-year flood events have been shown to be favorable for establishment of seedlings of *P. deltoides* in particular (Scott *et al.* 1997; Mahoney & Rood 1998). However, *P. deltoides* establishment also occurred under a wide range of flow conditions ranging from low to very high peak flows, and on a variety of surfaces, e.g., both bars and abandoned channels. Also, flow stage *variability* (rather than large floods) was found to “control most establishment” of *P. deltoides* seedlings (Cooper *et al.* 2003). However, *recruitment* of *P. deltoides* is episodic even along river channels (Mahoney & Rood 1998), but it is unclear if they mean recruitment of seedlings to the sapling stage, or merely seedling establishment, as they seem to use the two terms interchangeably. Seedling establishment is also affected by seed dispersal and viability, soil moisture conditions, and nutrient availability, in addition to flow stage (Kalliola *et al.* 1991; Hughes 1997; Naiman & Décamps 1997; Scott *et al.* 1997; Mahoney & Rood 1998; Robertson & Augspurger 1999; Bendix & Hupp 2000; Steiger *et al.* 2005); this may be particularly the case with rare species (Kalliola *et al.* 1991). Also, the *season* in which flooding occurs may be more significant than the magnitude or duration of the flood, or even the variability of flows, in determining survival of bottomland hardwood trees (Hall & Smith 1955). Establishment of *Populus* is closely associated with the seasonality of floods, particularly when occurring in conjunction with the timing of seed release in spring (Gurnell 1995; Scott *et al.* 1997).

In the case of a riparian system that is flooded for long periods of time, vegetation survival can be greatly affected by the duration of the hydroperiod, i.e., the

time an area is flooded, and by the level of the flood (Hall & Smith 1955; Hosner 1960; Hughes 1997; Hupp 2000). Species will experience greater mortality in areas flooded for longer periods of time. Tolerance to flooding varies considerably by species; for example, dogwood (*Cornus*) and hackberry (*C. occidentalis*) were found to be less tolerant to flooding than many other species, and *A. negundo*, *P. deltoides*, and *F. pennsylvanica* were more tolerant to flooding than other species tested (Hall & Smith 1955; Hosner 1960). Height of individuals may also affect their ability to survive, regardless of tolerance abilities, if flooding is of long enough duration (Hall & Smith 1955). Thus, height of flood levels may cause selective mortality, affecting community composition and structure (Hosner 1960). However, water level is likely only a limiting factor in areas that are flooded consistently and for long periods of time, such as swamps and sloughs (Hosner 1960).

Chambless & Nixon (1975) characterized the vegetation of a bottomland hardwood forest in east Texas (Nacogdoches County). They calculated the frequency, density, dominance and species importance values of all tree and shrub species, and correlated them with two different elevations, ridges and “flats”, a few meters apart in elevation. These were rather misleadingly referred to as “soil elevations”, although soil texture specifically was not correlated with most species. Rather, their study demonstrated that different drainage or moisture content of soils resulting from a difference in elevation could cause different species to establish, or persist based on tolerance.

Chambless & Nixon (1975) also provided a clear discussion of many specific species reactions to different elevations. For example, they pointed out that dominance of *F. pennsylvanica* could be expected in bottomland areas, stating that an earlier study showed that “most natural stands” [of *F. pennsylvanica*] were mostly confined to bottomlands. Sweetgum (*Liquidambar styraciflua*) and water oak (*Quercus nigra*) were found to be more abundant on the elevated areas of their sites, as these species were either intolerant or only fairly tolerant to flooding, depending partly on their life stage.

2.3. Influence of soil texture on vegetation establishment dynamics

Most plants in riparian areas germinate on alluvium (fine fluvial sediment) deposited by floods (Bendix & Hupp 2000). Species diversity and community composition are affected by the deposition and redistribution of sediment within the riparian system (Steiger *et al.* 2005). Soil and vegetation characteristics reflect hydrogeomorphological conditions associated with migration, erosion and deposition, flood frequency and duration, or flow stage at the time of deposition (Hughes 1997; Bendix & Hupp 2000; Steiger *et al.* 2005). Although alluvium may not be transported far downstream, it is still in a state of flux over geomorphological time (Naiman & Décamps 1997; Hupp 2000). Patterns of sediment deposition and therefore also grain size vary across different parts of the riparian area (Francis 2006). Deposition of fine textured sediment can occur during non-peak-flow years, allowing the creation of sites for seedling establishment (Cooper *et al.* 2003). Flood frequency and sediment texture

vary with elevation in the floodplain; lower frequency high-magnitude floods allow deposition of fine sediment at higher elevations (Cooper *et al.* 2003). Deposition of fine sediment is also facilitated by lower flow velocity; highest rates of deposition may occur in sloughs, where flow velocities are very low or non-existent (Hupp 2000). Substrate has an effect on vegetation establishment, but vegetation can also affect the substrate by slowing flow velocity and aiding deposition of sediment (Gurnell 1995; Naiman & Décamps 1997; Scott *et al.* 1997; Bendix & Hupp 2000; Hupp 2000). Sediment is deposited preferentially by overbank flows or floods, i.e., a hierarchy of deposition occurs, with coarser and heavier particles falling out first (Hupp 2000). Thus, it could be expected that coarser textured sediment would be found closer to the active river channel, and progressively finer textures with increased distance from the channel, particularly if vegetation is present to facilitate deposition of finer sediment (Gurnell 1995). Gradients in soil texture may cause more complex patterns of establishment than previously thought (Hughes 1997; Robertson & Augspurger 1999). Also, areas no longer receiving frequent overbank sediment deposition may be subject to autogenic rather than allogenic influences, i.e., interaction between species as being the cause of community changes rather than influences resulting from sedimentation (Nanson & Beach 1977; Naiman & Décamps 1997).

Soil texture (grain size) works in conjunction with elevation, in particular microtopographical variation, to determine the distribution of vegetation, as well as the germination and survival of species (Naiman & Décamps 1997; Robertson & Augspurger 1999; Steiger *et al.* 2005). In unregulated flow regimes, germination of *P.*

deltoides occurred on sandy loam and finer textured areas, particularly on silty soils (Cooper *et al.* 2003). This seems to be the case because fine sediment layers provide water for seedlings even after river and groundwater levels drop below the taproot level of trees (Cooper *et al.* 2003). Species richness was found to be higher in areas of fine textured sediment (Kalliola *et al.* 1991). Surface soil that had less than 90 percent sand was found to be associated with herbaceous and forest vegetation (Robertson & Augspurger 1999).

2.4. Summary

This research project aims to provide insights into the dynamics of riparian tree communities and soil texture on a single meander bend of the lower Trinity River. However, riparian vegetation communities continually evolve through time with changes in meander dynamics, flow variability, deposition of new sediment, and interactions between species. Thus, this study only provides a snapshot in time, as it were, of the dynamics present in this area. Nevertheless, it is an attempt toward characterizing the interconnectedness of dynamics of species and their environment, and will provide information that will contribute to the growing body of studies on the interactions between fluvial processes and riparian vegetation dynamics. Vegetation and fluvial dynamics separately are currently better understood than how these dynamics work in conjunction in a riparian system. However, as these dynamics are undeniably connected within a system, it is necessary to consider integration and interactions, perhaps more so

than considering the dynamics separately. Therefore, while providing information separately on observed vegetation patterns and soil texture variation on this site, this study also attempts to illustrate potential relationships between these components of this system.

3. STUDY AREA

The study site consists of a single meander bend of the Lower Trinity River, a meandering river in East Texas. The Trinity consists of numerous meanders with geometrical complexity ranging from simple bends (a single arc of curvature) to compound (i.e. multi-lobed) bends. A comparison of sequential aerial photography of the study site shows considerable channel migration over the last sixty years. In particular, the bend has rotated southward from its location in 1938. The site is located at 30° 08' 02" N, 94° 49' 02" W, approximately 9 km north of Liberty, TX (Fig. 1), on private property used for cattle grazing. However, the cattle appear to have had no or at most minimal impact on vegetation pattern or structure, and vegetation community composition seems unaltered as well. There is also some control on the wildlife population through hunting.

The site is located entirely within the broad floodplain of the Trinity River, although in recent years the site appears to have remained unflooded or only partly flooded in some areas close to the active channel, most likely as a result of recent intense droughts (particularly May 2010 to March 2011, the time encompassing most visits to the site), or from lower water levels in the river due to regulation. The Trinity River basin includes several urban areas (most notably the Dallas-Fort Worth area, as well as Houston downstream of the study site), and has also undergone regulation of flow through the placement of dams (Dahm *et al.* 2005). The nearest dam upstream of the site

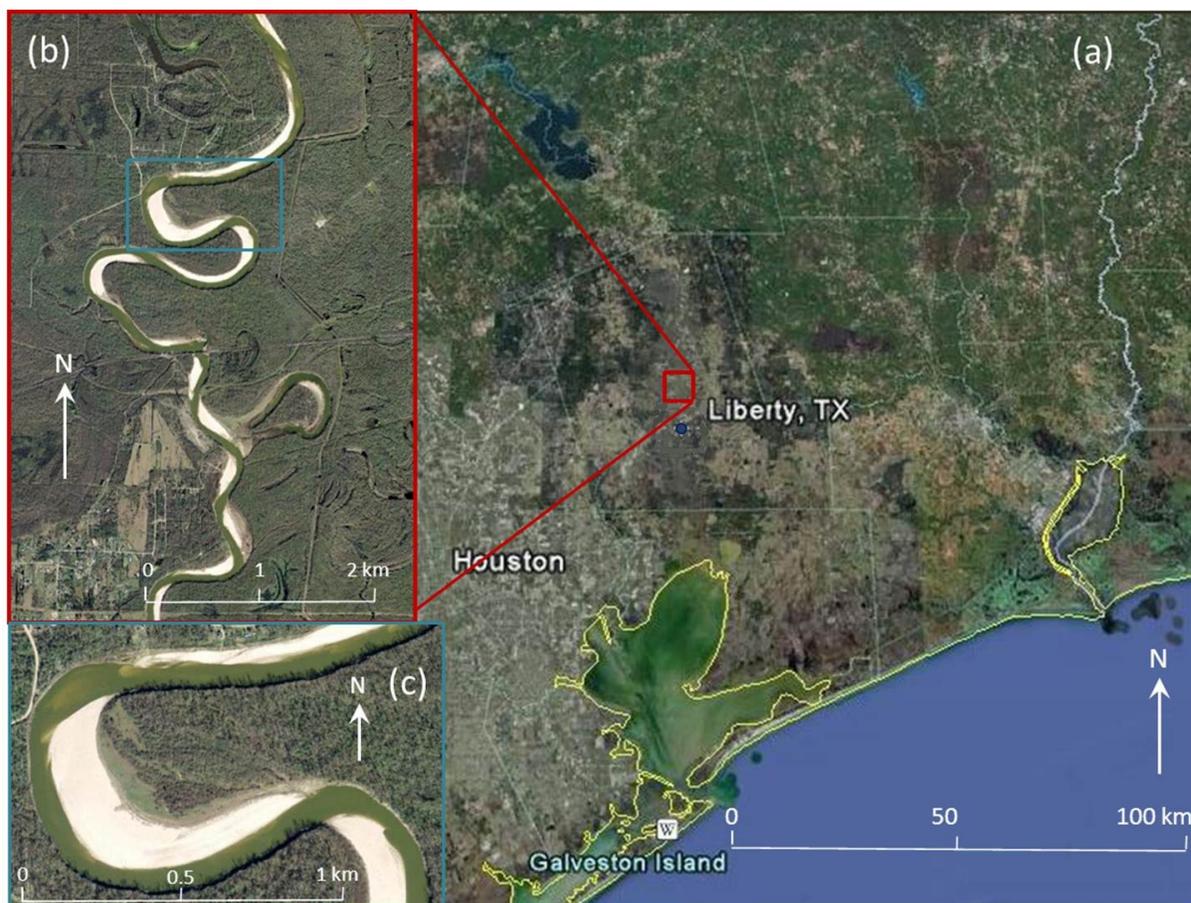


Fig. 1. Study site and context. a) East Texas and Galveston Bay. Site is to the north of Liberty and northeast of Houston. b) Trinity River north of Liberty. c) Study site (single meander bend) located at $30^{\circ} 08' 02''$ N, $94^{\circ} 49' 02''$ W. Google Earth[®], 2010.

is located at Lake Livingston, approximately 58 km NNW and approximately 107 km upstream of the site, and was constructed 1966-1969 by Forest and Cotton, Inc.

The land cover type on the site is chiefly mature forest, grading to smaller trees and shrubs, and finally to herbaceous vegetation progressively closer to the point bar. The forest appears from both aerial image analysis and also field observation to have remained undisturbed for at least the last sixty years; a small portion of the mature forest is likely first-growth. The tree community can be described as bottomland mixed hardwoods, or Southern Bottomland Forest *sensu* Chambless & Nixon (1975), which are located in East Texas river bottomlands. Dominant species on this site are American sycamore (*Platanus occidentalis*), hackberry (*C. occidentalis*), roughleaf dogwood (*Cornus drummondii*), *L. styraciflua*, and in the mature forest, *P. deltoides* as well. Chinese tallow (*Sapium sebiferum*) is a non-native species that is pervasive throughout the site, existing in all but the driest and sunniest areas. Two species of oak, *Q. nigra* and willow oak (*Q. phellos*), are found in a few areas, as well as a few individuals of the genus *Pinus*, specifically loblolly (*P. taeda*) and longleaf (*P. palustris*) pines. A list of all species found in the plots and their common names can be found in the Appendix. The area has experienced no logging since at least 1938, according to the aerial imagery. Elevation across the site varies between approximately 6 m at the edge of the active river channel to approximately 10.3 m at the highest point, which is located on the northern cutbank of the site in the mature forest.

Soil across the site is fine alluvial sediment, and ranges from loamy fine sands (≥ 50 percent fine sand) to silty clays (total of ≥ 40 percent clay and ≥ 40 percent silt). Grain sizes range from coarse sand (≥ 1 mm) to very fine clay (< 0.02 μm).



Fig. 2. Inlet transecting study site.

The site is partially transected by an inlet or chute cut of the river, running approximately halfway across the site, in a northwest direction (Fig. 2). The inlet also has a small sub-branch. This inlet enables water to periodically reach the interior of the site, except in extreme drought conditions, when the level of the river drops below the elevation of the inlet. (Drying of the inlet was observed on two separate visits to the site,

in September 2010 and in March 2011, respectively.) However, the level of the river also changes periodically, most likely as a result of releases from the Lake Livingston dam. The nearest two U.S. Geological Survey (USGS) gauges upstream and downstream of the site are located at Romayor and Liberty, respectively. Data for mean annual discharge at Romayor were available for the period 1924-2010 (Fig. 3a); the mean for this period was $224 \text{ m}^3/\text{s}$. Data for mean annual discharge at Liberty were available for the period 1973-1999 (Fig. 3b); the mean for this period was $610 \text{ m}^3/\text{s}$. Note that this period is all following the construction of the Livingston dam. However, discharge seems to remain both relatively high and also fairly variable, although less variable than at Romayor.

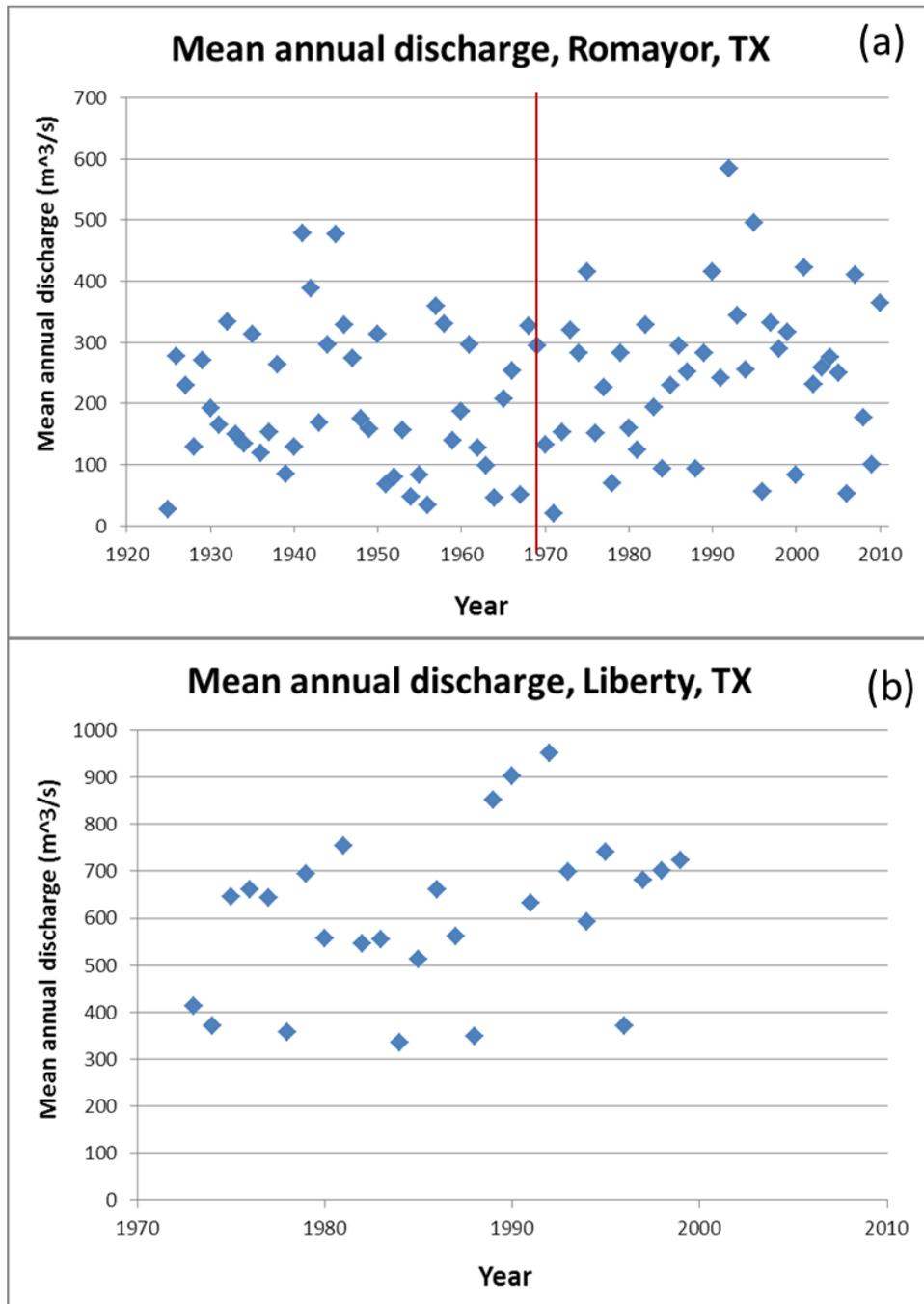


Fig. 3. Mean annual discharges (m^3/s). a) Mean annual discharges at Romayor, TX. This gauge is upstream of the study site but downstream of the Livingston dam. b) Mean annual discharges for Liberty, TX. Data for discharges were obtained from the USGS. The red line in Figure 3.a indicates the year of dam construction (not visible in Figure 3.b).

4. METHODS

4.1. Aerial imagery analysis

Visual-based interpretation of aerial imagery was conducted briefly prior to fieldwork, both to examine potential vegetation zonation to be sampled, and also to determine a suitable sampling scheme. Aerial imagery was also analyzed after the fieldwork portion of the project was completed, as field observations produced further questions on vegetation establishment and land cover change. Aerial imagery of the site was obtained from the USFWS for the period 1938 to 1994; approximately one image was available per decade (1938, 1952, 1964, 1972, 1988 and 1994). Data were not available for the time of year photos were taken. Aerial imagery for years since 1994 was obtained from Google Earth[®] and from the Texas Natural Resources Information System (TNRIS).

4.2. Field methods and data collection

The field methods for this study were based in part on a study conducted by Robertson & Augspurger (1999) on the Bogue Chitto River, Louisiana, and in part developed by the author. Robertson & Augspurger (1999) sought to determine feedbacks between channel migration processes and vegetation establishment on point bars. In their study, 16 parallel transects were established on one bend of the river, perpendicular to the point bar. Along these transects, quadrats were used to collect species data on all

recruits. Diameter at breast height (dbh) measurements of all trees on the focal bend were taken. The distribution of canopy tree species and their recruits on the focal bend were mapped (locations were approximated and later assigned coordinates). Robertson (2006) built on the earlier study by incorporating environmental gradient effects on vegetation pattern to a greater extent.

The theories and methods implemented by Robertson & Augspurger (1999) and Robertson (2006) are in part applicable to the Trinity River. However, their transect layout does not adequately account for diversity in pattern, such as small-scale zonation of vegetation. Therefore, some modifications to these methods were made for this study, particularly in the layout of the sampling scheme.

The locations of the plots for data collection (Fig. 4) were determined based on a coordinate grid (UTM NAD 1983); the exact location of the grid on the bend was determined through preliminary aerial photo examination of vegetation pattern zonation. Grid lines were laid roughly parallel to the meander bend and the direction of channel migration, i.e., perpendicular to the apex of the channel bend. Grid mesh sizes were varied (100m, 50m and 25m) to better incorporate the natural variability of the vegetation, particularly variation in density. Plots were located approximately at the intersections of the lines of this grid; however, some plot locations were varied based on perceived zonation from preliminary visual interpretation of aerial imagery. In the field, plots were navigated to and the center points and quadrats marked out using a Garmin® eTrex Venture HC® GPS unit with a sub-canopy capacity. Measurement of plot radii was done using survey tapes. It was also necessary to move some plots slightly in the

field as a result of the impenetrability of some vegetation; impenetrability also would have prevented the application of the transect method, had it been selected.

Field work was conducted from mid-June to late September of 2010, with an additional visit to the site in mid-March 2011. Field work involved the collection of detailed data on vegetation establishment (i.e., tree density, saplings, and seedlings) and sediment characteristics (i.e., grain size/texture distribution) of the meander bend. Vegetation data collection methods included: measuring tree diameter at a standard breast height (dbh) of 1.3 to 1.4 m; identifying all tree species; counting and identifying saplings and tree seedlings. These three stages (trees, saplings and seedlings) reflect the various stages of tree establishment and growth/development. For the purposes of this study, trees were defined as having a dbh of ≥ 5 cm, saplings as being less than 5 cm but greater than 1 cm, and seedlings as < 1 cm dbh (*sensu* Chambless & Nixon 1975) and also less than 0.5 m in height.

Thirty-two approximately 400 m² circular plots were established on the study site (radius 11.3 m). Within each plot, a smaller approximately 100 m² plot (radius 5.6 m) for sampling of saplings was centered. Two 1 m² quadrats within the main plot were used to sample seedlings. These were arbitrarily located at the north and south ends of each plot (Fig. 5).

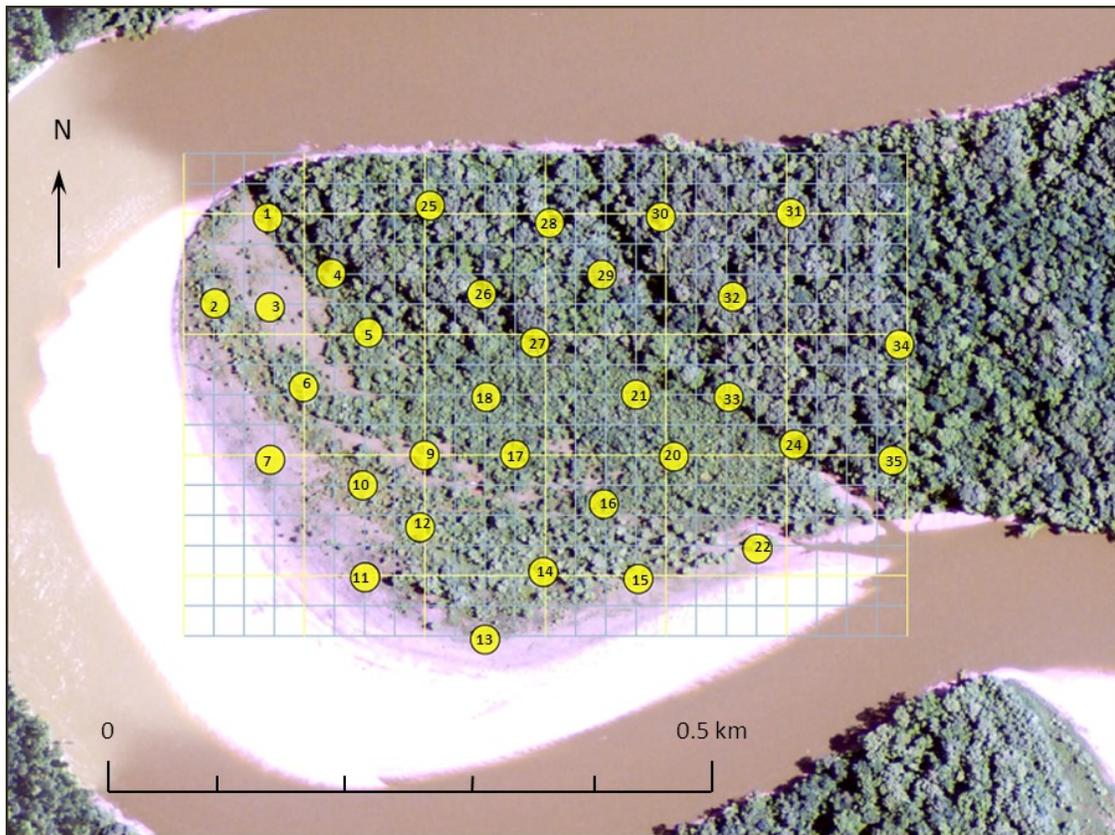


Fig. 4. Location of plots based on coordinate grid. Grid lines shown are 100 m (yellow) and 25m (blue) divisions. Plots are represented as numbered circles; the size of the circles denotes the actual size of the plots. Note some plots were moved very slightly in the field, but this is an accurate representation of their respective location. The aerial image is from 2008 and was obtained from TNRIS.

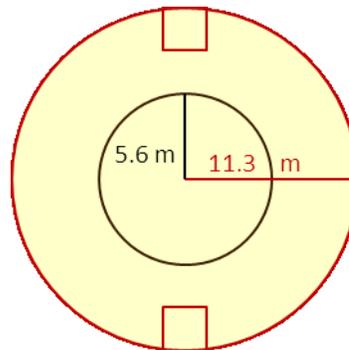


Fig. 5. Plot scheme for sampling vegetation.

Within each main plot, a soil sample was collected to be analyzed for grain size variation. Samples were taken to a depth of 10cm where possible; this has been indicated to be a suitable depth for seedling establishment (Robertson & Augspurger 1999). However, in many instances it was not possible to take samples below 5 cm.

Leaf litter was cleared from the ground surface before the samples were collected, and any large pieces of organic debris in the soil were removed in the field. Soil samples were then stored in airtight plastic bags until processing. Samples were analyzed to determine grain size distributions and gradients across point bars; these data would later be used to attempt to identify potential feedbacks between sedimentation resulting from channel processes, and vegetation establishment patterns and rates.

4.3. Laboratory procedures for soils

Soil samples collected in the field were stored in airtight plastic bags until they could be processed. Samples were spread out on paper to dry overnight before preparation. Large clayey aggregates were broken apart by hand as much as possible prior to drying, to minimize mortar preparation of samples. Once dry, samples were further broken up manually; aggregates were only broken up with mortar and pestle as necessary. Minimal mortaring is ideal, as excess mortaring can lead to unintentional crushing of larger sand grains (L.A. James, University of South Carolina, personal communication, 2007). Breakup of grains would skew results toward finer-textured sediment. However, the disadvantage to limiting mortar preparation of soils is that some extremely fine aggregates of clay remain that are too fine to be broken up manually. During manual disaggregation, samples were strained through a 1.18 mm mesh sieve to detect any remaining aggregates and to facilitate removal of any fine organic matter that was not already removed in-field. Any organic matter remaining in the sample after this procedure was too fine to be removed manually (either by sieving or with tweezers). No sand grains were found that were larger in diameter than this mesh size. Samples were returned to the plastic bags until they could be processed.

Pipette analysis was performed on the samples to obtain the proportions of sand, silt and clay (Kilmer & Alexander 1949; Steele & Bradfield 1934). Sediment size classes were determined using the standard U.S. Department of Agriculture (USDA) size classes (Soil Survey Staff 1993). Clays were further divided into categories of total clay ($< 20 \mu\text{m}$), fine clay ($< 2 \mu\text{m}$), and very fine clay ($< 0.2 \mu\text{m}$). Sands were categorized as very

coarse (VC; 1-2 mm = 1000-2000 μm), coarse (C; 500 μm), medium (M; 250 μm), fine (F; 100 μm) and very fine (VF; 50 μm). Percent silt of samples was then obtained by calculation (total sample – total sand – total clays = total silt). For pipette analysis, 10 g of each sample were weighed into bottles, and suspended in 400 mL of deionized water. 5 mL of a 10% $(\text{NaPO}_3)_6$ (sodium hexametaphosphate) solution (a dispersant) was added to each sample to disperse the remaining fine clay aggregates. Samples were shaken overnight, and pipetted the following day. Another 10 g of each sample were weighed into pans to obtain the moisture factors; samples were weighed, oven dried overnight at 105°C, and re-weighed.

Pipette analysis consisted of three runs: in the first run, a 5 mL aliquot was pulled from 5cm below the surface after 2 minutes of settling time to obtain the < 20 μm clay fraction. After an additional approximately 3-hour settling period, a 5 mL aliquot was drawn from 5cm below the surface to obtain clays <2 μm . These were then transferred to crucibles, which were oven dried overnight and then cooled in an airtight desiccator until weighing. To obtain the fraction of very fine clays (<0.2 μm), a 25 mL aliquot was taken from 4 cm depth. These were placed in 90 mL centrifuge tubes and centrifuged for 8-9 minutes (depending on temperature of the solution).

After pipetting was completed, samples were washed through a 50 μm sieve to remove all fines (composite of silts and clays, particle size <50 μm) and retain the sands. Samples were washed for 15 minutes or until all fines were removed. Sands were transferred to 100mL beakers, and oven dried overnight. Sands were then run through a series of sieves (as defined above) to obtain separate fractions. Each fraction was

weighed to 0.001g. Since it was impossible to remove the fine organic matter from each fraction without removing sands (in pipette processing, organic matter is too fine to be removed by any means other than chemical), sample weights included organic matter weight, but percent organic content of each fraction was estimated visually. However, dry organic matter weight is very light, and therefore in most cases is a negligible portion of the total weight.

Whereas it is possible to dry sieve a sample to obtain sand fractions plus fines, results will be skewed because many fine particles will adhere to sand grains (C. Hallmark, Texas A&M University, personal communication, 2011). Thus, it is necessary to wet sieve a sample prior to sand fractionation to remove fines (L.A. James, University of South Carolina, personal communication, 2007). However, if it is critical to retain the fines for further analysis, either a pipette or hydrometer procedure is necessary (C. Hallmark, Texas A&M University, personal communication, 2011). Also, whereas dry sieving alone may be adequate to determine sand texture, it is not sufficient to determine silt or clay content of soil; determining proportion of clay is necessary for analysis of soil moisture content, which may be a controlling factor of vegetation establishment and survival on a site.

4.4. Statistical analysis of vegetation and soil data

Vegetation data were ordered using Microsoft Excel[®]. Raw dbh values for all trees for all species were converted to percent relative dominance. Dominance is defined as the aggregation of basal area of individuals to the stand level (McCune & Grace 2002), and relative dominance is the percent dominance (total basal area) a given species has in a sample unit (hereafter referred to as plots) compared to the total basal area of all species in the plot. Tree species were also ordered according to relative density, another useful measure in community analysis (McCune & Grace, 2002). Relative density (or relative abundance) is the number of individuals of a given species compared to the total number of all individuals of all species in the plot. Raw dbh values were also converted into basal area for each species. Basal area for each species was extrapolated to a per hectare basis, and averaged for each vegetation zone observed in the field, including two potential sub-zones. Average density (the number of stems per hectare) was calculated per species per zone as well. Species richness (the number of species present) was also calculated for each zone. Note all saplings and seedlings were left out of the above analyses, as dbh values for these were not measured. Furthermore, they are not comparable to the tree data in that sampling of saplings and seedlings reflected only a portion of the plot instead of the total area.

Vegetation data were also distributed into size classes following Chambless & Nixon (1975), to examine for potential establishment, recruitment and growth patterns. However, the classification scheme has been slightly modified. Chambless & Nixon (1975) did not provide a size class for trees above 100 cm dbh; however, several

individuals (all species *P. deltoides*) were found across the study site that were slightly larger than this size class. Therefore, an additional class > 100 cm was created. Also, Chambless & Nixon (1975) did not distinguish between saplings and trees in the 1-10 cm dbh size class. This class does not adequately represent the vegetation characteristics of this study site, as it may not clearly reveal recruitment from sapling stage (< 5 cm dbh) to tree stage (≥ 5 cm dbh). Therefore, the original size class 1-10 cm has been divided into two separate classes, 1-4.9 cm and 5-10 cm, respectively, to better portray the separation between stages and the number of individuals that fall into each category. Note again that sapling data does not represent each plot as a whole, as it does with trees. Nevertheless, it is indicative of the approximate proportion of saplings on the study site as compared to slightly larger trees. Seedlings are placed in the < 1 cm dbh category. These are also indicative of the overall pattern of seedlings established across the site, as the quadrats, although randomly located, seemed to be representative of the plot as a whole.

Data on soils from pipette and sieving procedures were ordered into size classes using Excel[®]. Soil texture data from all plots were sorted based on all size classes, to examine for any patterns in decreasing grain size related to increasing relative distance from the point bar or from the nearest part of the active river channel. Absolute distance (in m) was not measured. Graphs were created for the five sand classes for each plot, as well as for the averages of the sand classes across all plots. In addition, a graph was created of the total sand, silt and clay averages across all plots. Graphs were created of the sand classes and the total sand, silt and clay content of three plots (Plots 2, 3 and 4)

on a transect across the open field on the north end of the site, to examine for any soil textural differences that might influence the highly specific variation in vegetation between grass and woody vegetation observed in that area. A ternary diagram following the USDA standard texture classes was created to represent the overall textural distribution across the site.

PC-ORD[®] was used to plot combined tree and soil texture data to analyze for any potential correlations. Each species was compared to each grain size class to determine if any influence on species basal area, density (stems/ha), relative density or dominance could be attributed to a particular grain size or texture. Species were also plotted against other species to examine for any interactions (i.e., did one species have any influence over another, and if so, what influence – increasing or decreasing trends?). Relationships such as possible facilitation of one species by another, the dependence of one species on another for increasing density or growth, the inhibition of one species by another, or the successful co-existence of two species without either negative or positive influences, were considered during analysis. Species basal area and density were also plotted against the total basal area (TBA) or density of each study plot, to further investigate potential relationships between species growth characteristics or species interactions. TBA and total density of species were also plotted against each soil texture class to examine for general relationships between species growth or density and soil texture. Species richness was also analyzed in conjunction with TBA, density, and soil texture, as well as with the basal area and density of each individual species. Excel[®] was then used to create graphs of the scatterplots.

4.5. Flow data

Data for mean annual discharge in cubic feet per second (cfs) were obtained from the website of the USGS for the two gauges upstream and downstream of the study site (located at Romayor and Liberty, respectively). Flow data were converted to m^3/s , and graphed. Flow data were examined to see if any changes had occurred in discharge following the regulation of this part of the Trinity River with the construction of the Livingston Dam (1966-1969). Data were particularly examined for any decreases in discharge following dam construction, which could be expected to occur. Mean annual discharge data were available for the period 1924-2010 for Romayor, and 1973-1999 for Liberty.

5. RESULTS

5.1. Aerial image analysis

Preliminary, visual-based analysis of aerial imagery of the site prior to fieldwork indicated three distinct zones (or communities) of vegetation. Progressively closer to the point bar, these were a mature, closed-canopy hardwood forest consisting of trees likely ≥ 15 m tall (typical of southern bottomland hardwood forest); a shrub-small tree zone consisting of much smaller individuals (likely ≤ 6 m tall) interspersed with open grassy patches; and a thin, relatively sparse zone of only small trees, just inland of the herbaceous- grass zone on the sand bar. It could not be determined from the imagery what species this zone consisted of, but they appeared to be mostly if not all the same species. There was also a large, open area towards the northern end of the site; it was not clear whether this was a natural phenomenon or whether the area had been previously clear cut. The latter could have been possible, as it seemed to be directly adjacent to the mature forest, with no shrub zone in between, as in other areas of the site. Additionally, there appeared to be an inlet of the river or a stream channel bisecting the site, but canopy cover prevented the extent of the channel from being determined.

It could also not be determined from aerial imagery how often and when the site may have been flooded, as insufficient imagery exists, but it appeared to be not to be more than once every few years, with the exception of low-lying areas close to the active river channel, i.e., chiefly the current point bar and adjoining areas, as well as the inlet.

5.2. Field observations

In the field, it was determined that there were more zones or distinct communities of trees present than revealed by the aerial imagery. On this site, vegetation consisted of five distinct communities or zones, varying with increasing distance from the river (Fig. 6). Sampling plots associated with each zone are listed in Table 1. The five major zones, progressively closer to the point bar are as follows: 1. mature hardwood forest, consisting chiefly of a sycamore-cottonwood-hackberry-elm community (*P. occidentalis*, *P. deltoides*, *C. occidentalis*, various species of *Ulmus*); 2. a zone of younger, smaller trees, mostly persimmon (*Diospyros virginiana*) and *F. pennsylvanica*; 3. a mixed small tree-shrub zone with a community composed principally of *F. pennsylvanica*, hawthorn (*Crataegus sp.*) and honey locust (*Gleditsia triacanthos*), interspersed with small open grassy areas; 4. a mixed small tree and sapling cohort of *C. drummondii*, *P. occidentalis* and *A. negundo*, heavily overgrown with blackberry (*Rubus*) and mustang grape (*Vitis mustangensis*); finally, 5. a zone of almost exclusively *P. occidentalis*, with a few instances of *P. deltoides*. On the point bar itself, only herbaceous vegetation is present, with a few small *P. occidentalis* saplings and seedlings beginning to establish. There is potentially also a sixth zone, consisting of plots located along or very near the central inlet, which exhibited different characteristics from other areas of the site. For example, this zone or sub-zone contained a species (*Forestiera acuminata*) not found elsewhere on the site, as well as having higher densities of the invasive species Chinese tallow (*Sapium sebiferum*) than other plots.

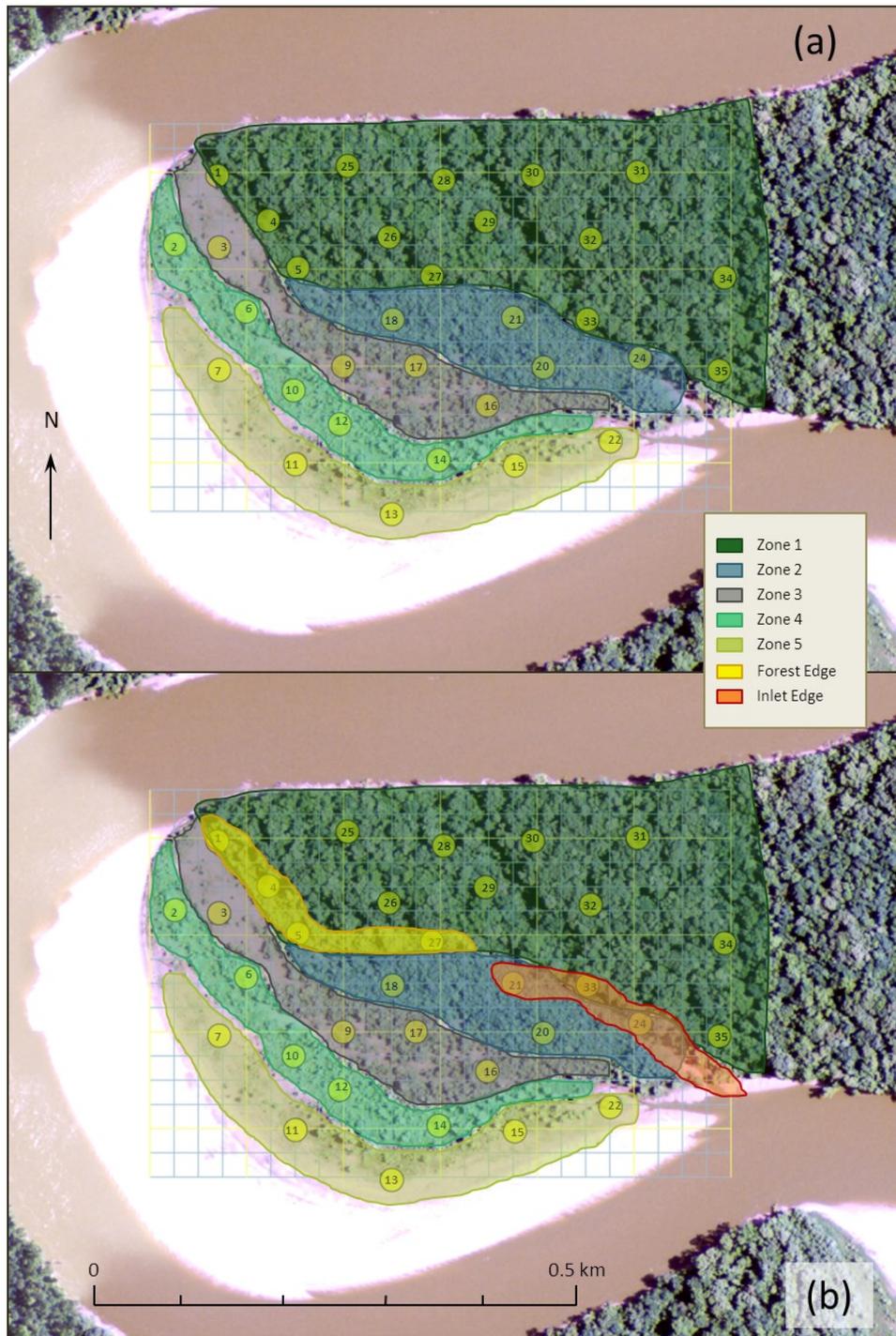


Fig. 6. Vegetation zones. a) The five major tree zones on the site. b) The two other potential zones (forest edge and inlet edge).

This zone is also included in Table 1 and Figure 6b. Another potential zone would be mature forest edge, which exhibited a transition between the mature forest and the next zone, characterized by a mix of the two zones' dominant species. This zone would consist of Plots 1, 4, 5 and 27 (Fig. 6b).

Table 1. Perceived zones of vegetation observed in the field and corresponding plots. The major zones 1-5 are numbered with decreasing distance toward the point bar (i.e. Zone 1 is farthest away, in the mature forest). Zones 6 and 7 are the potential sub-zones. Zone 6 is inlet edge, and Zone 7 is mature forest edge.

Zones	1	2	3	4	5	6	7
Plots	1, 4, 5, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35	20, 21, 24	9, 16, 17, 18	2, 6, 10, 12, 14	7, 11, 13, 15, 22	20, 24, 33	1, 4, 5, 27

These communities varied both in species composition and in age and size classes. Individuals were generally larger and likely older with increasing distance from the active river channel. For most hardwood species with the exception of *P. deltooides*, relative age can be assumed from both larger dbh and greater height in the mature forest community (farthest from the river) than individuals of the same species closer to the river. Species size classes can thus potentially indicate age, and also reinforce the theory that vegetation communities in floodplains form in bands as the active channel migrates, with progressively older vegetation with increasing distance from the point bar and

active river channel (e.g. Nanson & Beach 1977; Robertson & Augspurger 1999; Bendix & Hupp 2000).

This study found no apparent relationship between elevation and species, as most species, with few exceptions, could be found in most or all areas of the site. For most species, and even communities, no difference in composition was observed in the field between ridges and neighboring swales, often several meters apart in elevation. For example, *L. styraciflua* and *F. pennsylvanica* were present throughout the study site regardless of changes in elevation. The only exception that could be determined was that of *F. acuminata*, which was primarily found in the wettest area of the site, along or near the central inlet. However, it was difficult to determine any definite pattern of abundance for this species, as very few individuals existed. The highest density of *D. virginiana* was found in a plot near the inlet. However, this species could be found in all areas of the site, including the driest areas near the point bar, and relatively high densities were observed in other areas away from the inlet. Water hickory (*Carya aquatica*) was present in areas ranging from the driest to the wettest, and both *C. aquatica* and deciduous holly (*Ilex decidua*) were present in all zones.

Some interesting characteristics and possible responses by species to environmental conditions were noted in the field. For example, *P. occidentalis* is the first tree species to establish on newly-deposited sediment as the bend progressively migrates westward. This was the only tree species present in the zone nearest the point bar, and a few saplings had begun to establish on the point bar itself, outside the tree zone. Also, many of these saplings and some of the saplings within Zone 5 had been top killed and

had successfully resprouted. It was assumed that this was a result of tolerance to flooding, as no herbivory by cattle of this species was observed (herbivory is another possible cause of mortality in young saplings of many species). *S. sebiferum* is a highly prolific invasive species found in this area as well as many other areas on the Texas Coastal Plain. *S. sebiferum* was found in almost every plot, although it was limited in extent in the two outermost zones closest to the point bar. It was extremely prevalent in Zone 2 (*Fraxinus-Diospyros*).

Some highly-localized variations in zones did not seem to be explained either by vegetation establishment characteristics or by cattle herbivory. For example, there was a particularly large, open field on the northwest part of the bend, characterized by a monoculture of a single grass species, interspersed with a few vines. However, no tree or seedling establishment had taken place. The effect of cattle herbivory was obvious on grass height, but otherwise had no noticeable impact on the vegetation. The abrupt change in zonation from mature hardwood forest to open field (with no intermediate transition zones) was thought to potentially be accounted for by a difference in local soil characteristics, either grain size or soil type. These discoveries in the field provided an impetus for both a careful examination of soil texture, and also for a second analysis of aerial imagery to determine if this sharp break in zonation could be explained by factors other than herbivory.

The level of the river was low to extremely low for most of the study period, likely as a result of drought or lack of releases from the dam upstream; the inlet was at most only partially filled, and the point bar usually very wide (> 50 m) and clearly

visible. Even the highest flow level in the river observed during the study period was well below the elevation of all sampling points, and the site remained dry during the entire fieldwork period, with the exception of two days of heavy precipitation during the second week of data collection (early July 2010).

5.3. Post-fieldwork analysis of aerial imagery

Visual interpretation of sequential imagery from the period 1938-1994 (Fig.7) showed that the large, open field on the north end of the site was not a result of clear-cutting or overgrazing (the alternative theories considered). Rather, it is a product of natural infilling resulting from vegetation establishment. Prior to 1988, this area and adjoining areas closer to the active river channel were all open grassy areas, recently developed as a result of point bar migration and subsequent deposition of new sediment. The only trees on the site were in the mature forest, which since 1964 has had the same extent as the current range at the time of fieldwork (i.e. the 2010 image, Figs. 1, 2). Prior to 1964, especially in 1952, a portion of the present-day mature forest was still developing, and was composed of younger trees (the northern and central edges of the current range, specifically). The site has not been logged since at least 1938, although considerable channel migration in the form of southward rotation and widening of the arc of curvature has occurred since then. Trees had begun to establish on this newly-created open area by 1988, and had formed a clearly curved pattern by 1994. This initial curve explained the pattern seen in the field, where the east side of the open area was

bordered directly by mature forest, and the outer (western) edge closer to the active channel had a zone of small trees and saplings, essentially creating the interrupted pattern that was unlike the zone progression typical of the rest of the site. Trees have increased in density and area covered till the present. This trend of infilling was confirmed by a second, post-fieldwork visit to the study area in March 2011, which showed that infilling of the open area by vegetation had slightly progressed even since the previous summer of the study period. Several new tree saplings and numerous vines had established at the edges of the open area, particularly at the lower (southeast) end.

5.4. Statistical analysis

5.4.1. Patterns of tree density and dominance

Table 2 shows the average basal area and density per hectare for all tree species, per major zone (Zones 1-5), and also for Zones 6 and 7 (the two potential sub-zones of the edge of the inlet and the edge of the mature forest, respectively). Total basal area (TBA) per zone of the five major zones was greatest in the mature forest, and decreased progressively toward the point bar, as expected. However, the greatest TBA was found at the edge of the central inlet, and slightly exceeded the TBA of the mature forest (32.92 and 31.47 m²/ha, respectively). TBA of the mature forest edge zone (Zone 7; 10.23 m²/ha) was considerably less than that of the mature forest, but slightly greater than that of the nearest zone it borders, which is the thorny small trees zone (Zone 3; 8.93 m²/ha). Basal area of *S. sebiferum* was greatest at the inlet edge (Zone 6) and



Fig. 7. Aerial imagery of the site, 1938-1994. Images were obtained from the USFWS office in Liberty, TX. The present mature forest zone seems to have established by 1938. Note the southward rotation of the meander bend, and the gradual establishment of vegetation younger than the mature forest zone on the bare sandy area.

second greatest in Zone 2. Basal area for this species was much greater in these zones than in any other zone, by more than 300 percent. Average density was the lowest in the zone closest to the point bar (Zone 5; 155 stems/ha), and next lowest in the mature forest (834 stems/ha). Density was greatest in the two small-tree zones (Zones 2 and 3) and decreased steadily from Zone 2 to Zone 4, with a sharp decline by Zone 5. Density was second greatest at the inlet edge and third greatest at the edge of the mature forest; these areas are roughly comparable in density to Zones 2 and 3, respectively. Density of *S. sebiferum* was extremely high in Zone 2, and almost equally high in Zone 6.

Average species richness of zones was greatest at the mature forest edge (8 species) and in the mature forest (7 species), as expected. Species richness was lowest near the point bar (Zone 5), which was also expected. What was unexpected was the relatively high species richness of Zone 4 (7 species). Individual plots within Zone 1 (mature forest) contained a total of 23 species out of the 27 found across all plots on the site. Plots within Zone 4 contained 17 out of 27 species.

Table 3 shows all species by size class (after Chambless & Nixon, 1975). Analysis of Table 3 revealed several distinct species and life stage characteristics. One of the most noticeable examples was that of *P. deltoides*, which are all in the larger size classes, especially >70 cm dbh. There were no seedlings, saplings or younger trees in any plot, indicating no re-establishment in the last 60+ years. Also, no seedling establishment was noted during the study period for this project, and in many cases, the understory of plots with *P. deltoides* contained a high number of saplings of *S. sebiferum*. Table 3 also showed that *S. sebiferum* was a highly successful species across

Table 2. Average basal area (m²/ha), density (stems/ha) and species richness (# species) per zone. Species indicated by a genus name followed by “sp.” were unable to be identified to the species level, and denote any individual of that genus, most likely individuals of the other species.

Genus	Species	Average Basal Area (m ² /ha)							Average Density (stems/ha)						
		1	2	3	4	5	6	7	1	2	3	4	5	6	7
<i>Acer</i>	<i>negundo</i>	0.71	0.05	0.63	0.49		0.05	0.23	18	8	125	95		8	19
<i>Carya</i>	<i>aquatica</i>	0.15						0.06	7						6
<i>Carya</i>	<i>illinoensis</i>	1.07		0.07	0.12	0.01	2.48		11		6	15	5	17	
<i>Carya</i>	<i>sp.</i>	0.78							4						
<i>Celtis</i>	<i>occidentalis</i>	1.63	0.16		0.11		1.18	0.07	89	8		55		25	19
<i>Cornus</i>	<i>drummondii</i>	0.55		0.17	0.31			0.96	168		88	210			375
<i>Crataegus</i>	<i>sp.</i>	0.54		0.31	0.04			1.77	70		75	30			225
<i>Diospyros</i>	<i>virginiana</i>	0.15	1.35	0.24	0.06		1.24	0.03	7	200	31	30		183	13
<i>Forestiera</i>	<i>acuminata</i>	0.01	0.09				0.03		5	75				17	
<i>Fraxinus</i>	<i>pennsylvanica</i>	0.77	0.59	0.33	0.01		0.03		11	83	75	20		8	
<i>Fraxinus</i>	<i>sp.</i>	0.31		0.01					4		13				
<i>Gleditsia</i>	<i>triacanthos</i>	0.00		0.27				0.01	2		19	5			6
<i>Ilex</i>	<i>americana</i>														
<i>Ilex</i>	<i>decidua</i>	0.18	0.02	0.08	0.05		0.02	0.38	93	8	44	70		8	194
<i>Ilex</i>	<i>vomitorea</i>														
<i>Liquidambar</i>	<i>styraciflua</i>	1.59			0.36	0.01		0.83	45			40	5		50
<i>Pinus</i>	<i>taeda</i>				0.53							5			
<i>Platanus</i>	<i>occidentalis</i>	6.74			0.68	2.06	6.52		80			85	145	42	

Table 2, continued.

		Average Basal Area (m ² /ha)							Average Density (stems/ha)						
Zones		1	2	3	4	5	6	7	1	2	3	4	5	6	7
Genus	Species														
<i>Populus</i>	<i>deltoides</i>	12.54							27						
<i>Quercus</i>	<i>nigra</i>	0.25			0.11			0.89	2			5			6
<i>Quercus</i>	<i>phellos</i>	0.08						0.27	4						13
<i>Sapium</i>	<i>sebiferum</i>	2.75	19.42	6.69	1.41		21.32	3.83	164	1283	531	170		1242	344
<i>Sideroxylon</i>	<i>lanuginosa</i>	0.14			0.02			0.49	5			10			19
<i>Ulmus</i>	<i>alata</i>		0.04					0.04		8				8	
<i>Ulmus</i>	<i>americana</i>	0.13			0.10				4			20			
<i>Ulmus</i>	<i>rubra</i>	0.20		0.11	0.07			0.39	11		13	35			19
<i>Ulmus</i>	<i>sp.</i>	0.22							5						
TOTAL		31.47	21.70	8.93	4.47	2.08	32.92	10.23	834	1675	1019	900	155	1558	1306
Average Species Richness (# species)															
		Zone	Zone	Zone	Zone	Zone	Zone	Zone							
		1	2	3	4	5	6	7							
		7	4	6	7	1	4	8							

the entire site, not only in density, but also in dominance. Almost all individuals had already recruited into the sapling stage or above, with two-thirds of all individuals already in the young tree stage. However, very few individuals seemed to reach a considerable size. Only half of all individuals of *C. drummondii* had recruited into the small tree stage, and almost none were larger. *D. virginiana* had an approximate rate of one-thirds recruitment to tree stage, and very few individuals exceeded 20 cm dbh. A few individuals larger than 20 cm were noted elsewhere in the study area, but not in the plots. Also, *S. sebiferum* was prolific in many plots with the highest densities of *D. virginiana*. *Crataegus* was a small-tree species as well, with only half recruiting to the tree stage. With both *I. decidua* and *F. acuminata*, no individuals existed above the 5-10 cm dbh class; these species were very branching, shrubby-type trees, and individual stems rarely were large, even if numerous. *L. styraciflua* and *P. occidentalis* both had increasingly fewer individuals with increased growth, and none existed in the largest size classes in any of the plots (although elsewhere on the site, there were larger individuals); this pattern appeared very steady. Table 3 also demonstrated that very few individuals of certain species existed compared to other species, which was also observed during scatterplot analysis of species density and dominance. Therefore, no clear patterns could be determined for these species.

Species richness was not related to TBA of plots ($r^2 = 0.039$; Fig. 8), and was only very weakly related to total density ($r^2 = 0.104$). Basal area of *S. sebiferum*, as was the case with most species, had no direct relationship with TBA ($r^2 = 0.058$; Fig. 9). In other words, neither a direct increase nor decrease emerged. However, a characteristic

Table 3. Species counts (# individuals) across all plots, by size class (cm dbh). (After Chambless & Nixon 1975.) Dbh values were rounded to the nearest whole number to place trees in appropriate size classes. Saplings are 1-1.49 cm dbh. Seedlings are defined as <1 cm dbh and less than 0.5m in height.

Genus	Species	<1	1-4.9	5-10	11-20	21-30	31-40	41-50	51-60	61-70	70-100	>100	Species Totals (Trees)
<i>Acer</i>	<i>negundo</i>	6	44	35	12	2		1					50
<i>Carya</i>	<i>aquatica</i>			1	2	1							4
<i>Carya</i>	<i>illinoensis</i>		2	3	4	1	1	1	1				11
<i>Carya</i>	<i>sp.</i>		5					1	1				2
<i>Celtis</i>	<i>occidentalis</i>	7	38	26	26	4	2						58
<i>Cornus</i>	<i>drummondii</i>	10	242	143	5								148
<i>Crataegus</i>	<i>sp.</i>	1	75	45	12								57
<i>Diospyros</i>	<i>virginiana</i>	3	72	27	11	1							39
<i>Forestiera</i>	<i>acuminata</i>		1	10									10
<i>Fraxinus</i>	<i>pennsylvanica</i>	4	17	23	5	1		2					31
<i>Fraxinus</i>	<i>sp.</i>			2			2						4
<i>Gleditsia</i>	<i>triacanthos</i>	1	12	1	3								4
<i>Ilex</i>	<i>americana</i>		1										0
<i>Ilex</i>	<i>decidua</i>		87	74									74
<i>Ilex</i>	<i>vomitorea</i>	4	5										0
<i>Liquidambar</i>	<i>styraciflua</i>		13	10	15	7	3						35
<i>Pinus</i>	<i>taeda</i>						1						1
<i>Platanus</i>	<i>occidentalis</i>		36	25	35	10	7	10	2	1			90
<i>Populus</i>	<i>deltoides</i>							1	3	1	8	2	15
<i>Quercus</i>	<i>nigra</i>		1		1			1					2
<i>Quercus</i>	<i>phellos</i>				2								2
<i>Sapium</i>	<i>sebiferum</i>	6	163	172	162	26	6						366
<i>Sideroxylon</i>	<i>lanuginosa</i>		1	2	2	1							5

Table 3, continued.

Genus	Species	<1	1-4.9	5-10	11-20	21-30	31-40	41-50	51-60	61-70	70-100	>100	Species Totals (Trees)
<i>Ulmus</i>	<i>alata</i>	6	28	1									1
<i>Ulmus</i>	<i>americana</i>		1	3	2	1							6
<i>Ulmus</i>	<i>rubra</i>	4	20	11	3	1							15
<i>Ulmus</i>	<i>sp.</i>	3	4	1	1		1						3
TOTAL		55	868	615	303	56	23	17	7	2	8	2	

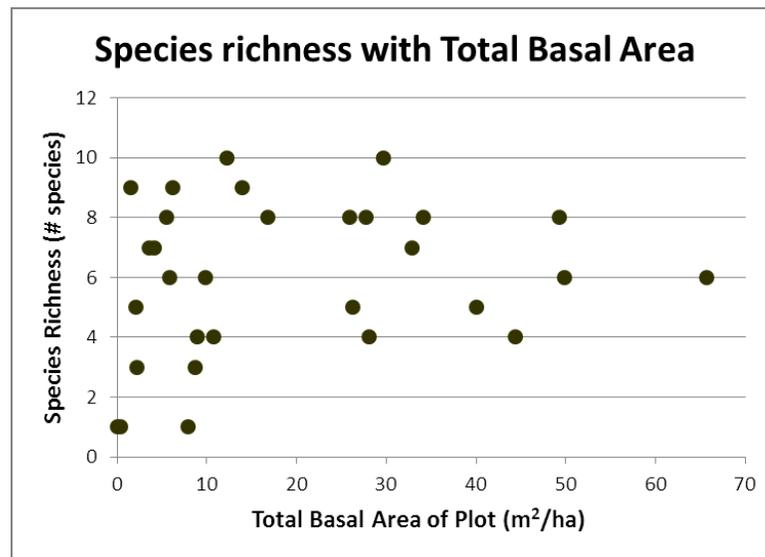


Fig. 8. Species richness versus total basal area.

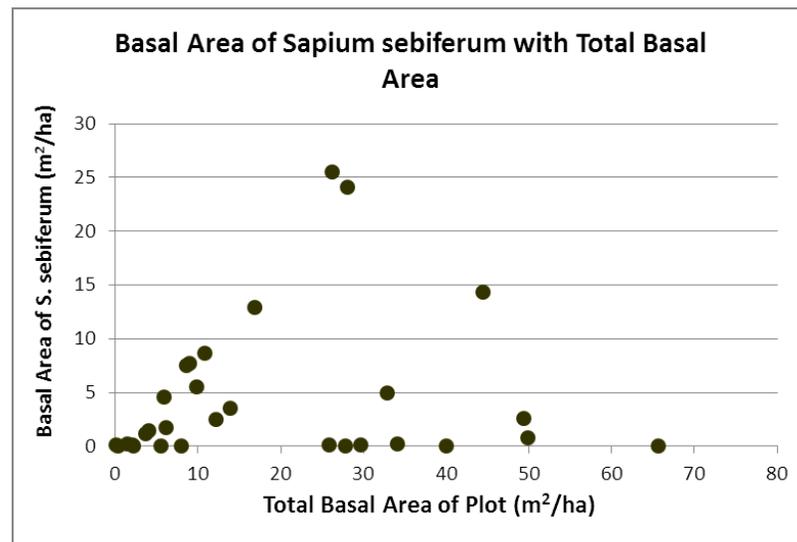


Fig. 9. Basal area of *Sapium sebiferum* versus total basal area.

unimodal distribution of points was apparent, with basal area of *S. sebiferum* strongly limited by low and high TBA (e.g. no individuals of *S. sebiferum* exist with TBA in excess of approximately 66 m²/ha), and greatest in the central range of TBA (28-30 m²/ha). *S. sebiferum* had similar unimodal distributions of basal area ($r^2 = 0.031$) and density ($r^2 = 0.032$) with species richness. Species richness did not vary based on basal area or density of *S. sebiferum*. Density and basal area of *F. acuminata* may decrease with increased TBA, but there were too few occurrences of the species to determine any relationship conclusively.

Basal area of most individual species was not related to species richness. *C. drummondii* showed weak increases with species richness in basal area ($r^2 = 0.346$) and in density ($r^2 = 0.340$). Basal area and density of *I. decidua* increased weakly with species richness ($r^2 = 0.221$ and $r^2 = 0.209$, respectively). *U. rubra* increased weakly in basal area with greater species richness ($r^2 = 0.217$).

Species by species basal area and density showed few relationships, and most of these were weak. Basal area of *C. drummondii* increased with basal area of *C. illinoensis* ($r^2 = 0.360$), as did basal area of *P. occidentalis* ($r^2 = 0.362$).

Most species did not show any discernible trends in relative density or dominance when plotted with other species. However, *U. rubra* decreased with increased dominance of *A. negundo* ($r^2 = 0.763$; Fig. 10). *P. occidentalis* had a very weak decrease in dominance with increased *A. negundo* ($r^2 = 0.129$), as did *F. pennsylvanica* ($r^2 = 0.151$). *P. deltoides* had a slight decreasing trend (from 51.3 to 19.5 percent) with increased dominance of *C. occidentalis* ($r^2 = 0.355$), and *U. rubra*

decreased with increased *Crataegus* ($r^2 = 0.265$). *D. virginiana* increased weakly with increased *S. sebiferum* ($r^2 = 0.169$).

Species by species relative density likewise resulted in few clear relationships, and all were relatively weak. *C. drummondii* seemed to decrease with increased *C. aquatica*, but too few plots contained *C. aquatica* to provide enough evidence. For most species, weak or no relationships were also the case. *S. sebiferum* decreased with increased *C. drummondii* ($r^2 = 0.279$). Other *Fraxinus* species besides *F. pennsylvanica* (i.e. *Fraxinus* sp.) seemed to increase in density with *F. pennsylvanica* and decline with increased *S. sebiferum*. However, too little data on *Fraxinus* species other than *F. pennsylvanica* was available. *C. drummondii*, on the other hand, showed a weak decreasing trend with increased *F. pennsylvanica* ($r^2 = 0.283$). *Ulmus* sp. seemed to increase gradually with an increased density of *P. deltoides* ($r^2 = 0.430$), but there were

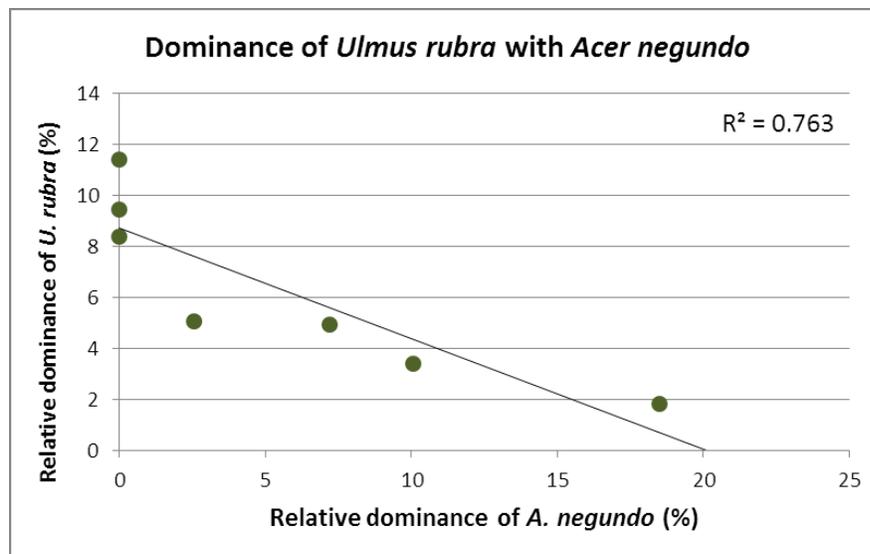


Fig. 10. Relative dominance of *Ulmus rubra* with *Acer negundo*.

too few instances of non-zero density, as fewer individuals exist on the site than of the three other species of *Ulmus*.

Several species that were rare on this meander bend (i.e. very few individuals existed across all plots) seemed to show fairly clear potential relationships of basal area, density, or relative density or dominance with various other species. However, so few plots contained individuals that it was impossible to confidently determine any relationship with the existing data. These species are *G. triacanthos*, both species of *Quercus*, *F. acuminata*, *C. aquatica*, individuals of *U. rubra* greater than sapling size, and *Sideroxylon lanuginosa*. For example, basal area and density of *F. acuminata* seemed to decrease with greater species richness, and *S. lanuginosa* seemed as if it would increase in dominance with increased dominance of *L. styraciflua*. *U. rubra* seemed to increase very slowly in basal area with greater species richness ($r^2 = 0.217$), and with increased *Gleditsia*.

5.4.2. Soil texture patterns

Figure 11 shows total sand, silt and clay averaged across all plots. Graphs of the five USDA sand classes for all plots on the site showed that all plots except 2, 3 and 12 exhibited a strong skew toward the very fine sands (VFSand), with increasing amounts with finer size classes. Figure 12 shows this trend averaged across all plots. Many of the percentages in sand size classes in the plots were very small, particularly with the coarser sands. Figure 13 (a-c) shows a sample of three such graphs of sand classes (Plots

2, 3 and 4). These three plots are located on a transect across the open grassy area at the north end of the study site (see Fig. 6). They were selected to examine for a possible pattern in texture variation from the eastern side of the field (Plot 4, mature forest edge) to the western side closer to the river channel, in vegetation Zone 4 (Plot 2). Plot 3 was located in the center of the open field, and contained only grass. Plot 4 had a high proportion of VFSand (20.3 percent), and almost no other sands. Plot 4 also had a much higher percentage of total clay (TClay; 25 percent; Fig. 13d) than either of the other two plots, nearly twice as high as Plot 3 (13.1 percent), and more than three times as high as Plot 2 (8.2 percent). Plot 3 contained more coarse and medium sands than either of the other two plots, and had more total sand (TSand) than Plot 4 (63.3 and 22.8 percent TSand, respectively). Percent TSand decreased gradually with increasing distance from the point bar, and percent total silt (TSilt) and TClay increased (Fig. 13d). Percent TSilt increased faster with distance from the point bar than percent TClay. Plot 2 was classified as a loamy fine sand, Plot 3 as a fine sandy loam, and Plot 4 as a silt loam (Fig. 14). Vegetation at Plot 4 was mature forest edge, Plot 3 contained only grass, and Plot 2 had young individuals of woody species (Zone 4).

No trends emerged with any grain size from sorting of texture classes, other than a possible slight trend of increasing TSilt percentage with increasing distance from the nearest part of the active river channel. However, distances were only visually estimated, which may not be sufficient to determine a trend.

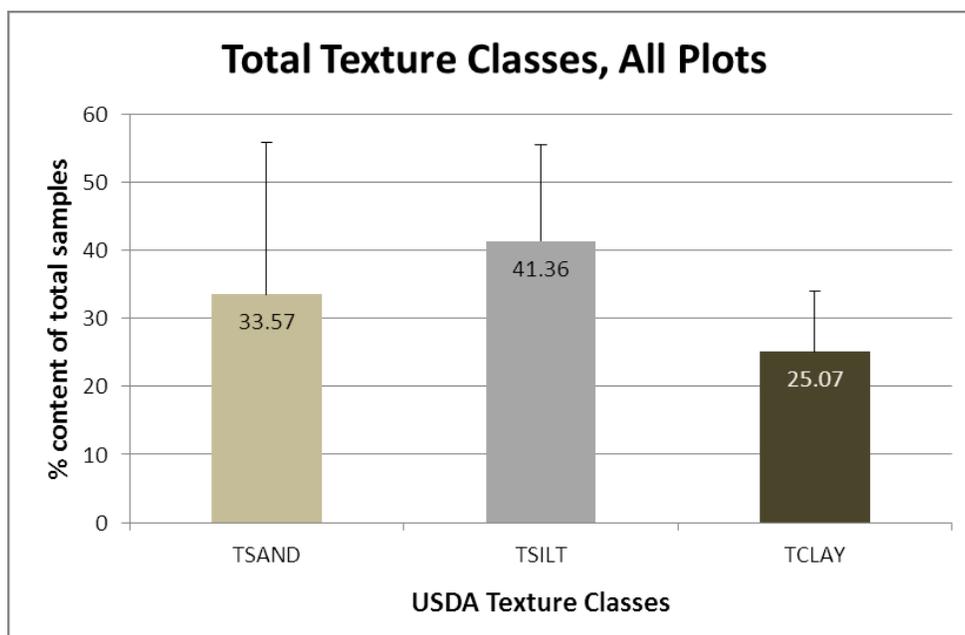


Fig. 11. Average TSand, TSilt and TClay for all plots. Texture classes are USDA standards. Error bars show the standard deviation for each texture class.

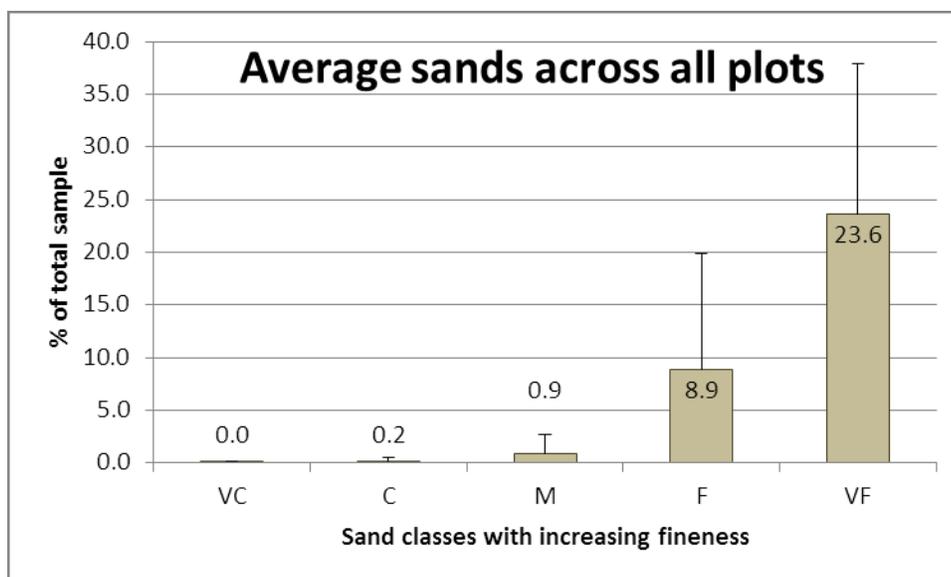


Fig. 12. Average sand classes across all plots. Sand classes are as follows: VC = very coarse sand (1-2mm), C = coarse sand (0.5-1mm), M = medium sand (0.25-0.5mm), F = fine sand (0.1-0.25mm), and VF = very fine sand (0.05-0.1mm). Size classes are according to USDA standards. Error bars show the standard deviation for each size class.

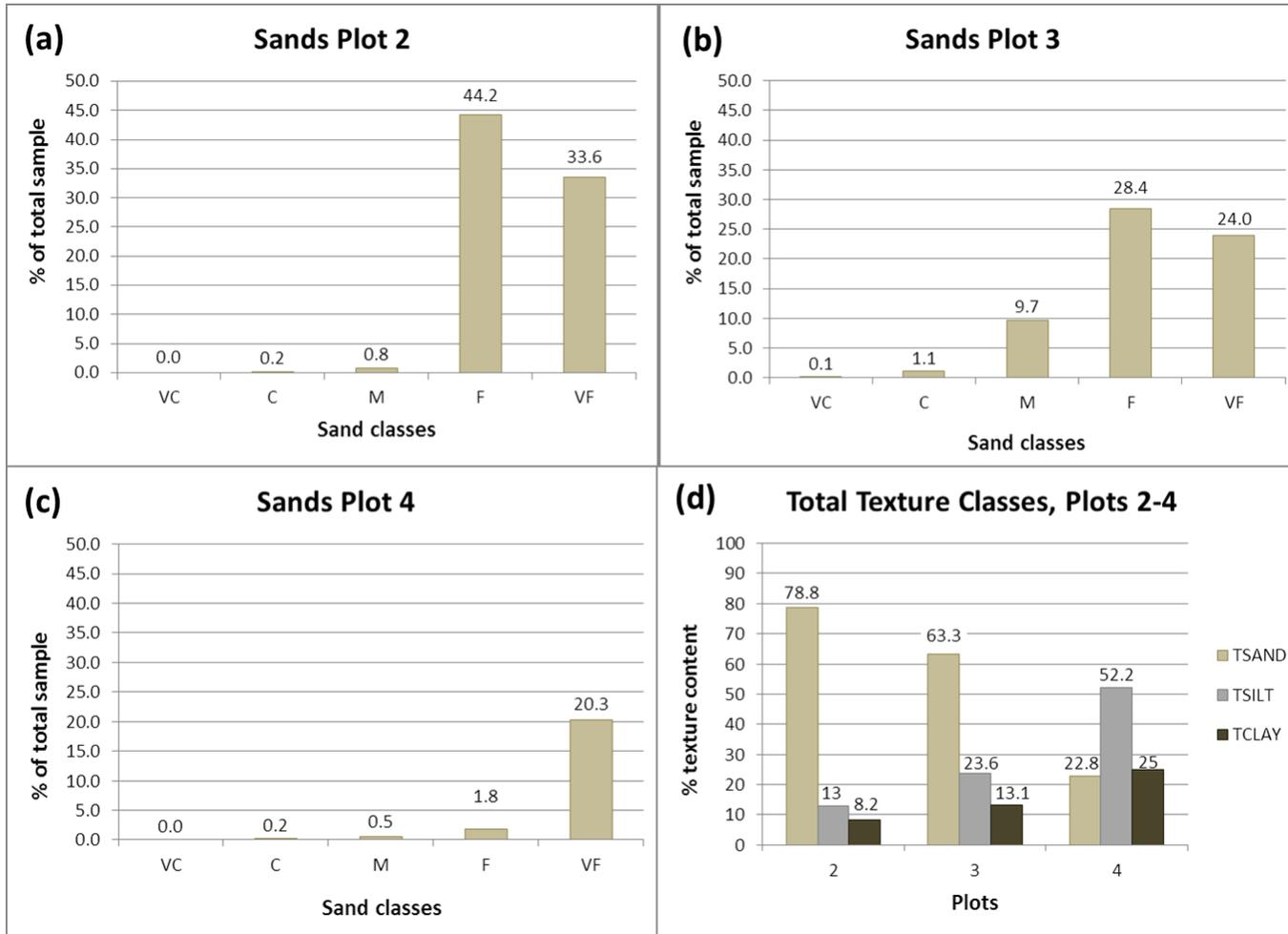


Fig. 13. Sand fractions and total sand, silt and clay for Plots 2, 3 and 4. These graphs were created to examine for a trend of soil texture across the open grassy field on the north end of the meander bend. Size classes are as described for Figure 12.

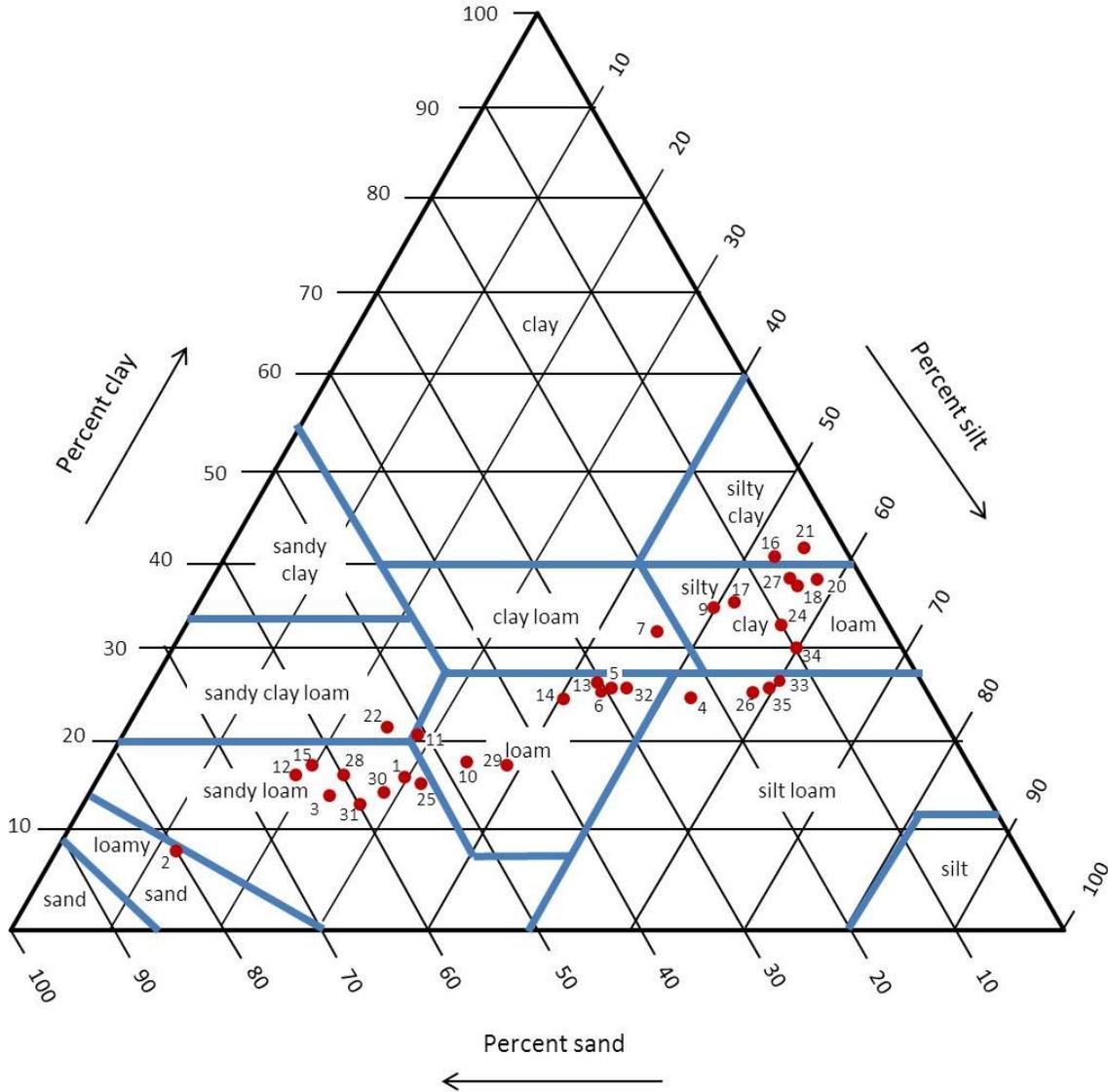


Fig. 14. USDA soil texture classes for all plots. All plots were classified as loams with the exception of plots 2, 16 and 21.

5.4.3. *Potential relationships and feedbacks between soil texture and community types*

Plots located in Zone 3 (small thorny trees) were all of a similar soil texture, silty clay loam to silty clay (Fig. 14). Zone 2 was also entirely composed of these two texture classes (Plots 20, 21 and 24 all fall within a very small area to the extreme center right edge of the USDA-type triangle; Fig. 14). Soil in these plots contained almost no sand. Most plots in Zone 1 (mature forest) fell into either the loam or the silty clay loam categories. No other zones were characterized to such a great extent by a single texture class.

Species richness was not related to any soil texture. TBA increased with coarse silt (CSilt; $r^2 = 0.326$; Fig. 15) but no other texture. Total density of plots showed very weak increases with CSilt ($r^2 = 0.140$), fine silt (FSilt; $r^2 = 0.233$), TSilt ($r^2 = 0.220$), fine clay (FClay; $r^2 = 0.234$) and TClay ($r^2 = 0.230$), and a very weak decreasing trend with VFSand ($r^2 = 0.203$), but with no other sands.

Most species' relative density and dominance either had no discernible relationship with soil texture, or showed an extremely weak relationship. However, for a few species, distinct patterns of either increased or decreased relative density or dominance were apparent for certain grain size classes. Results of initial analysis showed no relationship with TSilt for most species (TSilt seemed to have the most likely relationship with distance from the active river channel). An exception was *S. sebiferum*,

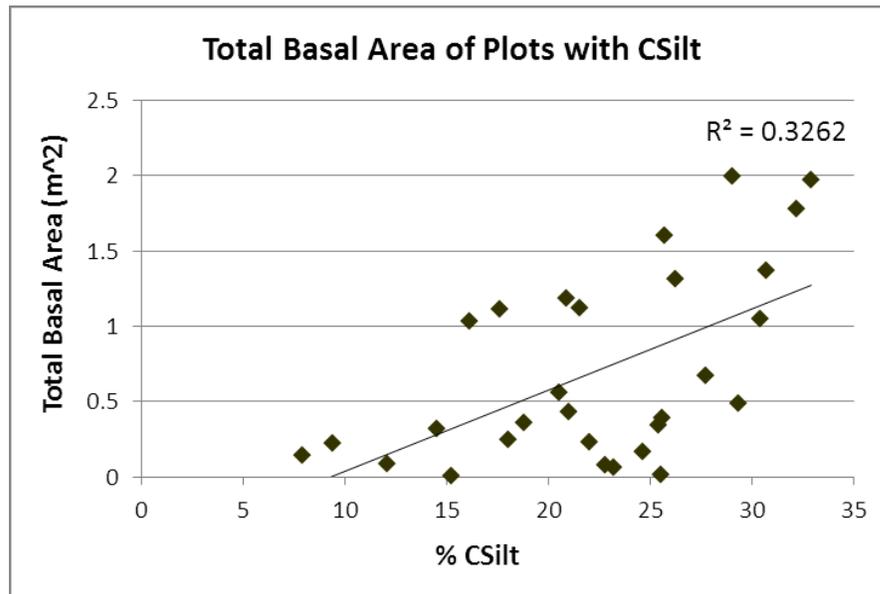


Fig. 15. Total basal area of plots with CSilt.

which clearly increased in density with an increase in TSilt ($r^2 = 0.549$; Fig. 16a). Density of *S. sebiferum* increased even more clearly with FSilt ($r^2 = 0.655$; Fig. 16b) but not with CSilt ($r^2 = 0.132$) when analysis of TSilt was broken down into fractions. Similar increases in density were found with both TClay ($r^2 = 0.627$; Fig. 16c) and FClay ($r^2 = 0.646$; Fig. 16d). However, density of *S. sebiferum* clearly decreased with an increase in TSand ($r^2 = 0.629$; Fig. 16e). No discernible relationship was found for this species' density with most other sand size classes; this was true for most other species as well. However, density of *S. sebiferum* decreased with increasing amounts of VFSand ($r^2 = 0.647$; Fig. 16f). No pattern was discernible with medium or fine sands, which were present in all samples. Also, in the field, *S. sebiferum* was observed to be much less dense out on or near the point bar (greater percentage of sands), and denser in areas with

more trees (greater percentage of silts and clays), particularly in areas with small to medium sized trees, such as the shrub-small tree zone.

Two other species that showed some relationship with silts, although not as strongly as *S. sebiferum*, were *F. pennsylvanica* ($r^2 = 0.290$ and 0.301) and *C. drummondii* ($r^2 = 0.357$ and 0.383). Both increased with increased TSilt and FSilt content (respectively); however, there was no relationship with these species and CSilt. *F. pennsylvanica* also had moderate increasing relationships with both TClay ($r^2 = 0.431$) and FClay ($r^2 = 0.419$).

Results of species' relative dominance by soil type were similar to those of relative density in that very few species showed any obvious relationship with a particular texture class. Most species had very weak if any relationships with different grain sizes; usually, relationships of dominance tended to be somewhat weaker than those of relative density for the same species. However, a few species' dominance was clearly related to a particular grain size class, and results were comparable to the corresponding results with soil texture and density. *S. sebiferum* dominance again had a decreasing trend with increased TSand ($r^2 = 0.683$; Fig. 17a). The relationship between dominance of *S. sebiferum* and VFSand ($r^2 = 0.694$; Fig. 17b) was slightly stronger than with TSand. Dominance for this species had somewhat less clear of an increasing trend with TSilt ($r^2 = 0.487$) than did its relative density, but the trend with FSilt ($r^2 = 0.614$) was comparable to that of relative density. *S. sebiferum* also showed a very clear

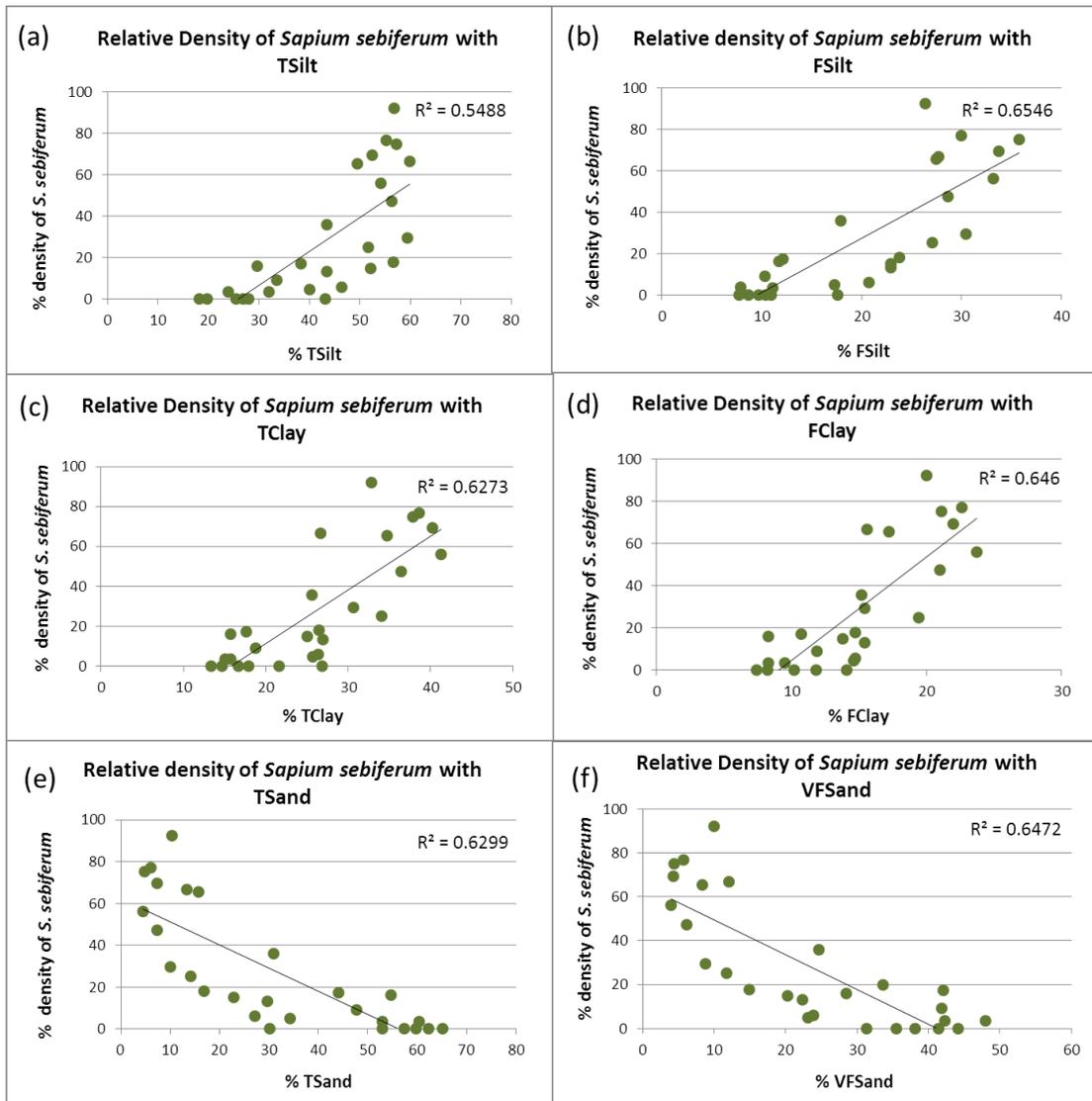


Fig. 16. Relative density of *Sapium sebiferum* with various soil textures. Soil textures are a percent of the total sample.

increase in dominance with increasing FClay ($r^2 = 0.701$; Fig. 17c), and likewise with TClay ($r^2 = 0.661$; Fig. 17d). Early analysis of soil samples indicated that plots 24, 20, 21 and 16 contained some of the highest percentages of clay on the site (Fig. 14); these plots were all located on or near the banks of the central inlet (Zone 6 and vicinity). Plot 24 contained > 90 percent relative density and dominance of *S. sebiferum*, and Plots 20, 21 and 16 all contained 56-75 percent relative density and 70-80 percent dominance of this species.

Other species that had clear relationships with soil textures included *U. rubra*, and to a lesser extent, *P. deltoides*. *U. rubra* increased in relative dominance with TSand ($r^2 = 0.666$; Fig. 18a), and even more clearly with VFSand ($r^2 = 0.716$; Fig. 18b). *U. rubra* also decreased in dominance with increased FSilt ($r^2 = 0.744$; Fig. 18c), FClay ($r^2 = 0.614$), TClay ($r^2 = 0.664$; Fig. 18d) and TSilt ($r^2 = 0.628$).

Species that had weaker relationships with soil texture included, for instance, *P. deltoides* and *P. occidentalis*. Dominance of *P. deltoides* decreased with VFSand, ($r^2 = 0.437$; Fig. 19) and increased with TSilt ($r^2 = 0.271$), FClay ($r^2 = 0.295$) and TClay ($r^2 = 0.343$). Dominance of *P. occidentalis* increased with VFSand ($r^2 = 0.259$) and decreased with FSilt ($r^2 = 0.198$). Species relationships of basal area and density with soil textures were generally weaker than comparable species-soil relationships using relative density and dominance measures. For example, basal area of *S. sebiferum* still increased with FClay ($r^2 = 0.373$) and TClay ($r^2 = 0.333$), but the relationships were weaker than those of relative density and dominance with the corresponding soil textures. Raw density

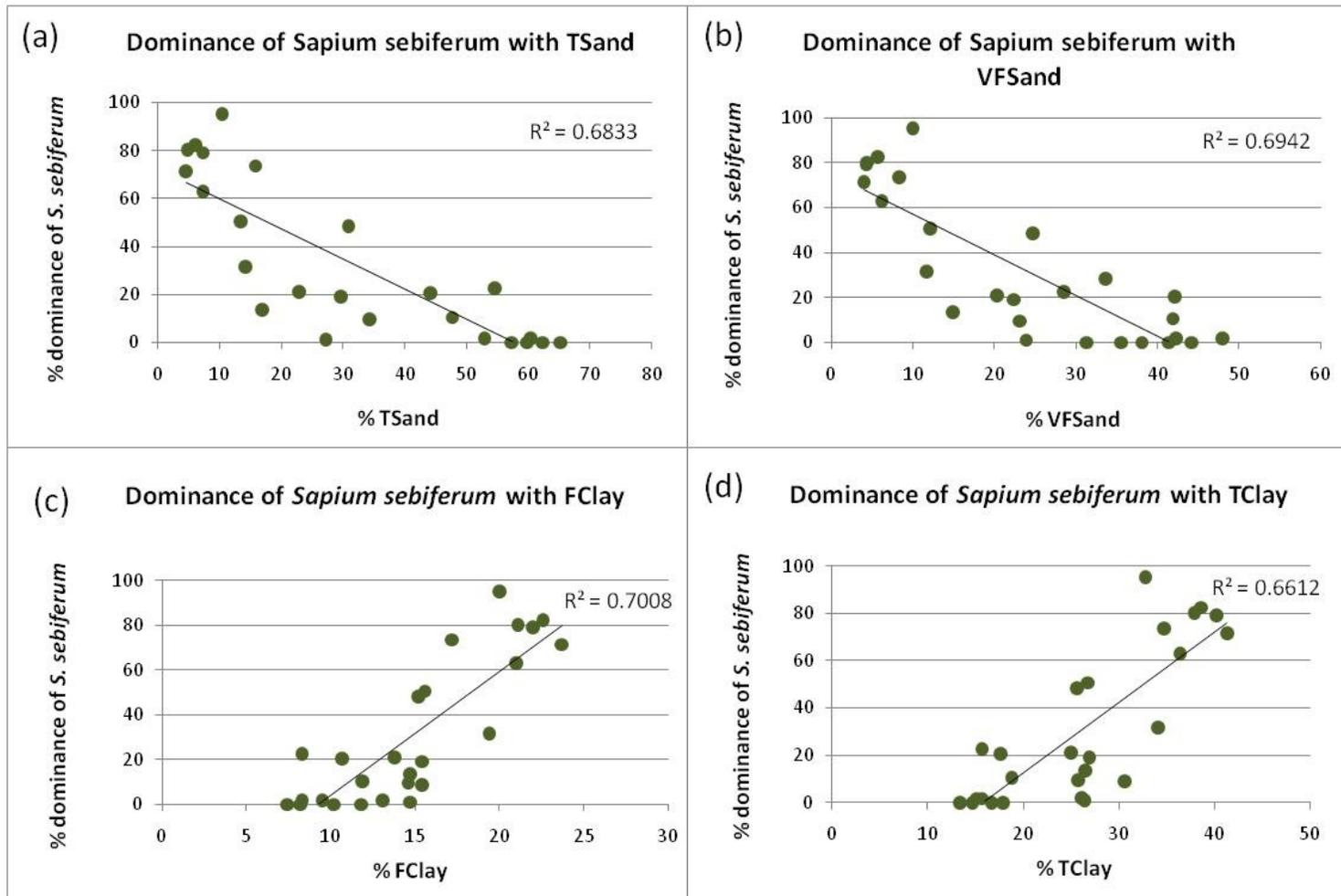


Fig. 17. Relative dominance of *Sapium sebiferum* with soil textures.

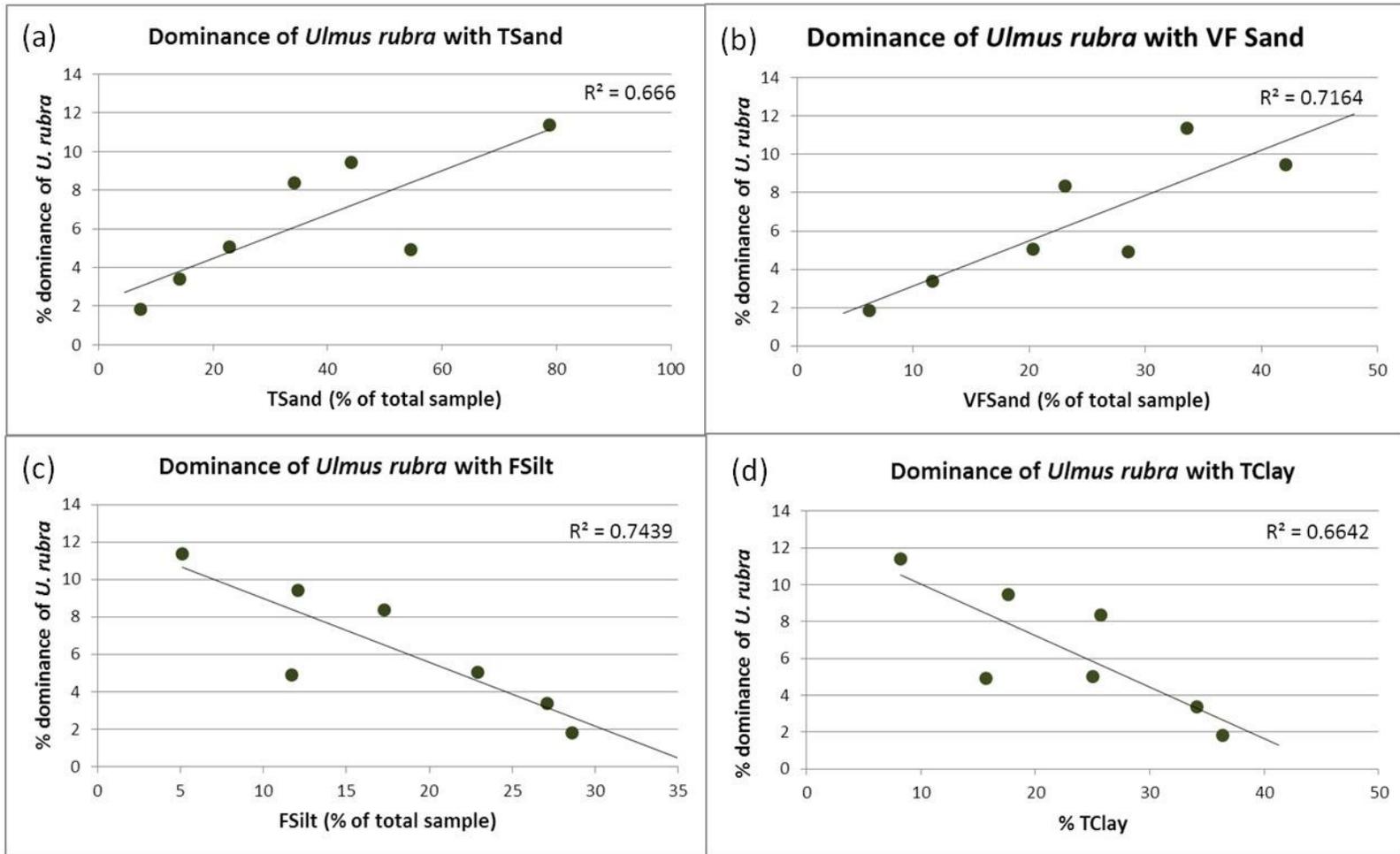


Fig. 18. Relative dominance of *Ulmus rubra* with soil textures.

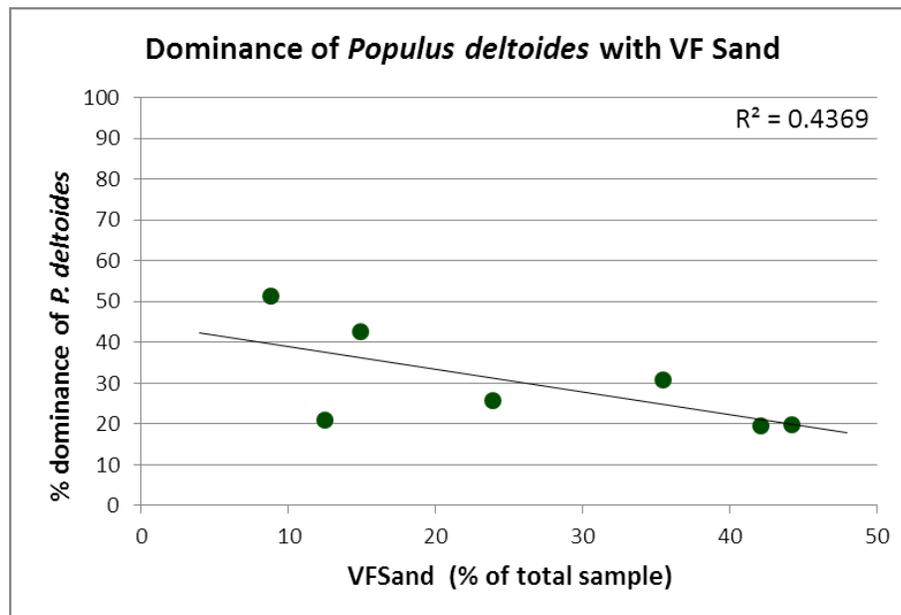


Fig. 19. Relative dominance of *Populus deltoides* with very fine sands.

(number of species per hectare) of *S. sebiferum* only showed relationships with CSand, TSand and VFSand, and not with any other soil texture, whereas relative density of *S. sebiferum* was related to all soil textures except CSilt (Fig. 16). An exception was *U. rubra*, which increased weakly in basal area with increased CSilt ($r^2 = 0.335$), but showed a strong decrease in density with increased CSilt ($r^2 = 0.702$), comparable to its decrease in relative dominance with FSilt (Fig. 17c).

Again, as was the case with species by species relationships, rare species seemed to show fairly clear relationships with various soil textures. However, in this case it was also impossible to determine relationships with certainty because of limited data. For

example, *Gleditsia* seemed to increase in basal area and relative dominance with FClay, and decrease in basal area and relative dominance with TSand and VFSand, but this could not be determined.

At this site, the only plot containing individuals of *Q. phellos* did not have a particularly high clay content (26.9 percent, comparable to 29.6 percent sands). Silt content, by contrast, was nearly twice as high (43.5 percent). The soil texture of the plot was defined as a loam according to USDA standards (Soil Survey Staff 1993).

5.5. Flow data

Mean annual discharge data did not show any noticeable changes in annual discharge following the date of dam construction, as expected (Fig. 3 a,b). Mean annual discharge stayed almost identical between pre- and post-dam construction periods for Romayor. Mean annual discharge data for Liberty showed considerable variation, but less so than at Romayor.

6. DISCUSSION

Species composition (and also both individual and dominant species) in this study differed somewhat from those found by Chambless & Nixon (1975) in a riparian area in East Texas, likely as a result of regional variation (southeast and Coastal Plain, vs. northeast Texas for Chambless & Nixon 1975). Nonetheless some species common to both studies showed similar patterns of establishment. For example, Chambless & Nixon (1975) found that sweetgum (*L. styraciflua*) and green ash (*F. pennsylvanica*) were present throughout the site regardless of elevation, which was also the case in this study area. However, this study found no apparent relationship between elevation and any species, as most species, with few exceptions, could be found in most or all areas of the site. This was a rather unexpected finding, as the literature on variation of community composition in riparian zones indicates that communities vary between ridges and lower lying areas e.g., swales or slough banks. The only exception to the findings of this study that could be determined was that of *F. acuminata*, which was primarily found in the wettest area of the site, along or near the central inlet. This would indicate that this species may require high soil moisture levels, or at least that it thrives in wetter environments. Chambless & Nixon (1975) likewise found greater abundance ‘swamp privet’ (one of several common names for this species) on sloughs or streams. At this study site, however, it would be difficult to determine any definite pattern of abundance specifically, as very few individuals of the species exist. Chambless & Nixon (1975) found that *D. virginiana* was more prevalent in poorly drained areas. This was

largely the pattern seen at this site as well, as the highest density of *D. virginiana* was found in a plot near the inlet. However, this species could be found in all areas of the site, including the driest areas near the point bar, and relatively high densities were observed in other areas away from the inlet. Chambless & Nixon (1975) mentioned that they found *I. deciddua* and *C. aquatica* to be more prevalent on elevated soils, but also referenced studies that indicated these species favored ‘unelevated’ areas, or areas that were periodically flooded. Neither of these was the case at this site, where *C. aquatica* was present in areas ranging from the driest to the wettest, and both species were present in all zones. Therefore, it is likely that many species on this site may be more influenced by other environmental factors than only moisture availability.

Cooper et al. (2003) found that establishment of *P. deltoides* depended highly on water availability and flood pulse. Establishment of *P. deltoides* also occurred under a large variety of flow stages, which would indicate that this species is very hardy with high tolerance for changing environmental conditions, making it a successful pioneer species able to colonize newly created low-elevation sites rapidly. However, their study was conducted in an arid environment, so it is possible that in more humid environments such as in this study, where water is more readily available, that it may not be the only or major controlling factor for survival of *P. deltoides*. Soil texture and time since establishment may be more important controlling factors than water availability at this site.

It is assumed that the establishment and re-sprouting of *P. occidentalis* observed on the point bar is a result of tolerance to flooding, as no herbivory by cattle of this

species was observed (herbivory is another possible cause of mortality in young saplings of many species). The prevalence of *S. sebiferum* in Zone 2 appears to be due to the fact that the inlet provides water to the central part of the bend. Also, the absence or lower abundance of *S. sebiferum* in Zones 4 and 5 (closer to the point bar and in full sun) indicate that this species may not be tolerant of high levels of light. It is therefore possible that the growth of *S. sebiferum* is facilitated by increased water availability, and is somewhat inhibited by direct sunlight where mature trees that provide shade or partial shade are absent. It is also possible that the ability of *S. sebiferum* to establish on the point bar is restricted by coarser soil texture, as the highest densities of *S. sebiferum* were found in plots that had finer textured sediment.

The lack of seedling establishment of *P. deltooides* noted during the study period and also from results presented in Table 3 may indicate that this species may become rare or non-existent on this site when the present mature individuals die. Competition from *S. sebiferum* may prevent seedling establishment, as in many cases the understory of plots with *P. deltooides* contained a large number of saplings of *S. sebiferum*. It is also possible that favorable conditions for establishment in those plots (mature forest) do not exist; e.g., there may not be sufficient light or water available for seedlings. Results from Table 3 indicate that most individuals of *S. sebiferum* recruit quickly into the young tree stage. It may be encouraging that very few individuals seem to reach a considerable size; however, this could merely be a factor of the time since invasion, and not a result of life history characteristics of endurance or competitive capability. The size characteristics of *C. drummondii* depicted in Table 3 may be expected considering that *C. drummondii* is a

small understory species. It is interesting to note, though, that approximately half of all individuals seemed to have reached the tree stage (i.e. adulthood) at the time of this study, especially considering the low number of seedlings present. In other words, this does not appear to be a species with prolific seed dispersal to counteract mortality (an r-type species). It is possible that either all seedlings had recruited to sapling stage before the study period, or else had died as a result of drought or heat stress. *Crataegus* tends to be a small-tree species as well. The recruitment rate to tree stage and size of individuals of *D. virginiana* is likely a result of competition for light resources at certain locations, especially with *S. sebiferum*, as a few individuals larger than 20 cm dbh were seen elsewhere in the study area. Also, *S. sebiferum* was prolific in many plots with the highest densities of *D. virginiana*. With both *I. decidua* and *F. acuminata*, the absence of individuals above the 5-10 cm dbh class is most likely because of the growth characteristics of these species, which are very branching, shrubby-type trees. Individual stems, although very numerous, rarely grow to a large size. Table 3 also demonstrates that very few individuals of certain species (e.g. *S. lanuginosa*, *G. triacanthos*) exist on this site compared to other species. Although no clear patterns could be determined for these species, it seems likely that clear patterns might emerge if more individuals were present.

The unexpected greater TBA of the inlet than the mature forest is most likely merely a result of greater density, as the average basal area of each individual was considerable smaller at the inlet edge than of individuals of the same species in the mature forest. Also, average density of the inlet zone was considerably greater than that

of the mature forest (Table 2). The edge of the mature forest consists of several small tree species or otherwise small individuals of species not found in the mature forest (e.g. *Crataegus*, *Q. phellos*) or found to a lesser extent (e.g. *I. decida*). Also, large individuals of species e.g. *P. deltoides* and *P. occidentalis* were absent in the mature forest edge. Thus, this zone had a much lower TBA than the mature forest, but the presence of some larger individuals of certain species caused the TBA to be larger than that of Zone 3, where such individuals are absent.

The high average species richness noted in Zone 4 did not fit the general pattern of decreasing species richness with proximity to the point bar, i.e. newly established surface. It is unclear why this zone's species richness is so much greater than that of Zone 5, and comparable to the mature forest. One possibility is that there is more variation between plots in this zone than in Zone 5, so that individual plots with higher species richness may increase the average of the zone. Another possibility is that Zone 4 formed considerably before Zone 5, i.e., that there is greater temporal difference between the formation of Zones 4 and 5 than between Zones 3 and 4. This variation would allow more time for secondary species to establish in greater numbers. The sharper decline in density between Zones 4 and 5 than between other zones may be an indication of this temporal variation.

The pattern of average basal area and density of *S. sebiferum* across all zones (Table 2) indicates that this species may be greatly facilitated by increased water availability. Basal area and density were greatest in areas at the edge of the central inlet (Zone 6) or in close proximity to it (Zone 2 is for the most part relatively close to the

inlet). Also, *S. sebiferum* may benefit from proximity to high densities of *F. pennsylvanica* and especially *D. virginiana* (Zone 2), or at least is very successful at out-competing those two species. *S. sebiferum* was almost or completely absent in Zones 4 and 5 (closer to the point bar).

The unimodal pattern seen with basal area of *S. sebiferum* and TBA is most likely a result of the combination of two factors, growth rate and disturbance rate. These two factors are influenced by external environmental factors; in conjunction, these factors lead to the peak of species function in the intermediate range, where resource conditions are relatively favorable but interspecific competition is still moderate (see Huston 2004). In areas of high productivity and disturbance (e.g. most riparian environments), species establishment can be expected to be greater than in most other areas (Huston 2004). Basal area i.e., growth of *S. sebiferum* may be limited at the lower range of TBA by unfavorable environmental conditions, or the fact that there may not have been sufficient time for growth since deposition. Basal area at the upper range of TBA is most likely limited by stronger competition between species for available resources.

The decrease in relative density of *S. sebiferum* with increased *C. drummondii*, although fairly weak, may be worth noting when considering behavior of *S. sebiferum* with other species. *C. drummondii* may resist invasion by *S. sebiferum*, at least until *S. sebiferum* becomes larger (i.e. more dominant); dominance could be expected at later life stages of *S. sebiferum*, as it is able to grow larger than *C. drummondii*, which is typically an understory tree. The increase in relative density of *Fraxinus sp.* with

increased density of *F. pennsylvanica* may indicate that *F. pennsylvanica* facilitates the establishment of other species of its genus. However, too little data on *Fraxinus* species other than *F. pennsylvanica* was available at this site to clearly determine this relationship.

Several species that are rare on this meander bend (i.e. very few individuals across all plots) seemed to have fairly clear potential relationships of relative density or dominance with those of various other species. However, so few plots contain individuals (most plots have zero percent density and dominance for these species) that it is impossible to conclusively determine any relationship with the existing data. These species are *G. triacanthos*, both species of *Quercus*, *F. acuminata*, *U. americana* and *Sideroxylon lanuginosa*. *S. lanuginosa* seems as if it would increase in dominance with increased *L. styraciflua*. However, this species is present in very few plots. Relative density of *C. drummondii* seemed to decrease in a near-linear trend with increased density of *Gleditsia*; *U. rubra* seemed to increase very slowly with increased *Gleditsia*. The few plots that contained *U. americana* showed a sudden and sharp decrease in density of that species with increased *S. sebiferum*, but again, an absence of enough individuals to provide clear data was apparent.

The observed strong skew of average sand textures toward finer sand classes can be expected in a fluvial system, where sediments are primarily very fine textured. The trend of increased finer sediment noted with Plots 2-4 may indicate that grain sizes of sediment in fluvial systems decrease with distance from the point bar. Also, it would seem that a higher percentage of coarser sands as at Plot 3 would favor grass and

perhaps herbaceous vegetation, similar to that found on the point bar, whereas higher percentages of fine sands, or lower percentages of sands overall and higher clay or silt content, would facilitate the growth of woody vegetation. The highest densities of woody vegetation (or at least of some species) may be found in areas that have a combination of high silt *and* clay percentages, as at e.g. Plot 4 (mature forest edge).

The lack of a pattern of decreased density and dominance of *S. sebiferum* with coarser sand textures is most likely merely a result of the fact that very few plots (3 out of 32) contained any very coarse sand. However, no pattern was discernible with medium or fine sands either, which were present in all samples. Also, in the field, *S. sebiferum* was observed to be much less dense on or near the point bar (greater percentage of sands in general, and coarser sands in particular), and denser in areas with more trees (these areas had a greater percentage of silts and clays, and VFSand), particularly in areas with medium sized trees, such as the shrub-small tree zone. Furthermore, soils analysis showed that plots with the highest relative density and dominance of *S. sebiferum* also had the highest percentage of clays. Therefore, this particular species may be at least partially dependent on soil texture, and high clay content may greatly increase density and dominance of *S. sebiferum*. Relative density of *S. sebiferum* also increased clearly with FSilt but not with CSilt, further indicating that this species (and ultimately also community composition) may be affected by very specific and restricted particle size ranges. Specifically, growth and density of *S. sebiferum* may be facilitated by very fine textured sediments. *S. sebiferum* is able to exist on this site in both high and low-light environments, as well as in areas of both

greater and lower water availability, making it a highly competitive invasive species. However, it is likely that its establishment and survival in some areas may be partially inhibited by soil texture, particularly in areas of coarser textured sediments, such as nearer to the point bar. The results with dominance of *U. rubra* also suggest that species can be influenced by soil texture. Further work in analyzing certain species to determine if they are influenced more strongly by soil texture than by other variables (and more so than are other species) would be beneficial.

Contrary to certain theories put forth by Huston (2004), it may not be the case that invasive species are influenced by all of the same environmental factors that influence native species, or at least not to the same extent. Certain factors may influence invasive species more strongly than native species, or vice versa. Also, interspecific competition may not be one of the principal controls on success of establishing. For instance, there was no relationship between species richness or TBA and *S. sebiferum*, and likewise no relationship when basal area and density of *S. sebiferum* were tested as possible influences on species richness. Native species in this study did not have nearly as strong relationships with soil textures as did *S. sebiferum*. Furthermore, the strength of the soil texture-vegetation growth results may also indicate that it is soil texture (rather than disturbance or even competition) that has the greatest influence on *S. sebiferum* in particular; this may perhaps apply to other invasive species as well. This study was not able to test this possibility, as *S. sebiferum* was the only non-native tree species found in the study area.

Chambless & Nixon (1975) indicated that conditions for the growth of *Q. phellos* became 'less favorable' with a higher clay content in the soil, which they found in the 'unelevated soils'. At this site, the only plot containing specimens of *Q. phellos* did not have a particularly high clay content; however, silt content was considerable, and nearly twice as high as clay content. Thus it is not clear if this species' growth is restricted by clay content specifically, or only by a high percentage of fines in general. Silty clay loam or silty clay may inhibit the growth of tree species (such as those found in plots 16-18, 20, 21 and 24) beyond a certain size and height. However, size may merely be a factor of time. It is more likely that extremely fine soils, and in particular extremely silty soils (> 50 percent silt) facilitate the establishment and growth of certain species which are characteristically small tree species that are hardy and may possess thorns (e.g. *Crataegus*, *Gleditsia*), and at the same time prevent the establishment of many other species that may be restricted by an intolerance of high percentages of silt and clay.

Unlike individual species, most vegetation zones did not seem to be clearly connected with one particular texture class. Therefore, it is unlikely that zonal formation in general is merely a result of the soil texture present. Rather, community development that results in the variation in zonation is likely to be more influenced by a combination of the time since channel migration (and therefore a difference in sediment from a different stage of deposition), interspecific competition, and soil texture.

Even very high-resolution imagery (50 cm per pixel) was insufficient for this study for the accurate determination of tree communities, apart from a general indication of community type (e.g. mixed hardwood vs. conifer) and relative size (mature trees vs.

saplings or shrubs). This may indicate that imagery may not be sufficient for various types of studies on vegetation, particularly where species and communities need to be determined with accuracy. Such studies would likely require a field component. Also, minor distinctions between different communities may be impossible to distinguish. For example, Zone 2 and Zone 3 looked almost identical on the imagery; the division between zones was indistinguishable.

Distances of plots from the active river channel were only visually estimated when examining for trends of soil texture with distance; this method may not be sufficient to determine trends. Analysis should ideally include measurements of distances from the river channel to the plots to obtain exact numerical values; these measurements would provide quantitative data that could then be compared to textural data. If soil texture variation were indeed related to distance from the river channel, i.e. resulting from different periods of deposition, this would perhaps further explain the fact that riparian vegetation tends to vary in bands, with different cohorts of trees at different distances from the river.

In many instances it was not possible to take soil samples below 5 cm as a result of the extremely dry condition of the soil. There appeared to be a moderate drought during late June to September 2010, when all vegetation and soil samples were collected; this was apparent both from the dry soil conditions, as well as the low level of water in the river (except when releases from the Livingston dam upstream occurred). Also, in many cases, trees had lost a portion of foliage by September, most likely due to

drought stress; stress had also enabled widespread insect herbivory of some species by September, *D. virginiana* in particular.

Modifications made to the vegetation sampling scheme for this study, although an improvement on methods employed by Robertson & Augspurger (1999), are nevertheless not the most precise for comparing tree community establishment to sedimentation resulting from meander migration. This is particularly the case if the aim is to capture processes over time, rather than a brief instance of the current dynamics as this study has done. Ideally, line transects for sampling vegetation should be laid out in a fan shape, with curved rather than straight transects, following the paths of former flow and sediment deposition. This would incorporate the natural variability of the vegetation to the greatest extent possible, and would account for varying erosion and deposition as a result of meander migration (see Hickin 1974; I. Güneralp, Texas A&M University, personal communication, 2010). Because of time constraints, it was not possible to implement the fan transect method in this study. However, similar results to that of the fan shape in capturing pattern complexity can be achieved through the modified grid method.

It seems that relative measures (i.e. relative density and dominance) may be better for comparing tree species growth and density to soil textures than are raw values such as basal area and density. Results for relationships between vegetation and soil texture were considerably stronger when using relative measures. This may be the case because relative measures are calculated as percentages and are therefore more readily comparable with soil texture, which is also given as a percentage.

7. CONCLUSIONS

Riparian vegetation community dynamics and their interaction with their environments are still insufficiently understood. This is not unexpected, considering that riparian areas can vary widely with species composition in different regions (e.g. Nanson and Beach 1977; Chambless & Nixon 1975), and also locally on a much smaller scale (Ward 1998). Species composition may vary by distance from the river, as increasingly older vegetation forms with progressive migration. Species density, basal area and relative dominance may depend on several factors, including soil texture, water availability, and competition from other species. In particular, invasive species may be most strongly influenced by soil texture, as was the case in this study. Species persistence and tolerance may also be affected by environmental factors such as flooding, which can either prohibit establishment altogether, or partially or entirely kill existing saplings if sufficiently large in magnitude or long in duration. This may particularly affect rare species, which may be rare due to extinction resulting from high flow stages (Kalliola et al. 1991). Rare species at this site included *S. lanuginosa*, *G. triacanthos*, *F. acuminata*, and both species of *Quercus*. This study attempted to demonstrate and provide some insights into these characteristics of riparian zones. Specifically, some species were found to vary clearly in relative density or dominance with certain soil textures, or with other species.

Rare species present at this site seemed to show clear relationships with various soil textures or other species, but due to insufficient data, these phenomena could not be

determined with certainty. The only invasive species found at this site (*S. sebiferum*) showed strong relationships with soil texture and not with other variables tested; similar relationships may be the case with other invasive species. This study was not able to test the possibility that other invasive species besides *S. sebiferum* may be influenced by soil texture. Potential trends in relative density and dominance of rare species point to the need for studies that would provide more evidence on these species. Further studies on invasive species and their potential relationships to soil texture may perhaps be a valuable alternative to the characteristic focus on interspecific competition. Studies investigating the dynamics of rare and invasive species would contribute to a better understanding of riparian species' growth characteristics and interactions.

It may not be possible to adequately measure rare and invasive species relationships in the field, necessitating plantation-based studies of these species' interactions with the environment and with each other. In other words, studies could be designed using artificially created outdoor environments, where rare species are planted together with other species or on particular soil types, to test for such interactions. This method has been used in the numerous Free Air Carbon dioxide Enrichment (FACE) type studies conducted over the past few decades, where species are planted together to test for altered growth rates or interactions under elevated CO² conditions. Plantation-based methods could easily be applied to studies testing for potential environmental influences such as soil texture or competition on riparian species as well, and might be able to demonstrate clearer trends than field studies, as more than a few individuals of these species would be present. Growth of trees could be more easily monitored than in

the field, as could their interaction with other species that result in density patterns. (Alternately, field studies using permanent plots could be made in areas where there are greater numbers of individuals of these rare species, provided the environment is comparable, i.e., riparian and in the temperate zone, and perhaps in meandering rivers specifically.) Plantation-based studies may provide valuable insights into these species' growth patterns and tolerances related to a particular soil texture, and thus prove extremely beneficial to expanding scientific understanding of species-soil interactions in riparian areas. For example, a study examining stands containing more than a few individuals of *U. americana*, and that have been invaded by *S. sebiferum*, may provide more conclusive evidence in support of these trends. However, it is not surprising if it is the case that *U. americana* declines with increased *S. sebiferum*, that it should decline, as most native species do not compete well with invasives that have no natural biological or environmental controls present. Nevertheless, the *rate* of decline may be interesting to study, particularly in a case where appropriate timing of eradication of *S. sebiferum* is in question (prompt and timely removal of the species may enable recovery of not only *U. americana*, but other species as well).

Although this study found no certain relationship between grain size and distance from the active river channel, this relationship may be interesting to investigate in future studies. Could soil texture perhaps be one of the factors controlling vegetation establishment and zonation in some riparian areas, in addition to time since deposition?

Results from this study can provide local landowners with information on fluvial dynamics-related vegetation growth patterns and also species interactions they may

expect to see in the area, potentially enabling them to improve the management of their property. Knowledge of invasive species dynamics may be particularly important if control of those species is the objective. Results such as those of relative density and dominance of *S. sebiferum* with specific soil textures may assist managers of property in riparian areas in predicting in which locations the highest density (i.e. greatest number of individuals) of this species could be found. This would enable them to make more informed decisions on which areas to focus eradication treatments in. This study may also inform riparian ecosystems managers and restoration practitioners about the importance of the role of vegetation-soil interactions in integrated systems, as well as predict potential vegetation patterns and species dynamics resulting from certain soil textures, enabling them to determine better and more site-specific practices for river restoration; i.e., restoration can be made highly localized, and designed for a particular location. Alternately, if results with soil texture prove to be similar for other invasive species besides *S. sebiferum*, or in other riparian areas, it may enable the use of management techniques that could be applicable to many riparian systems. Also, hard engineering techniques such as riprap and cementing of channels are still widely implemented in the stabilization of channels and channel banks. This research provides information on vegetation establishment characteristics that can be applied to inform soft engineering techniques (e.g. using vegetation, particularly the natural vegetation of a given area) to stabilize river banks. Soft engineering approaches allow management of river banks in a manner that has less of a detrimental impact on the environment than other methods (Gurnell 1995). Also, better management or control of flows may be

beneficial or even necessary to the survival of some riparian tree species or for species diversity in general (Hughes 1997; Scott *et al.* 1997). Natural rivers, or rivers that have been restored as close to natural conditions as possible, benefit ecosystem processes and interactions (e.g. improved habitat for aquatic species). They are also beneficial to society as a whole, both aesthetically (e.g. for recreation) and economically (e.g. improved water quality through natural filtration in the riparian zone). Understanding of species dynamics, and species interactions with fluvial processes and their environment, as well as understanding the use of vegetation in management techniques, are all critical for the natural-based restoration of riparian ecosystems.

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APPENDIX

LIST OF SPECIES FOUND IN THE STUDY PLOTS AND THEIR COMMON
NAMES

Acer negundo (Boxelder)
Carya aquatica (Water hickory)
Carya illinoensis (Pecan)
Carya sp. (various other species of hickory)
Celtis occidentalis (Hackberry)
Cornus drummondii (Roughleaf dogwood)
Crataegus sp. (various species of Hawthorn – these interbreed and are indistinguishable)
Diospyros virginiana (Persimmon)
Forestiera acuminata (Swamp forestiera, Swamp privet)
Fraxinus pennsylvanica (Green ash)
Fraxinus sp. (other species of ash)
Gleditsia triacanthos (Honey locust)
Ilex americana (American holly)
Ilex decidua (Deciduous holly, Possumhaw holly)
Ilex vomitoria (Yaupon, Yaupon holly)
Liquidambar styraciflua (Sweetgum)
Pinus taeda (Loblolly pine)
Platanus occidentalis (American sycamore)
Populus deltoides (Eastern cottonwood)
Quercus nigra (Water oak)
Quercus phellos (Willow oak)
Sapium sebiferum (Chinese tallow)
Sideroxylon lanuginosa (Gum bumelia)
Ulmus alata (Winged elm)
Ulmus americana (American elm)
Ulmus rubra (Slippery elm)

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