CHARACTERIZING ALLUVIAL BENCHES AND INCIPIENT FLOODPLAINS IN A PIEDMONT STREAM AND INVESTIGATING BIOGEOMORPHIC FEEDBACKS AS A POSSIBLE MECHANISM FOR THEIR OCCURRENCE

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ABSTRACT

In-channel benches are bank-attached, planar and narrow, fine-grained sediment deposits occurring between the river bed and the floodplain. Benches are often vegetated and sometimes paired and are formed predominately by suspended load deposition. These unique in-channel features are referred to by several different terms, such as berms, inner berms, shelfs, inset floodplains, and incipient floodplains which raises questions as to their formative processes and functionality within the fluvial system. As indicated by the broad terminology used to label benches, these features have considerable variation in characteristics. Two main classification systems have been developed for benches, one based on the elevation of the bench surface above the channel and the other based on the position of the bench along the channel. Several theories exist as to the formation and persistence of in-channel benches that are related to several different overarching controls, including: hydrologic variability related to drought and river regulation, accelerated sedimentation caused by anthropogenic disturbance, and rapid vegetation establishment under low-flow conditions.

The geomorphic function of benches is a matter of some debate. In some cases, benches appear to function as incipient floodplains. In other locations benches are means of bank reconstruction in overwidened channels, and in some cases, benches are short-lived in-channel sediment storage feature

This research aimed to better understand bench stratigraphy in order to interpret the instances in which benches act as incipient floodplains and to investigate what information about benches can be obtained by applying rudimentary dendroecological techniques. The research was conducted at several locations within Talladega Creek, Alabama. Five benches and their adjacent floodplains were cored to allow comparison of bench/floodplain stratigraphic and organic matter composition that would facilitate identification of incipient floodplains. In addition to sediment cores, tree cores were obtained for a minimum age analysis of bench surfaces and used to investigate historic hydroclimatic conditions that might be conducive to bench development. A tree species inventory of the benches was also recorded to compare to a theoretical model of riparian vegetation recently proposed by Corenbilt *et al*. (2007) that seeks to characterize biogeomorphic feedbacks.

Stratigraphic interpretations based on particle size analyses indicate some differences exist between benches and floodplains. The benches were generally finer than the floodplains. Both benches and floodplains showed general fining upward, with some exceptions. Variations, however, are site specific, with both benches and floodplains exhibiting differences in organic matter content and median particle size by site. Tree cores revealed that in all cases, the establishment date of the oldest tree sampled at each site coincided with a drought period. The species inventory suggests some differences with the riparian vegetation model proposed by Corenbilt *et al*. (2007).

The main conclusions that resulted from this research are that bench stratigraphy and organic matter content is determined by site-specific hydrogeomorphic and vegetation conditions rather than by broader influences. Based on the dendroecological analyses, it would appear that hydrologic variability associated with drought dominated hydroclimate is a factor in the formation of in-channel benches in Talladega Creek, Alabama. This is supported by the tree establishment dates and climatological data. The tree species inventory was not consistent with the Corenbilt *et al*. (2007) model, the species compositions indicating that as an environment for vegetation, in-channel benches function more like floodplains than in-channel features such as bars.

LIST OF ABBREVIATIONS

(US)	Upstream
(DS)	Downstream
D_{50}	Median particle size
OM	Organic Matter

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1.0 Introduction

In- channel alluvial benches were first described by Kilpatrick and Barnes (1964) and are bank-attached, planar and narrow, fine-grained sediment deposits occurring between the river bed and floodplain (Vietz *et al.* 2004). Benches are often vegetated and sometimes paired (Erskine and Livingstone 1999) and are formed predominately by suspended load deposition (Woodyer 1968). Benches (Figure 1) represent distinct in-channel features that are referred to often by several different terms, such as berms, inner berms, shelfs, inset floodplains, and incipient floodplains (Royall *et al.* 2010). The variety of terms used when referring to benches, specifically inset and incipient floodplains, raises questions as to their formative processes and function. Previous research indicates that in-channel benches, because of their contribution to channel complexity, likely play an important role in the storage of nutrients and organic matter (Sheldon and Thoms 2006). Additionally, Thoms and Olley (2004) noted that temporary floodplain deposits, such as in-channel benches, are important sediment storage units, containing up to 87% of a small river's sediment budget. Jayakaran and Ward (2007) found that benches within agricultural channel systems in Ohio, USA function as miniature floodplains, that fine outward from the channel, and upward from the bed because of a lack of meandering from valley and/or bedrock confinement. Similar observations of floodplain sedimentation patterns were made by Nanson and Young (1981) in Australia.

1.1 Bench Classification

As indicated by the many terms used to label them, benches have considerable variation in characteristics. Several attempts have been made to design a classification system that can account for these variations. Kilpatrick and Barnes (1964) first proposed a bench classification system based on the relative elevation of the bench surface above the channel. This system described benches as 'low,' 'medium,' or 'high' and was later adopted by numerous authors (Woodyer 1968; Erskine and Livingstone 1999; Thoms and Olley 2004; Royall *et al*. 2010). However, Vietz *et al*. (2004) noted that classifying benches by elevation does not allow for individual bench identification in the field or independent interpretation of bench elevation along a reach, and it does not lead to an understanding of the processes driving bench formation. Making the assumption that bench formation is largely driven by local hydrogeomorphic processes, many authors have classified benches by their relationship to channel features such as bends or obstructions (anthropogenic and/or natural). Using this system of classification, formally proposed by Vietz *et al*. (2004), six types of depositional benches have been identified: concave benches, point benches, lateral benches, marginal benches, tributary confluence benches, and lee benches.

Initially documented by Kilpatrick and Barnes (1964), concave benches are the most well studied bench type based on available literature (Woodyer 1975; Woodyer *et al*. 1979; Page and Nanson 1982; Nanson and Page 1983; Erskine and Livingstone 1999; Chiangxing *et al*. 1999; Vietz *et al*. 2004; Vietz *et al*. 2005; Vietz *et al*. 2012). Concave or counterpoint (Chiangxing *et al*. 1999) benches derive their name from their position on the concave or cut-bank of meander bends, upstream of the bend axis (Page and Nanson 1982). Benches form in this location because of a large expansion zone, accelerating rates of accretion or reduced rates of destruction as the channel migrates away from the concave bench (Vietz *et al*. 2005). Concave benches are often paired with point benches (Chiangxing *et al*. 1999).

Point or convex (Woodyer *et al*. 1979) benches form over point bar deposits. Coarse bed–load material is overlain by fine, suspended load material. This typically leads to vegetation establishment and a discoloration of the sediment from higher organic matter content, which differentiates point benches from bars (Vietz *et al*. 2004).

Figure 1: Alluvial bench (shown on left) located at an elevation below the floodplain but also attached to the bank, above the channel bed.

Two types of benches have been identified in straight channel reaches. Lateral benches are sediment deposits that occur in flow expansion zones resulting from recent or historic erosion along straight reaches (Vietz *et al*. 2004). Marginal benches form as a result of backwater effects (reverse flow) that develops because of anthropogenically or naturally induced flow obstructions that lead to slack-water deposition downstream of the flow obstruction (Chiangxing *et al*. 1999; Vietz *et al.* 2004). Marginal benches occur infrequently because of their dependence on channel-wide obstruction for development (Chiangxing *et al*. 1999; Vietz *et al.* 2004).

Tributary confluence benches, common in upland regulated streams (Chiangxing *et al*. 1999), occur downstream of a tributary confluence of the main channel as a result of high sediment supply from a tributary and mismatched flood peaks (Vietz *et al*. 2004).

Lee and feature benches are the result of deposition in dead–water zones downstream of or between obstacles. Lee benches are fine sediment deposits on the lee side of channel obstacles such as rocks, bedrock outcrops, coarse woody debris (CWD), vegetation or anthropogenic objects. Feature benches differ from lee benches in that bench formation characteristics are controlled by a downstream obstacle (Vietz *et al*. 2004).

1.2 Bench Formation

Several theories exist as to the formation and persistence of in-channel benches including: drought-dominated conditions (Warner 1994; Royall *et al*. 2010), anthropogenic disturbances such as the existence of mill dams (Hughes *et al*. 2009; Royall *et al.* 2010; Rustomji and Pietsch 2007; Changxing *et al.* 1999), and rapid vegetation establishment on in-channel features during low flow conditions (Page and Nanson 1982; Webb *et al*. 1999; Webb *et al.* 2002; Vietz *et al.* 2004; Vietz *et al.*, 2011; Erskine *et al.* 2009; Erskine *et al.* 2012; Jayakaran and Ward 2007; Hupp and Rinaldi 2007).

Accelerated sediment erosion and deposition from human disturbance has been suggested as a contributing factor to bench formation in over-widened, human-impacted streams (Hughes *et al*. 2009; Royall *et al*. 2010). Streams with perturbed sediment dynamics may respond to small magnitude flood events or sub–bankfull flow–pulses (Tockner *et al.* 2000) by depositing the excess sediment that cannot otherwise be transported downstream during normal flows laterally, within the channel, in the form of benches (Royall *et al*. 2010). In such cases, in-channel deposition that results in the formation of benches may be response to the crossing of a geomorphic threshold. Some studies related their formation to the mean annual flow or other significant discharges, such as bankfull discharge (Osterkamp and Hupp 1984; Harman 2000; Doll *et al*. 2002).

Vertical accretion has been shown to be a dominant form of bench sediment accretion in many valley and bedrock confined channels (Erskine and Livingstone 1999; Jayakaran and Ward 2007; Vietz et al. 2005). Several studies (Erskine and Livingstone 1999; Jayakaran and Ward 2007; Chiangxing *et al*, 1999; Page and Nanson 1982) found that the basal sediment layers of benches are often composed of gravel or pebble size bedload particles that are then overlain by horizontally-bedded finer, suspended particles. These same studies have found that the finer sediments can both course or fine upwards independently of bench location (concave, point, marginal, etc.). This trend of coarse basal layers overlain by finer sediments has led to the hypothesis that benches can develop from bars by flow regime alteration by the coarse sediments leading to the gradual accretion of finer suspended load particles to form alluvial benches.

1.3 Biogeomorphic Processes

Riparian vegetation plays an important role in stabilizing banks and floodplain environments, and it is possible that vegetation is also important in the formation, development, and persistence of in-channel benches (Page and Nanson 1982; Webb *et al*. 1999; Chiangxing *et* *al*. 1999; Webb *et al*. 2002; Erskine *et al*. 2012). Smith (1976) found that vegetated bank sediment with 16-18 % by volume of roots and a 5 cm root mat was 20,000 times more resistant to erosion than non-vegetated bank sediment in anastomosed rivers in Canada. Abernathy and Rutherfurd (1999) found that bank stability was increased by up to 175 % when *Eucalyptus camaldulensis* roots were introduced to an otherwise degraded stream–bank profile in Australia. These studies show that when vegetation is present in bank and near channel environments it has the potential to stabilize sediment, and raises the possibility that vegetation contributes to bench formation by stabilizing stored sediment.

Research previously conducted in floodplain environments also supports the idea that vegetation and hydrogeomorphic processes are linked. Hupp (2000) noted that floodplain vegetation in the Coastal Plain of the U.S. creates microsite velocity regimes that affect sedimentation patterns. The "flood pulse concept" in river–floodplain systems (Junk *et al*. 1989) links community establishments to flood regimes, noting that flood pulses produce and maintain diverse and dynamic habitat structures allowing for high plant species diversity despite physical stresses on biota. Tockner *et al*. (2000) expanded the flood pulse concept to include flow pulses at sub–bankfull flow, which may be particularly important in over-widened channels that experience less frequent bankfull and over bankfull events. The reworking of sediment deposits and subsequent re-deposition and population by herbs and small diameter woody plants, all within the channel, appears to be the dominant form of bench formation in bedrock confined streams in southeast Australia (Webb *et al*. 2002). The presence of trees and herbs have been shown to promote sediment deposition and stabilize channels in Tuscany, Italy (Hupp and Rinaldi 2007) and dry-land regions in Australia (Erskine *et al*. 2012). Several of the biota accounting for the stabilization of the benches and inset floodplains in Tuscany are of the same genus as those found in riparian areas of the U.S. Southeast (*Ulmus*, *Acer,* and *Platanus*), and they noted that the presence of a given species on a particular landform has the potential to provide information on the hydrogeomorphic conditions of that landform. The distributional pattern of that species may be limited by certain stresses or tolerances that could aid in better understanding the environment in which it has established (Hupp and Rinaldi 2007). Several bench studies (Royall *et al*. 2010; Jayakaran and Ward 2007; Hupp and Rinaldi 2007; Erskine *et al*. 2012) stress the importance of further study of bench vegetation to understand its influence on bench formation.

Corenbilt *et al*. (2007) integrated geomorphic and ecological literature and designed a theoretical model for fluvial biogemorphology as a subdiscipline in earth system sciences. Their model focused on the direct linkages between fluvial systems and ecological communities that inhabit those systems. It considered landscape structures as stable or variable biogeomorphic emergent structures in which abiotic and biotic determinants are closely linked. The goal of the model was the integration of riparian plant ecology and fluvial geomorphology to better understand the cohesive and destructive forces that control succession and regeneration dynamics within the fluvial corridor. The model makes specific note of an ecological boundary that appears to be relevant in the case of alluvial benches. This boundary falls between riparian and terrestrial systems where the upper elevation consists of strictly terrestrial species and the lower elevation consists of more inundation-tolerant terrestrial riparian species. The model also proposed to distinguish between high and low frequency flood zones as topographic discontinuities have a strong influence on inundation and sediment dynamics. Alluvial benches are defined as narrow, planar sedimentary structures with a gradual downstream longitudinal slope (Vietz *et al*. 2004), therefore topographic discontinuities may be rare on such small surfaces. Benches may instead be large topographic discontinuities at the reach-scale, functioning independently from floodplains and bars when classifying zones by flood frequency. Osterkamp and Hedman (1982) proposed mean annual floods as the most important relevant discharge for active channel morphological changes, which is supported by the flood pulse concept (Tockner *et al*. 2000). In terms of alluvial bench vegetation, this flood pulse or mean annual flood regime could illicit hydrogeomorphic control on three phases of vegetation dynamics: reproduction and dispersal of diaspores, recruitment, and adult plant development (development and stabilization of communities)(Corenbilt *et al*. 2007).

1.4 Summary

Alluvial benches are unique, in-channel geomorphic features that are planar, narrow, bank-attached, and fine-grained. Benches are important to the functioning of both the fluvial system, as sediment, nutrient and organic matter stores, and to the biological system within the riparian corridor, as habitat. Benches are referred to by a number of terms and are classified loosely by height above the channel, stratigraphic properties, and/or position in the channel. Their formation may be the result of broad-scale land disturbance within a watershed leading to influxes of sediment into the fluvial system and/or hydrologic variability that leads to fewer bank topping flows. Vegetation has been shown to be an important influence on sediment deposit stability, and vegetation establishment and community development have been cited as a possible mechanisms for the formation, development, and persistence of benches.

1.5 Research Objectives

To better understand bench features, I asked two questions: (1) How does bench stratigraphy and organic matter content compare to that of floodplains?; and (2) Can vegetation that has colonized bench surfaces reveal any information about the formation of alluvial benches? The first question is worth addressing because of the fact that benches have been shown to serve as incipient floodplains, but few studies have examined their stratigraphy to determine whether or not stratigraphic analyses support such a classification. Direct comparisons between benches and floodplains would allow similarities and differences to be identified that could improve incipient floodplain identification. The latter question is of interest because there is still much confusion about why benches are discontinuous temporally and spatially. Dendroecological analyses have the potential to reveal information about the hydrological conditions experienced in bench environments that could be useful in explaining bench occurrence and formation.

2.0 Site Description

2.1 Talladega Creek

This study was conducted on five bench sites located along Talladega Creek in Talladega County, Alabama (Figure 1.2). Talladega Creek is part of the Middle Coosa watershed. It has a drainage area of 241.4 km and flows in a bedrock channel through the Piedmont Physiographic Province. It is bound by varying degrees of valley and bedrock confinement. In the Piedmont, forest clearance for agriculture has led to an estimated loss of 7.6 to 30.5 cm depth from Piedmont upland soils, and it has been estimated that the southern Piedmont (from Virginia to Alabama) has lost an average depth of 17.8 cm (Costa 1975). Only 20-25% of the land in Talladega County is used for crops or pasture. Much of the eastern and southern portions of the county are not suited for crop farming because of steep, shallow, erosion-prone soils. This land is instead used for timber production.

Talladega Creek is part of the Quercus-Pinus section of the southern mixed forest region (Dyer 2006). Most of the floodplain forests in the Piedmont physiographic region are secondary forests that have recovered from past agricultural use (Greene and Blossey 2011). The southern Piedmont falls within the southeastern region of the United States, which is now host to an estimated 1.09 million forested hectares of alien *Ligustrum sinense*, now common in riparian habitats (Grove and Clarkson 2005; Greene and Blossey 2011). *Ligustrum sinense* is a shrub/tree species native to China that has established invasive populations in the U.S. Southeast (1850s), elsewhere New Zealand, Australia, Argentina, and several Pacific islands (Morris et al. 2002;

Grove and Clarkson 2005; Greene and Blossey 2011). The plant was often used as decorative shrub or hedgerow (Grove and Clarkson 2005) and has escaped cultivation via roads, waterways,animal transport, and established in native landscapes (Hanula *et al.* 2009). *Ligustrum sinense* has been found to lower native herb and shrub diversity, lower native tree seedling densities, and reduce forest regeneration (Hanula *et al.* 2009) as well as reduce native species richness and abundance (Merriam and Feil 2002; Hanula *et al.* 2009).

The study sites were dispersed along the creek from an eastern, upstream site on the edge of Talladega National Forest to the westernmost, downstream site located at Kymulga Grist Mill (Figure 2). Sites were chosen based on ease of access. Kymulga Grist Mill was chosen as the most downstream site because of concerns of backflow from the Coosa altering the results of sediment samples taken further downstream.

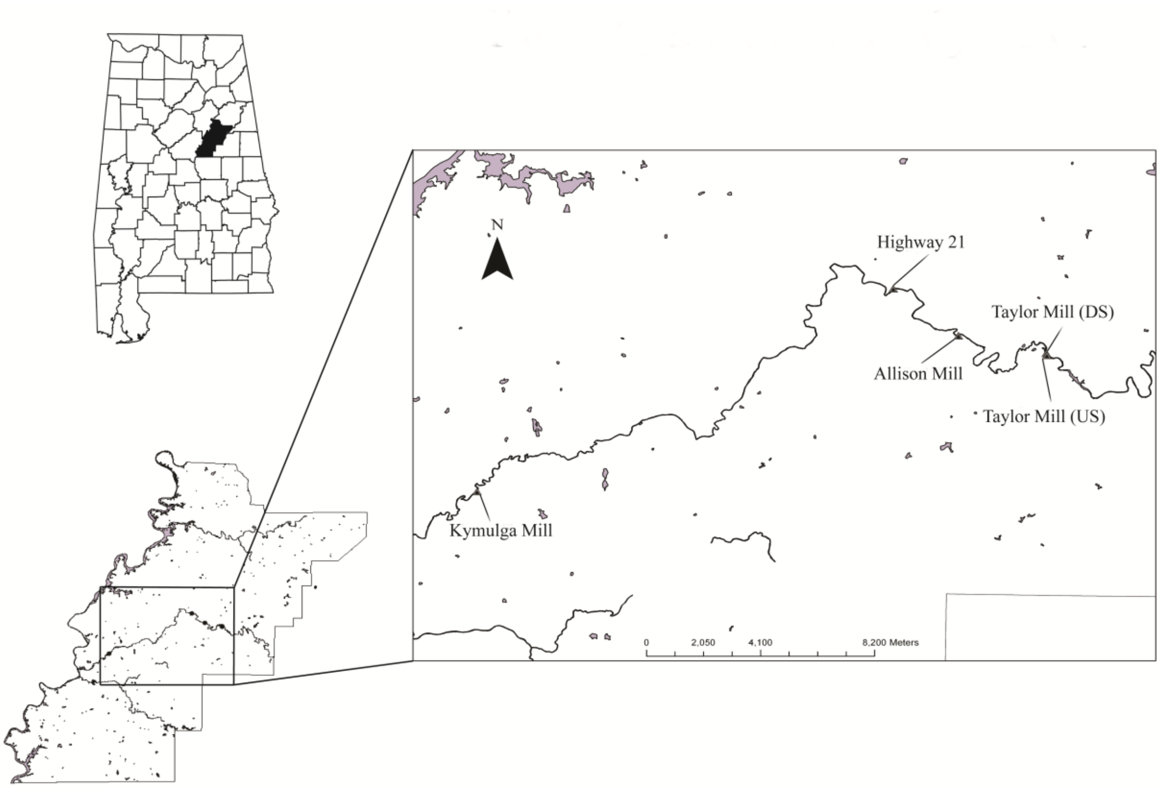

Figure 2: Map of study sites along Talladega Creek, Talladega County, Alabama

2.2 Hydroclimatological Characterization

Talladega County averages 143.76 cm of rainfall per year. Much of the precipitation occurs from December through July, with a distinctly drier period from August through November. The average temperature is 17.1° C with monthly temperature averages ranging from the ~6.1° C in January to ~32.7° F in July. Talladega Creek has been gauged intermittently since 1900, although only 40 years of continuous data are available. From the available data, the average annual discharge of the Creek at the gauge site is 71.76 cubic meters per second. The highest average annual discharge recorded is 137.95 cubic meters per second (2003) and the lowest is 32.73 (2007). The Palmer Drought Severity Index (PDSI) data for the nearest index point (229; in the Georgia Piedmont) shows that since 1900, the area has fluctuated between moderately wet and severe drought conditions. The drought periods have often occurred on a decadal scale with brief interludes of incipient to moderately wet periods.

2.3 Sample Sites

This study was performed at five benches located along Talladega Creek (Figure 2). The sites located furthest upstream were Taylor Mill upstream (US) and Taylor Mill downstream (DS). These sites were located within the same reach, but were on opposite banks from one another and opposite sides of an active grist mill dam. Both of the benches occur within a narrow valley, with exposed bedrock at its base, which restricts the meandering of the channel and floodplain development. The site appeared to be largely free of anthropogenic disturbance. The sampled bench was also the only bench within that section and was a mid-to high-level surface. The downstream site was in a distinctly different condition. Two benches occurred at this site. The sampled bench was a mid-level bench, 114.7 meters in length adjacent to a smaller, low level bench not sampled. The bench was heavily trafficked by anglers and other recreationalists, as was evident by their presence during sampling and the presence of refuse of many varieties as well as graffiti on the non–functional rail bridge at the downstream extent of the bench. At the downstream site, *Ligustrum sinense* is so densely concentrated that humans accessing the creek via this bench have cut tunnel–like paths to reach the channel.

Figure 3: Alluvial bench and portion of floodplain located at Taylor Mill site.

The Allison Mill site (Figure 5) was unique among the benches sampled in this study. It was largely unvegetated aside from some patches of short grasses and a few saplings along the seam at the base of the neighboring, higher level bench. It was the lower of two benches at the site. The bank opposite this bench was exposed bedrock. The adjacent benches and floodplain are host to a well established *Ligustrum sinense* population.

The sample site at Highway 21 (Figure 6) lies within a horse enclosure. This bench was one of three within the reach and was high above the channel bed. Much of the bench area supports equine foot traffic as is evident by the droppings and worn paths. Native woody shrubs and tree seedlings were largely absent from the site, but *Ligustrum sinense* was scattered throughout the site in dense pockets.

Figure 4: Taylor Mill (DS)

Figure 5: Allison Mill

Figure 6: Highway 21

The main body of the *Ligustrum* stand was encroaching on the bench from the upstream end near the highway overpass, the patchiness possibly illustrating grazing activity from the horses. While the fruit and leaves of *Ligustrum sinense* have been shown to be poisonous to humans and livestock, livestock have been shown to browse the plant (Grove and Clarkson 2005) and the plant has been shown to make up a considerable portion of winter deer browse (Grove and Clarkson 2005).

Kymulga Grist Mill (Figure 7) is a privately owned tourist attraction. Staff claims it to have been open and functioning since the 1540s. A more conservative, but perhaps more likely estimate is that the mill has been operational since the 19th century given that Talladega County was established in 1832. The bench surface was sparsely vegetated, with no more than six to eight trees, some of which had been damaged by anthropogenic activities or vandalism. The surface of this bench was cleared of undergrowth and maintained in a lawn-like state for use by recreationists. It supports several picnic tables and shows erosion along several footpaths. The Kymulga Mill is maintained as a tourist attraction and clearly the bench vegetation has been altered for these purposes. This site is located the furthest from the headwaters. No exposed bedrock was present above the water line and Talladega Creek flows along the southern side of a wide valley with no clear evidence of strict valley confinement.

Figure: 7: Kymulga Grist Mill

3.0 Methods

Field work took place over the course of six days in October and November 2011. This period was chosen because it corresponded to the driest portion of the year in central Alabama. This allowed for the bench sites to be accessed with minimal chance of inundation.

3.1 Bench and Floodplain Stratigraphy

The length of each alluvial bench was recorded, as well as the widths of the bench ends and center. At each bench site, two sediment cores were taken: one at the center of the width and length of the bench and one in the adjacent floodplain riparian zone (Fetherston 1995) along the same transect as the bench core. Cores were taken with an AMS two-inch sludge and sediment sampler with a plastic tube liner. The cores were taken to a depth of one meter or otherwise maximum achievable depth. Four of the sediment cores were extruded in the field while six were extruded in the lab. All of the samples were brought back to the Earth Surface Dynamics Lab at the University of Alabama and prepared for particle size analysis and loss-on-ignition.

In the laboratory, each core was divided in half along its length. Detailed profiles were constructed of each core that included sediment/soil color (Munsell), the presence of rock or coarse particulate organic matter, including macroscopic charcoal fragments. The cores were then divided into five cm increments. Each five cm increment was dried in an oven at 105° C for twenty-four hours and then weighed. The dried and weighed samples were then combusted at 450° C for eight hours and reweighed to account for organic matter loss. The combusted samples were then lightly ground with a mortar and pestle to break down any aggregates prior to particle size analysis. Each sample was then sieved to measure particle size. The contents of each sieve were weighed and recorded for statistical analyses.

3.2 Vegetation Composition

Several tree cores were taken at breast height at each bench site using an increment borer. In the event that no or few coreable trees were available, cross-sections of saplings were taken. The number of cores and cross-sections varied from three to 10, based on the available vegetative cover of the benches. Cores were taken from trees subjectively sampled to represent the oldest of the bench community; taking into account bole diameter, canopy dominance, and species. The cores were all taken moving along the bench from the downstream end toward the upstream end. Early successional tree species such as *Liriodendron tulipifera*, *Betula nigra* and *Platanus occidentalis* were targeted because on a young surface, these species would likely be the oldest inhabitants, unless there was a lack of coreable trees, in which case cores were taken in a manner that best represented the established bench community (Table 1). The cores were stored in paper straws and transported back to the Forest Dynamics Lab at the University of Alabama. Once in the lab, the cores, in their straws, were allowed to dry and then were mounted and sanded in accordance with standard methods (Stokes and Smiley 1996). Annual rings were dated and the innermost dates were grouped by site for further interpretation.

3.3 Statistical Analyses

To test how bench stratigraphy and organic matter content compare to that of floodplains, independent-sample t-tests were used to compare the median particle size (D_{50}) of each type of feature and percent organic matter (OM) within each bench and floodplain sample pairing as well as between all benches and all floodplains. Tests of normality revealed that neither data set was normally distributed. The OM data were log transformed while the D_{50} data were converted to phi (ϕ) units. Both transformations resulted in normally distributed data sets.

At the watershed scale, D_{50} and OM of all of the sampled marginal bench depth intervals (n=78) were compared to those of all of the floodplains (n=88) using t-tests. The t-test for D_{50} between benches and floodplains was significant ($p<0.001$) as was the t-test for OM ($p<0.001$). After establishing that there were significant differences in D_{50} and OM between benches and floodplains at the watershed scale, t-tests were performed on each individual bench/floodplain pairing from Taylor Mill upstream (US), the site closest to the headwaters, to Kymulga Grist Mill, the sample site furthest downstream, to determine in which pairing(s) the differences occurred.

Scientific Name	Common Name
*Acer barbatum**	Florida Maple
Acer negundo	Box Elder
*Acer rubrum**	Red Maple
Ailanthus altissima	Tree-of-heaven
*Betula nigra**	River Birch
*Carya aquatica**	Water Hickory
*Fagus grandifolia**	American Beech
*Ligustrum sinense**	Chinese Privet
*Liriodendron tulipifera**	Tulip Poplar
*Nyssa sylvatica**	Blackgum
*Platanus occidentalis**	American Sycamore
*Quercus alba**	White Oak

*Quercus nigra**	Water Oak
*Quercus phellos**	Willow Oak
*Ulmus americana**	American Elm

Table 1: Recorded species (Burns and Honkala 1990). (*) indicates sampled species.

Maximum inner tree–ring dates were adjusted to account for growth lag to breast height using data from the Silvics of North America (Burns and Honkala 1990) and the USDA PLANTS database (USDA, NRCS 2011) (Table 2). After correcting tree–ring dates for lag in growth time to breast height, the corrected dates were plotted with mean monthly precipitation and Palmer Drought Severity Index (PDSI) (Figure 7) from the National Ocean and Atmospheric Association (NOAA) National Climate Data Center (NCDC) to determine if drought was an influential factor on tree establishment and thereby, bench formation. Precipitation was used as a surrogate for discharge for several reasons. Talladega Creek has been gauged intermittently since the early 1900s, but the discontinuities in the discharge data overlapped with the establishment dates determined for the trees sampled for this study.

Kymulga Mill	**Highway 21**	**Allison Mill**	**Taylor Mill (DS)**	**Taylor Mill (US)**
1960	1930*	1991*	1994	1958
1961	1946	2003	1992	1952*
1959*	1956	2000	1974*	1959
1979	1930*		1985	1970
1968	1933		1994	1958
	1969		1989	1963
	1970		1987	1967
	1940		1993	1958
				1981

Table 2: Adjusted inner tree–ring dates per sample site. (*) indicates oldest tree sampled.

4.0 Results

4.1 Bench and Floodplain Stratigraphy

The t-tests for the individual pairings resulted in significant differences in D_{50} at Taylor Mill (US) (p=0.007) and Allison Mill (p=0.006) and significant differences in OM at Taylor Mill (DS) (p<0.001), Highway 21 (p<0.001), and Kymulga Mill (p=0.010).

Test Variable	Grouping Variables	Significance
D_{50}	benches, floodplains	<0.001
D_{50}	Taylor Mill (US) bench, Taylor Mill (US) floodplain	0.007
D_{50}	Taylor Mill (DS) bench, Taylor Mill (DS) floodplain	0.178
D_{50}	Allison Mill bench, Allison Mill floodplain	0.006
D_{50}	Highway 21 bench, Highway 21 floodplain	0.489
D_{50}	Kymulga Mill bench, Kymulga Mill floodplain	0.177
OM	benches, floodplains	<0.001
OM	Taylor Mill (US) bench, Taylor Mill (US) floodplain	0.344
OM	Taylor Mill (DS) bench, Taylor Mill (DS) floodplain	<0.001
OM	Allison Mill bench, Allison Mill floodplain	0.205
OM	Highway 21 bench, Highway 21 floodplain	<0.001
OM	Kymulga Mill bench, Kymulga Mill floodplain	0.021

Table 3: Statistical test results for D_{50} and OM. In all cases α=0.05. All t-tests significance values assume unequal variances.

Initial statistical testing revealed that D_{50} and OM was significantly different between all sampled benches and floodplains. Further testing revealed that D_{50} was significantly different between individual bench and floodplain pairings at Allison Mill and Taylor Mill (US). Median particle size (D50) was found to be generally finer in benches than in floodplains (Figure 10). Both benches and floodplains followed a general trend of upward fining. OM between bench/floodplain pairings was significantly different at Kymulga Grist Mill, Taylor Mill (DS), and Highway 21. Organic matter content is generally higher in benches than floodplains. To better interpret these patterns, each site pairing was examined individually using the D_{50} and OM plots (Figure 10) in conjunction with a detailed, textural diagram of each five cm interval of the sediment cores (Figure 11).

4.2 Vegetation Composition

Taylor Mill (US) was the furthest site upstream. The oldest tree sampled (*Fagus grandifolia*) dated to 1952, which corresponds to a 7 year period of incipient dryness to severe drought (Figure 1.9). Given *Fagus grandifolia*'s preference of moderately shaded sites for seedling growth and development (Burns and Honkala 1990), it is possible that this tree was not the first to establish on the bench. However, since the limiting factor to *Fagus* establishment and seedling development on open sites is often soil moisture, the bench site and its proximity to the creek may have provided the *Fagus* seedling with adequate moisture to mature on the site.

Taylor Mill (DS) showed a group of establishment dates from 1985 through 1994 (Table 2), however, the 1974 date is that of an *Ulmus americana* that appeared to form the upstream end of the bench. The bench, which sees heavy foot traffic from anglers and other recreationalists, ended as it reached the horizontal extent of the tree’s root zone. It appeared as though the *Ulmus* was stabilizing the upstream end of the bench. Observational evidence (Figure 1.8) suggests that the *Ulmus* established on a bedrock outcropping and therefore may be an outlier, but the lack of cohort trees could be because of any number of factors from anthropogenic disturbance to succumbing to competition with the pervasive *Ligustrum sinense* and *Ailanthus altissima* presence on the bench. *Ailanthus altissima* has been determined to be allelopathically disruptive to native species' seedling budding and subsequent growth (Heisey 1990; Lawrence *et al*. 1991; Heisey 1996; Lin *et al*. 1996; Gomez-Aparicio and Canham 2008). While there is some evidence that *Ligustrum sinense* may be allelopathic (Grove and Clarkson 2005), its disruption of native plants is attributed to the tendency to develop in dense, homogenous stands as well as its rapid colonization and proliferation on disturbed sites (Hanula *et al.* 2009; Greene and Blossey 2011; Grove and Clarkson 2005). Another phenomenon that points to the lone *Ulmus americana* being an outlier is the lack of subsequent establishments for more than a decade. If instead the 1985 date (*Platanus occidentalis*) is used as the minimum surface age, then a consistent progression of tree establishments over the next ten years occurs: 1987 (*Betula nigra*), 1989 (*Quercus alba*), 1992 (*Acer rubrum*), 1993 (*Ligustrum sinense*), 1994 (*Acer rubrum*, *Liriodendron tulipifera*). The PDSI and precipitation records indicated that the 1970s were characterized as slightly to moderately wet, whereas 1985 was the beginning of a four year period of incipient dryness to moderate drought (Figure 9).

Figure 8: Bole base and exposed root system of *Ulmus americana* at Taylor Mill (DS).

Assuming the oldest trees at each site show minimum age of the bench deposits, there is a 33 year difference in minimum deposit age between the two Taylor Mill benches that are geographically closer to each other than any of the other sampled benches. They are both adjacent to the one of the only two existing mill dams on Talladega Creek, whereas the *Ligustrum sinense* was densely concentrated on the downstream site.

The sediment core taken from the Allison Mill bench only reached a depth of 50 cm and was massive in structure (Erskine and Livingstone 1999). Each five cm increment was composed of fine to coarse grain sand and showed no trend in fining or coarsening vertically. The 1991 date is from a *Betula nigra* that may be a marker for the actual bench establishment trigger because of its horizontal location. The *Betula nigra* was situated on the seam at the base of a mid-level bench adjacent to the lower bench sampled for study and has grown at an angle over the stream. The 2000 date was obtained from a *Liriodendron tulipifera* sapling cross-section from the upstream edge of the bench, once again, along the seam of the low and mid-level benches. Evidence in both the PDSI and precipitation (Figure 3) records that shows 2000 as a drier than normal year. Beyond the tread between benches, there was little to no vegetation beyond scattered grass on this bench.

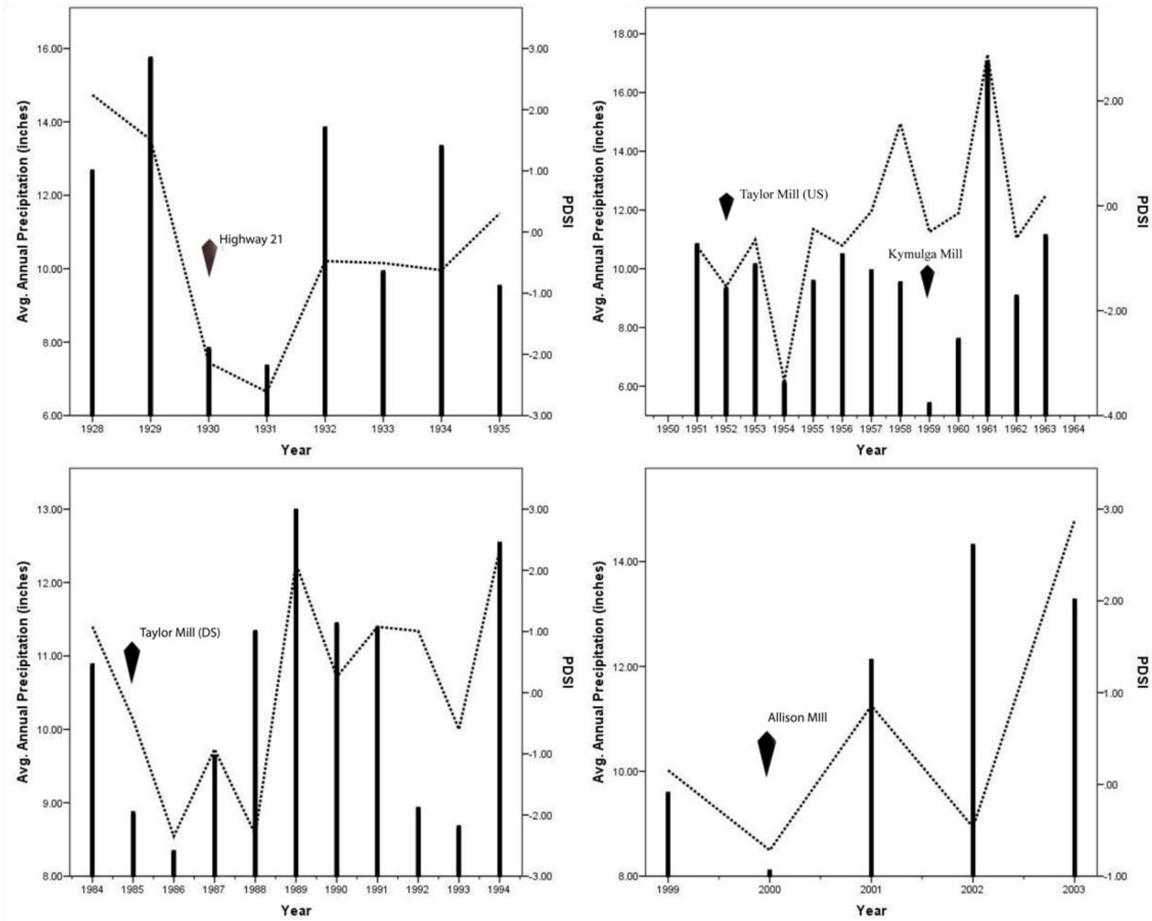

Figure 9: Mean annual precipitation (bars) plotted with PDSI (lines) and earliest establishment dates by bench site.

The oldest trees at the Highway 21 site were two *Quercus* spp. that had an adjusted establishment in 1930 (Table 2), which marks the beginning of a two-year period of moderate drought that follows two years very wet to moderately wet conditions. This four-year period was preceded by extreme drought in 1925 (Figure 9). The bench surface of this site lies along Highway 21. The species composition of mostly *Quercus alba* and *Quercus nigra* which have medium to high drought tolerances and medium to low anaerobic tolerances (Table 9), may reflect the rarity of overbank flows affecting this site. This bench surface was located higher above the channel bed than at any of the other bench sites.

At Kymulga Grist Mill, the oldest tree (*Acer rubrum*) dated to 1959 with two others quickly following in 1960 (*Quercus alba*) and 1961 (*Carya aquatica*) (Table 2). The PDSI for 1959 was -0.496 (Figure 9), an incipient dry spell following a single slightly wet year that was preceded by seven years of drier than normal climactic conditions ranging from incipient dry spells to severe droughts. Interestingly, the majority of the tree species that have persisted on the bench are listed in the *Silvics of North America* (Burns and Honkala 1990) as popular shade and landscape trees.

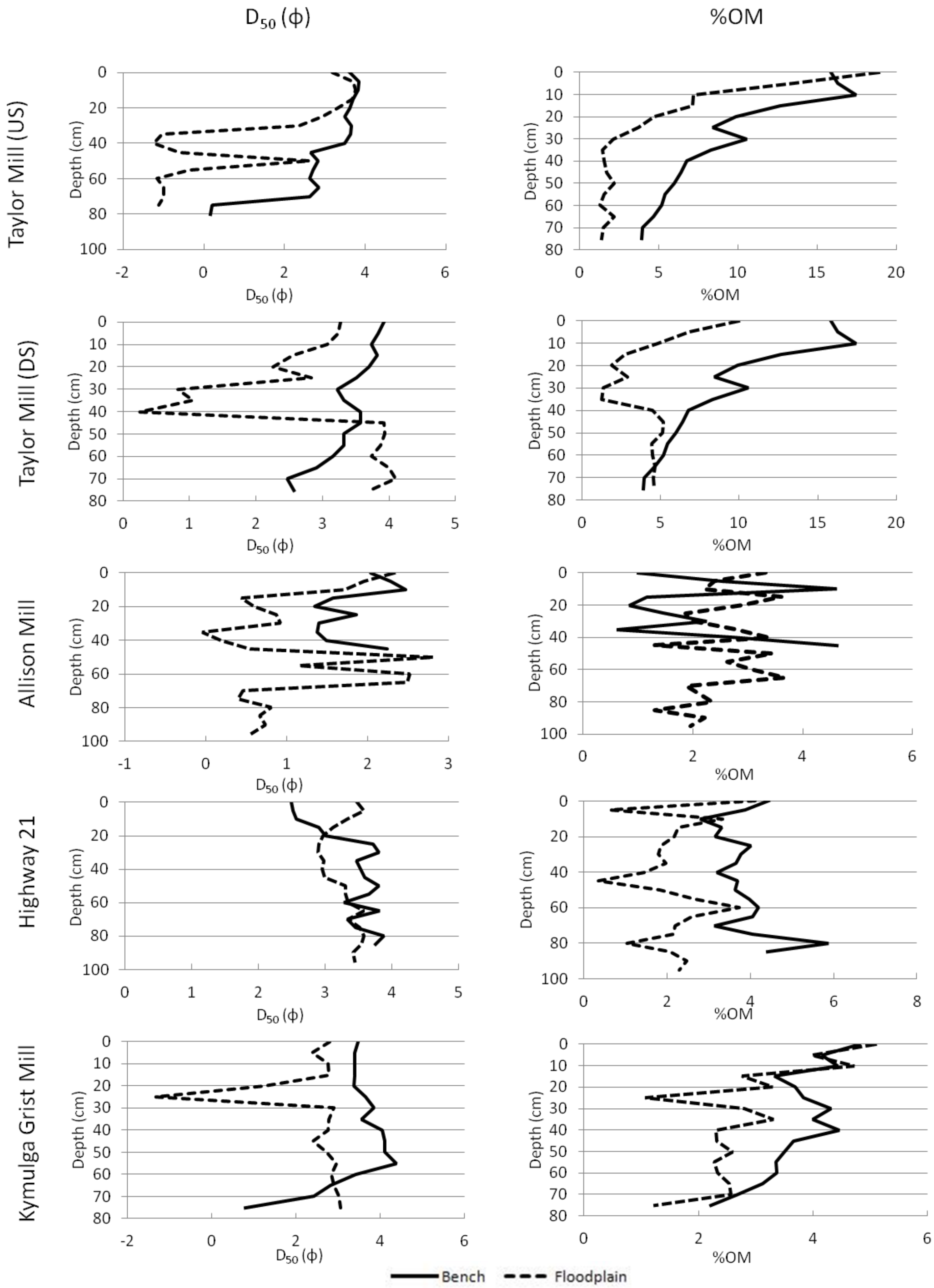

Figure 10: D_{50} (left) and OM (right) for each site pairing.

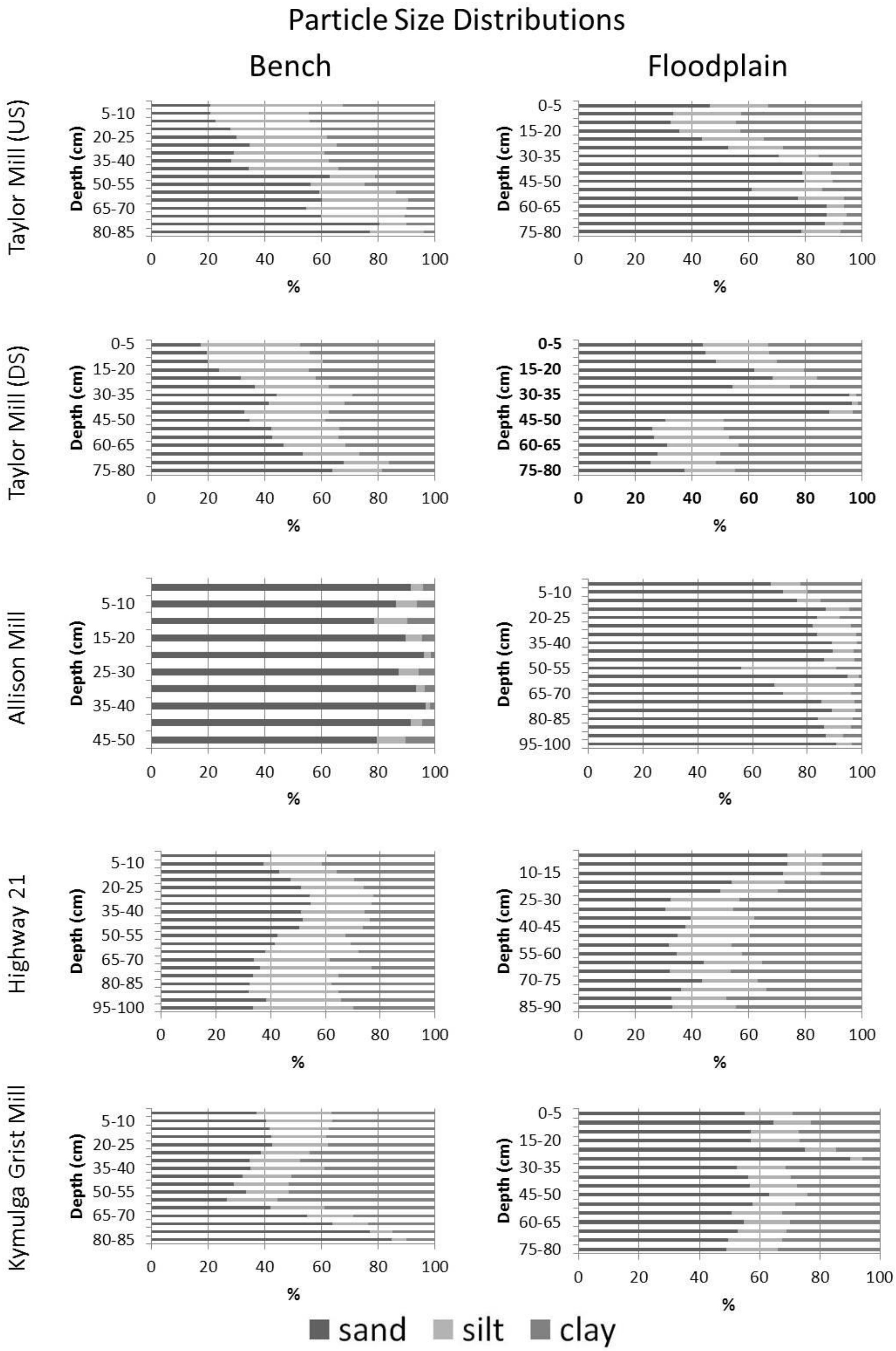

Figure 11: Particle size distributions for each bench (left) and floodplain (right) pairing.

5.0 Discussion

5.1 Comparison of Bench and Floodplain Stratigraphy and OM Composition

Taylor Mill upstream (US) and Taylor Mill downstream (DS), were the located within the same reach, but were on opposite banks from one another and opposite sides of a mill dam. The Taylor Mill (US) site was distinct among the sample sites in that it was likely the least anthropogenically disturbed. It was isolated from anything more than foot traffic by steep hills surrounding the site. The vegetation at the site was the least disturbed of any of the sites, there were no signs of invasive *Ligustrum sinense* nor *Ailanthis altissima*, both of which had established populations on the Taylor Mill (DS) site immediately downstream. It was determined through statistical testing that there was a significant difference in D_{50} between the bench and floodplain at the Taylor Mill (US) site. During floodplain coring, it was onserved that bedrock or regolith occurred at 35-40 cm which continued for roughly 15 cm, gave way to a finer texture gap at 50-55 cm, then resumed at 55cm, continuing to the extent of the core. A similar situation occurred during the bench coring, but the rock was encountered deeper in the profile, around 75 cm. This pattern was evident when D_{50} is plotted (Figure 10). In the textural profile, (Figure 11) the pattern is also realized. Both the bench and floodplain show a general fining upward. The bedrock/regolith was encountered at the bottom of the profile on the bench which maintained a stronger upward fining pattern from the base of the profile. The floodplain appeared to remain evenly coarse up to the 35-40 cm interval where the bedrock was initially encountered at which point the profile shows a strong fining sequence toward the surface, matching the trend in the bench profile. Structurally, this bench/floodplain pairing fell in the cumulic (Erskine and Livingstone 1999) category, above the bedrock. This was supported by blocks of consistent color in the profile ranging from 15-60 cm in depth and a strong organic component (>5%) throughout both the bench and floodplain profiles.

Taylor Mill (DS) was heavily disturbed. The site has seen heavy foot traffic from anglers and other recreationalists as made evident by the amount of refuse present on the bench and floodplain surface. Additional evidence for heavy disturbance was found in the vegetation structure. The bench surface is inhabited by a dense *Ligustrum sinense* population. The alien invasive had grown so dense that the recreationalist visitors had cut tunnel-like paths through the stand in order to access the creek. This bench was bound on the upstream end by an exposed bedrock outcropping and on the downstream end by a defunct rail-bridge. The bench at this site is anomalous in several ways. D_{50} at this pairing was smaller at the bench surface than in any of the other benches (Figure 9). This could be attributed to the density of the of the vegetation increasing surface roughness and therefore decreasing flow velocity during overbank flood events, resulting in increased deposition of fine sediment that would otherwise be deposited on the floodplain (Hupp 2000; Webb *et al.* 2002). An alternative explanation is that this site has a finer sized suspended sediment load than the upstream site. This could be due to the settling of coarser particles upstream leaving only the finer sediments to deposit downstream of the dam. The D_{50} at the upstream site was generally coarser than the downstream site (Figure 10). The small diameter, multi-stemmed *Tristaniopsis laurina* cited by Webb *et al*. (2002) leading to deposition of homogenous sediments closely resembles the situation observed on the bench at this site. The textural profile (Figure 11) shows a fining upward sequence and the D_{50} (Figure 10) has a range of 0.115 mm throughout the 80 cm profile. It appears as though expansion of the

Ligustrum sinense population on this bench has been a determining factor in the bench/floodplain textural profiles. *Ligustrum sinense* may also be a determining factor in the OM difference revealed through statistical testing. Organic matter makes up 8.5% of the entire profile, which is >2.2 times the organic content of the next highest content deposit (Taylor Mill (US) bench: 3.8% OM). While the *Ligustrum* individuals undoubtedly contribute OM to the deposit through shedding leaves and high seed-fruit production (average 2,500 per shoot per year, maximum of 10,000 (Morris et al. 2002)), because the latitude of the site and the climate of the Alabama Piedmont, the plants likely do not experience leaf-off (USDA, NRCS, 2011). The species' major contribution may be trapping litter contributed by the hardwood inhabitants of the bench as well as intercepting coarse woody debris (CWD) and litter during bench–inundating flows. Observational evidence after a high flow event between site visits revealed that while the footpaths and other unvegetated surfaces were scoured to the bare sediment surface, micro-stand edges had accumulated knee-deep drifts of litter and CWD and within-stand litter appeared unaltered. Based on the textural properties, presence of 20+ cm color blocks, and strong organic component, this bench deposit would be structurally classified as cumulic as well (Erskine and Livingstone 1999). The floodplain appears to be two cumulic deposits separated by a 15 cm massive sand deposit between 30-45 cm.

The Allison Mill pairing was unique in that both the bench and floodplain were composed of the coarsest D_{50} in their respective feature classes. The floodplain D_{50} fluctuated by several mm in 5-10 cm depth intervals in the uppermost 70 cm of the profile, after which the D_{50} levels off. The bench appears to mimic this pattern, although at a finer D_{50} (Figure 10). The textural profiles (Figure 11) show the fluctuations well. Statistical testing highlighted this pairing as having a significant difference in D_{50}, but this is likely because of the disparity in sample size.

The bench core at this site was limited to 50 cm by contact with the bedrock of the channel bed. Both deposits exhibited heavy fluctuations in organic matter content, but the patterns appear to be fairly similar between the two, with the floodplain having a higher organic content. This is likely because of the near complete lack of vegetation aside from random grass on the bench surface and the heavy coarse and medium sand components of the deposits. These factors indicate this bench may be in the very early stages of development. Abrupt boundaries between beds and textural properties point to both deposits being massive in structure (Erskine and Livingstone 1999).

The Highway 21 site pairing showed a significant difference in organic matter content between the bench and floodplain. Native woody shrubs and tree seedlings were largely absent from the site, but *Ligustrum sinense* was scattered throughout in dense pockets. The OM content of the floodplain was characterized by extremes in its distribution. Both deposits show an increase in mean OM content (Figure 10) at the surface and at depth. Interestingly, this site shows a gradual coarsing upward trend in particle size distribution (Figure 11). The bench deposit coarsens upward to the 25-30 cm depth interval, where it begins to show a gradual fining upward trend. The floodplain maintains a dominant coarsing trend throughout the profile, and based on particle size distributions and organic matter peaks (Figure 10), seems to have been formed by several different depositional episodes with varying sediment sources. The sediment profiles at Highway 21 appear to cumulic in nature based on the deep, relatively uniform fine grained sediments, and color groupings (Erskine and Livingstone 1999), but the organic component of this bench is considerably lower than the other cumulic sediments sampled by comparison.

Kymulga Grist Mill is a privately owned tourist attraction. The bench surface was limited to no more than six to eight trees, some of which had been damaged by anthropogenic activities. The surface of this bench was cleared of undergrowth and maintained in a lawn-like state for use by tourists. It supports several picnic tables and shows erosion along several footpaths. This site may pose problems in terms of profile analysis. The mill site is maintained as a tourist attraction and clearly the bench vegetation has been altered to best suit the management objectives of the owner. The OM content, found to be significantly different between the bench and floodplain at this pairing, appears to be related directly to particle size distribution rather than to differences in vegetation as was the case with the other pairings. The sediment profile of the floodplain also appears to be altered by development. This alteration is evident in the uppermost 30 cm of the profile. The sediment is interspersed with granite gravel likely used as a base layer for the concrete slab of a pavilion built on the edge of the floodplain deposit. The D_{50} spikes to 2.5 mm at the 25-30 cm of the profile in association with an abundance of pebble ($\geq$2mm) and gravel ($\geq$4 mm) particles (Figure 10). The floodplain was also heavily compacted, likely because of heavy foot and vehicle traffic during the construction of the pavilion. Reaching the 80 cm extent of the core taken from the floodplain took roughly one and a half hours, and the corer was broken in the process. Compaction appeared to be less severe in the bench. The marginal bench at the Kymulga site lies directly upstream of a functional grist mill and its associated dam. Flow pulses (Tockner *et al.* 2000) during the drought period (1952-1957, Figure 3) could have led to the accretion of sediment on top of a gravel bar and gradual development into a bench. This is supported by the heavy sand/gravel component found at the depth of 60-85 cm in a sediment core and gradual fining toward the surface of the bench deposit (Figure 1). The sediment deposits at Kymulga appear to be diverse in structure. The bench has a stratic structure from 70-85 cm as the sediment deposits are thinly bedded and sandy overlying a gravel/pebble-rich basal layer. The sediments above 70 cm appear to be more cumulic, showing characteristic finer grained sediments in deep, uniform deposits, supported by coloration, but without a strong organic component (Erskine and Livingstone 1999). The floodplain appears to be a series of massive, sandy-clay deposits characterized by 25-30 cm deposits of relatively uniform particles size and color distributions that coarsen slightly upwards (Erskine and Livingstone 1999).

5.2 Bench Establishment and Hydroclimatological Variability

One theory as to the origin of in-channel benches or perhaps a trigger related to their formation is the presence of grist mills and their associated dams. Three of the five sites sampled for this study were formerly adjacent to mill dams, and in the case of the Kymulga site, a functioning grist mill. Additionally, a fourth site, Allison Mill, was sampled, and although there is no active dam or mill at the site, the name of the road signifies proximity to a historic mill likely located somewhere within that reach at some point in the past. Kymulga Grist Mill claims to have been open and functioning since the 1540s, but that is unlikely. One could assume, with caution, that these mills were operational during the 19th and possibly early 20th centuries given that Talladega County was established in 1832. If the grist mills and their dams were a causal factor in the formation of in-channel benches, we might expect to see significantly older trees than those sampled for dating, also the sediment would have more of a lacustrine-type appearance and be very fine because of the pools created by the dams. However, given the eight-year drought that preceded the establishment date, a hypothesis about the nature of the bench formation can be constructed. Changxing *et al.* (1999) noted that benches have a tendency to develop on regulated/dammed streams. Flow pulses (Tockner *et al.*, 2000) during the drought period (1951-1957, Figure 9) could have led to the accretion of sediment on top of a bar and gradual development into a bench. This is supported by the heavy sand/gravel component found at the depth of 60-85 cm in the bench sediment core and gradual fining toward the surface of the bench deposit. Grasses and woody shrubs would have likely populated and stabilized the bench initially, allowing for later establishment by the *Acer rubrum*, *Quercus alba*, and *Carya aquatica*. All three species produce seeds that can utilize fluvial transport for dissemination, possibly making post drought wetter periods important for their establishment on bench features. Because of this selective maintenance, the trees at this site may not prove useful to understanding the establishment date of the trees and their relationship to the minimum age of the bench. The pervasive presence of *Ligustrum sinense* and to a lesser extent *Ailanthus altissima* as well as selective management, may have led to a disruption in the regeneration of native tree species on the sites, accounting for the lack of older trees on some of the benches. The oldest individuals sampled were located at the Highway 21 site, which is the only site that does not have a clear connection to some kind of grist mill. Based on this information it may be that regulation of a stream causes lag time in the establishment of benches near dams in response to the alteration of flooding regimes post-application of best management soil practices.

The most plausible explanation for bench formation in Talladega, based on the results of this study, is hydrologic variability tied to decadal drought. Several studies support this theory (Royall *et al*. 2010; Erskine and Linvingstone 1999; Warner 1994). Results show that with adjustment for growth lag to breast height, all of the earliest established trees sampled in this study established within a time period of some degree of drought (Figure 9). At each site, several of the subsequent adjusted ring dates coincide with drought periods and often occur in the first drought year after a wet period. This trend appears valid as many of the species produce seeds such as acorns, samaras, and beech nuts that have the potential to be transported by water. A flow pulse may briefly inundate a bench surface, picking up propagules and transporting them downstream to be deposited on other benches where they can establish after water levels drop.

If drought dominated hydroclimates are a causal factor in bench formation, then vegetation may be the key to stabilizing benches against high flow events. Data compiled from a combination of the *Silvics of North America* (Burns and Honkala 1990) and the NRCS PLANTS database (USDA, NRCS 2011) for each species documented on the sampled benches represents three traits that may be critical to tree establishment on in-channel benches: anaerobic tolerance, drought tolerance, and moisture use (Table 4). Of the eleven species recorded, seven have anaerobic tolerances of low or none. These species cannot persist in an environment of frequent or prolonged inundation. Nine of the eleven species have medium to no drought tolerance. Even though more than half of the recorded species cannot survive frequent or prolonged inundation, most cannot survive extensive drought periods either. Finally, every species recorded has a medium to high moisture use capacity (USDA, NRCS 2011; Burns and Honkala 1990).

In-channel benches may have something close to ideal conditions for many of these species to establish and develop in a drought dominated hydroclimate. High magnitude flow events are unlikely to be frequent or prolonged enough to cause mortality in maturing trees of these species. Since the majority of these species have low or no drought tolerances, the bench surfaces offer a regularly aerobic deposit from which grow with close access to a water source. The proximity of the water source could also aid these species medium to high moisture requirements. These species resemble many of the species recorded on the benches and incipient floodplains by Hupp and Rinaldi (2007) who noted *Platanus* sp., *Ulmus* sp., *and Acer* sp. as some of the most common species present on fluvial landforms in Tuscany. Hupp and Rinaldi

(2007) also described both benches and inset floodplains as being more stable with the presence of these species than without.

Species	**Anaerobic Tolerance**	**Drought Tolerance**	**Moisture Use**
Acer barbatum	None	Low	Medium
Acer negundo	Medium	High	Medium
Acer rubrum	Medium	Medium	High
Ailanthus altissima	Medium	Medium	Medium
Betula nigra	Medium	Low	High
Carya aquatica	None	Medium	Medium
Fagus grandifolia	Low	High	Medium
Ligustrum sinense	N/A	N/A	N/A
Liriodendron tulipifera	None	Low	Medium
Nyssa Sylvatica	Low	Low	Medium
Platanus occidentalis	Medium	Low	High
Quercus alba	None	Medium	Medium
Quercus nigra	Medium	Low	High
Quercus phellos	Low	None	High
Ulmus americana	Low	Medium	High

Table 4: Species traits (Burns and Honkala 1990; USDA, NRCS 2011)

5.3 Vegetation Dynamics

The theoretical model of vegetation dynamics proposed by Corenbilt *et al*. (2007) does not appear to fit the vegetation on benches in Talladega Creek. The tree–ring dates from the samples in this study show only two instances, Allison Mill (*Betula nigra* or *Liriodendron tulipifera*) and Taylor Mill (DS) (*Platanus occidentalis*), where a targeted early successional species was the oldest tree on the bench surface. Given the method of tree sampling undertaken for this study and the growth traits of many early successional species, it is unlikely that an older, early successional specimen was overlooked on the remaining three sites.

The model makes an attempt to draw clear boundaries between zones of terrestrial versus riparian vegetation types where inundation is a key factor. The species of vegetation found on the benches in Talladega Creek blur the proposed boundary line between riparian and terrestrial vegetation. Some diverse communities exist on the sampled benches where present species vary from having no anaerobic tolerance to having a medium anaerobic tolerance. This leads to the conclusion that the benches represent a surface of opportunity for colonization under drought conditions rather than a surface of distinct successional processes based on the species present and their recorded ages, but the sampling methods of this study were not designed to account for succession and therefore the conclusion is merely observational.

6.0 Conclusions

At the watershed scale, there are several phenomena discernible from the data gathered in terms of deposit texture. Statistical testing concerning D_{50} revealed that the Allison Mill bench is an anomaly in the dataset. It was the shallowest bench, with the least vegetation, and assuming a minimum age of 12 years (Table 2), it was the youngest deposit sampled. It is hypothesized that this bench is in the early stages of development, making its stratigraphical characteristics significantly different than those of other, older, more well established benches within the watershed. The Kymulga floodplain also seems to be significantly different in the floodplain feature class. This is likely because of strong anthropogenic disturbance at the site. Other patterns in sediment texture are not apparent in the variables tested in this study. There appears to be no significant correlation between textural properties and position in the watershed, proximity to grist mills or mill dams, or vegetation type. Patterns in sediment structures were also not readily apparent. Based on these findings, I conclude that sediment structure and texture is likely controlled by localized hydrogeomorphic conditions rather than outside influences such as vegetation or mill dams.

Organic matter content of benches appears to be driven by a combination of particle size and vegetation cover, perhaps even species specific vegetation properties. Similarities in organic matter content follow a textural gradient, with lower levels of content being attributed to coarser particle size and higher levels of content being attributed to smaller particle size. The Taylor Mill (DS) bench may have shown how a specific species can influence OM content. While *Ligustrum* *sinense* was found on another bench, and in several floodplains, its presence was not nearly as pervasive on those sites as it was at the Taylor Mill (DS).

This preliminary study has found some interesting issues with the formation and persistence of in-channel benches. Comparisons between the D_{50} and OM content of benches and floodplains have lead to the conclusion that the features' similarities or differences are site specific rather than general. A more detailed stratigraphic study accounting for lateral and longitudinal variations in bench sediments and a more detailed land–use history of the watershed could prove useful in addressing the locations of grist mills, agricultural plots, dams, and other features and interpreting stratigraphic results.

Royall *et al.* (2010) stated that a dendroecological study could provide some understanding as to the causes of bench formation. The physical and functional traits of the species recorded on the sites support the idea that benches may form in drought dominated hydroclimates and that while the stability of these benches may depend on the development of these tree species, these species may depend on the in-channel benches for suitable habitat during drought periods, representing a reciprocal biogeomorphic relationship. Validating these possibilities will require a far more extensive and detailed tree–ring record.

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