Floodplain Vegetation and Soil Dynamics of the Alabama Piedmont Across a Gradient of Stream Channel Incision

by

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Abstract

Erosion resulting from past land use in cultivated uplands of the Alabama Piedmont has contributed to variable stream conditions throughout the region, with high degrees of channel incision often typifying degraded riparian corridors. Reduced flood frequency and lowered water tables characterize incised headwater streams of the region, thus reducing stream and floodplain function. The objectives of this study were twofold: (i) determine the effects of channel incision upon riparian vegetation assemblages and (ii) quantify the degree to which the aggradation of erosional material that inundated the region's floodplains has affected soil properties. Stream channel incision was described using bank height ratio (BHR), defined as the ratio of bankfull depth to stream bank height. Shallow groundwater wells were installed at all study sites to examine the effect of channel incision upon floodplain water tables. Study sites were selected across a gradient of BHR values (1.0-5.2); ten sites were chosen for the vegetation component of the study, six sites for the soils component. Results of the floristic component of this study indicate stream incision is correlated with a shift of community type in the ground flora stratum, from wetland-adapted species at low degrees of incision to plants typical of upland habitats at incised sites. Canonical Correspondence Analysis (CCA) was performed to evaluate if select environmental and hydrologic variables were significantly related (α=0.05) to herbaceous species composition. Results of the CCA indicate that species composition of the ground flora layer was significantly related to median groundwater depth, tree stem density, and BHR. Species diversity of the herbaceous layer also showed a distinct unimodal response to the incision gradient, suggesting that diversity may be greatest in riparian areas that receive intermediate amounts of flooding. The results of this study indicate that lowered water table levels and decreased soil moisture due to channel incision are driving compositional changes of herbaceous/ground flora in floodplains of the Alabama Piedmont.

Soil organic carbon (SOC), percent nitrogen (%N), and bulk density (BD) were analyzed to determine edaphic differences between reference and incised floodplain soils. At each study site, soils were sampled from three transects established perpendicular to stream flow in transects previously delineated for vegetation sampling. Samples were taken from the following depths: 0-5 cm, 0-15 cm, 15-30 cm, 30-45 cm. Significant differences in SOC, %N, and BD were observed between stream types, with increased amounts of SOC and %N, 58% and 39%, respectively, found at reference sites. In addition, BD of the floodplain soils was significantly greater at incised sites. Significant differences in groundwater levels between stream type were also observed during the study period (p value < 0.0001). The results of this study suggest that alluviation and subsequent channel incision has altered floodplain soil characteristics in the AL Piedmont, potentially limiting the ability of these soils to sequester C in the upper 45 cm. These findings, combined with the results of the vegetation component of this study, suggest that channel alterations due to past erosion in Piedmont uplands has led to significant changes in floodplain vegetation and soils relative to reference conditions.

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I. Literature Review

Abstract

Stream channel incision in the Alabama Piedmont has resulted in a loss of stream and floodplain functions. Channel incision is linked to anthropogenic disturbances, most notably channelization of streams and historic soil loss in Piedmont uplands. Alluvium and colluvium delivery to stream channels outpaced natural levels of sediment transport, resulting in the accumulation of erosional material in the region's streams and riparian corridors. As sediment supply decreased throughout the 20th century, streams in the region began to equilibrate to natural hydrologic regimes. Downcutting of the stream channel into erosional material has left many of these systems hydrologically disconnected from the floodplain; consequently, water table levels are lowered and the floodplain is rarely inundated by overbank flooding. The lack of frequent or seasonal flooding in these systems may be linked to shifts in soil condition and riparian vegetation. Stream channel incision may be described using bank height ratio (BHR), defined as the ratio of bankfull depth to stream bank height. Ten headwater streams with catchment sizes ranging from 0.26 to 9.1 km^2 were selected across a gradient of BHR values (1.0-5.2).

The objectives of this study are to (i) characterize floodplain vegetation of the Alabama Piedmont and determine the extent to which stream incision influences plant community composition and (ii) identify the effects of channel incision on soil carbon in Piedmont riparian areas. Woody vegetation and herbaceous cover were sampled at all sites after leaf out in May 2012. Soil carbon was quantified across a selection of reference and incised sites. An assessment of active carbon pools in these environments

will provide a greater understanding of riparian function as it relates to stream morphology.

Introduction

Riparian areas exist at the interface of aquatic and terrestrial environments, and the ecological functions of these habitats are innumerable. Riparian zones serve to buffer aquatic environments from overland sedimentation and pollution (Hill 1996), provide habitat and refugia for organisms (Gregory et al. 1991), act as sinks for carbon (Mitsch and Gosselink 2007), and are often sites of high biodiversity within the landscape (Naiman et al. 2010). A landscape feature typical of riparian environments is the flood plain, an area of relatively smooth land bordering a fluvial system that may be inundated by streamflow at times of high water (Leopold and Wolman 1957). The formation, maintenance, and degradation of flood plains can be attributed to the balance (or imbalance) of two primary processes: erosion and deposition. In a natural alluvial system, equilibrium between erosive and resistive forces results in a relatively static hydrologic, biotic, and geomorphic system. The linkages between hydrology, morphology, and biota that characterize a healthy flood plain system may be disrupted due to anthropogenic disturbance, thus degrading ecosystem function.

Land-use activities may impact alluvial systems through increased sediment and pollutant loading, increased runoff, and decreased amounts of carbon and nutrient inputs (Mitsch and Gosselink 2007). These factors have been shown to have a deleterious effect on stream biota (Sweeney 1992; Harding et al. 1998), watershed flood abatement (Wolman and Leopold 1957), and stream channel morphology (Leopold and Wolman 1964). Increased discharge or alterations to sediment delivery in a watershed may result in channel incision. Channel incision is best defined as the lowering of the base level of a stream or river, resulting in the disconnection between stream flow and the flood plain surface (Leopold and Wolman 1964).

Channel incision affects floodplain function in a number of ways. Stream flow within an incised channel will deposit sediment onto the floodplain with less regularity than streams under natural conditions. Floodplain microtopography is dependent on periodic scouring and deposition that contribute to habitat heterogeneity (Opperman et al. 2010) The effect of shear stress and discharge may be exacerbated under conditions of high bank exposure, thus leading to high degrees of mass wasting (Schumm 1984; Simon and Rinaldi 2006). The lowering of groundwater levels in riparian zone leads to a condition known as “hydrologic drought,” a condition defined by changes in soil type, soil morphology, and ecosystem structure due to decreased soil moisture (Groffman et al. 2003).

Riparian corridors of the U.S. may exhibit varying degrees of channel incision, with the primary cause of degraded stream condition attributable to land use history. In regions of the U.S. where intensive agriculture was the dominant land use, massive soil losses have been well documented (Happ 1945; Costa 1975; Trimble 1975; Schumm 1984). In the Piedmont region of the Eastern U.S., estimates of soil loss range from 7.5 cm in the states of Maryland and Virginia to over 30 cm in the Southern Piedmont (Trimble 1975). In the Piedmont of South Carolina, Happ (1945) estimated that soil loss due to agriculture had resulted in the deposition of 1.5m of sediment in the region’s streams and riparian areas. Extreme soil aggradation in floodplains and streams simply outpaced the sediment transport capacity of the region’s watersheds, resulting in profound changes to the aquatic resources of the Piedmont. Incised channels, along with substrate condition (Shields et al. 1994), water quality, and riparian forest condition (Giese et al. 2000; Wigginton et al. 2000; Darst and Light 2008; Hardison et al. 2009) may be symptomatic of degraded riparian function due to historic land use.

The streams and riparian corridors of the Alabama Piedmont exhibit varying degrees of incision that may lead to degraded function (Ruhlman and Nutter 1999). Like the Piedmont of South Carolina, headwater streams in this region may have been most affected by the sediment loss in agricultural uplands (Happ 1945; Costa 1975). Incised stream channels in low-order streams are frequently observed in the Alabama Piedmont, and the extent to which channel incision has affected the function of the region's forested floodplains is not well understood. As observed in other wetland systems, changes in groundwater dynamics drive changes in vegetative community structure, species composition, and soil carbon levels. The objective of this study was to determine the effects of channel incision upon floodplain function as measured by differences in riparian vegetative communities and floodplain soil carbon levels between reference and incised streams.

The Piedmont Region of Alabama

Geography

The Piedmont region of Alabama represents the southwestern terminus of the Piedmont eco-region, a 100-160 km wide physiographic province that extends from Alabama to southern New York (USDA-NRCS, 2006). The Piedmont of Alabama lies in the east-central portion of the state, and encompasses all or part of 12 Alabama counties. The topography of the region can best be described as an eroded peneplain, characterized by gentle slopes and broad interfluves (Trimble 1975). This area is included within the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) Major Land Resource Area (MLRA) 136 (Southern Piedmont), (USDA-NRCS 2006). The elevation of this region varies from 150-200 m in the southern portion to approximately 300 m in the northernmost extent of the province.

Geology

The Alabama Piedmont is underlain by igneous and metamorphic rocks (e.g. granites, schists, gneisses, quartzite, and phyllite) (USGS 1988). The region can be sub-divided into three separate areas based on bedrock stratigraphy: the Talladega slate zone, the Ashland plateau, and the Opelika plateau (Golden 1979). Geologic units of the Piedmont province are Precambrian or Paleozoic in age (USDA-NRCS 2006).

Soils

Soils of the Alabama Piedmont are residual in origin, derived from the weathering of igneous and metamorphic rocks. Dominant soil series of the region (i.e. Cecil, Helena, Appling) are formed from acid, igneous rocks and are classified under the Udic moisture regime and Thermic soil temperature regime (USDA-NRCS 2006). The primary soil orders in this region are Inceptisols, Ultisols, and Alfisols (USDA-NRCS 2006). Average saprolite thickness ranges from 7-15 m (Trimble 1975).

Pre-settlement status and land use history

Prior to European settlement, *Carya* and *Quercus* species were the dominant components of Piedmont forests (Golden 1979; Oosting 1942; Cowell 1995; Nelson 1957). The earliest descriptions of the Alabama Piedmont come from colonial-era explorers and naturalists, whose descriptions of the region point to a landscape dominated by late-successional forests and “clear, salubrious streams flowing over stone” (Harper 1943). William Bartram and his contemporaries made note of the clear streams in the Southern Piedmont region, lending credence to the idea that fluvial systems of this regions were not inundated with sediment prior to colonial expansion (Trimble 1975). Pre-colonial explorers characterized floodplain soils of the southern Piedmont as dark in color and “rich” (Harper 1943), indicating negligible rates of overland sediment deposition (Trimble 1975). Happ (1945) characterized the alluvium in modern Piedmont floodplains as brown to reddish-brown, similar to the topsoil in upland environments and often overlaying the former soil surface.

The 18th and 19th centuries were marked by the migration of American settlers into the Southern Piedmont and subsequent deforestation of the landscape. The clearing and cultivation of Piedmont uplands led to unprecedented soil loss, with the greatest period of erosive land use occurring between 1860-1920 (Trimble 1975). Cotton (*Gossypium hirsutum*) was the dominant row crop in the Alabama Piedmont (Trimble 1975; Ferguson 1994). Continuous cotton cultivation before the advent of soil conservation techniques was highly conducive to soil loss (Nyakatawa et al. 2001), and the high annual precipitation rates of the region (110-150 cm annually) exacerbated the crisis (USDA-NRCS 2006). The Great Depression marked the end of intensive agriculture in the Alabama Piedmont, and by this time it was estimated approximately 18 cm of topsoil was lost due to erosion (Trimble 1975). The concomitant declines of soil erosion and agriculture in the region can be attributed to the soil conservation techniques, conversion of croplands to timber, and field abandonment after the Great Depression (Trimble 1975).

Channel Incision

Stream channel incision results from an imbalance in the sediment load and sediment transport capacity of a fluvial system (Schumm 1984; Leopold et al. 1964; Simon and Rinaldi 2006). Channel entrenchment is often an inherent process in landscape evolution, such as valley development, but the exceedance of certain geomorphic thresholds due to anthropogenic disturbance may lead to disequilibrium and channel response in the form of incision (Schumm 1984). Soil loss due to land use change may lead to the inundation of streams and floodplains with sediment, and when sediment supply slows, subsequent downcutting of the system into this sediment leads to incision. Watershed response to stream channel incision involves a complex set of geomorphologic processes, with soil type, land-use history, vegetation, and climate as the principal drivers (Leopold 1964; Schumm 1984; Magilligan and Stamp 1997, Simon and Rinaldi 2006; Hardison et al. 2009). In headwater streams, for example, lowering of the stream base level results in the headward advancement of nickpoints, triggering greater erosion loss in uplands (Ferguson 1996; Schumm 1984).

In the field, an incised stream may be characterized by bank heights that exceed the natural floodplain elevation. In order to quantify degree of incision, a ratio of bank height to bankfull depth may be used (Rosgen 1994; Hardison et al. 2009). Bankfull depth is the height of channel-forming discharge within a stream or river channel; flows of this magnitude are typified by a recurrence interval of 1.5 years (Leopold 1964). Mass wasting of bank sediments often typifies an incised stream, along with reduced floodplain width and slumping of floodplain trees and shrubs into the channel (Schumm 1984). Channel adjustment to stream incision is dependent upon floodplain vegetation, soil type, flow velocity and flow regime (Leopold et al. 1964). The process of equilibration to current hydrological dynamics is time-dependent, but the basic step-wise evolution of a stream channel post-disturbance is best described by Simon and Hupp (1986) in the following steps: degradation, degradation and widening, aggradation and widening, and quasi-equilibrium (Figure 1).

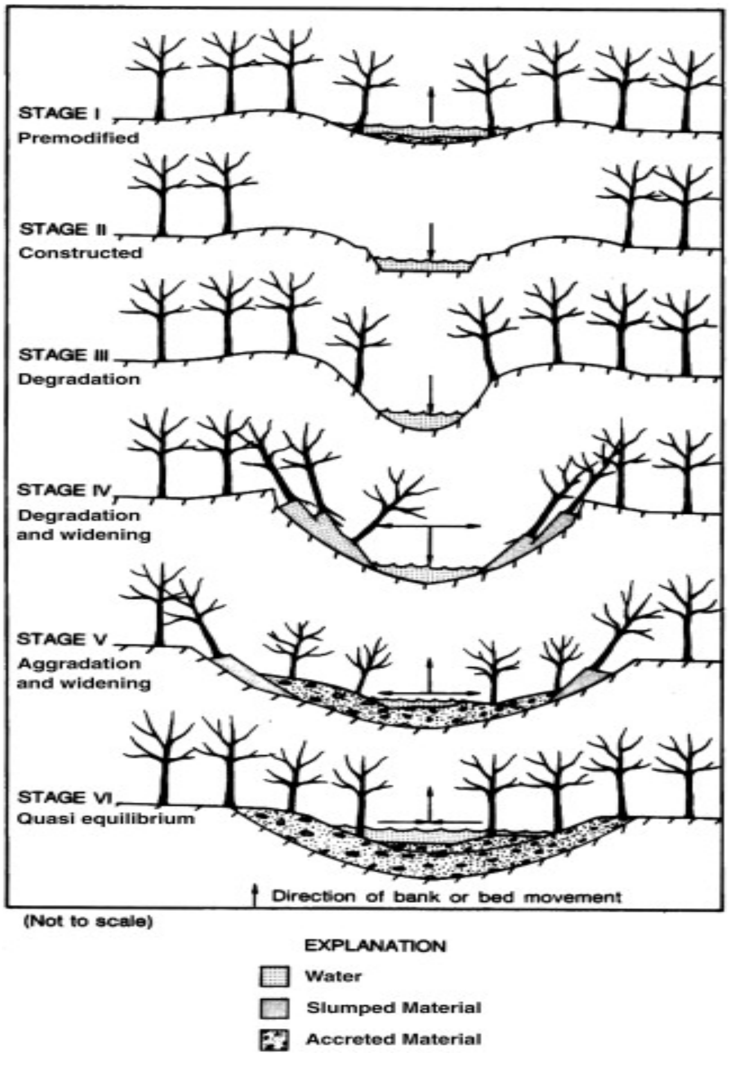

Figure 1: Six-stage diagram of channel incision following disturbance (Simon and Hupp 1986)

Channel Incision in the Alabama Piedmont

The abrupt reduction of soil loss in the uplands of the Alabama Piedmont after the Great Depression triggered a complex set of geomorphologic responses in the landscape. Old field conversion and natural succession patterns resulted in secondary growth throughout the region (Ferguson 1997, Costa 1975, Trimble 1975). Alluvial sediments entrained on the floodplains of Piedmont riparian zones remained in place via secondary growth and reduced stormwater flashiness (Ferguson 1997). With the sediment source diminished, watersheds in the Piedmont began to equilibrate to current patterns of sediment transport and retention. Streams incised into the colluvium and alluvium that had accumulated in the region's valleys and riparian corridors. The status of Piedmont streams post-Cotton era can be described as quasi-equilibrium, with secondary vegetative growth in floodplains stabilizing the alluvium *in situ* (Jennings 2012).

Floodplain changes due to channel incision

Channel incision has been shown to influence a variety of stream and floodplain functions. The loss of stream-floodplain connectivity due to incision leads to decreased flood frequency, lowered water tables, reduced soil moisture, and reduced allocthonous input to the lotic environment (Junk 1989; Steiger and Gazelle 1998; Amoros and Bornette 2002). Toledo and Kaufman (2001) found that riparian vegetation in incised reaches had lower percentages of root biomass than similar plants in unincised sections.

Riparian plant distribution

The composition and distribution of floristic communities in riparian settings depends upon a variety of hydrologic, environmental, and edaphic factors. Depth to seasonal water table, along with streamside elevation and soil texture, are the principal drivers in riparian plant distribution; these factors are dependent upon the hydrologic flow regime of the watershed (Poff et al. 1997; Tabacchi et al. 1998). Flood frequency, episodic and seasonal, is a primary driver of riparian forest composition in North American fluvial systems (Osterkamp and Hupp 1984; Everitt 1968; Auble and Scott 1998). Infrequent large floods serve as large-scale perturbations in the riparian zone, affecting stream morphology, floodplain topography, sediment types, and plant recruitment (Stromberg et al. 1997; Rood et al. 1998). Seasonal flooding leads to frequent, meso-scale disturbances throughout the riparian system that affect substrate microtopography and water-table dynamics (Allen-Diaz 1991; Dwire et al. 2006; Stromberg et al. 1997). The relative importance of flood frequency versus water-table depth in the determination of riparian plant composition and distribution is largely dependent upon site variables, such soil texture (Osterkamp and Hupp 1984; Law et al. 2000; Mouw et al. 2009) and life histories of the native plant species (Everitt 1968). Much of the scholarship concerning floristic response to groundwater changes has involved testing community response along an elevation gradient. Titus (1990) observed that elevation was the environmental variable most strongly associated with species distribution of woody seedlings in a floodplain system in Florida. In contrast, Robertson et al. (1978) found that simple elevational analysis in riparian zones did not accurately elucidate the complexity of hydrologic and edaphic factors influencing floodplain community dynamics. Hupp and Osterkamp (1985) observed that fluvial processes, specifically flood frequency and flow duration, were the primary driver of woody plant distribution in Passage Creek in northern Virginia via the creation of distinct geomorphic features; the authors found a significant correlation between floodplain features and certain vegetative assemblages. Bledsoe and Shear (2000) observed that water-table depth and seasonal flood frequency were both significantly related to plant species distribution between two riparian wetlands. The establishment of cottonwood (*Populus deltoides*) in the floodplain of the Little Missouri River was linked to seed deposition on floodplain terraces during infrequent flood events (Everitt 1968). Goebel et al. (2011) found that periodic and episodic flooding were secondary influences in the determination of herbaceous plant community composition, with landform boundaries and local nutrient availability being the principal drivers.

Flood frequency in fluvial systems is often tightly coupled with the water-table dynamics of the system. Groundwater in the riparian zone is dependent upon a myriad of spatial and temporal factors inherent to the site. Soil type, climate, landscape position, vegetative composition, land use history, and flow regime are some of the primary processes that affect water-table levels (Mitsch and Gosselink, 2007). Wetland and riparian plants are adapted to the saturated soils that characterize these environments. Alluvial water-tables and associated capillary fringe maintain riparian habitats via zones of saturation that preclude those species adapted to drier, upland setting; anaerobic conditions often typify saturated soils in the subsurface (Mitsch and Gosselink, 2007).

Correlations between water-table depth and plant community composition have been observed across a variety of fluvial systems (Bryan 1928; McDermott 1954; Hall and Smith 1955; Bravard et al. 1997; Shafroth et al. 2000; Law 2000; Dwire et al. 2006; Hammersmark et al. 2009). Mouw et al. (2009) found that depth to water-table, rather than flood disturbance, was the primary determinant of plant species richness in montane flood plains. Recent studies of North American alluvial systems have adopted a holistic approach towards understanding riparian plant dynamics, accepting flood frequency, groundwater behavior, and edaphic conditions as intrinsic to riparian plant distribution (Everson and Boucher 1998; Lyon and Sagers 1998; Bledsoe and Shear 2000).

Effects of channel incision on biota

Stream channel incision results in a decrease in floodplain-stream connectivity, thus reducing the exchange of stream flow, nutrients, sediments, and organisms (Opperman et al. 2010). The decrease in overbank flood frequency coupled with a concomitant reduction in ground-water levels leads to decreased soil moisture levels in the subsurface. Reductions in flood frequency may lead to shifts in floodplain disturbance regime and topographical heterogeneity, thus affecting plant species composition and diversity (J. Steiger et al. 1998; Ward et al. 2002; J. Steiger et al. 2005; Opperman et al. 2010).

In-stream biota

The deleterious effects of channel incision are not limited to terrestrial biota. In-stream organisms often utilize floodplain habitats during periods of inundation, gaining access to the nutrients entrained on the floodplain surface and using the vegetated, low-velocity zone as refugia (Kwak 1988, Sommer et al. 2001). In a study comparing fish assemblages in reference and downcut Mississippi streams, Shields et al (1994) found that species richness was reduced in incised channels; the authors attributed this finding to reductions in stream base flow and degraded in-stream habitats.

Effects of incision upon floodplain vegetation

Channel incision affects riparian plant communities through two primary mechanisms: (i) reduction in overbank flooding and (ii) riparian groundwater decline. Reduction in flood frequency due to channel incision has been observed in a number of alluvial systems (Shankman and Samson 1991; Bravard 1997; Steiger et al. 1998). The severing of floodplain/stream connectedness due to incision results in disruptions to the natural cycles of sediment movement and transport on the floodplain, resulting in decreased habitat heterogeneity and altered edaphic conditions (Ward et al. 2002). Topographical relief on the micro scale leads to localized areas in which soil moisture and nutrients may persist after depositional events—these zones increase habitat heterogeneity in the riparian corridor and provide conditions ideal for plant growth. Abernathy and Wilby (1999) found that the recruitment of seeds and propagules in floodplain habitats was positively correlated with the substrate heterogeneity. A similar study conducted by Guilloy-Froget et al. (2002) found that survivorship of riparian-specific black poplar (*Populus nigra*) was heavily dependent upon soil moisture at time of germination.

Water-table decline due to channel incision, or “hydrologic drought,” often leads to significant changes in riparian plant distribution, composition, and diversity (Groffman et al. 2003). Groffman (2003) observed that low-order reference streams of the Maryland Piedmont had relatively stable water-table levels that were often 1 to 2 meters higher than groundwater levels observed at similar urban streams. In addition to greater depths, water-table levels in the urban floodplains were more seasonally variable (Groffman 2003). Similar patterns of water-table decline were reported in floodplains of the North Carolina Coastal Plain: Hardison et al. (2009) found that channel incision in urban sites had resulted in lowered water-tables and high seasonal variability relative to rural settings. Schilling et al (2004) observed similar groundwater declines in an incised stream in Iowa.

Community-level response of vegetation to water-table declines has been observed across fluvial systems worldwide. Significant die-offs of woody vegetation in the floodplain of the incised Garonne River in France have been attributed to declining water tables (Steiger et al. 1998). Frequently observed in studies of vegetation response to water-table decline is a compositional shift of wetland-type plant species to vegetation assemblages typical of drier, upland settings. Darst and Light (2008) observed that water-table declines along the Apalachicola River due to channel incision had resulted in a canopy-level shift towards species more typical of upland settings.

Vegetation response to declining water tables has been well studied in the western United States, especially in areas where water resource issues are of great concern. In Western montane meadows, water-table levels have been shown to influence the prevalence of hydrophytic vegetation (Law et al. 2000; Dwire et al. 2006; Hammersmark et al. 2009). In a study of headwater streams in northeastern Oregon, Toledo and Kauffman (2001) reported a compositional shift of vegetation assemblages from wetland-obligate plants to dry site, upland-adapted species in riparian areas affected by declining water table levels. In addition, Toledo and Kauffman observed a positive feedback between vegetation and stream channel incision: decreased soil moisture due to incision led to drier vegetation communities and decreased root biomass, resulting in increased erosive capacity of the stream bank and thus facilitating further channel response (2001).

Soil changes due to channel incision

The variable nature of water-table levels in incised floodplains leads to patterns of soil development that would not be typical in natural floodplain settings. Groffman et al. (2003) observe that floodplain soils in incised streams will often exhibit redoximorphic features at shallower depths than post-disturbance zones of saturation. Soil horizons in incised floodplains may be characterized by buried surface horizons and topsoil representative of recent erosional material (Nakamura et al. 2000; Groffman et al. 2003; Ritchie and McCarty 2003; Gomez et al. 2004; Schilling et al. 2009). Gold et al. (2001) reported that nitrate (NO_3^-) levels in riparian soils of incised streams are higher in concentration and less available for denitrification than soils of forested, unimpacted riparian areas.

Floodplain SOC

Soil organic carbon (SOC) in riparian zones may exist in large quantities relative to upland settings due to saturated soil conditions that promote retention of subsurface carbon (Mitch and Gosselink 2007). Although the distribution and extent of SOC in riparian settings is highly variable, vegetation is the primary driver of soil organic carbon relative to water, climate, and soil factors (Van Cleve and Powers 1995). Vegetation affects SOC levels via species-specific litter and root carbon content; litter type (leaves, woody debris, flowers) and site productivity will drive subsurface incorporation of the organic carbon (Van Cleve and Powers 1995). Studies of SOC dynamics in disturbed and reference floodplains at the Savannah River Site (GA) have shown that forest successional status is a primary determinant of SOC in riparian zones (Giese et al. 2000; Wigginton et al. 2000; Giese et al. 2003). In their study of floodplain and depressional wetlands in southwestern GA, Craft and Casey (2000) found that land use history, specifically land use related to soil erosion, was significantly correlated with carbon retention in depositional areas. Similar patterns of carbon retention of riparian soils were observed in a study conducted by Blazejewski et al. in 2005; the authors found that flooding and deposition were substantial drivers of subsurface SOC distribution in riparian soils. Ricker et al. (2012) investigated SOC sequestration in New England headwater streams, and their findings suggest that riparian zones affected by historic land use may serve as carbon and sediment sinks.

The results of these studies demonstrate the importance of anthropogenic disturbance upon floodplain SOC. However, a relative dearth of research exists on the effects of channel incision upon floodplain SOC stocks relative to unimpacted sites. In addition, there is a paucity of data regarding carbon levels in floodplain soils of the Southern Piedmont; the degree to which alluvial deposition and channel incision have affected riparian SOC is unknown.

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II. Floodplain Vegetation of the Alabama Piedmont Along a Gradient of Stream Channel Incision

Abstract

Stream channel incision in the Alabama Piedmont has resulted in a loss of stream and floodplain functions. Reduced flood frequency and lowered water tables typify incised headwater streams of the region. The objective of this study was to determine if a quantifiable shift in riparian vegetation assemblages and community structure could be documented along a gradient of channel incision. Stream channel incision was described using bank height ratio (BHR), defined as the ratio of bankfull depth to stream bank height. Ten headwater streams were selected across a gradient of BHR values (1.0-5.2). Canonical Correspondence Analysis (CCA) was performed to evaluate if select environmental and hydrologic variables were significantly related to herbaceous species composition. Results of this study indicate stream incision is correlated with a shift of community type in the ground flora stratum, from wetland-adapted species at low degrees of incision to plants typical of upland settings at incised sites. Species composition of the ground flora layer was significantly related to median groundwater depth, tree stem density, and BHR. Species diversity of the herbaceous layer also showed a distinct unimodal response to the incision gradient, suggesting that diversity may be greatest in riparian areas that receive intermediate amounts of flooding. The results of this study indicate that lowered water table levels and decreased soil moisture due to channel incision are driving compositional changes of herbaceous/ground flora in floodplains of the Alabama Piedmont.

Introduction

Riparian areas exist at the interface of aquatic and terrestrial environments, and the ecological functions of these habitats are innumerable. Riparian zones serve to buffer aquatic environments from overland sedimentation and pollution (Hill 1996), provide habitat and refugia for organisms (Gregory et al. 1991), act as sinks for carbon (Mitsch and Gosselink 2007), and are often sites of high biodiversity within the landscape (Naiman and Decamps 1997). The composition and distribution of vegetation in riparian settings depends upon a variety of hydrologic, environmental, and edaphic factors. Depth to seasonal high water table, along with streamside elevation and soil texture, are principal drivers in riparian plant distribution; these factors are dependent upon the hydrologic flow regime of the watershed (Poff et al. 1997, Tabacchi et al. 2000). Wetland and riparian plants are adapted to the saturated soils and high water tables that typify these environments (Mitsch and Gosselink 2007), although frequency, duration, and magnitude of overbank flooding events may also significantly affect riparian vegetation assemblages (Goebel et al. 2012).

A landscape feature typical of riparian environments is the floodplain, an area of relatively smooth land bordering a stream or river that may be inundated by flow during flooding events (Wolman and Leopold 1957). Floodplain function is reduced when channel morphology prevents flow connection between the stream and floodplain surface, leading to alterations in flood frequency, soil morphology and function, and groundwater dynamics. Disconnections between stream flow and the floodplain surface can often be attributed to channel incision, a condition best defined as the lowering of the base level of a stream or river (Leopold and Wolman 1964). Channel incision is a common symptom of anthropogenic disturbance of fluvial systems, with features readily identified in the field: unnaturally high banks, with high degree of mass wasting and slumping of soil and vegetation into the active channel (Simon and Rinaldi 2006). Channel incision results from an imbalance in the sediment load and sediment transport capacity of a fluvial system (Leopold et al. 1964, Schumm 1984, Simon and Rinaldi 2006). Entrenchment of the active channel is often an inherent process in landscape evolution, such as valley development, but the exceedance of certain geomorphic thresholds due to anthropogenic disturbance may lead to disequilibrium and channel response in the form of incision (Schumm 1984).

Stream channel incision results in a decrease in floodplain-stream connectivity, thus reducing the exchange of stream flow, nutrients, sediments, and organisms (Opperman et al. 2010). Reduced soil moisture is also symptomatic of disconnected floodplains, as channel incision leads to decreased flood frequency and the lowering of water tables throughout the riparian soil system (Junk 1989; Steiger and Gazelle 1998; Amoros and Bornette 2002). Alterations to the flood regime may lead to shifts in disturbance dynamics and topographical heterogeneity, thus affecting floodplain species composition and diversity (Steiger et al. 1998,Ward et al. 2002, Steiger et al. 2005, Opperman et al. 2010). Incision is also linked to high seasonal variability in floodplain water tables that results in significantly lower groundwater levels in comparison to non-incised, reference systems (Groffman et al. 2003, Schilling et al. 2004, Hardison et al. 2009). Soil conditions in disconnected floodplains may also differ significantly from reference counterparts, as alluvium from upland erosion may result in thicker accumulation of sediments over older stable surfaces (Trimble 2008).

Prior to European settlement, hickory and oak species were the dominant components of Piedmont forests (Oosting 1942, Nelson 1957, Golden 1979, Cowell 1995). The earliest descriptions of the Alabama Piedmont come from colonial-era explorers and naturalists, whose descriptions of the region point to a landscape dominated by late-successional forests and "clear, salubrious streams flowing over stone" (Harper 1943). William Bartram and his contemporaries noted the clear streams in the Southern Piedmont region, lending credence to the idea that fluvial systems of this regions were not inundated with sediment prior to colonial expansion (Trimble 2008). Pre-colonial explorers characterized floodplain soils of the southern Piedmont as dark in color and "rich" (Harper 1943), indicating negligible rates of overland sediment deposition (Trimble 2008).

Row crop agriculture dominated the Piedmont region during the 19th and early 20th centuries, but a large-scale shift in land use after the Great Depression led to the conversion of large swaths of arable land to secondary succession, timberlands, and residential development (Cowell 1995). The heyday of row crop cultivation, referred to as the Cotton Era (ca. 1860-1920), was characterized by vast amounts of soil loss throughout the southern Piedmont; modern estimates of topsoil loss in the Alabama Piedmont range from 15-18 cm (Happ 1945, Trimble 2008). Alluvial material from cultivated lands accumulated in the streams and riparian corridors of the Piedmont region, resulting in high-degrees of stream degradation and geomorphic channel alterations in headwater and low-order streams (Bennett 1931, Happ 1945, Ruhlman and Nutter 1999, Trimble 2008). Land-use changes in the latter half of the 20th century led to the gradual reduction of eroded material entering the region's floodplains and waterways, therefore allowing these alluvial systems to equilibrate to the current sediment regime (Trimble 2008). A consequence of the increased downcutting of streams was incision, channel enlargement, and decreased overbank flooding events in low-order streams in the Southern Piedmont.

Groffman et al. coined the term "hydrologic drought" to describe the alterations in riparian habitats due to anthropogenic changes in stream morphology, specifically channel incision (2003). One of the central ideas of hydrologic drought as stated by Groffman et al. relates to shifts in riparian plant community composition and structure due to lowered groundwater tables. A similar study involving incised streams in the Coastal Plain of North Carolina found that Channel Incision Ratio, was a reliable surface indicator of floodplain water table decline (Hardison et al. 2009). Hardison et al. observed significant differences in ground-water depth between incised and reference streams, although no analysis of floristic dynamics was presented (2009). A consequence of hydrologic drought is likely a lack of hydrophytic species present in the floodplains and riparian habitats, therefore an analysis of vegetation composition in regards to stream channel incision is needed to paint a complete picture of hydrologic drought and its effects.

The relationship between groundwater and vegetation communities has been demonstrated in a variety of habitat types and environments, but few studies exist which examine plant community responses to the groundwater changes induced by channel incision, and no such studies were found for the Piedmont eco-region. The objective of this study was to test the concept of "hydrologic drought" in the field and determine if a quantifiable shift in vegetation assemblages could be documented along a gradient of stream channel incision. Floodplain vegetation of the Alabama Piedmont was analyzed to determine if community and species level changes in diversity, richness, and abundance structure existed in response to channel incision. We expected these data to show a correlation between the prevalence of hydrophytic plant species and magnitude of channel incision; significant differences in species diversity and richness were also expected along the gradient of incision.

Site Description

This study was conducted in the Piedmont region of Alabama, an area comprised of 12 counties in the East-Central portion of the state. The Alabama Piedmont represents the southwestern terminus of the Piedmont eco-region, a 100-160 km wide physiographic province that extends from Alabama to southern New York (USDA-NRCS, 2006). Mean annual precipitation ranges from 110-150 cm and mean annual temperatures range from 12 to 18° C (USDA-NRCS 2006). Floodplain soils of the Alabama Piedmont are comprised of alluvium and colluvium derived from metamorphic rocks (Golden 1979). Representative soils of Piedmont floodplains include the Toccoa (coarse-loamy, mixed, active, nonacid, thermic Typic Udifluvent), Chewacla (fine-loamy, mixed, active, thermic Fluvaquentic Dystrudept), and Cartecay (coarse-loamy, mixed, semiactive, nonacid, thermic Aquic Udifluvent) series (USDA-NRCS 2013). Happ (1945) characterized the alluvium in modern Piedmont floodplains as brown to reddish-brown, similar to topsoil in upland environments, and often overlaying a former soil surface.

Ten headwater streams that had a continuum of channel incision were selected for this study (Figure 2). Watershed land cover was largely consistent across all sites with low impervious surface cover and dominant land use best characterized as a matrix of secondary growth hardwood forests, pine plantations, and pasture. Stream sites had minimal invasive, exotic species, unconstrained valleys, and negligible upstream alterations (e.g. channeling). Floodplain width was a primary determinant of site suitability, as adequate distance between valley walls and transect placement was critical to reduce confounding interactions between study sites and hillslope groundwater seeps.

Materials and Methods

Vegetation measurements

Vegetation data were collected after leaf out in May and June of 2012. Five transects were placed at intervals of 50 m along a 250m stream segment. Transects were established perpendicular to stream flow, with dimensions of 5 X 20 m (0.01 ha^2). Plants were identified to the species level, and 3 layers of vegetation were assessed according to diameter at breast height (dbh) and height above soil surface: canopy layer, understory, and groundflora/herbaceous vegetation. All trees and shrubs in each transect were measured for dbh, counted, and identified to the species level. Stems greater than 2.5 cm at dbh were ranked as canopy-level species; stems less than 2.5 cm at dbh but greater than 1m above soil surface were ranked in the shrub/understory class. Woody stems and herbaceous vegetation < 1m in height were identified and ranked according to species abundance and cover class. The herbaceous and woody ground-flora component were assessed using 1 m^2 quadrats placed at 5m intervals in the 0.01 ha transects; each quadrat was placed equidistant from transect margin, and the final quadrat in the transect straddled the terminal transect boundary. A total of 25 herbaceous/ ground flora surveys were conducted at each site using the 1 m^2 quadrats (250 across all sites).

Cover class was estimated visually using the Braun-Bouquet-scale, in which a cover percentage is assigned to individual plants based on logarithmic scale: 1: 0-2%, 2: 3-10%, 3: 11-25%, 4: 26-50%, 5: 51-100% (Causton, 1988).

All species were categorized according to their wetland indicator status: obligate upland (UPL), facultative upland (FACU), facultative (FAC), facultative wetland (FACW), and obligate wetland (OBLW) (US Army Corps of Engineers 2012).

Importance values (IV_{200} and IV_{300}) were calculated for canopy, shrub, and herbaceous-level species with data pooled from each transect to provide importance values per stream. Importance values of canopy species (IV_{300}) were calculated using the following formula:

Equation 1: IV_{300} = Relative density of species X+relative frequency of species X+relative dominance of species X

Importance values of understory and shrub species were calculated on an IV_{200} scale, in which the sum of relative frequency and relative density was determined.

Equation 2: IV_{200} = Relative density of species X+ relative frequency of species X

The importance values of herbaceous and ground-flora were also assessed on an IV_{200} scale, with relative cover class percentage used in conjunction with relative frequency. Species diversity and richness were assessed to evaluate community-level changes in floodplain vegetation across the study sites. Shannon-Weiner diversity indices (H’) for the herbaceous/ground flora of each study site were calculated with EstimateS (Colwell 1997), a software package that computes diversity using the following formula:

Equation 3:

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

Shannon-Weiner Index equation (Causton 1988)

Where*:* *H'*= Shannon-Weiner index score

R= Species richness

P_i= Proportion of *R* made up of the *i*th species

Species richness was calculated as the sum of unique species encountered at each site. Prevalence Indices (PI) were calculated for each forest layer across all sites. Prevalence Indices are weighted averages that combine relative abundance and wetland indicator status categories in order to determine the prevalence of hydrophytic vegetation at a particular site (Peet et al. 1988). Mean PI scores of the canopy and understory strata at each site were generated by calculating PI of the sample layer in each transect and averaging among the 5 transects. The PI of each 1 m^2 quadrat was calculated and averaged among the 25 quadrats sampled per site in order to determine a PI score for the herbaceous/ground flora layer of each study site.

Equation 4: Prevalence Index= $\sum A_i W_i / \sum W_i$

Where A_i= abundance of species I, W_i= Wetland Indicator Category value for species I (UPL=5, FACU=4, FAC=3, FACW=2, OBL=1)

i= species

Prevalence index scores <3.0 typically indicate that the site has a dominant component of hydrophytic vegetation, therefore representative of a wetland-type habitat (Peet et al. 1988, US Army Corps of Engineers 2012).

Groundwater monitoring wells were installed 10 m from the floodplain-stream boundary at 3 sites along each stream site in transects previously delineated for vegetation analysis. Well depth varied among sites (0.63-2.1 m), with maximum depth often dependent on water table height and proximity of bedrock. Maximum well depth for most sites was 20-30 cm below water table elevation at time of installation. Wells were constructed from 10.16 cm diameter slotted PVC pipe and encased in geotechnical fabric. Pressure transducers (Solinst Levelogger Gold) were placed in one well per site to provide a continuous log of groundwater levels over the year-long study period (March 2012-March 2013). Transducers were placed in well sites most representative of overall geomorphic condition of stream site. Groundwater levels were also monitored at all sites on a monthly basis.

Channel morphology

Bank height ratio was used to determine the degree of channel incision at all study sites. Bank height ratio (BHR) is a geomorphological diagnostic tool that utilizes bankfull depth and bank height to quantify channel incision in a fluvial system (Rosgen 1996). Bank height ratio was assessed at all stream sites using the following protocol:

1.)Determine most stable upstream riffle

2.)Measure depth from thalweg to bankfull (D_{max})

3.)Measure depth from thalweg to top of bank (D_{TOB})

4.) Divide D_{TOB}/D_{MAX}

In severely incised streams a field determination of bankfull depth is often unreliable, therefore a consistent measure of D_{max} was unattainable in a small sample of the study sites. A regional curve developed by Helms et al. of D_{max} plotted against watershed size was used to generate a function for predicting bankfull (2013) (Figure 3). This method was used to determine BHR at 3 highly incised study sites (Forest Eco, Bird, and Coon creeks). Watershed boundaries were delineated using digital elevation models in ArcGis 10.0.

Statistics

Data were compiled with Microsoft Excel (Microsoft Corporation 2008). R 2.15.2 software (R Development Core Team 2012) was the primary statistical software used for analysis. Linear and non-linear regressions were performed to determine level of association between vegetation data and independent variables (BHR, mean groundwater depth). Canonical correspondence analysis (CCA) was used to test community structure of ground flora to measured environmental variables. CCA uses multiple regression techniques to relate environmental variables to species composition. Analysis was based on species importance values, with rare species (less than 5 individuals) omitted from examination. Monte Carlo permutation tests were used to test for significance in CCA analysis, testing the null hypothesis of no relationship between species composition and environmental variables. The Shapiro-Wilk test for normality was utilized to test for linear assumptions with no transformations required. Statistical significance for all tests was set at α=0.05. SigmaPlot version 11.0 (Systat Software) was used to generate graphs and figures.

Results

Geomorphology and Hydrology

Bank height ratios varied among study sites and ranged from 1.00 at the least incised, reference-type streams to 5.17 at the most incised study site (Table 1).

Groundwater depths varied throughout the study period (March 2012-March 2013) and among study sites (Figure 5). Linear regression of BHR and mean annual groundwater indicated a significant relationship ($p=0.003$, $R^2=0.66$) (Figure 5). Mean rainfall of the study area, calculated as mean precipitation across the 10 study sites for the study period, was 100.17 ± 4.59 cm. This value is markedly lower than the 30-year average annual precipitation (134.26 cm) for Wadley, AL, a municipality located in the central portion of the Alabama Piedmont, (NCDC, 2013).

Vegetation Community Structure

A total of 94 unique plant species were identified across 10 study sites. The dominant canopy-level species among all sites were *Liquidambar styraciflua* (10 sites, mean IV_{300}: 53.7±7.7), *Liriodendron tulipifera* (10 sites, mean IV_{300}: 37.10±6.4), *Carpinus caroliniana* (9 sites, mean IV_{300}: 50.8±11.7), *Acer rubrum* (9 sites, mean IV_{300}: 17.4±3.9), and *Quercus nigra* (7 sites, mean IV_{300}: 40.9±18.1).

The most common shrub species among the study sites were *Smilax rotundifolia* (10 sites, mean IV_{200}: 27.4±6.9), *Carpinus caroliniana* (7 sites, mean IV_{200}: 28.2±5.4), *Halesia carolina* (6 sites, mean IV_{200}: 25.9±9.9), *Vitis rotundifolia* (6 sites, mean IV_{200}: 11.7±2.8), and *Quercus nigra* (5 sites, mean IV_{200}: 28.3±14.1). The composition of ground flora species was highly variable among study sites, with pteridophytes (*Athyrium filix-femina, Woodwardia areolata*) and *Arundinaria gigantea* dominating at low degrees of incision. Graminoids and forbs with FACU and FAC wetland indicator statuses tended to increase in abundance as degree of incision increased. Top three species per site ranked by importance value are listed in Table 2.

Taxa richness varied among the stand layers and across study sites (Table 3). Analysis by linear regression indicated no significant level of association between BHR and species richness of the canopy, shrub, and ground flora layers (Table 4) (Figures 6-8). Similarly, regression of taxa richness and mean groundwater depth indicated no significant linear relationship between floodplain hydrology and richness across all forest layers (Table 4, Figures 9-11). Linear regression did not yield a significant relationship between BHR and species diversity of herbaceous/ground flora ($p=0.899$, $R^2=0.002$), however non-linear quadratic regression did indicate a significant relationship between the two variables ($R^2=0.47$ $p= <0.0001$) (Figure 12). Quadratic regression of ground flora diversity and mean groundwater was also significant ($R^2=0.51$, $p= <0.0001$) (Table 4, Figure 13). Similar significant, unimodal responses were observed in quadratic regression analysis of ground flora richness in relation to BHR ($R^2=0.08$, $p=<0.0001$) (Figure 14) and mean groundwater depths ($R^2=0.027$, $p=0.036$) (Figure 15).

Vegetation Composition (Prevalence Indices)

Prevalence index (PI) scores were used to assess abundance of hydrophytic vegetation in the overstory, understory, and herbaceous strata at each study site (Table 5). A significant linear correlation was observed between mean PI scores of herbaceous/ground flora plants and BHR ($R^2=0.64$, $p=0.005$) (Figure 16). In contrast, no relationship was found via regression analysis of shrub and canopy layer PI scores and BHR (Figures 17 and 18). Mean PI scores of the herbaceous/ground flora across all sites also showed a significant level of association with mean groundwater depth ($R^2=0.52$, $p=0.028$) (Figure 19). Linear regression indicated no significant relationship between mean groundwater depth and PI scores of the midstory and overstory strata (Table 4, Figures 20 and 21).

Percent composition of FACW/OBL species in the ground flora layer ranged from 27.16 to 0% along the gradient of stream incision. A significant correlation ($p < 0.001$) was observed between BHR and percent composition of FACW/OBL in the herbaceous/ground flora layers, with increasing BHR typically indicating lower prevalence of FACW/OBL species across all sites (Figure 22). In contrast, linear regression analysis of percent FACW/OBL and mean groundwater depth did not indicate a significant relationship between the two parameters (Figure 23).

Canonical Correspondence Analysis

Canonical correspondence analysis was used to relate species composition of the herbaceous/ground flora level to key environmental and hydrologic variables (mean and median groundwater depths, bank height ratio, stem density, and percent time groundwater level was within 50 cm of floodplain surface). CCA axes 1-4 explain 40-13% of herbaceous species composition, respectively (Table 6). The CCA plot indicates clear distribution of herbaceous species along the gradient of channel incision. Pteridophytes and forbs with FACW/OBL designations are organized spatially in sites exhibiting reference-type geomorphic conditions (*Woodwardia areolata, Osmunda regalis*) (Figure 24). In contrast, incised sites have species typical of dry, upland settings (*Rubus argutus, Prenanthes altissima*). Permutational ANOVA testing of the CCA indicates a significant correlation between species composition and BHR, median groundwater height, and stem density (Table 6).

Discussion

The results of this study suggest that channel incision in low-order streams of the Alabama Piedmont has led to shifts in vegetation structure and composition. Bank Height Ratio, or BHR, was strongly correlated with the distribution and composition of riparian herbaceous layers. Prevalence index scores of the overstory, midstory, and herbaceous stratum show variation in the abundance of hydrophytic vegetation across the sites, but only ground flora PI values were significantly correlated with BHR and mean groundwater depths. These findings are similar to other studies that note the herbaceous layer is most responsive to changes in soil hydrology due to high plant turnover rates (Naiman et al. 2005, Goebel et al. 2006). Because forest strata respond to disturbance and microtopography in different ways, compositional patterns may differ by forest layer (Glenn-Lewin 1977). Herbaceous species are more sensitive to small-scale temporal and spatial changes in soil moisture and topographical heterogeneity than shrub or canopy layers, and therefore exhibit rapid response to environmental gradients (Lyon and Sagers 1998, Lite et al 2005, Steiger et al 2005).

Prevalence Indices

Examination of the PI for each forest stratum indicates that the herbaceous/ground flora layer was more responsive to changes in groundwater levels and BHR. Prevalence index scores of the least incised study sites (BHR= 1.0-1.11) are below 3.0 indicating a prevalence of hydrophytic vegetation in the ground flora layer (Peet et al. 1988, US Army Corps of Engineers 2012) (Table 4). studies in the western US report compositional shifts of the herbaceous layer from wetland-obligate plants to dry site, upland-adapted species in response to declines in groundwater (Allen-Diaz 1991, Law et al. 2000, Dwire et al. 2006, Hammersmark et al. 2009). In a comparable study conducted in the Midwestern US, Goebel et al. observed that changes in the composition of riparian ground-flora were strongly related to elevation above bankfull (2006). Prevalence index scores of the herbaceous/ground flora layer generally increased with increasing BHR, indicating a compositional shift from hydrophytic plant species at low degrees of incision towards an herbaceous layer comprised of plants more typical of upland, drier settings. These findings are in line with similar studies that have examined riparian vegetation distribution and may substantiate the idea of "riparian hydrologic drought" as defined by Groffman et al (2003). The significant decline in FACW/OBL species in response to increased BHR is another indication of a compositional shift from hydrophyte-dominated to FAC and FACU vegetation assemblages. Mean groundwater depth was not found to be a significant indicator of FAC/OBL herbaceous species. The p-value from this analysis (0.058) was not statistically significant, although a biologically significant relationship is probable.

Prevalence index scores of the overstory and midstory layers did not have significant levels of association with BHR or mean groundwater depth. The PI scores of the canopy layer ranged from 2.93 to 3.47 across the 10 study sites, with no clear trend of increasing PI score in accord with BHR or groundwater depth. Similar studies in western North America (Shafroth et al. 2000, Guilloy-Froget et al. 2002) and in floodplains of major river systems (Bravard et al. 1997, Steiger and Gazelle 1998, Darst and Light 2008) have observed canopy-level shifts in woody species composition due to water table decline, but no studies have demonstrated these changes in low-order streams of the eastern US. In his examination of Alabama Piedmont tree communities, Golden (1979) reported that small stream bottoms were populated by tree species that were otherwise typical of other Piedmont habitats: mesic uplands (*Quercus alba*), moist coves (*Liriodendron tulipifera, Fagus grandifolia*), and large bottomlands (*Liquidambar styraciflua, Acer rubrum*). Floodplain soils of this region are generally characterized as moderately well to well drained, therefore these habitats often favor woody species adapted to upland settings that would otherwise be ill suited for riparian areas (Golden 1979). These findings are in concurrence with results of this study that a mosaic of tree and shrub species adapted to variable habitats populates floodplains of Piedmont headwater streams. Therefore, a prevalence of hydrophytes in the midstory or overstory may not be a natural characteristic of these communities.

Species richness/diversity

As reported in similar studies, variations in groundwater depth can be tied to compositional shifts in riparian understory vegetation, richness and diversity (Bravard et al. 1997, Pollock et al. 1998, Toledo and Kauffman 2001, Dwire et al. 2006, Hammersmark et al. 2009). The results of this study showed a significant unimodal response of herbaceous diversity to BHR (Figure 12) and mean groundwater depth (Figure 13), with the highest levels of diversity occurring in the intermediate ranges of channel incision. The distinct unimodal correlation of species diversity to BHR is indicative of the “intermediate disturbance hypothesis,” in which high diversity is expected in areas where disturbance is infrequent; these intermediate sites will be populated by a mosaic of species adapted to both extremes of frequent and infrequent perturbations (Connell 1978).

The intermediate response pattern has been demonstrated in floodplains where overbank flooding serves as the dominant disturbance (Pollock et al 1998, Amoros and Bornette 2002, Lite et al. 2005). Flood events disturb riparian systems by scouring the floodplain surface, depositing and removing seeds and propagules, establishing habitat heterogeneity, and depositing organic and inorganic matter (Verry et al 2000). Channel incision has been shown to reduce the magnitude and frequency of flood events in fluvial systems, (Bravard et al 1997, Ruhlman and Nutter 1999, Schilling et al 2004), and alterations to flood regimes in the southern Piedmont have been specifically attributed to channel incision (Ruhlman and Nutter 1999). Examination of groundwater data from this study indicates that flood frequency is lower at incised stream sites. At Loombeam Spring, a reference site with BHR of 1.04, 290 overbank events were recorded over the duration of the study period (each events corresponds to 15 minute sample interval). In comparison, zero overbank events were recorded at the most highly incised sites (BHR ranges 2.41-5.18). Bank height ratio, therefore, may serve as a proxy for relating reductions in flood frequency due to channel incision.

The results of this study indicate that BHR and mean groundwater depth are not significant drivers of taxa richness in the understory, midstory, and overstory of riparian Piedmont forests. The lack of significant linear correlation between these hydrogeomorphic processes and richness suggest that the changes in soil moisture and flood frequency attributed to channel incision do not affect woody species to the extent which they influence the herbaceous layer. Riparian systems in mesic or temperate systems may not be water limited, thus limiting influence of soil moisture on vegetation composition (Tabbacchi et al 1996). Like diversity, richness is expected to exhibit a unimodal response along a disturbance gradient (Connell 1978). Taxa richness of riparian ground flora has been shown to exhibit patterns similar to that of riparian species diversity, with the highest degrees of richness occurring in areas with intermediate flood frequency (Pollock et al 1998, Lyon and Sagers 1998, Amoros and Bornette 2002, Lite et al 2005). Species richness of the herbaceous/ground flora stratum exhibited a weak unimodal response to the gradients of BHR and groundwater depth, indicating that richness of this forest layer is not as responsive to hydrologic alterations as diversity and species composition. These findings point to a compositional (rather than structural) shift in ground flora communities along the gradient of stream incision.

Canonical Correspondence Analysis

Canonical correspondence analysis (CCA) shows the spatial organization of herbaceous plant species along the continuum of channel morphology (Figure 24). Non-incised stream sites (<1.5 BHR) exhibit herbaceous/ground flora vegetation dominated by FACW/OBL species. Fern species with FACW/OBL (*Woodwardia areolata*, *Osmunda regalis*) designations are aligned with sites exhibiting reference-type geomorphic conditions. In addition, these sites have a high abundance of woody, hydrophytic species (*Magnolia virginiana*, *Sambucus nigra*). Results of the ordination analysis also reveal a strong association between upland-type woody species (*Quercus alba*, *Cercis canadensis*, and *Cornus florida*) and sites with high BHR values; these data indicate that sites exhibiting high degrees of channel incision are more favorable to vegetation adapted to dry settings (e.g. low flood frequency, low soil moisture). The distribution of ground flora in the ordination space show that channel incision drives compositional shifts in floodplain vegetation, suggesting that the changes wrought on floodplains due to groundwater declines and altered flood frequency are geomorphic in origin. Although no known studies relate ground flora composition specifically to channel incision, these findings are in line with comparable studies that examined vegetation assemblages in relation to fluvial landforms (Osterkamp and Hupp 1984, Hupp and Osterkamp 1985) and elevation above bankfull height (Lyon and Sagers 1998, Geise et al. 2000, Goebel et al. 2012).

Results of canonical correspondence analysis indicate that 3 environmental variables explain variability in species composition along a gradient of incision: BHR, median groundwater depth, and tree stem density. Although not statistically significant, mean groundwater depth ($p= 0.057$) is likely a biologically significant determinant of species composition. Decreased precipitation levels during the study period relative to the 30-year norm may have contributed to the lack of significant correlation between mean groundwater levels and herbaceous flora. BHR as a significant predictor of herbaceous species composition was expected, and this result emphasizes the hydrogeomorphic origin of the observed changes in floodplain floristic composition. Species with broad habitat tolerances were found in the center of the CCA plot and therefore showed no clear relation to environmental variables (*Callicarpa americana*, *Smilax rotundifolia*, and *Viola* spp.).

Density of stems greater than 2.5 cm at dbh was found to be a significant predictor of herbaceous species composition. Similar studies (Cole 2002, Lite et al. 2005) have also observed significant correlations between woody stem density and herbaceous/ground flora dynamics; these findings are attributed to canopy effects upon understory dynamics (canopy cover, litter) and surface water storage of floodwaters upon floodplain surface.

In riparian and wetland habitats, the attenuation of floodwaters during overbank events is often more dependent upon woody vegetation than herbaceous plants (Miller 1988, Verry et al. 2000, Cole 2002). Woody stems slow floodwaters on the floodplain surface, allowing for greater infiltration of surface water into the soil column and facilitating deposition of inorganic sediments (Naiman et al. 2010). Stem density and associated woody debris have also been shown to contribute to habitat heterogeneity, a significant driver of herbaceous species diversity and composition (Cole 2002). The observed patterns of ground flora diversity in Piedmont floodplains may be due to the interplay of flood frequency as explained by BHR and the affect of woody vegetation on habitat heterogeneity.

Groundwater-floodplain dynamics

Results of regression analysis for BHR related to mean groundwater depth suggest that BHR is an accurate predictor of water table depth in floodplains of the AL Piedmont (R^2=0.66, p=0.003). A study in the Coastal Plain of North Carolina reported that a comparable diagnostic of incision, Channel Incision Ratio, was an accurate predictor of groundwater levels in reference and incised streams (Hardison et al. 2009). The results of this study, along with the 2009 findings of Hardison et al., substantiate the groundwater component of Groffman's "hydrologic drought" concept (2003). According to Groffman et al., riparian zones affected by hydrologic drought will exhibit high seasonal variability in their groundwater. In the study period of March 2011 - March 2012, groundwater variability of the incised locations was greater relative to the reference floodplain conditions. Groundwater levels of reference sites (BHR<1.5) deviated 0.1-0.12 m from the yearly average. In contrast, groundwater fluctuations at the incised sites often ranged 0.25-0.30 m from the 2011-2012 average. Hardison et al. observed similar patterns of groundwater fluctuation between reference and incised streams (2009).

Conclusions

Stream channel morphology has been shown to affect floodplain function in variety of ways. The disconnect between the stream and floodplain environments due to channel incision has the potential to disrupt the tightly coupled relationship between aquatic and terrestrial environments resulting in a cascade of diminished function throughout the riparian ecosystem. This disconnection can be seen throughout the Alabama Piedmont, a region characterized by high degrees of incision in the region's riparian corridors. Results of this study demonstrate that floodplains of the Alabama Piedmont exhibit varied degrees of "hydrologic drought," as evidenced by compositional shifts in ground flora vegetation and lowered groundwater levels. Alterations to riparian water tables and diminished flood frequency may also be driving changes in understory diversity, creating areas of high diversity in floodplain sites that exhibit intermediate levels of incision. Bank height ratio was an accurate predictor of groundwater levels in Piedmont floodplains, and the use of this technique could be extended to scientists, land managers, and stakeholders concerned with assessing the hydrogeomorphic status of a headwater stream. In addition, BHR may provide a relatively simple diagnostic for evaluating plant species suitability for restoration efforts.

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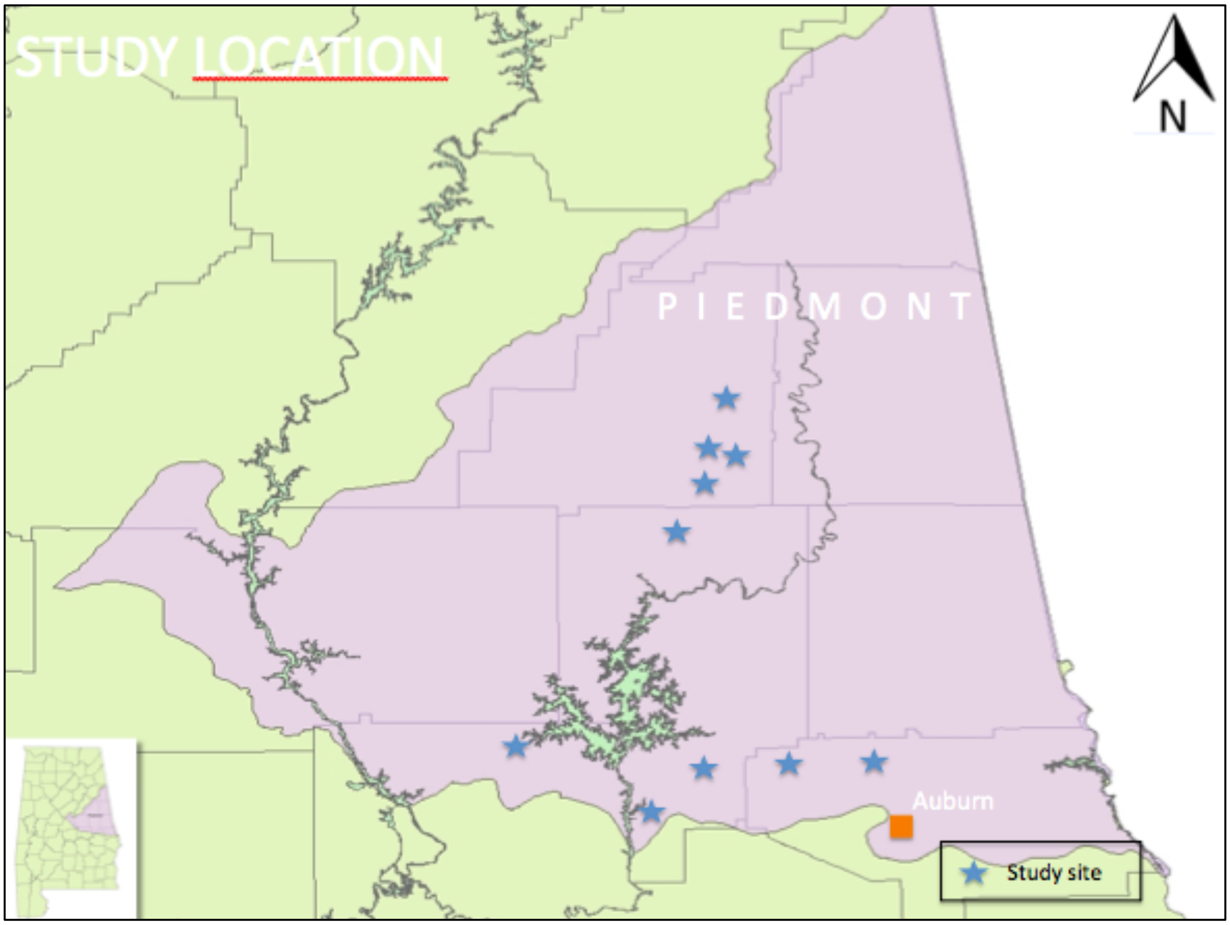

Figure 2: Location of 10 study sites in the Alabama Piedmont, USA.

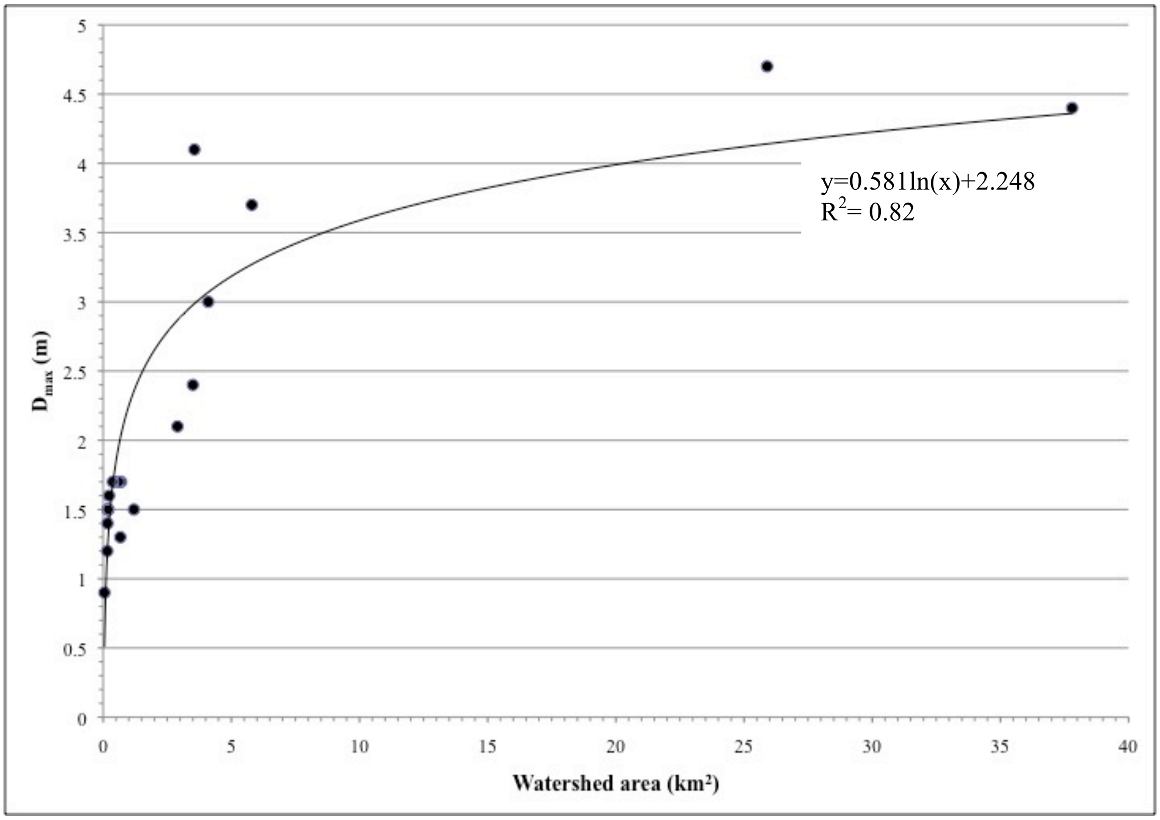

Figure 3: Maximum depth from thalweg to bankfull (D_{max}) in relation to watershed area. Data were collected at 15 reference stream sites in the Alabama Piedmont.

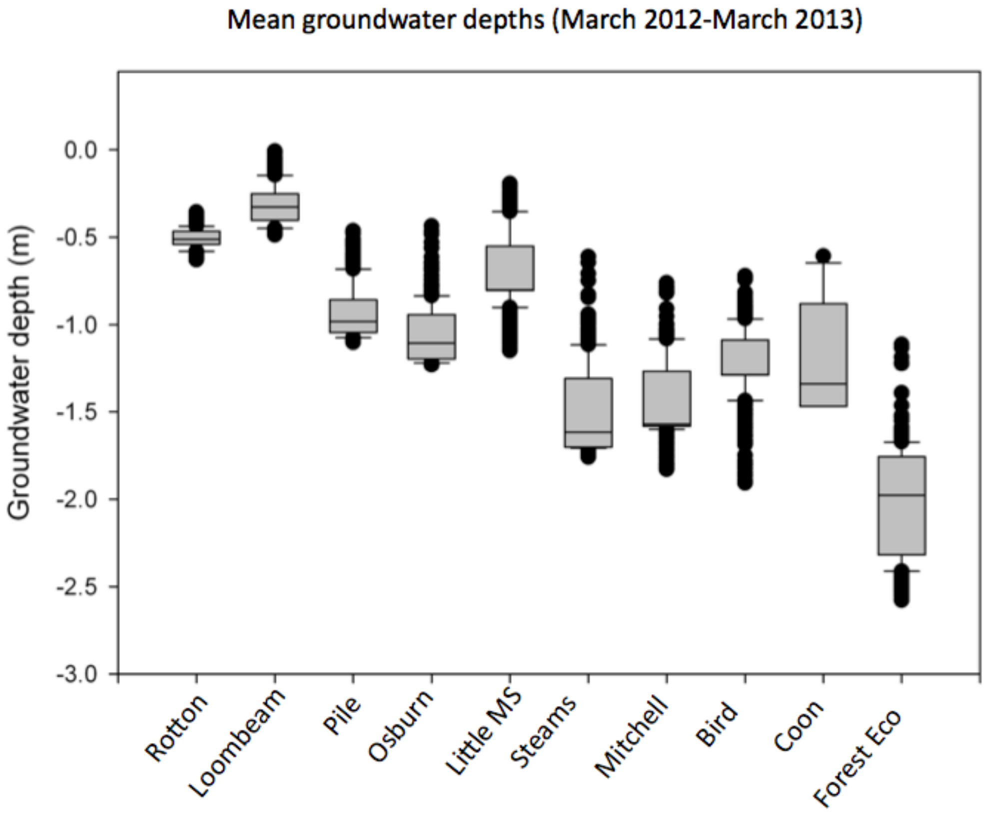

Figure 4: Mean groundwater depth, measured monthly, among study sites for 1-year study period (March 2012-March 2013); data presented in order of increasing Bank Height Ratio.

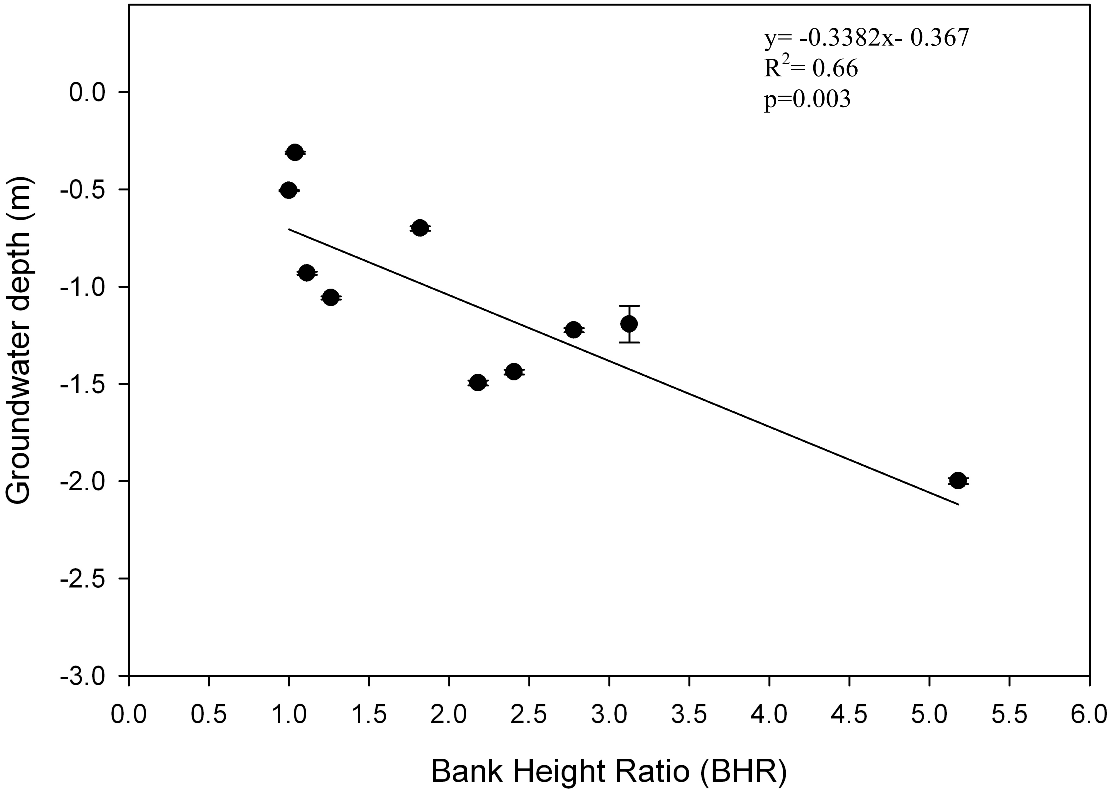

Figure 5: Significant linear regression relationship between mean groundwater depth and Bank Height Ratio across 10 watersheds of the Alabama Piedmont

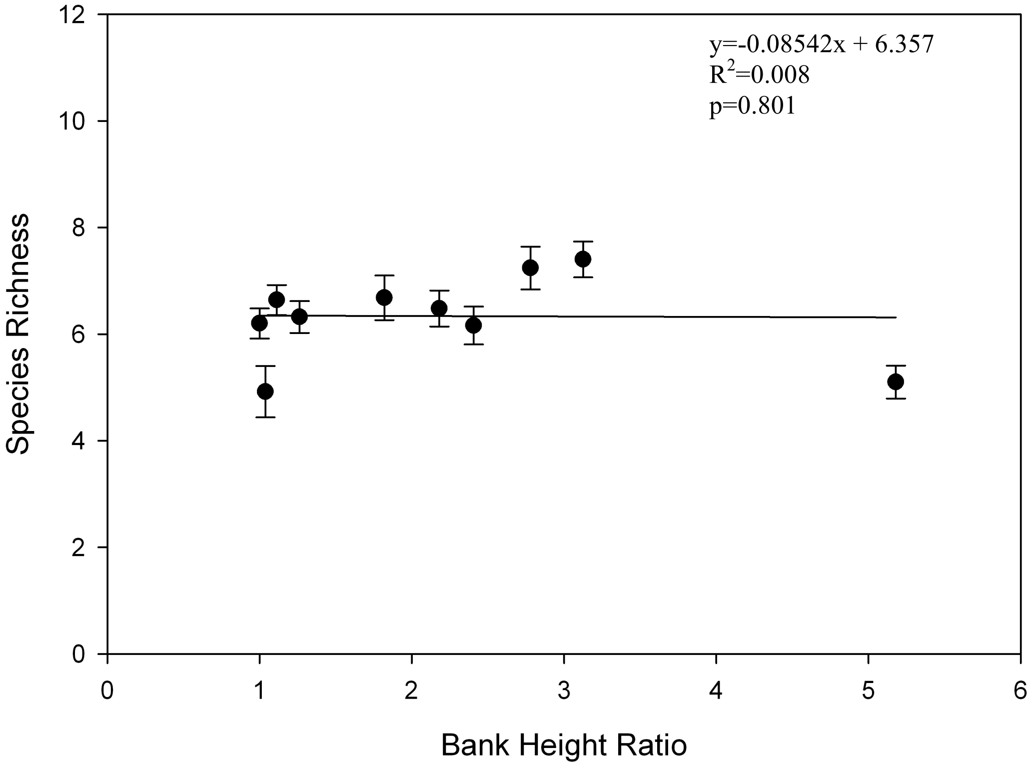

Figure 6: Linear regression relationship between herbaceous/ground flora taxa richness and Bank Height Ratio.

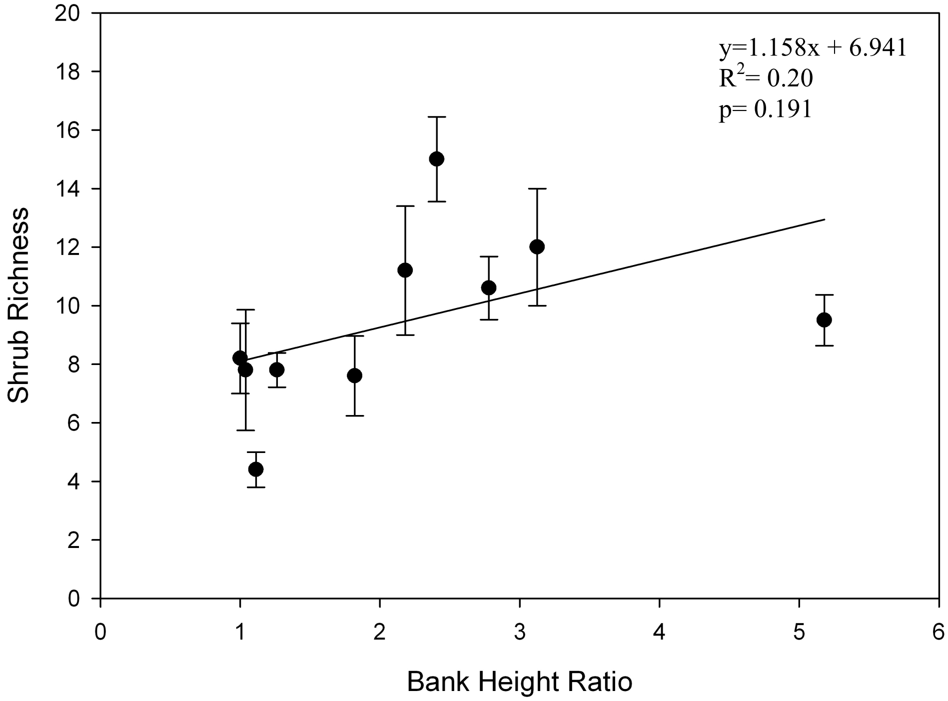

Figure 7: Linear regression relationship between midstory taxa richness and Bank Height Ratio.

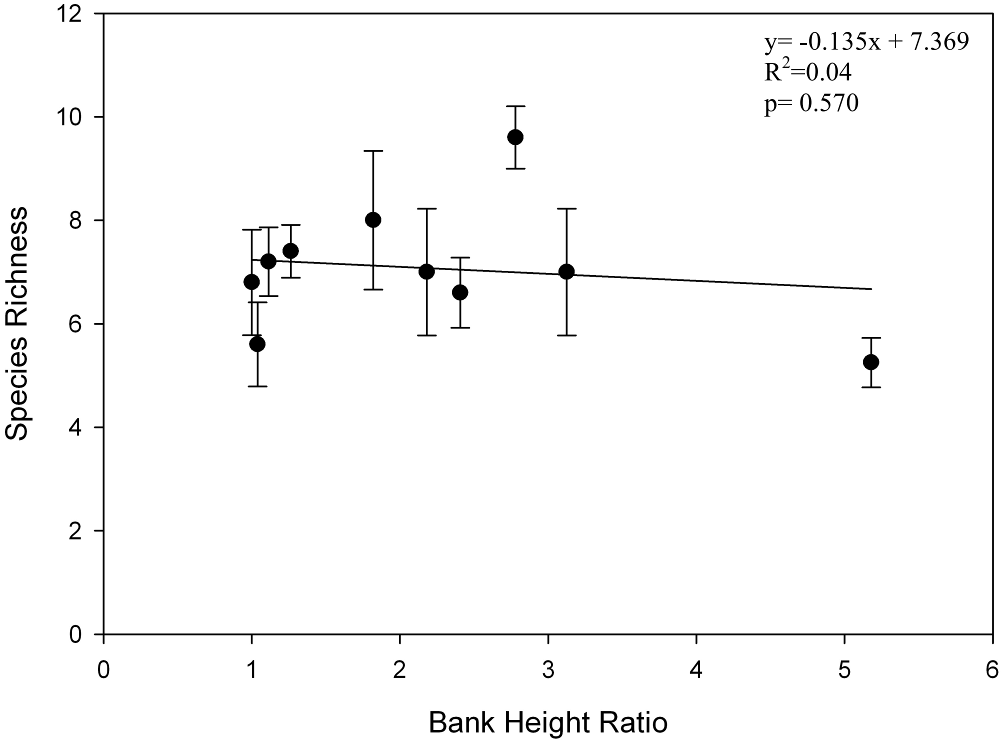

Figure 8: Linear regression relationship between overstory taxa richness and Bank Height Ratio.

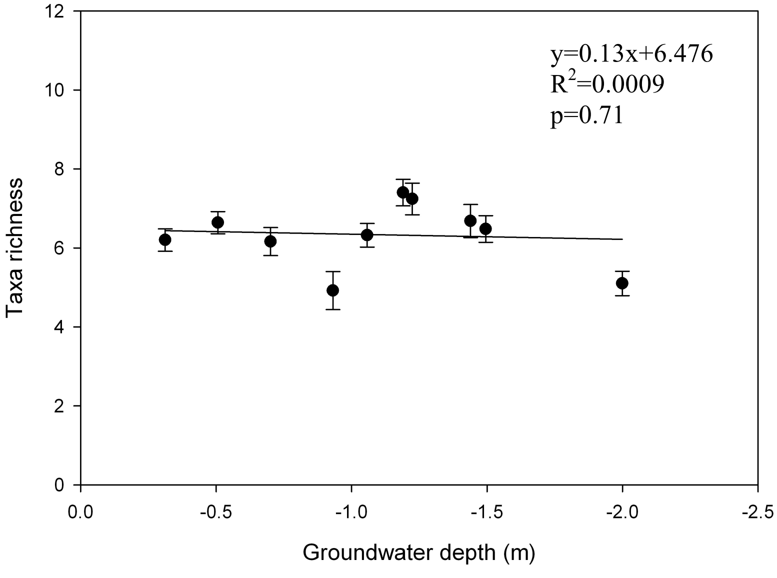

Figure 9: Linear regression relationship between herbaceous/ground flora and mean groundwater depth.

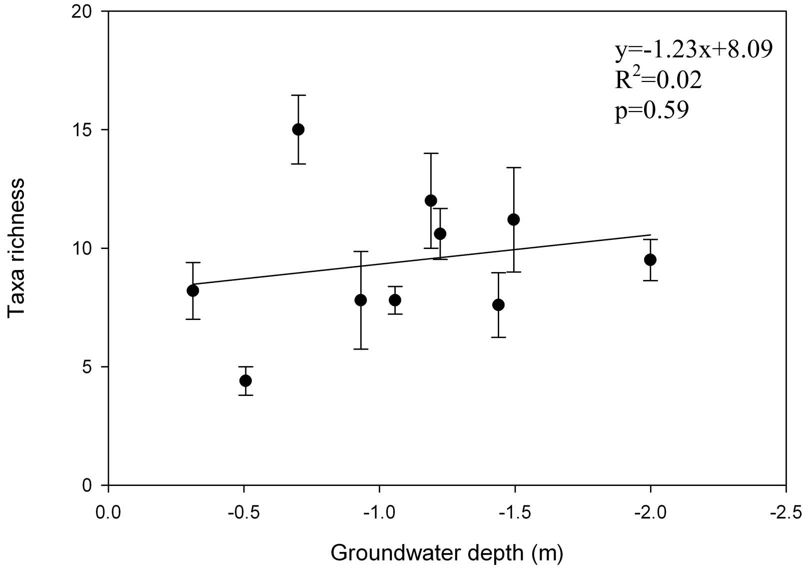

Figure 10: Linear regression relationship between shrub richness and mean groundwater depth

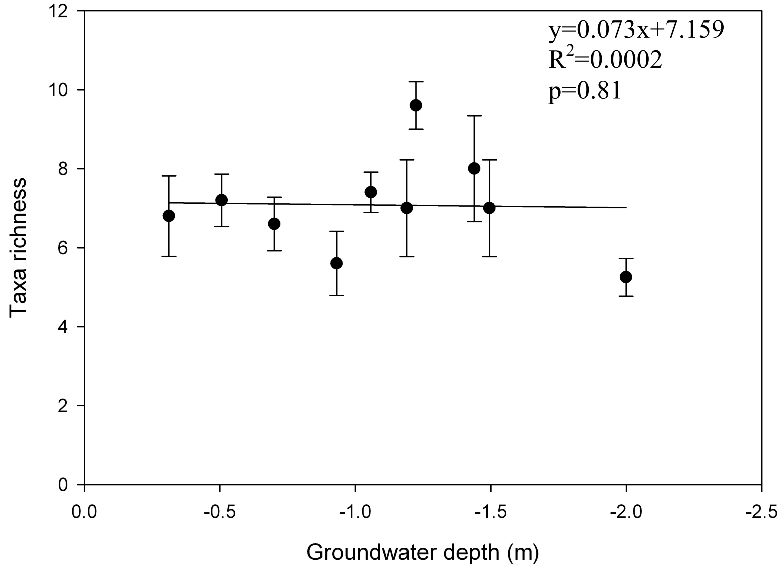

Figure 11: Linear regression relationship between overstory richness and mean groundwater depth

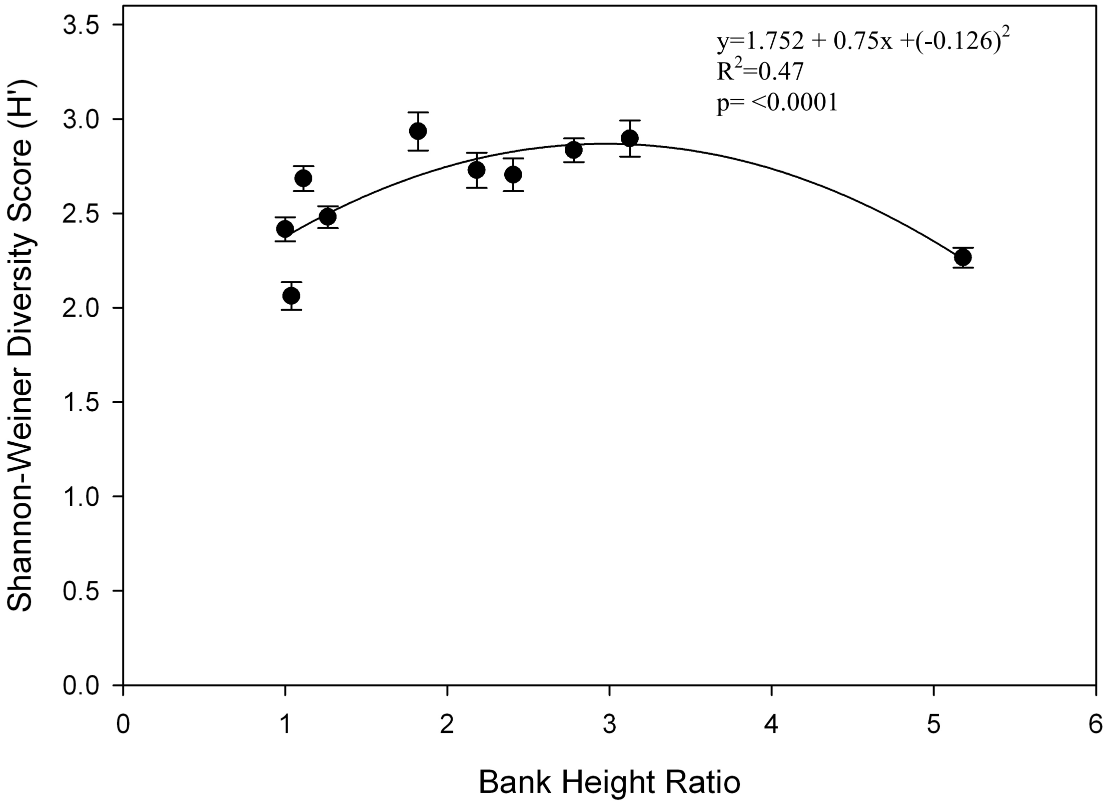

Figure 12: Quadratic regression relationship between Shannon-Weiner diversity scores of ground flora/herbaceous layers and Bank Height Ratio.

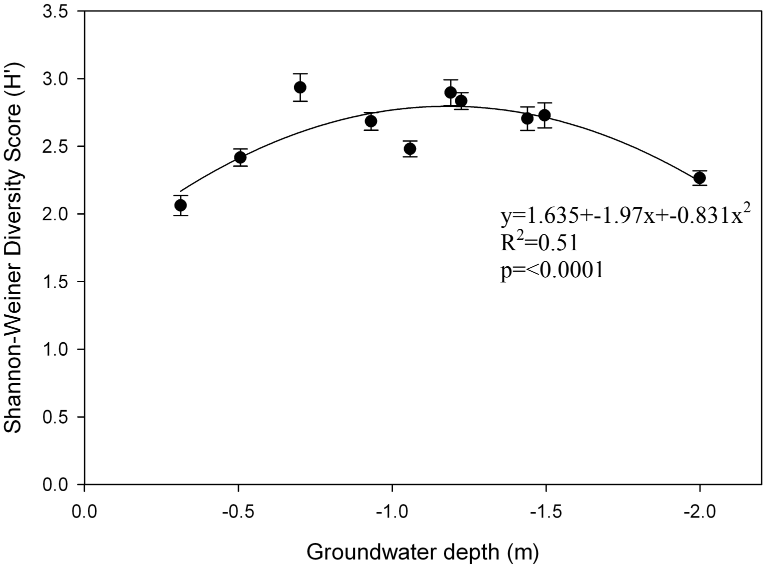

Figure 13: Quadratic regression relationship between Shannon-Weiner diversity scores of ground flora/herbaceous layers and mean groundwater depth.

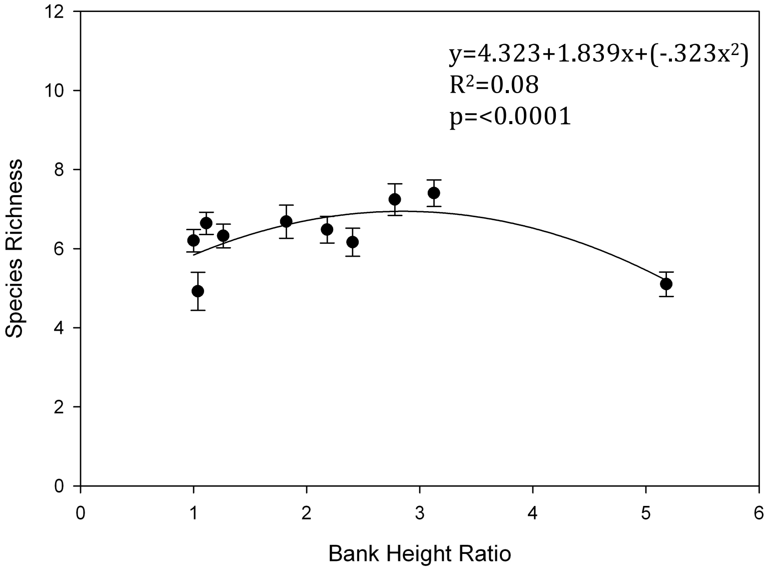

Figure 14: Quadratic regression relationship between species richness of the ground flora/herbaceous layer and Bank Height Ratio.

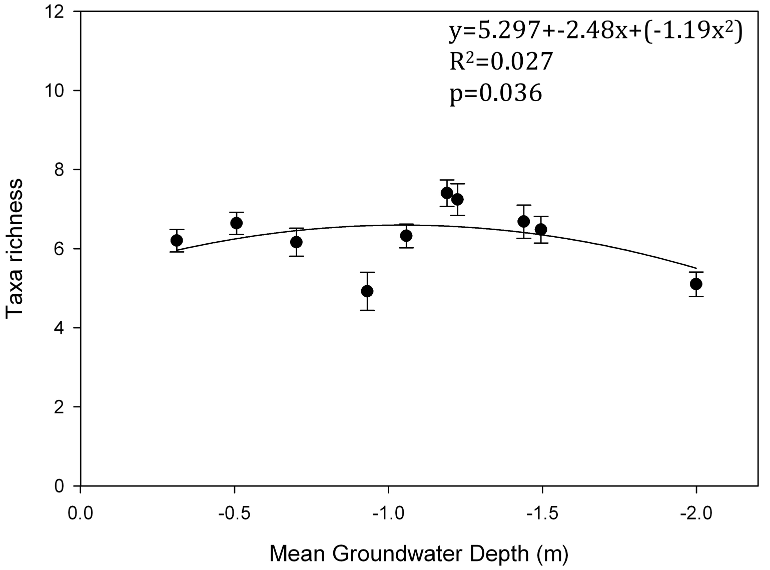

Figure 15: Quadratic regression relationship between species richness of the ground flora/herbaceous layer and mean groundwater depth.

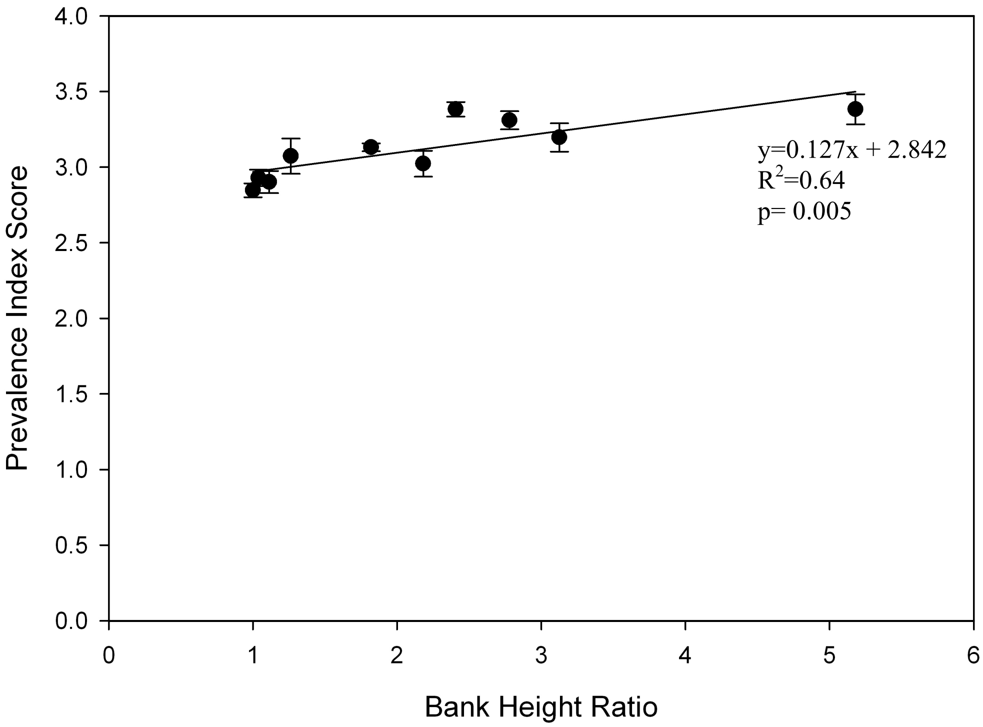

Figure 16: Significant linear regression relationship between herbaceous/ground flora Prevalence Index scores and Bank Height Ratio.

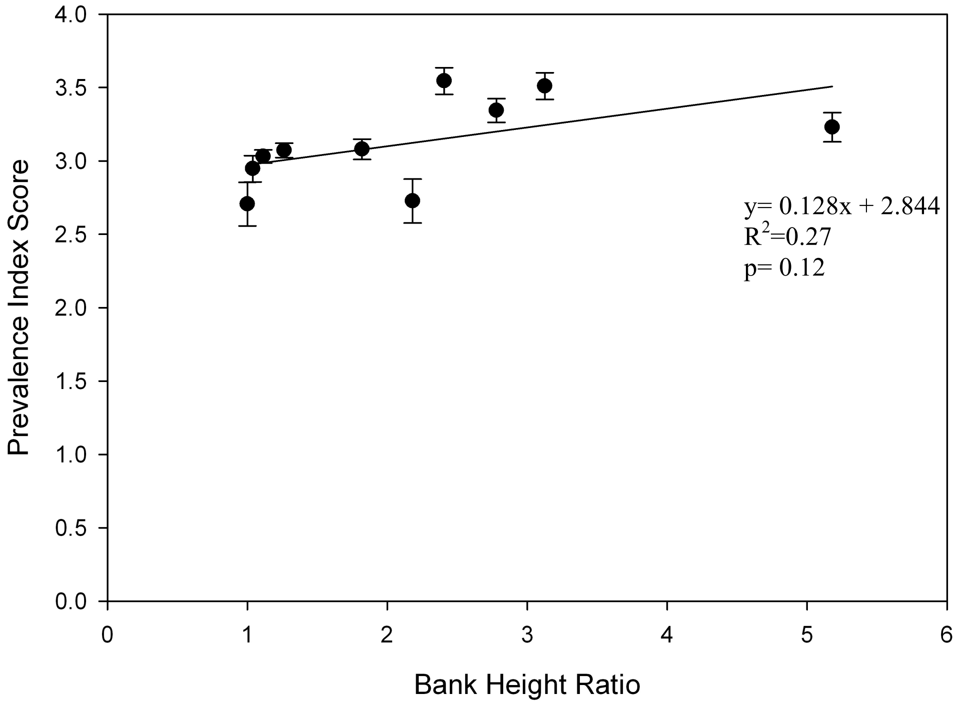

Figure 17: Linear regression relationship between shrub Prevalence Index scores and Bank Height Ratio.

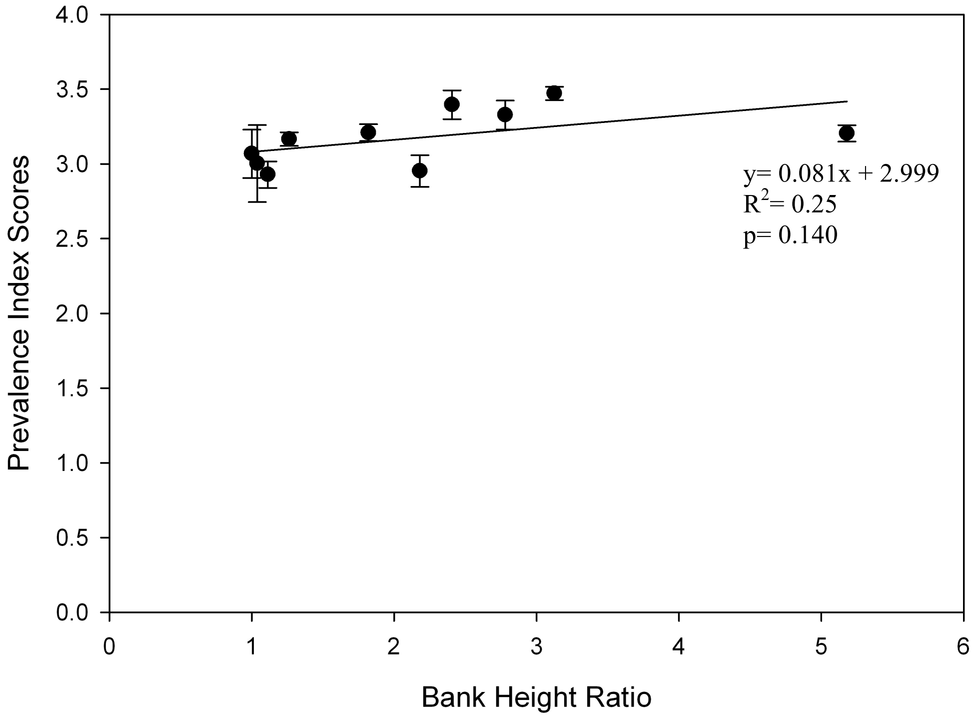

Figure 18: Linear regression relationship between canopy-level Prevalence Index scores and Bank Height Ratio.

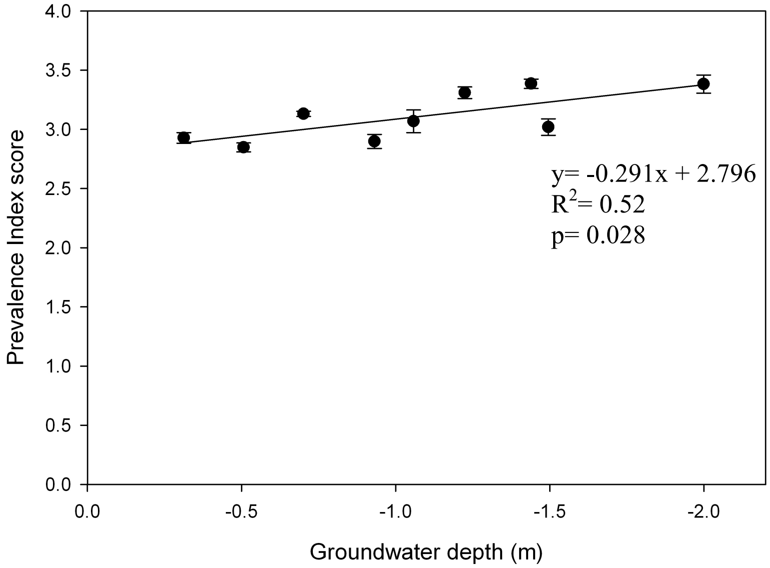

Figure 19: Significant linear regression relationship between herbaceous/ground flora Prevalence Index scores and mean annual groundwater depth

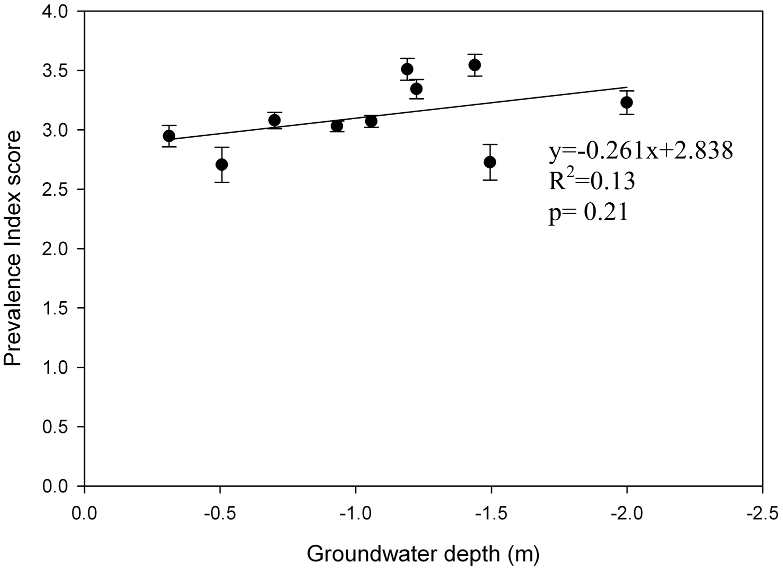

Figure 20: Linear regression relationship between shrub Prevalence Index scores and mean groundwater depth.

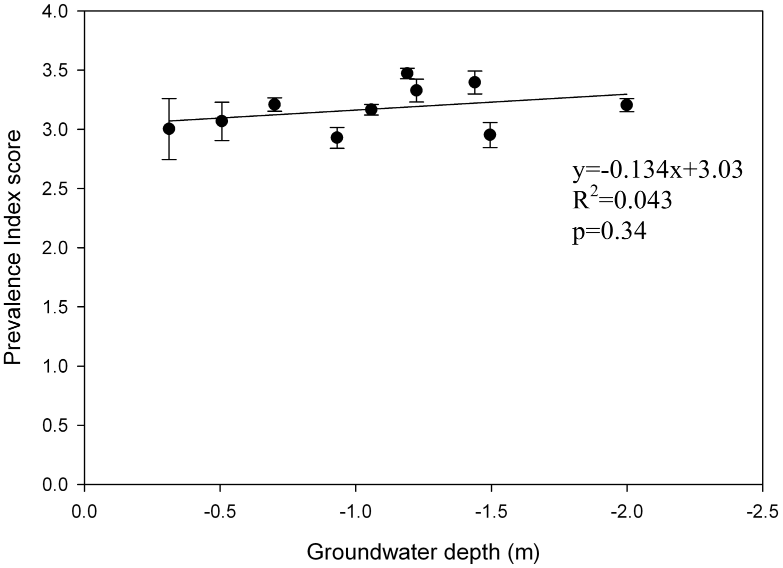

Figure 21: Linear regression relationship between overstory Prevalence Index scores and mean groundwater depth.

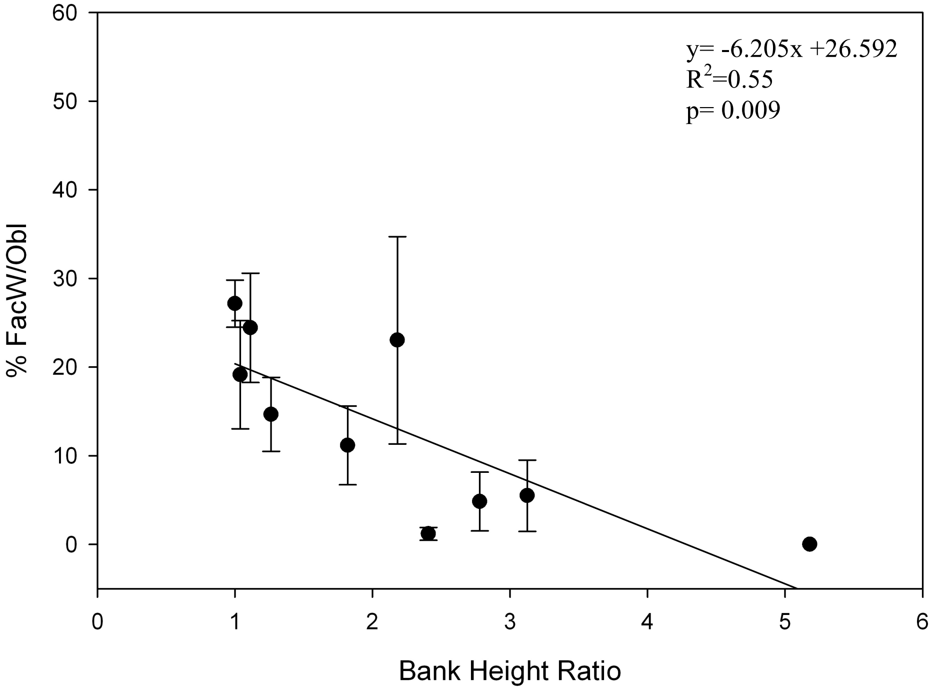

Figure 22: Significant linear regression relationship between percent Facultative Wet (FACW) / Obligate (OBL) flora of the herbaceous layer and Bank Height Ratio

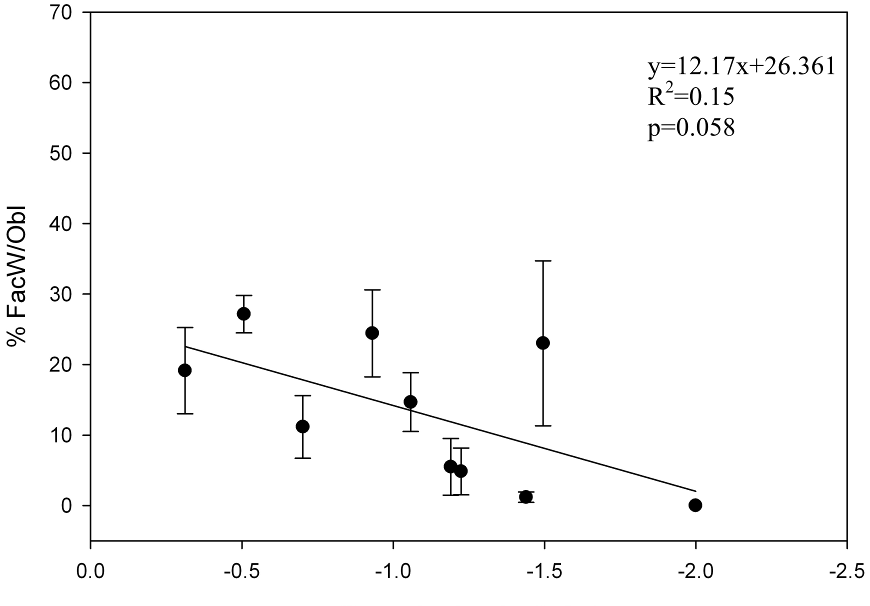

Figure 23: Linear regression relationship between percent Facultative Wet (FACW) / Obligate (OBL) species of the ground flora/herbaceous layer and mean groundwater depth

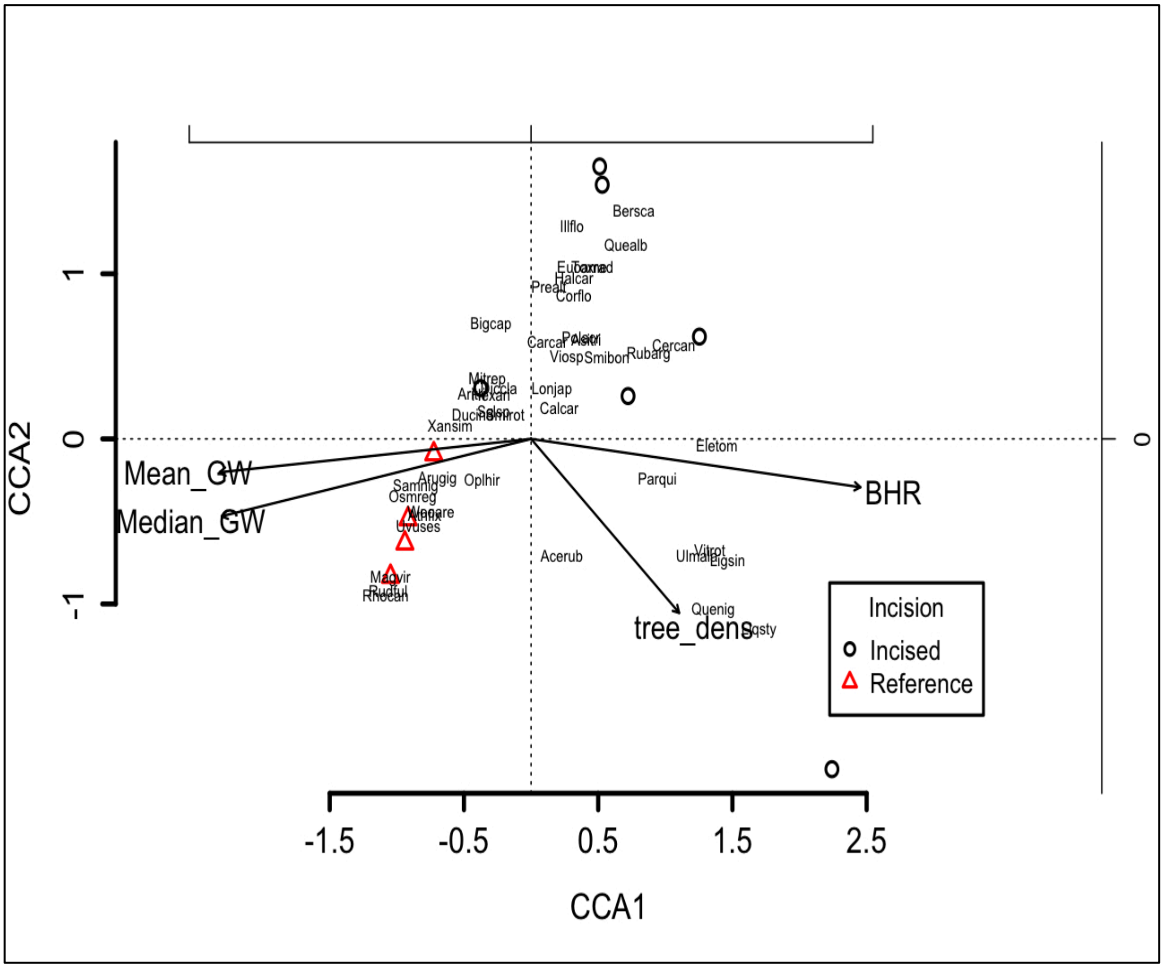

Figure 24: Canonical correspondence analysis (CCA) plot of herbaceous/ground flora species importance values and environmental variables (Mean groundwater depth, median groundwater depth, BHR, and tree stem density). Vectors on plot represent statistically significant drivers of ground flora species composition. See Table 6 for species codes

Table 1: Hydrologic and geomorphologic characteristics of study sites. Values in parentheses indicate standard deviation

Watershed	BHR	Watershed area (km^2)	Mean GW depth (m)	Median GW depth (m)
Rotton	1.00	2.59	0.51±0.003	0.51 (0.05)
Loombeam	1.04	1.27	0.31±0.006	0.33 (0.11)
Pile	1.11	6.09	0.93±0.008	0.98 (0.15)
Osburn	1.27	7.51	1.06±0.009	1.10 (0.16)
Little MS	1.81	7.10	0.70±0.011	0.80 (0.21)
Steams	2.18	4.22	1.50±0.013	1.62 (0.25)
Mitchell	2.41	5.00	1.44±0.012	1.57 (0.23)
Bird	2.78	1.89	1.22±0.011	1.29 (0.20)
UT Coon	3.13	0.60	1.19±0.09	1.34 (0.33)
Forest Eco	5.18	0.31	2.00±0.016	1.98 (0.29)

Table 2: Herbaceous/ground flora species with three highest importance values among 10 floodplain sites of the Alabama Piedmont; species listed in order of descending IV_{200} score

Watershed	Species	Importance value	Wetland indicator category
Rotton	*Athyrium filix-femina*	50.38	FAC
	Arundinaria gigantea	34.93	FACW
	Scleria sp.	25.14	FAC
Loombeam	*Athyrium filix-femina*	95.75	FAC
	Woodwardia areolata	29.41	FACW
	Arundinaria gigantea	10.25	FACW
Pile	*Arundinaria gigantea*	43.82	FACW
	Athyrium filix-femina	36.89	FAC
	Lonicera japonica	15.01	FAC
Osburn	*Athyrium filix-femina*	52.14	FAC
	Arundinaria gigantea	48.66	FACW
	Duchesnea indica	14.84	FACU
Little MS	*Scleria sp.*	26.52	FAC
	Athyrium filix-femina	25.84	FAC
	Michella repens	17.43	FACU
Steams	*Illiceum floridanum*	49.13	FACW
	Toxicodendron radicans	19.71	FAC
	Viola sp.	17.41	FAC
Mitchell	*Panicum sp.*	56.81	FAC
	Dicanthelium clandestinum	14.84	FAC
	Smilax bona-nox	14.66	FACU
Bird	*Scleria sp.*	23.19	FAC
	Parthenocissus quinquefolia	21.21	FACU
	Viola sp.	20.57	FAC
UT Coon	*Toxicodendron radicans*	39.62	FAC
	Acer saccharum	19.58	FACU
	Polystichum acrostichoides	18.71	FACU
Forest Eco	*Quercus nigra*	47.88	FACU
	Vitis rotundifolia	35.43	FAC
	Parthenocissus quinquefolia	20.08	FACU

Table 3: Shannon-Weiner diversity scores (H') and taxa richness of herbaceous/ground-flora data across 10 study sites. Overstory and midstory richness data also shown. Values are means followed by standard error. Sites listed in order of increasing BHR.

Watershed	H'	Herbaceous richness	Shrub richness	Tree richness
Rotton	2.42±0.06	6.20±0.28	8.20±1.20	6.80±1.02
Loombeam	2.06±0.07	4.92±0.48	7.80±2.06	5.60±0.81
Pile	2.68±0.07	6.64±0.28	4.40±0.60	7.20±0.66
Osburn	2.48±0.06	6.32±0.30	7.80±0.58	7.40±0.51
Little MS	2.93±0.10	6.68±0.42	7.60±1.36	8.00±1.34
Steams	2.73±0.09	6.48±0.34	11.20±2.20	7.00±1.22
Mitchell	2.70±0.09	6.16±0.35	15.00±1.45	6.60±0.68
Bird	2.83±0.06	7.24±0.40	10.60±1.08	9.60±0.60
UT Coon	2.90±0.10	7.40±0.34	12.00±2.0	7.00±1.22
Forest Eco	2.27±0.05	5.10±0.31	9.50±0.87	5.25±0.48

Table 4: Results of linear regression analysis between environmental variables (Bank Height Ratio, mean annual groundwater depth) and taxa richness, prevalence indices, and diversity. Quadratic regression was used to determine significance of association between diversity scores (H') and independent variables

	Independent variable	Forest layer	R^2	P-value
Richness	BHR	Ground flora	<0.01	0.80
		Midstory	0.20	0.19
		Overstory	0.04	0.57
	Mean GW depth	Ground flora	<0.01	0.71
		Midstory	0.02	0.59
		Overstory	<0.01	0.81
Prevalence Indices	BHR	Ground flora	0.64	0.005**
		Midstory	0.27	0.12
		Overstory	0.25	0.14
	Mean GW depth	Ground flora	0.52	0.03*
		Midstory	0.13	0.21
		Overstory	0.04	0.34
Diversity	BHR	Ground flora	0.47	<0.0001**
	Mean GW depth		0.51	<0.0001**

** Results of regression analysis significant at P<0.01

*Results of regression analysis significant at P<0.05

Table 5: Prevalence index (PI) scores of ground flora, shrub, and canopy layers across 10 study sites. Sites listed in order of increasing BHR.

Watershed	Herbaceous PI score	Shrub PI score	Canopy PI score
Rotton	2.86±0.05	2.71±0.15	3.07±0.16
Loombeam	2.92±0.05	2.95±0.09	3.00±0.26
Pile	2.88±0.07	3.03±0.04	2.93±0.09
Osburn	3.05±0.10	3.07±0.05	3.17±0.05
Little MS	3.13±0.02	3.08±0.07	3.21±0.06
Steams	3.00±0.08	2.73±0.15	2.95±0.11
Mitchell	3.40±0.04	3.54±0.09	3.40±0.10
Bird	3.31±0.05	3.34±0.08	3.33±0.10
UT Coon	3.21±0.08	3.51±0.09	3.47±0.04
Forest Eco	3.38±0.10	3.23±0.10	3.20±0.06

Table 6: Results of canonical correspondence analysis (CCA) of herbaceous/ground flora species composition as related to key hydrologic and environmental variables.

	CCA1	CCA2	CCA3	CCA4
Eigenvalue	0.5386	0.3546	0.2572	0.1769
Proportion explained (%) of species-environment relation	40.58	26.71	19.38	13.33
	ANOVA permutation test for CCA (reduced model)			
Environmental variable	Chi^2	*F*-statistic	P-value	
BHR	0.5158	3.905	0.005**	
Mean GW depth	0.2205	1.6691	0.06	
Stem density	0.2581	1.9535	0.05*	
Median GW depth	0.333	2.5206	0.005**	

**Environmental variable significant predictor of species distribution at P<0.01
*Environmental variable significant predictor of species distribution at P<0.05

Table 7: Herbaceous/ground flora species found at 10 floodplain sites of the AL Piedmont. Species codes used in CCA plot.

Species name	Species code	Wetland indicator
Acer rubrum	Acerub	FAC
Arisaema triphyllum	Aritri	FACW
Arundinaria gigantea	Arugig	FACW
Asimina triloba	Asitri	FAC
Athyrium filix-femina	Athfix	FAC
Berchemia scandens	Bersca	FACW
Bignonia capreolata	Bigcap	FAC
Callicarpa americana	Calame	FACU
Carpinus caroliniana	Carcar	FAC
Cercis canadensis	Cercan	FACU
Cornus florida	Corflo	FACU
Dicanthelium clandestinum	Diccla	FAC
Duchesnea indica	Ducind	FACU
Elephantopus tomentosa	Eletom	FACU
Euonymus americanus	Euoame	FAC
Halesia carolina	Halcar	FAC
Hexastylis arifolia	Hexari	FAC
Illiceum floridanum	Illflo	FACW
Ligustrum sinense	Ligsin	FACU
Liquidambar styraciflua	Liqsty	FAC
Lonicera japonica	Lonjap	FAC
Magnolia virginiana	Magvir	FACW
Mitchella repens	Mitrep	FACU
Oplismenus hirtellus	Oplhir	FACU
Osmunda regalis	Osmreg	OBL
Parthenocissus quinquefolia	Parqui	FACU
Polystichum acrostichoides	Polacr	FACU
Prenanthes altissima	Prealt	FACU
Quercus alba	Quealb	FACU
Quercus nigra	Quenig	FAC
Rhodendron canescens	Rhocan	FACW
Rubus argutus	Rubarg	FACU
Rudbeckia fulgida	Rudful	FAC
Sambucus nigra	Samnig	FACW
Scleria sp.	Sclsp	FAC
Smilax bona-nox	Smibon	FACU
Smilax rotundifolia	Smirot	FAC
Toxicodendron radicans	Toxrad	FAC
Ulmus alata	Ulmala	FACU
Uvularia sessifolia	Uvuses	FAC
Viola sp.	Viosp	FAC
Vitis rotundifolia	Vitrot	FAC
Woodwardia areolata	Wooare	FACW
Xanthorhiza simplicissima	Xansim	FACW

Ch. III Upland erosion and channel incision effects on Alabama Piedmont floodplain soils

Abstract

Erosion resulting from past land use in cultivated uplands of the Alabama Piedmont has contributed to variable stream conditions throughout the region, with high degrees of channel incision often typifying degraded riparian corridors. The purpose of this study was to determine the degree to which the aggradation of erosional material that inundated the region's streams and floodplains has affected soil properties of incised sites compared to non-incised, reference sites. Three headwater streams representative of each treatment type (reference and incised) were selected. Stream channel incision was described using bank height ratio (BHR), defined as the ratio of bankfull depth to stream bank height. Incision of reference streams ranged from 1.0-1.3; BHR of incised streams ranged from 2.4-5.2. Shallow groundwater wells were installed at all study sites to examine the effect of channel incision upon floodplain water tables. Soils were sampled from the following depths: 0-5 cm, 0-15 cm, 15-30 cm, 30-45 cm. Soil organic carbon (SOC), percent nitrogen (%N), and bulk density (BD) were analyzed to determine edaphic differences between stream type. Significant differences in SOC, %N, and BD were observed between stream types, with increased amounts of SOC and %N, 58% and 39%, respectively, found at reference sites. In addition, groundwater levels of the reference sites were significantly greater relative to incised sites ($p<0.0001$). The results of this study suggest that alluviation and subsequent channel incision has altered floodplain soil characteristics in the AL Piedmont, potentially limiting the ability of these soils to sequester C in the upper 45 cm.

Introduction

Floodplains and riparian zones act as sinks for nutrients, sediment, and carbon (C) in fluvial environments (Naiman et al. 2010). In addition, riparian areas are often centers of biodiversity in the environment, while also serving to buffer aquatic systems from overland and groundwater pollution (Verry et al. 2000, Gold et al. 2001). Soil organic carbon (SOC) in riparian zones originates from vegetation, allocthonous C inputs from overbank flows, and reduced breakdown of C due to saturated soil conditions (Naiman et al. 2010). Channel incision has resulted in alterations to groundwater dynamics and flood regimes of headwater streams of the Alabama Piedmont. These changes, coupled with the aggradation of upland soils over the former floodplain surface, may lead to discernible changes in riparian soil conditions. The degree to which channel alterations in the Alabama Piedmont have affected floodplain soils and SOC levels is not known, although significant differences in these edaphic characteristics are probable.

Soil organic carbon (SOC) in riparian zones may exist in large quantities relative to upland settings due to saturated soil conditions that promote retention of subsurface carbon (Mitch and Gosselink 2007). Although the distribution and extent of SOC in riparian settings is highly variable, vegetation is the primary driver of soil organic carbon relative to water, climate, and soil factors (Van Cleve and Powers 1995). Vegetation affects SOC levels via species-specific litter and root carbon content; subsurface incorporation of SOC is dependent upon litter type (leaves, woody debris, flowers) and primary productivity (Van Cleve and Powers 1995). Studies of SOC dynamics in disturbed and reference floodplains at the Savannah River Site (GA) have shown that forest successional status is a primary determinant of SOC in riparian zones (Giese et al. 2000; Wigginton et al. 2000; Giese et al. 2003). Retention of SOC in riparian areas has also been attributed to land use history (Craft and Casey 2000).

The variable nature of water-table levels in incised floodplains results in pedogenic processes and soil development atypical of natural floodplain settings. Groffman et al. (2003) observed that floodplain soils in incised streams often exhibit relic redoximorphic features at shallower depths than the current seasonal high water table, suggesting declines in riparian groundwater levels. Soil horizons in incised floodplains may be characterized by buried surface horizons and topsoil representative of recent erosional material (Nakamura et al. 2000; Groffman et al. 2003; Ritchie and McCarty 2003, Gomez et al. 2004, Schilling et al. 2009). Gold et al. (2001) reported higher nitrate (NO_3^-) levels in riparian soils of incised streams and less likely to undergo denitrification than soils of forested, unimpacted riparian areas. Numerous studies have shown that riparian soils sequester C at rates greater than upland soils, in part due to increased primary production and the tendency of these areas to behave as sinks for overland flow (Ritchie and McCarty 2001, Ritchie et al. 2003). Recent studies of floodplain soils subject to historic anthropogenic disturbance indicate that incised streams may serve as carbon and sediment sinks (Ricker et al. 2012) but C-enriched subsurface horizons may reduce SOC in stream flow and the hyporheic zone (Stofleth et al. 2004, Blazejewski et al. 2009). Soil profiles at incised stream sites exhibit C and N concentrations that vary with depth depending on the soil horizon, but overall trends of decreasing N and C with depth are often observed (Ritchie et al. 2003, Schilling et al. 2009). An examination of SOC stores in reference and incised streams of Mississippi showed a significant difference between percent C among the treatment types; carbon stocks of the upper 10 cm also decreased as degree of incision increased (Stofleth et al. 2004).

Piedmont Land Use History

Descriptions of the Alabama Piedmont prior to colonial settlement describe a landscape populated by late-successional forests, "clear, salubrious streams flowing over stone" and "rich" bottomland soils (Harper 1943). These descriptions, from early European explorers such as William Bartram, indicate that riparian areas and fluvial systems of the Alabama Piedmont were largely devoid of overland sediment deposition prior to European expansion.

Row-crop agriculture, specifically the cultivation of cotton, was the dominant land use in the Alabama Piedmont during the 19th and 20th centuries. The heyday of row crop cultivation, referred to as the Cotton Era (ca. 1860-1920), was characterized by vast amounts of soil loss throughout the southern Piedmont; modern estimates of topsoil loss in the Alabama Piedmont range from 15-18 cm (Happ 1945, Trimble 2008). Erosional material from cultivated uplands accumulated in the streams and riparian corridors of the Piedmont region, resulting in high-degrees of stream degradation and geomorphic channel alterations in headwater and low-order streams (Bennett 1931, Happ 1945, Ruhlman and Nutter 1999, Trimble 2008). Land use changes after the Great Depression led to the conversion of large swaths of arable land to secondary succession, residential development, and timberlands (Cowell 1995). The shift in land use away from intensive row crop cultivation led to a gradual reduction in the alluvial material entering the region's waterways, therefore allowing these systems to equilibrate to the current sediment regime (Trimble 2008). Consequently, these processes of channel equilibration led to incision, channel enlargement, and decreased overbank flooding in low-order streams of the Southern Piedmont (Ruhlman and Nutter 1999).

A host of studies have demonstrated the impacts of anthropogenic disturbance upon riparian SOC, however a relative dearth of research exists on the effects of channel incision upon floodplain soils and SOC stocks relative to unimpacted sites. In addition, there is a paucity of data regarding carbon levels in floodplain soils of the Southeastern Piedmont; the degree to which alluvial deposition and channel incision have affected riparian SOC is unknown. The purpose of this study was to assess floodplain soils of the Alabama Piedmont in order to determine the extent to which channel morphology and historic alluviation have altered edaphic conditions, specifically SOC, soil nitrogen (N), and bulk density (BD).

Site Description

This study was conducted in the Piedmont region of Alabama, an area comprised of 12 counties in the East-Central portion of the state. The Alabama Piedmont represents the southwestern terminus of the Piedmont ecoregion, a 100-160 km wide physiographic province that extends from Alabama to southern New York (USDA-NRCS, 2006). Mean annual precipitation ranges from 110-150 cm and mean annual temperatures range from 12 to 18° C (USDA-NRCS 2006). Floodplain soils of the Alabama Piedmont are comprised of alluvium and local colluvium derived from metamorphic rocks (Golden 1979). Representative soils of Piedmont floodplains include the Toccoa (coarse-loamy, mixed, active, nonacid, thermic Typic Udifluvent), Chewacla (fine-loamy, mixed, active, thermic Fluvaquentic Dystrudept), and Cartecay (coarse-loamy, mixed, semiactive, nonacid, thermic Aquic Udifluvent) series (USDA-NRCS 2013). Happ (1945) characterized the alluvium in modern Piedmont floodplains as brown to reddish-brown, similar to topsoil in upland environments and often overlaying the former soil surface.

Six headwater streams with varied degrees of channel incision were selected for this study (Figure 25). Watershed land cover was largely consistent across all sites with low impervious surface cover and dominant land use best characterized as a matrix of secondary growth hardwood forests, pine plantations, and pasture. Catchment size ranged from 0.31 to 7.51 km^2 (Table 8). Stream sites had minimal invasive, exotic species, unconstrained valleys, and negligible upstream alterations. Floodplain width was a primary determinant of site suitability, as adequate distance between valley walls and transect placement was critical to reduce confounding interactions between study sites and hillslope groundwater seeps.

Methods

At each site, 3 transects perpendicular to stream flow were established along representative sections of the floodplain. Soil samples were collected at depth intervals of 0-5, 0-15, 15-30, and 30-45 cm at 4 locations per transect. Sampling sites at each transect were established at 5 m intervals beginning at edge of stream bank, with the farthest sample taken 15 m from bank edge. Samples were taken in accordance with the core method, as outlined by Blake and Hartge (1986). Soil samples were air dried, mixed to a uniform consistency and passed through a 2-mm sieve. Samples were ground with a mortar and pestle prior to analysis via dry combustion. Samples were analyzed for C and N by LECO TruSpec CN analyzer (Leco Corp, St. Joseph, MI). Total C (g/m^2) and percent N (%N) of each sample was determined using bulk density values (g/cm^3) and concentration values derived from results of dry combustion.

Groundwater monitoring wells were installed 10 m from the floodplain-stream boundary at 3 sites along each stream site. Well depth varied among sites (0.63-2.1 m), with maximum depth dependent on water table height and depth to bedrock. Maximum well depth for most sites was 20-30 cm below water table elevation at time of installation. Wells were constructed from 10.16 cm diameter slotted PVC pipe encased in geotechnical fabric. Pressure transducers (Solinst Levelogger Gold) were placed in one well per site to provide a continuous log of groundwater levels over the study period; loggers recorded water level every 15 minutes. Transducers were placed in well sites most representative of overall geomorphic condition of stream site. Average daily precipitation values for each study site were obtained from NOAA-operated NEXRAD weather radar (SCONC 2013).

Bank height ratio was used to determine the degree of channel incision at all study sites. Bank height ratio (BHR) is a geomorphological diagnostic tool that utilizes bank full depth and bank height to quantify channel incision in a fluvial system (Rosgen 1996). Bank height ratio was assessed at all stream sites using the following protocol:

1.)Determine most stable upstream riffle

2.)Measure depth from thalweg to bankfull (D_{max})

3.)Measure depth from thalweg to top of bank (D_{TOB})

4.) Divide D_{TOB}/D_{MAX}

In severely incised streams a field determination of bankfull depth is often unreliable, therefore a consistent measure of D_{max} was unattainable in 2 of the incised sites. A regional curve developed by Helms et al. showing D_{max} plotted against watershed size was used to generate a function for predicting bankfull (2013) (Figure 26). This method was used to determine BHR at 2 highly incised study sites (Forest Eco and Bird creeks). Bank height ratio was used to make determination of treatment type for stream site. Sites with BHR less than 1.5 were classified as reference; sites with BHR greater than 1.5 were classified as incised (Rosgen 2001). Watershed boundaries were delineated using ArcGis 10.0 (ESRI 2009).

Vegetation Measurements

In order to determine the level of herbaceous vegetative cover present at the study sites, sampling of ground flora vegetation and gound flora and canopy/shrub strata was conducted. Vegetation data was collected after leaf out in May and June of 2012. Five transects were placed at intervals of 50 m along a 250m stream segment. At each study site, three of the five vegetative transects were later used for delineation of soil sampling locations. Transects were established perpendicular to stream flow, with dimensions of 5 X 20 m (0.01 ha^2). All stems greater than 2.5 cm at diameter at breast height (dbh) were counted, identified to the species level, and measured for dbh; these measures were used to assess basal area (BA) of canopy species at each study site.

Herbaceous and woody species < 1m in height were classified as ground flora. Percent cover and species composition of ground flora were assessed using 1 m^2 quadrats placed at 5-m intervals in the 0.01 ha transects; each quadrat was placed equidistant from transect margin, and the final quadrat in the transect straddled the terminal transect boundary. A total of 25 herbaceous/ ground flora surveys were conducted at each site using the 1 m^2 quadrats (150 across all sites). Percent cover class was estimated visually using the Braun-Bouquet-scale, in which a cover percentage is assigned to individual species based on logarithmic scale: 1: 0-2%, 2: 3-10%, 3: 11-25%, 4: 26-50%, 5: 51-100% (Causton, 1988).

Statistics

Data were compiled with Microsoft Excel (Microsoft Corporation 2008). R 2.15.2 software (R Development Core Team 2012) was the primary statistical software used for analysis. The Shapiro-Wilk test for normality was utilized to test for linear assumptions with log transformations required for comparison of samples from the 0-5 cm depth. Comparisons between treatments were made by pooling sample data among depths. Linear regressions were performed to determine level of association between bulk density and total SOC in the 0-5 sampling depth.. Statistical significance for all tests was set at $\alpha=0.05$. SigmaPlot version 11.0 (Systat Software)was used to generate graphs and figures.

Results

Groundwater hydrology and channel morphology

Bank height ratios varied among study sites and ranged from 1.00 at the least incised, reference-type streams to 5.17 at the most incised study site (Table 8). Groundwater depths varied throughout the study period (March 2012-March 2013) and among study sites (Figure 27). Rainfall data, calculated as mean precipitation of the 6 study sites for the yearlong study period, was 94.35 ± 2.62 cm. This value is lower than the 30-year average of 134.26 cm for Wadley, AL, a municipality centrally located in the AL Piedmont (NCDC, 2013). Groundwater levels of the reference sites were significantly lower than those of the incised sites for the duration of the study period ($p<0.0001$).

Floodplain vegetation

A comparison of basal areas (m^2/ha) between treatments does not indicate a significant difference between floodplain status, although BA of reference sites is less variable (33.97-46.01 m^2/ha) than those of the incised floodplains (12.05-49.53 m^2/ha) (Table 9). Percent cover of herbaceous/ground flora vegetation was significantly greater at reference sites ($p = 0.0001$).

Physical and chemical soil properties

The results of this study indicate significant differences between reference and incised streams across a spectrum of edaphic conditions. Total SOC (kg/m^2) varied among sites and between treatment types (Figures 28a-28d, Table 10). At each study site, SOC levels were highest in the 0-5 cm depth increment (Figure 29), with mean values of 1.84±0.06 for the reference sites and 2.10±0.13 for the incised sites. Comparisons of SOC concentrations of the 0-5 cm depths show little variation between treatment type; however, the proportion of total SOC in the reference group was greater relative to the incised streams. Mean TOC pooled across all sample depths was 9.22 ± .13 kg/m^2 and 5.83±.15 kg/m^2 for reference and treatment sites, respectively. Although SOC levels in the surface stratum (0-5 cm) of the treatment types did not significantly differ, significant differences in SOC were observed among the remaining sample depths and when samples were pooled across all depths ($p < 0.0001$) (Figure 29). Across all sites, total SOC decreased with depth (Figure 29).

Bulk density (BD) also varied among sites and between treatment groups (Figures 30a-30d). The lowest BD values across all sites were found in the upper sampling depths (0-5 cm, 0-15 cm), with BD generally increasing with depth (Figure 31). Mean BD of the 0-5 cm depth of reference sites was 0.939±0.03 and BD increased to 1.278±0.04 in the deepest sampling depths (30-45 cm). Bulk density of the uppermost sampling depth (0-5 cm) at the incised sites had a mean value of 1.151±0.017, with an increase to 1.434±0.028 at the deepest sampling depths (30-45 cm). T-tests indicated that BD values of incised floodplain soils were significantly greater across all depths than those of reference sites (p=6.94e-16) (Figure 31).

Percent N across the treatment types and among individual sites was variable (Figures 32a-32d), but the general distribution of these values was similar to distribution to SOC (Figure 33). Like SOC, there was no significant difference between the amounts of soil N in the 0-5 cm depths among treatment types (p=0.085). However, significant differences were observed between treatments among the remaining sample depths and when SON values were pooled across all depths (Figure 33) ($p<0.0001$).

Regression analysis of bulk density in relation to total C values was performed on both treatments for the 0-5 sampling depth (Figures 34-35). Results indicate a significant, but weak, negative relationship between BD and total C for the reference sites (p=0.0005, R^2=0.169); no significant relationship was observed for the incised sites (p=0.235, R^2=0.033).

Discussion

The results of this study suggest significant differences between reference and incised floodplain soils of the Alabama Piedmont, specifically bulk density, percent N, and TOC. The observed shift in edaphic conditions is attributed to the combined effects of altered floodplain hydrology due to incision and the accumulation of eroded upland soils over former stable surfaces. Ground water data indicate significant differences in water table elevation and variability between reference and incised sites (Table 11). Over the course of the study period (March 2012-March 2013), ground water levels in reference floodplains of the AL Piedmont was commonly shallower than 1-m (32.4-100% of the data record within 1 m). In contrast, incised floodplains showed relatively few instances of water table depth within 1-m (0.17-14.39% of study period). In addition, the incised sites were found to have essentially zero instances of ground water above 0.5 m from the floodplain surface (0.01-0.00%); these data indicate that soil samples taken from the sampling extent (0-45 cm) are representative of an aerobic soil system largely devoid of long-term saturation, anearobicity, and reducing conditions. As expected, the least incised sites (Loombean and Rotton) exhibiting the highest ground water depths (Figure 27) and greatest proportion of the study period with water levels above 0.5 m (Table 10). These data mirror similar studies that have examined groundwater levels in incised floodplains (Schilling et al. 2004, Hardison et al. 2009), suggesting that incision due to historic soil erosion leads to significant changes in the hydrology of degraded Piedmont riparian zones.

Bulk Density

Bulk density values were slightly lower than those observed in upland Piedmont soils (Metz 1954, Gent et al. 1983, Franzleubbers et al. 2000) No studies evaluating BD of Piedmont floodplain soils are presently known. As expected, BD values were lowest in the upper 5 cm of the sampling depths, with significant differences between treatments observed ($p<0.0001$). Bulk density is directly tied to SOM (Fisher and Binkley 2000), therefore a decline in BD with depth is expected. The increased proportions of TOC and percent N in the reference floodplains soils are indicative of greater amounts of SOM, therefore it is likely that increased organic matter is a contributing factor to the observed differences in BD between treatments. The influence of upland-derived sands and clastic materials upon the floodplains of incised streams cannot be discounted, however; Jolley et al. (2010) observed significant increases in bulk density in riparian areas impacted by high sedimentation rates. A similar study of wetland soils found that sediment accretion resulted in decreased OM and increased BD of near-surface horizons (Koning 2004). The increased BD of soils in the upper 45 cm of incised floodplain soils is therefore likely a product of decreased SOM and alluviation of accumulated clastic materials derived from uplands.

Total organic carbon (TOC)

The significant differences between TOC and percent N of reference and incised floodplains (p values of 3.384e-06 and1.693e-06, respectively) indicate that hydrology and recent deposition of material are important drivers of edaphic conditions in the AL Piedmont. The results of this study parallel those of similar research which show that C and N stocks are greatest at the surface and tend to decrease with depth (Craft and Casey 2000, Jobbágy and Jackson 2000, Ritchie and McCarty 2001, Stofleth et al. 2004). The lack of a significant difference in pooled TOC values between treatments of the 0-5 cm sample depth suggest that primary production rates of the floodplain forests are similar, as these values largely reflect surficial inputs of organic matter from vegetation (Fisher and Binkley 2000). Allocthonous OM inputs on disconnected floodplains have been shown to be reduced due to incision (Amoros and Bornette 2002, Noe and Hupp 2005, Steiger et al. 2005, Kroes and Hupp 2010), therefore TOC of the 0-5 cm sample depths were expected to be higher in the reference soils. Significantly greater TOC was observed in reference soils relative to incised soils as sampling depth increased ($p<0.0001$)

indicating that periodic saturation, flood frequency, and soil texture may be driving organic C distribution in subsurface riparian systems. Comparable studies have shown that soil particle size is a significant determinant of SOC in riparian systems. Morozova and Smith (2003) found that the organic content of floodplain soils is related to amount of alluvial material, and a negative correlation between soil particle size and SOC was observed. As noted in previous examinations of the Southern Piedmont, upper layers of floodplain soils are often composed of erosional material from degraded uplands, the main components of which are sand-sized particles (Happ 1944, Hoover 1949, Jacobson and Coleman 1986, Trimble 2008). Jacobson and Coleman (1986) observed that modern Piedmont floodplains have an abundance of sand and gravel in riparian sediments due to the migration of streams in riparian corridors and subsequent reworking of stored sediments, leading to the removal of fine grained particles and the accretion of sands and gravels. Thus, particle size differences between reference and degraded Piedmont bottomlands may be driving the observed differences in TOC and organic N. Anecdotal examination of soil texture between treatments points to greater proportions of sands in the upper 45 cm of incised floodplain soils.

A study of incised streams in Mississippi found that the concentration of total C was significantly associated with riparian canopy density and extent of channel incision (Stofleth et al. 2004). In addition, considerably higher amounts of TOC were found in non-incised riparian sites relative to sites exhibiting significant channel entrenchment; the authors concluded that the significance of canopy density to TOC was due to the inputs of organic matter under higher degrees of tree cover and diminished vegetation in floodplains characterized by channel degradation (Stofleth et al. 2004). Higher levels of

TOC were observed in reference floodplain soils, suggesting that SOM may persist longer in the subsurface of these systems relative to incised sites (Table 9). In addition, the extent of herbaceous flora at reference sites, coupled with the prevalence of hydrophytic species of this forest stratum, is likely a product of groundwater proximity near the floodplain surface.

Soil Nitrogen (% N)

Percent N distribution in the floodplain subsurface mirrored that of TOC. Nitrogen content of the upper sampling depth (0-5 cm) was not significantly different between treatments (p= 0.085), a similar result to TOC from the same depths. The close correspondence between the distribution of SOC and N suggests that N of these floodplain soils originates primarily from organic matter, likely N-rich organic residues (Brady and Weil 2008). The observed differences in percent N between reference and incised riparian soils serve to reiterate the disparity in SOM among the treatment types. A comparable examination of soils from the riparian zone of a low-order stream in Maryland also showed similar distribution of C and N by depth (Ritchie and McCarty 2003). In their examination of riverine wetlands in China, Bai et al. (2005) also found that organic N distribution in wetland soils was similar to that of SOM.

Carbon storage in Piedmont floodplains

Recent scholarship on carbon dynamics of floodplain systems has focused on the ability of these systems to sequester C after significant periods of alluviation. Studies have shown that riparian zones may accumulate C stocks if sediment aggradation has led to the burial of coarse woody debris, carbon lenses, or relic A horizons (Blazejewski et al. 2005, Blazejewski et al. 2009, Ricker et al. 2012). The results of this study do not demonstrate that incised floodplain sites, characterized by the deposition of alluvial material over former soil surfaces, contain higher amounts of TOC relative to undisturbed floodplains. Mean TOC for the reference sites was 9.22 ± .13 kg/m^2; mean TOC of the reference sites was considerably lower (5.83±.15 kg/m^2). This finding is likely attributable to the sampling depths chosen for this study, as the lower limit of sampling (45 cm) may not have reached buried A horizons in the incised soil profiles. As this study has demonstrated, increased alluviation may not lead to retention of SOC throughout the solum. In their study of floodplain dynamics of a blackwater Coastal Plain stream, Kroes and Hupp (2010) found that decreases in floodplain groundwater levels due to incision led to reductions in saturated soil conditions and therefore increased decomposition of riparian SOM; reduced OM inputs in disconnected riparian reaches were also observed.

Examinations of Piedmont fluvial systems have demonstrated that channel incision has led to significant reductions in overbank flooding events in low-order and headwater systems (Costa 1975, Jacobson and Coleman 1986, Ruhlman and Nutter 1999). Reduced allocthonous inputs of OM on Piedmont floodplains are a likely consequence of alterations to the flood regime of these systems. Blazejewski et al. (2009) also found that geomorphology, particularly floodplain width and watershed size, were significant drivers of SOC distribution in floodplain alluvium.

The ability of incised floodplain soils to sequester C may also be limited by soil texture. As mentioned previously, a negative correlation between particle size and SOC retention has been observed in a number of studies (Fisher and Binkley 2000). In an examination of SOC in riparian soils of New Zealand, Gomez et al. (2004) found that the supply of inorganic, large particles (sands and gravels) had a significant, negative relationship to SOC of floodplain soils. In riparian sites in the Southern Piedmont now characterized by channel incision, a mantle of sandy alluvial material often overlies the former surface horizon (Happ 1945, Hoover 1950, Jacobson and Coleman 1986). Therefore, the capacity of floodplain soils of the Alabama Piedmont to sequester C in the upper 45 cm may be reduced in areas characterized by large-scale deposition of erosional sediments.

Conclusions

Historic soil loss in cultivated uplands has resulted in significant alterations to floodplains of the AL Piedmont. At floodplain sites characterized by channel incision, soil bulk density, percent N, and SOC were significantly different than soils of reference, non-incised riparian sites. Pooled TOC and organic N were greater in reference soils (58% and 39%, respectively) relative to incised soils, indicating that alterations to floodplain hydrogeomorphology are likely the principal drivers of edaphic gradients in these systems. In addition, reduced overbank flooding due to channel entrenchment may be altering the delivery of allocthonous OM from upstream sources. Results of this study suggest that floodplain soils largely free from the aggradation of legacy sediments and channel degradation are better suited to sequester C in the upper 45 cm of the solum than those sites characterized by severe alluviation, although additional examination of incised sites is needed to determine C stocks at greater depths. Continued study of floodplain systems of the AL Piedmont would allow for further understanding of the impact of past and current land use on the region’s fluvial systems.

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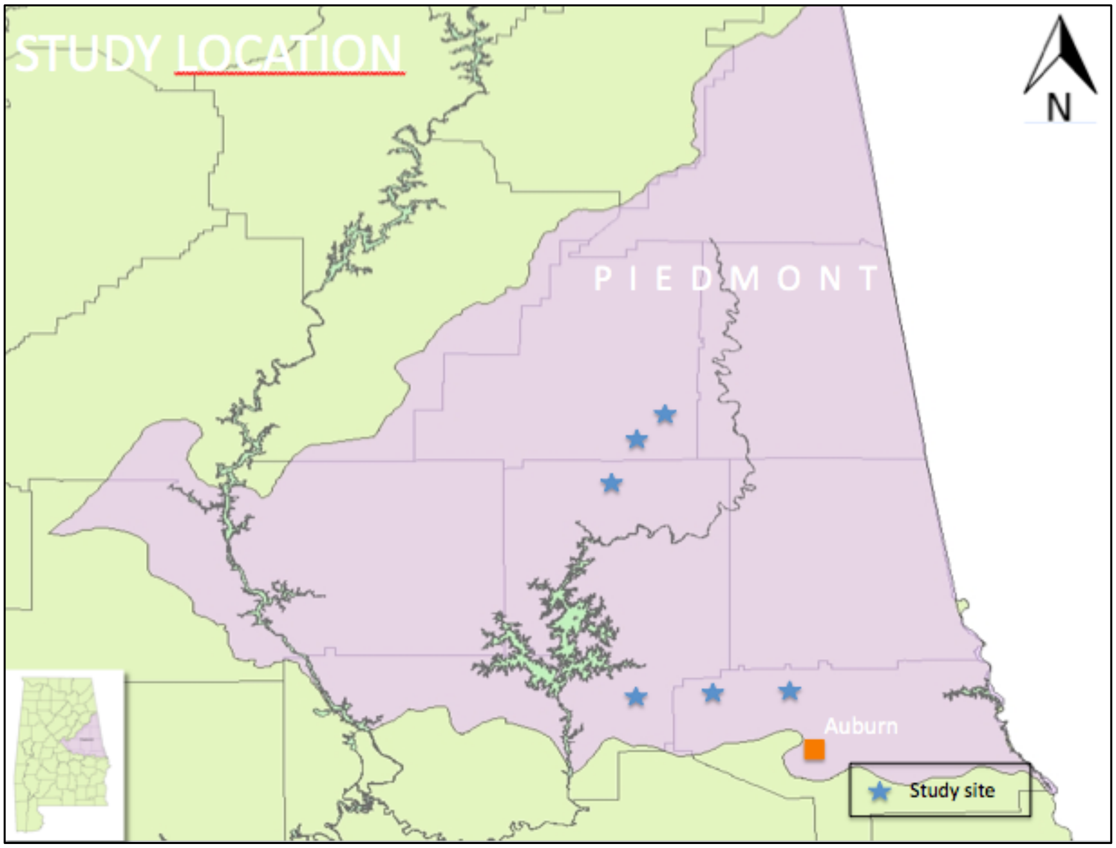

Figure 25: Location of 6 study sites in the Alabama Piedmont, USA.

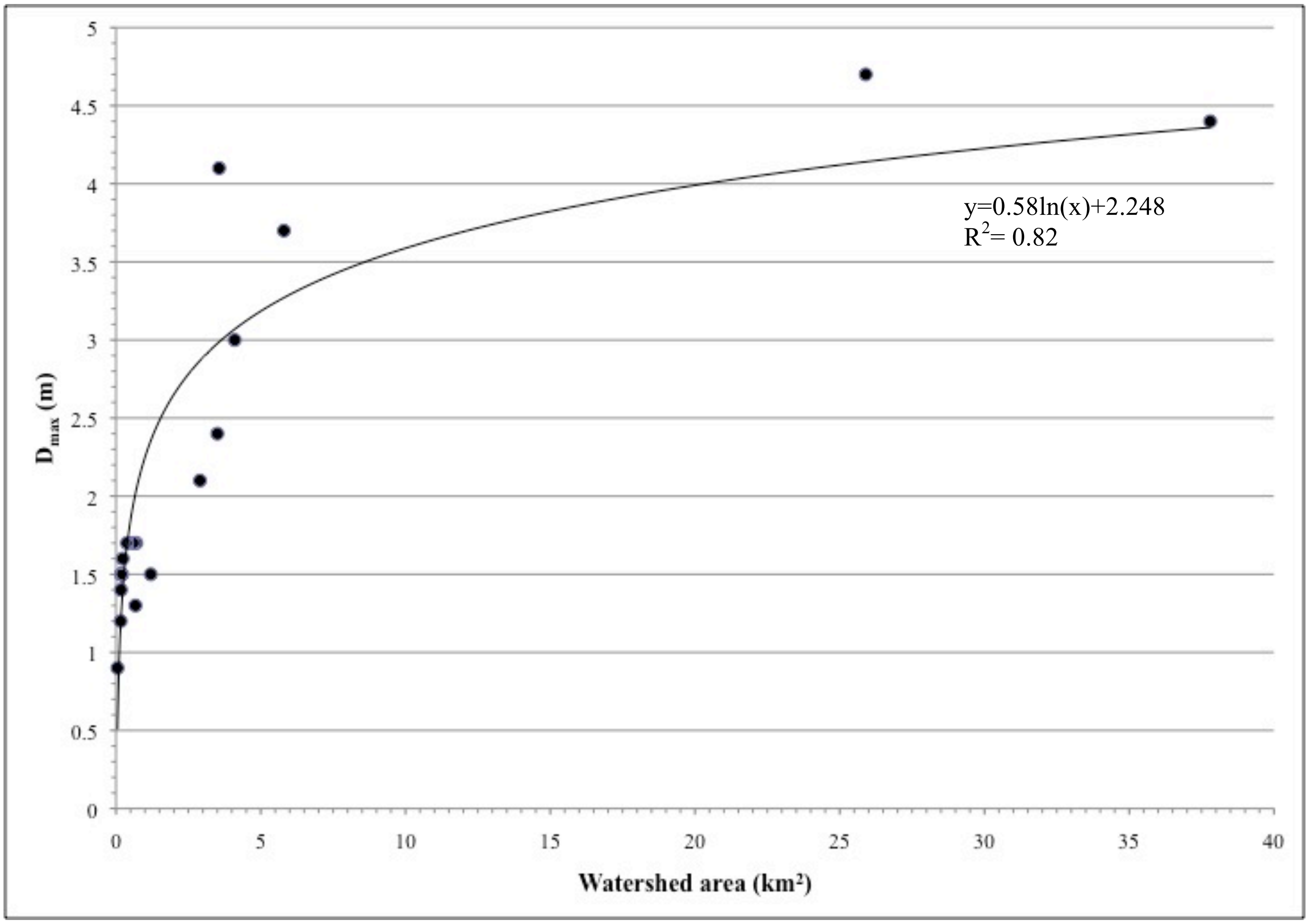

Figure 26: Maximum depth from thalweg to bankfull (D_{max}) in relation to watershed area. Data were collected at 15 reference stream sites in the Alabama Piedmont.

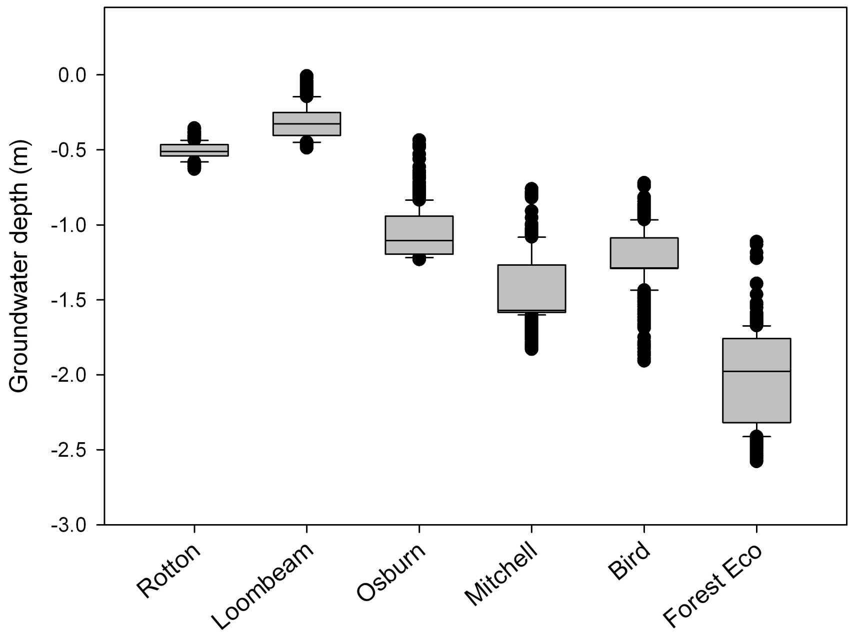

Figure 27: Mean groundwater depth among study sites for 1-year study period (March 2012-March 2013); data presented in order of increasing Bank Height Ratio.

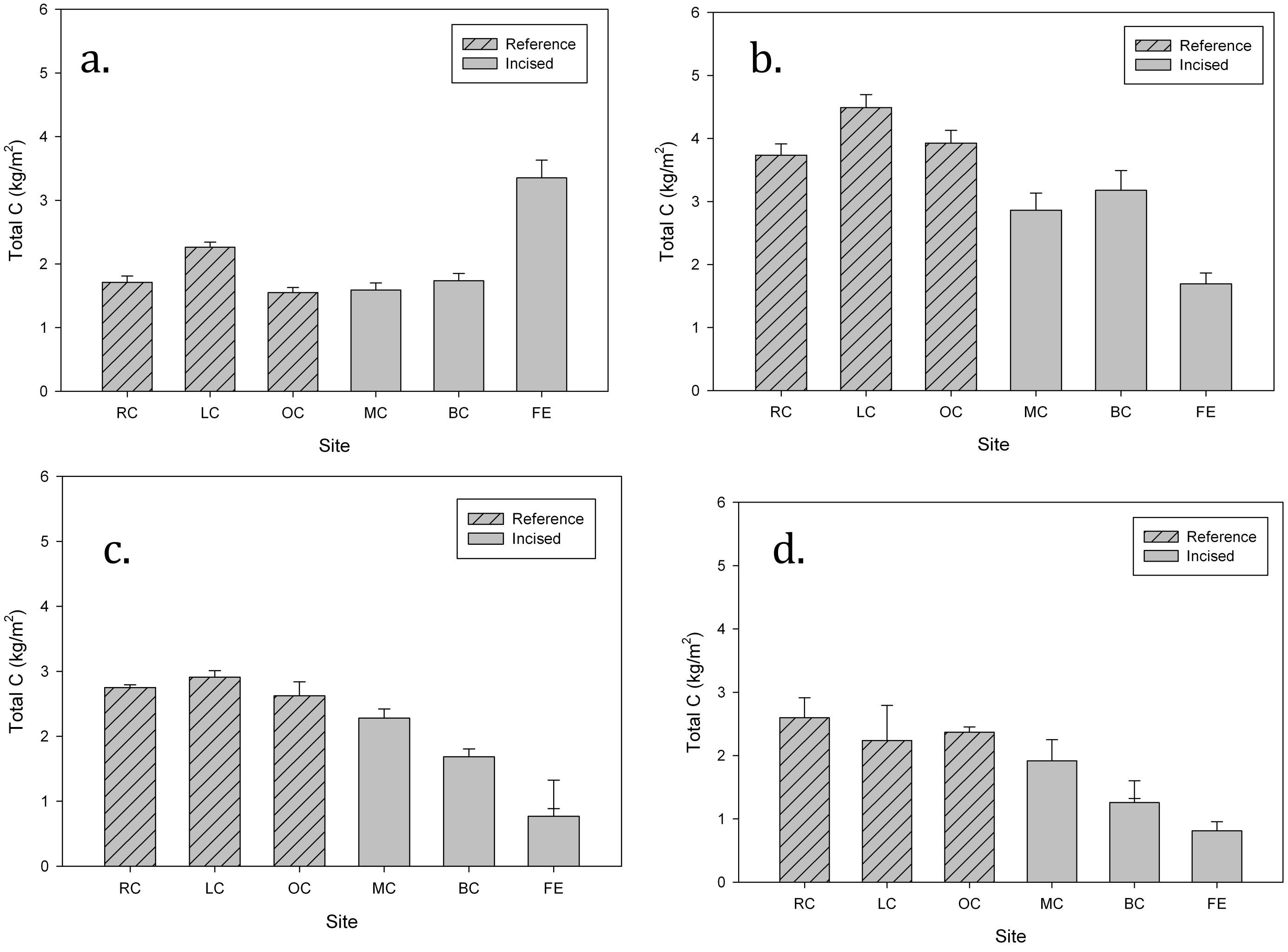

Figure 28: Total soil organic carbon (SOC) for reference and treatment sites for the following sample depths: 0-5 cm (a.); 0-15 cm (b.); 15-30 cm (c.); 30-45 cm (d.)

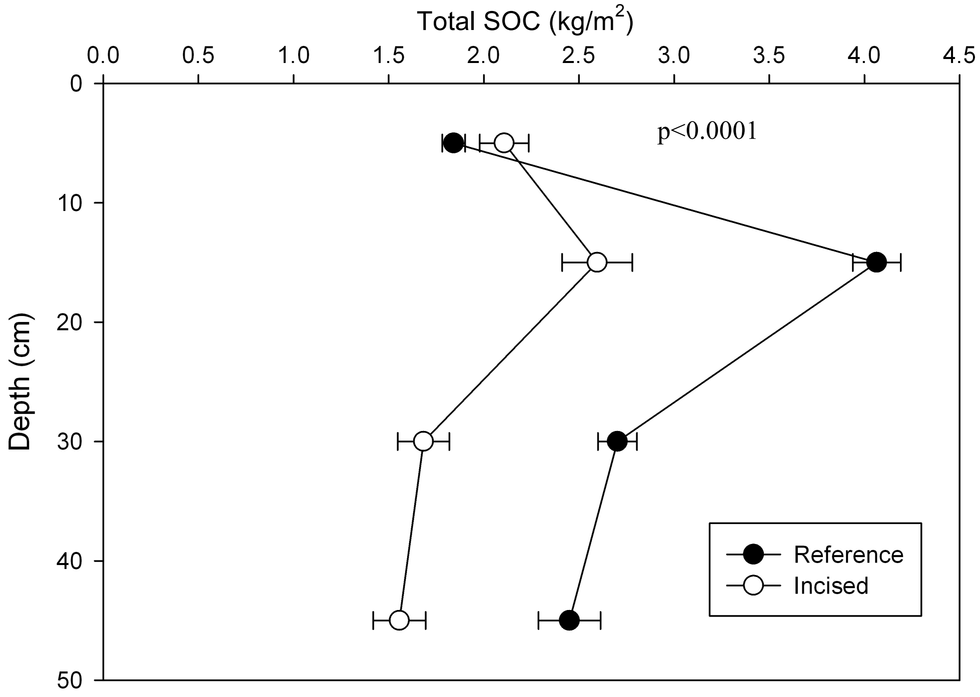

Figure 29: Total soil organic carbon (SOC) (kg/m^2) at 4 sampling depths for reference and incised floodplain soils of the AL Piedmont

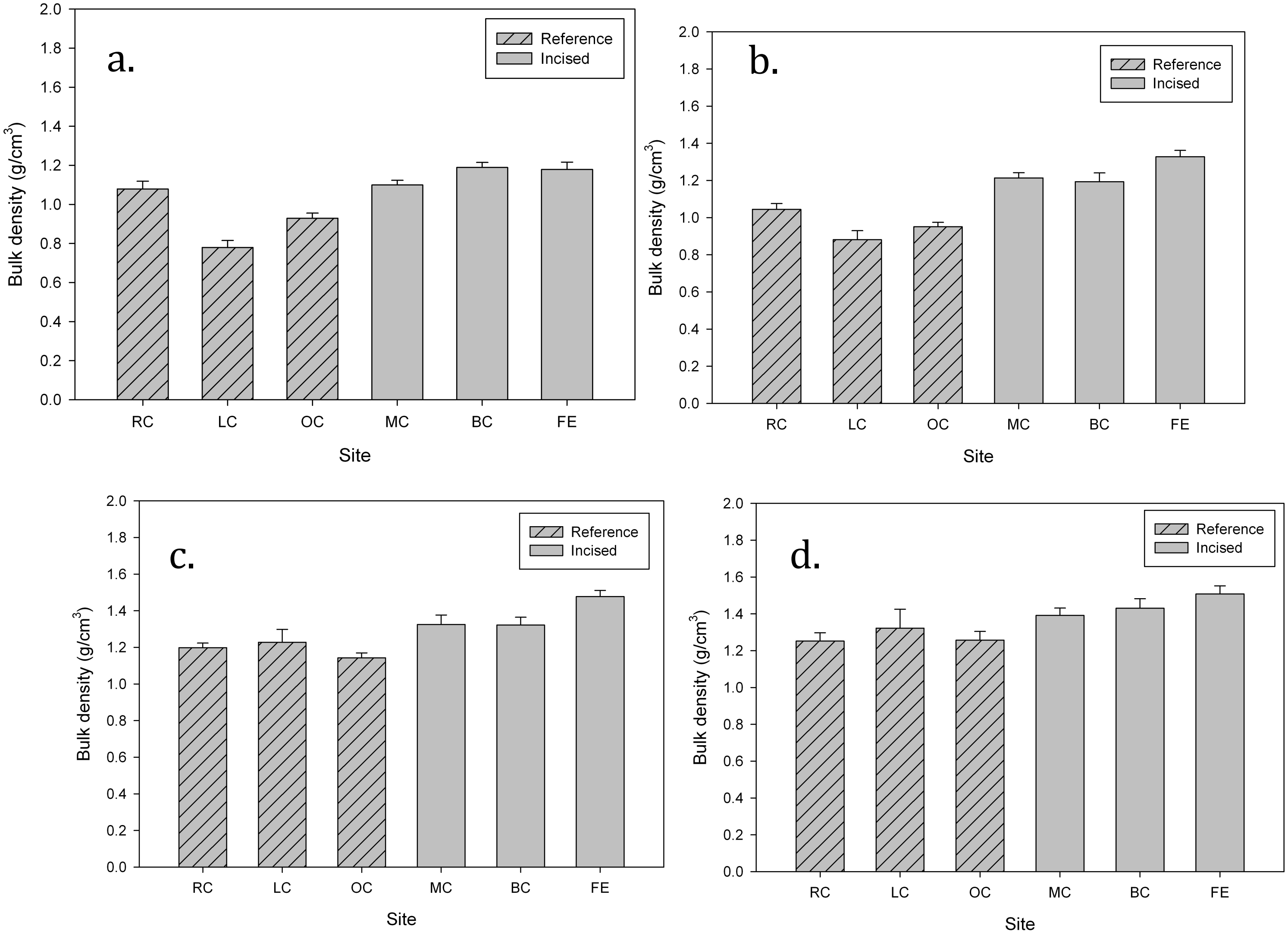

Figure 30: Bulk density (BD) (g/cm^3) for reference and treatment sites for the following sample depths: 0-5 cm (a.); 0-15 cm (b.); 15-30 cm (c.); 30-45 cm (d.)

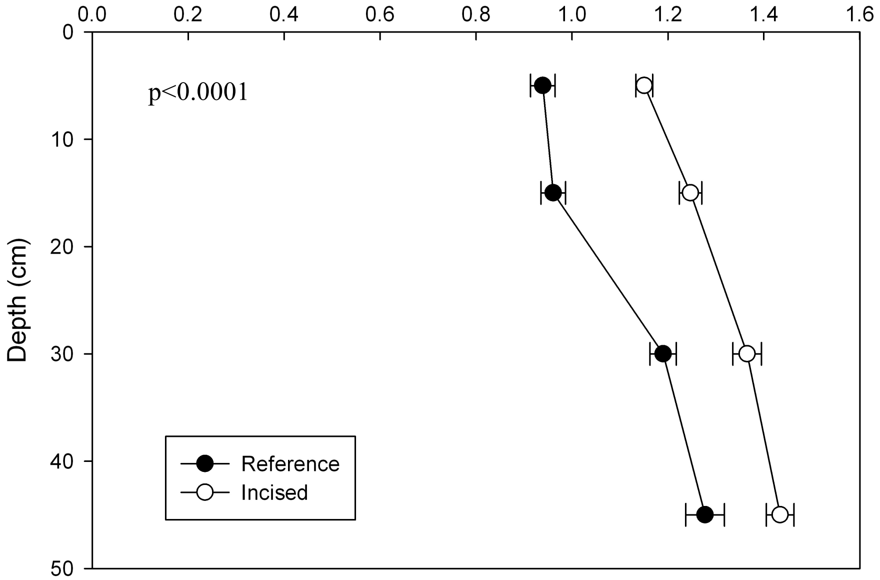

Figure 31: Bulk density (BD) (g/cm^3) at 4 sampling depths for reference and incised floodplain soils of the AL Piedmont

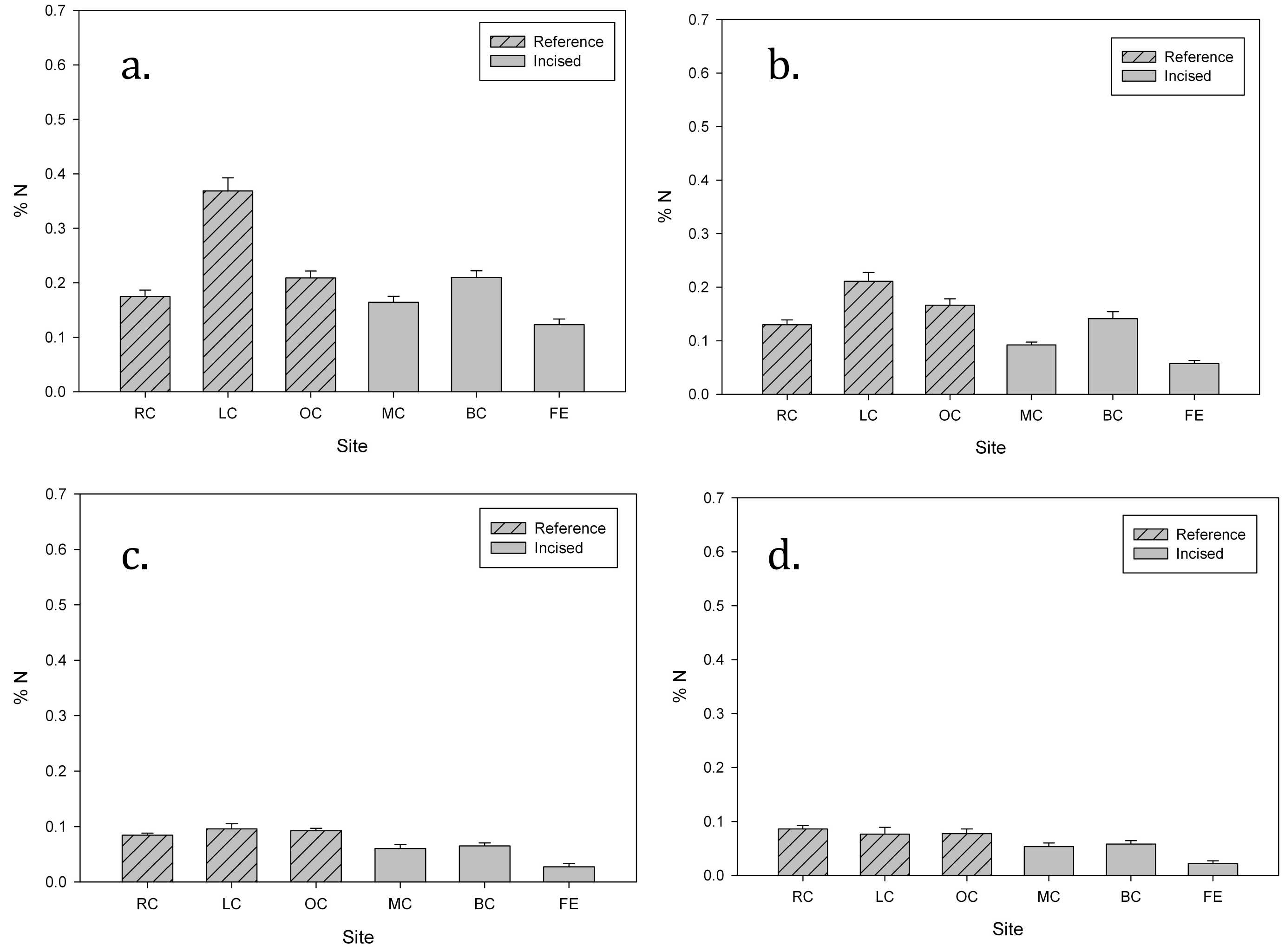

Figure 32: Percent nitrogen (N) for reference and treatment sites for the following sample depths: 0-5 cm (a.); 0-15 cm (b.); 15-30 cm (c.); 30-45 cm (d.)

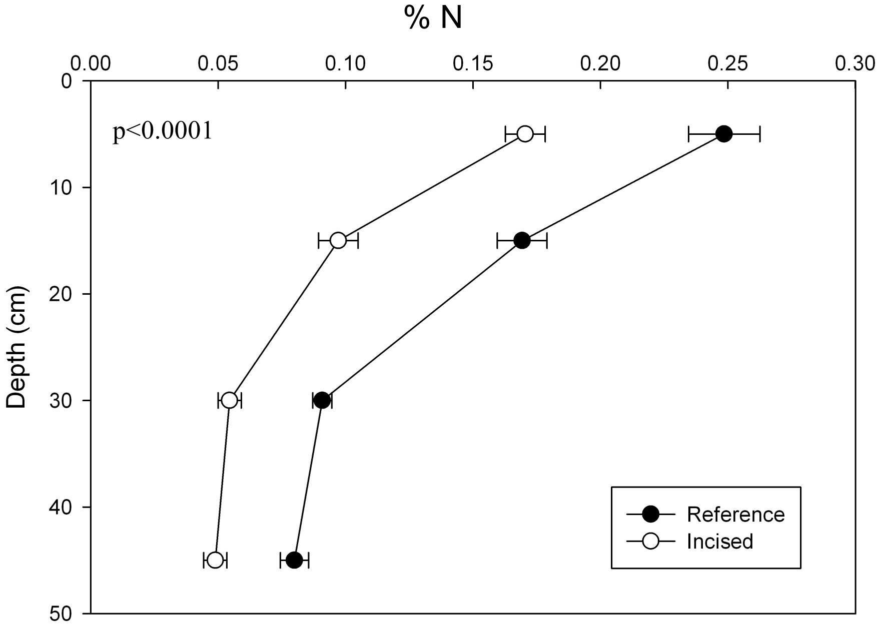

Figure 33: Percent nitrogen (N) at 4 sampling depths for reference and incised floodplain soils of the AL Piedmont

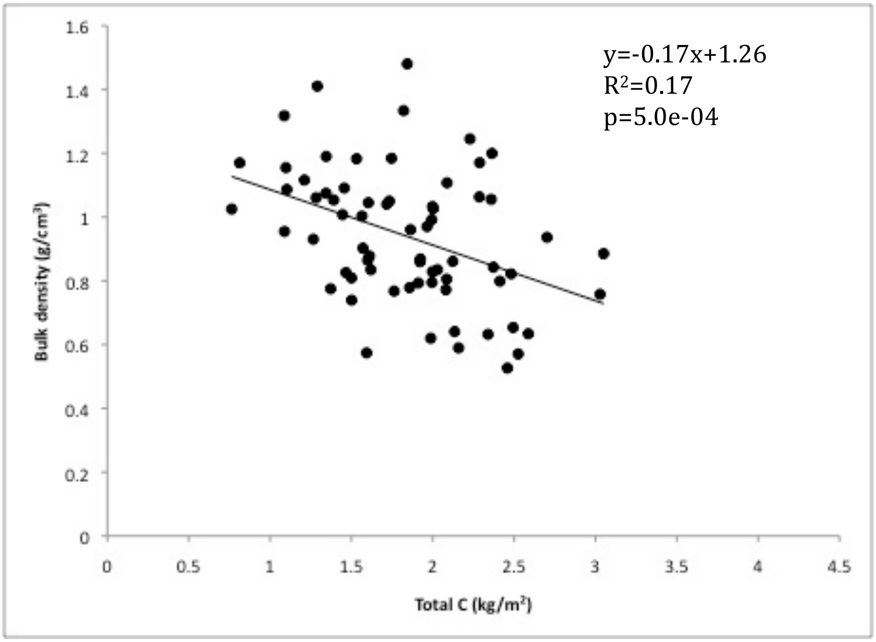

Figure 34: Regression analysis of bulk density in relation to total carbon (C) (kg/m^2) for the 0-5 sampling depth of reference floodplain soils

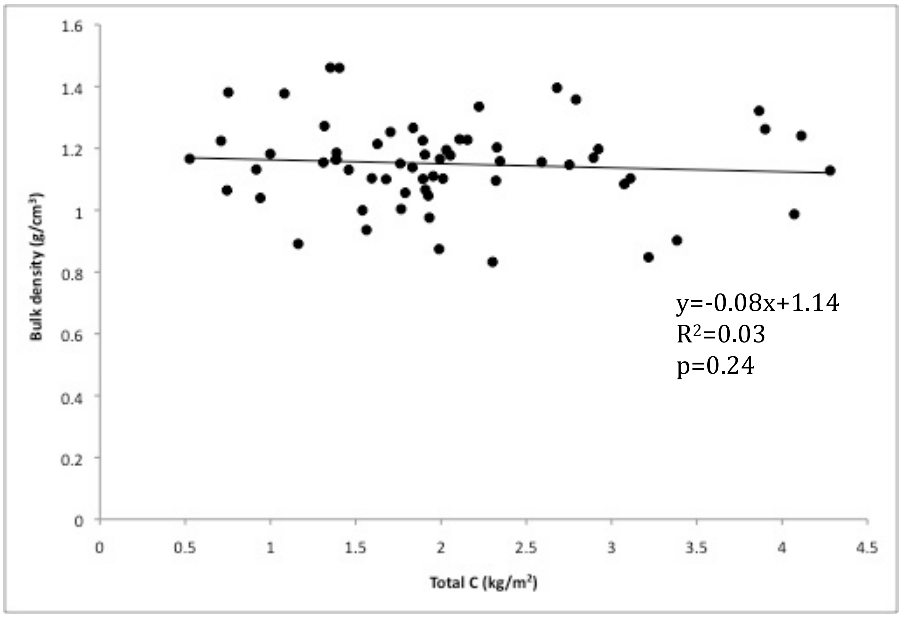

Figure 35: Regression analysis of bulk density in relation to total carbon (C) (kg/m^2) for the 0-5 sampling depth of incised floodplain soils

Table 8: Hydrologic and geomorphologic characteristics of study sites. Values after ± indicate standard error. Values in parentheses indicate standard deviation.

Watershed	BHR	Watershed area (km^2)	Mean GW depth (m)	Median GW depth (m)
Rotton	1.00	2.59	0.51±0.01	0.51 (0.05)
Loombeam	1.04	1.27	0.31±0.01	0.33 (0.11)
Osburn	1.27	7.51	1.06±0.01	1.10 (0.16)
Mitchell	2.41	5.00	1.44±0.01	1.57 (0.23)
Bird	2.78	1.89	1.22±0.01	1.29 (0.20)
Forest Eco	5.17	0.31	2.00±0.02	1.98 (0.29)

Table 9: Basal area (m^2/ha) and percent herbaceous cover of reference and incised floodplains of the AL Piedmont

Treatment	Watershed	Basal area (m^2/ha)	Herbaceous cover (%)
Reference	Rotton	39.99	43.56 ± 0.73
	Loombeam	33.97	65.12 ± 1.78
	Osburn	46.01	54.02 ± 1.28
Incised	Mitchell	12.05	44.16 ± 1.1
	Bird	49.53	30.84 ± 0.58
	Forest Eco	30.11	31.28 ± 0.85

Table 10: Mean and median values for select chemical and physical soil properties of reference and incised floodplain soils of the AL Piedmont. Values after ± indicate standard error. Values in parentheses indicate standard deviation.

	Depth (cm)	Total C		% N		Bulk Density	
		Mean	Median	Mean	Median	Mean	Median
Reference	0-5	1.84±0.06	1.86 (0.49)	0.11±0.01	0.10 (0.03)	0.94±0.02	0.93 (0.21)
	0-15	4.07±0.13	4.01 (0.71)	0.23±0.01	0.23 (0.05)	0.96±0.03	0.95 (0.15)
	15-30	2.70±0.11	2.73 (0.61)	0.16±0.01	0.16 (0.03)	1.19±0.03	1.18 (0.16)
	30-45	2.45±0.16	2.48(0.97)	0.14±0.01	0.15 (0.04)	1.28±0.04	1.23 (0.24)
Incised	0-5	2.10±0.13	1.91 (1.02)	0.10±0.01	0.10 (0.04)	1.15±0.02	1.16 (0.14)
	0-15	2.59±0.18	2.48 (1.07)	0.18±0.01	0.15 (0.07)	1.25±0.02	1.28 (0.14)
	15-30	1.68±0.14	1.55 (0.74)	0.11±0.01	0.11 (0.04)	1.37±0.03	1.35 (0.16)
	30-45	1.56±0.14	1.34 (0.76)	0.10±0.01	0.10 (0.04)	1.43±0.03	1.42 (0.15)

Table 11: Groundwater levels of reference and incised floodplains of the AL Piedmont. GW<30 corresponds to percentage of the study period (March 2012-March 2013) in which water table was less than 30 cm below floodplain surface. GW<45 corresponds to percentage of study period in which water table was less than 45 cm below surface. GW<1.0 corresponds to percentage of study period in which water table was less than 1.0m below surface

Treatment	Watershed	GW< 0.3m	GW<0.45m	GW<1.0m
Reference	Rotton	0.38%	16.10%	100%
	Loombeam	39.31%	90.97%	100%
	Osburn	0.09%	0.42%	32.43%
Incised	Mitchell	0.00%	0.01%	3.44%
	Bird	0.00%	0.00%	14.39%
	Forest Eco	0.00%	0.00%	0.17%

IV. Appendix

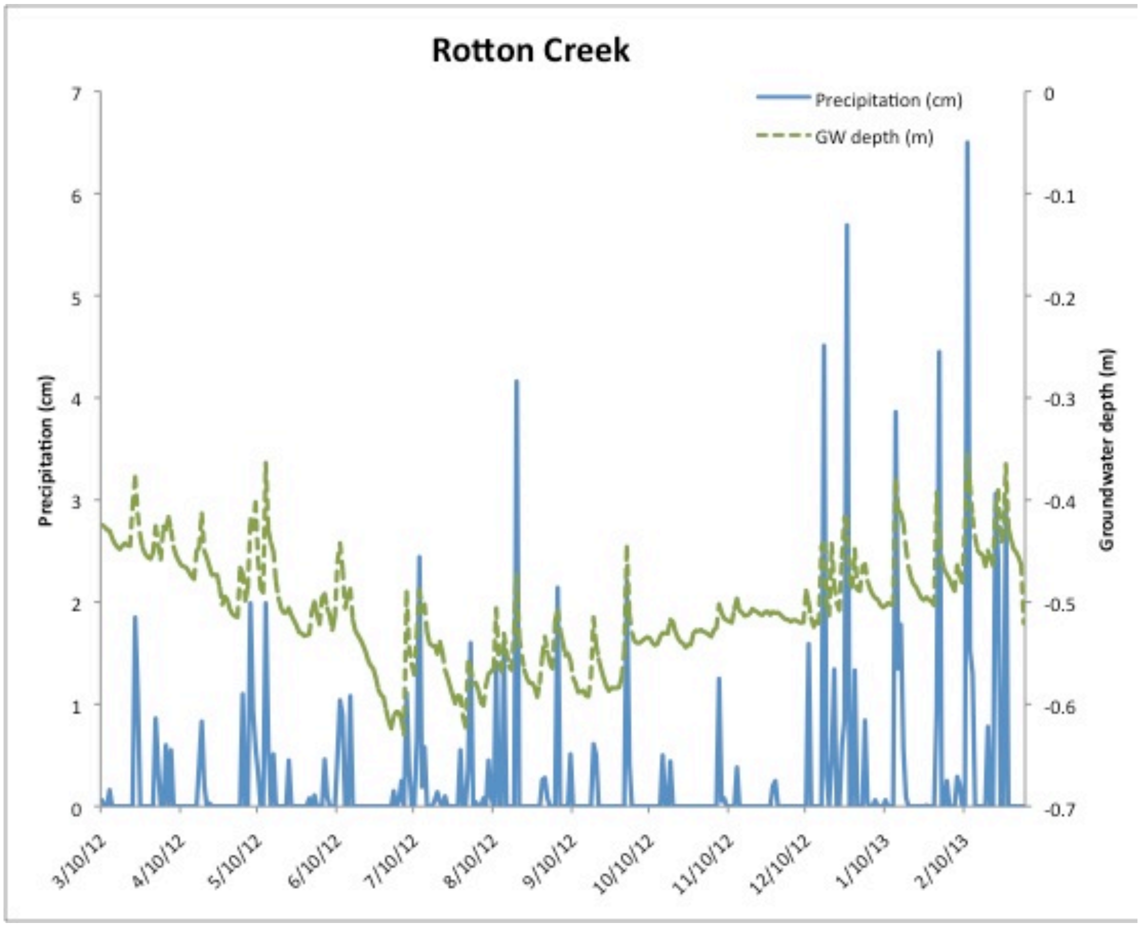

Figure 36: Groundwater values (m) and precipitation (cm) at Rotton Creek for duration of study period (March 2012-March 2013)

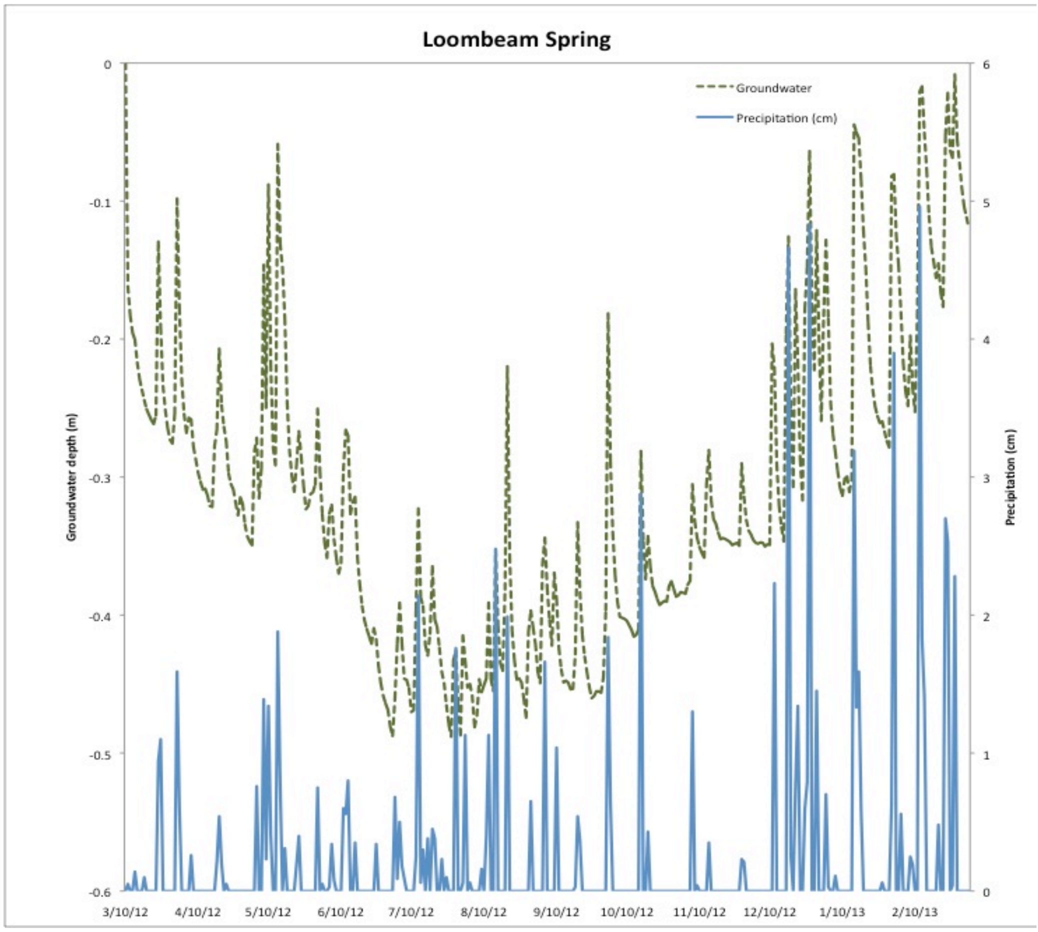

Figure 37: Groundwater values (m) and precipitation (cm) at Loombeam Spring for duration of study period (March 2012-March 2013)

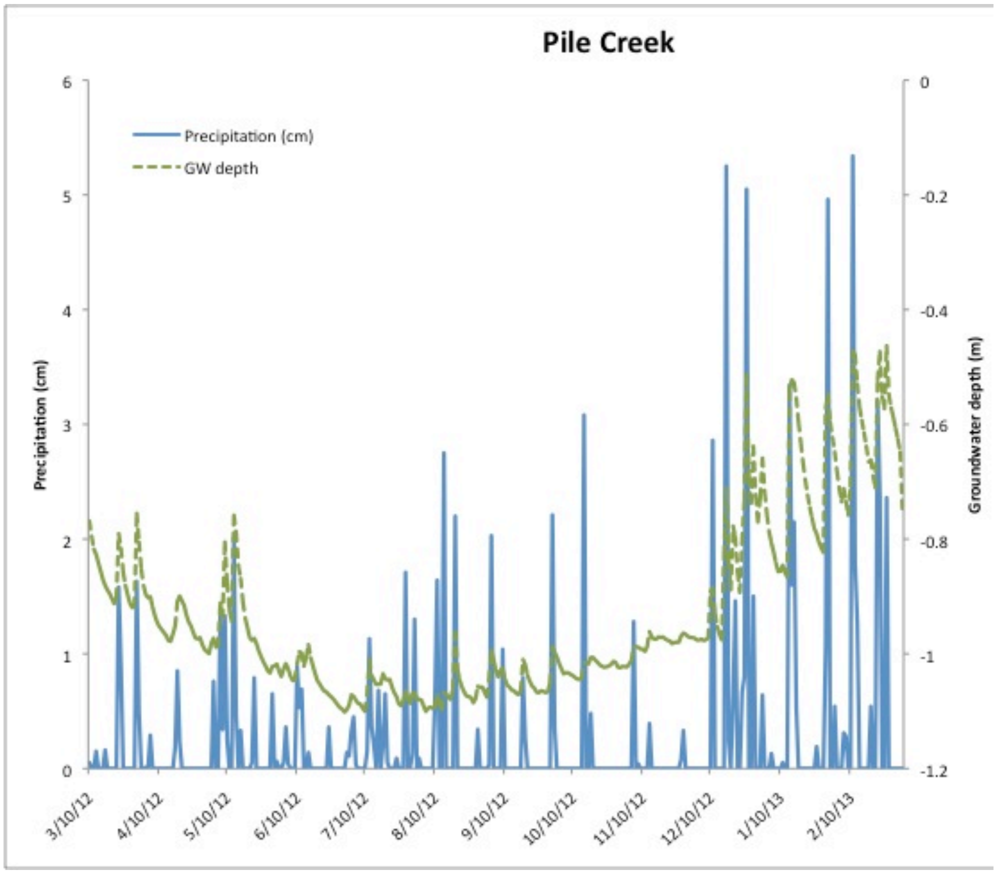

Figure 38: Groundwater values (m) and precipitation (cm) at Pile Creek for duration of study period (March 2012-March 2013)

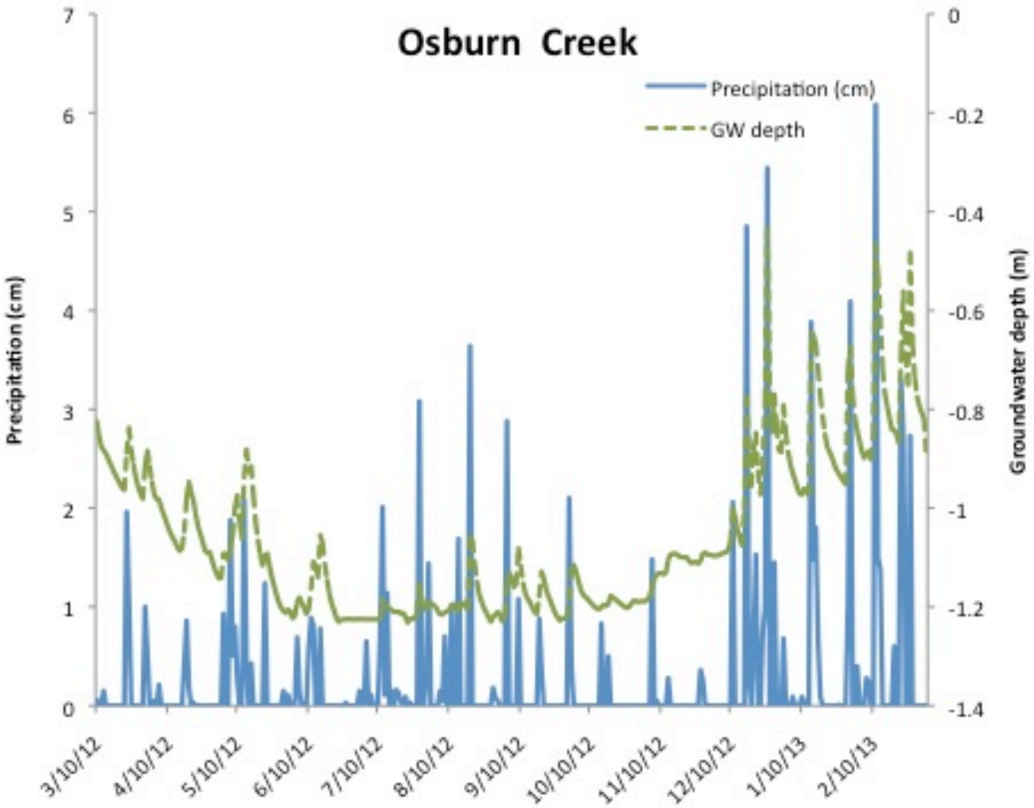

Figure 39: Groundwater values (m) and precipitation (cm) at Osburn Creek for duration of study period (March 2012-March 2013)

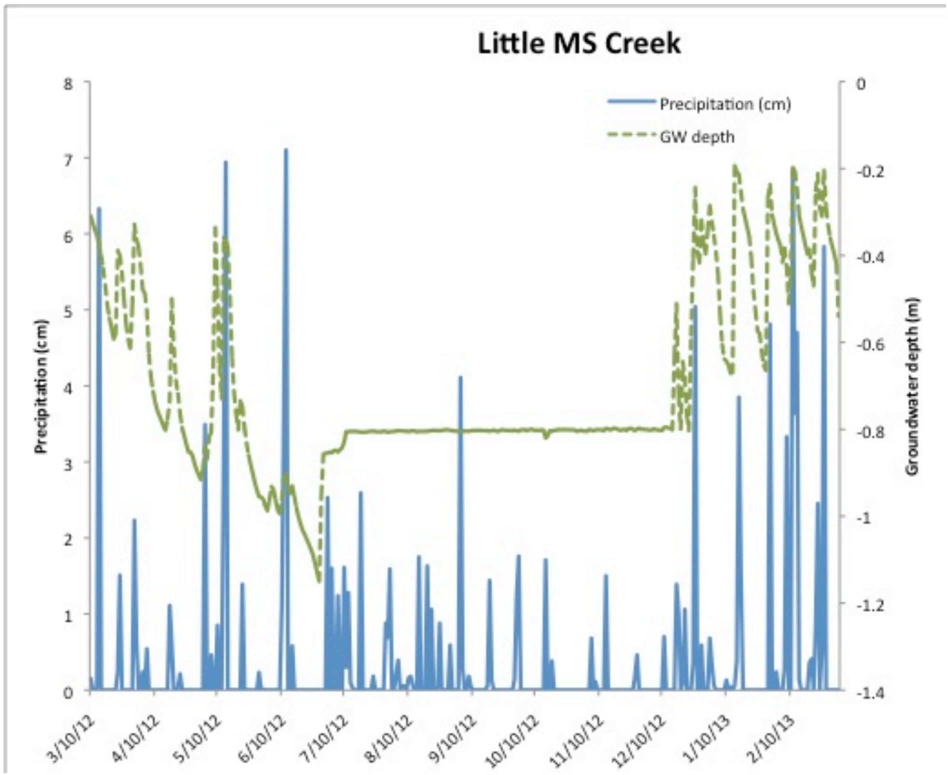

Figure 40: Groundwater values (m) and precipitation (cm) at Little Mississippi Creek for duration of study period (March 2012-March 2013)

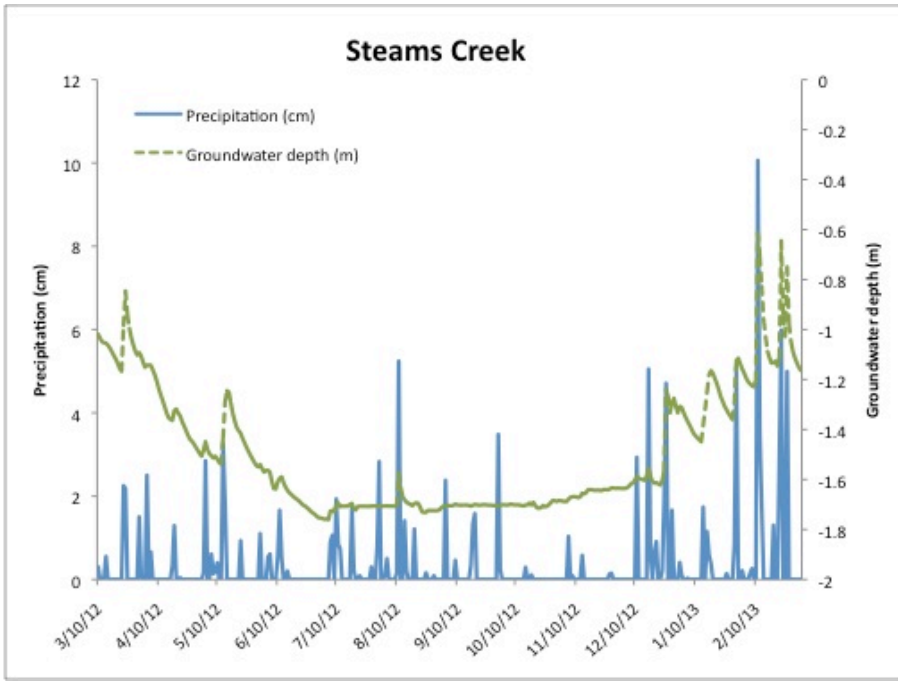

Figure 41: Groundwater values (m) and precipitation (cm) at Steams Creek for duration of study period (March 2012-March 2013)

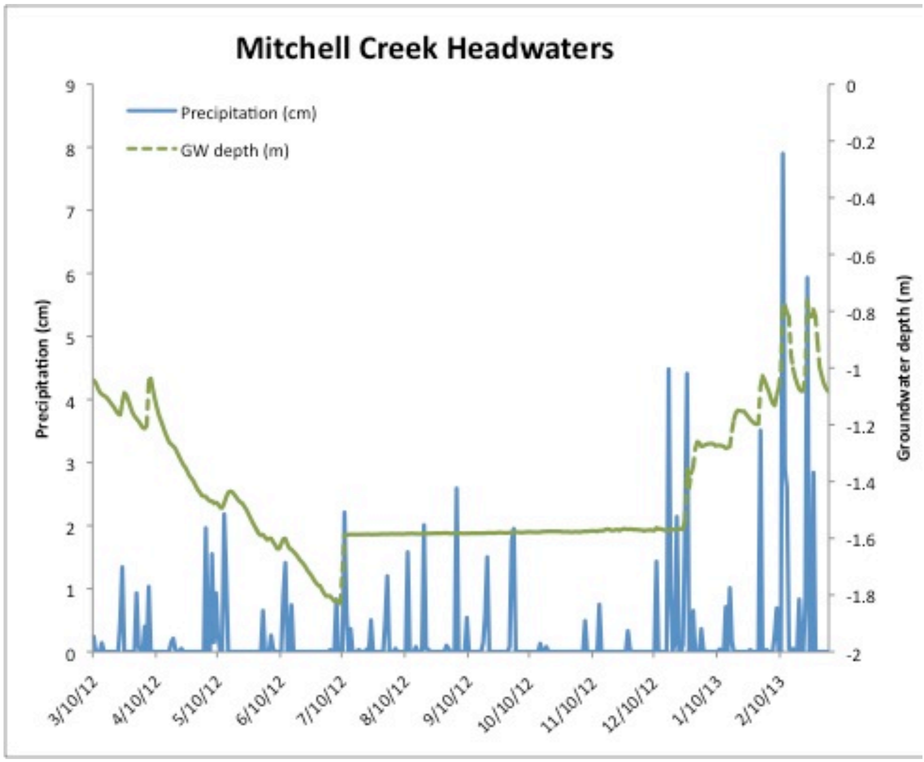

Figure 42: Groundwater values (m) and precipitation (cm) at the headwaters of Mitchell Creek for duration of study period (March 2012-March 2013)

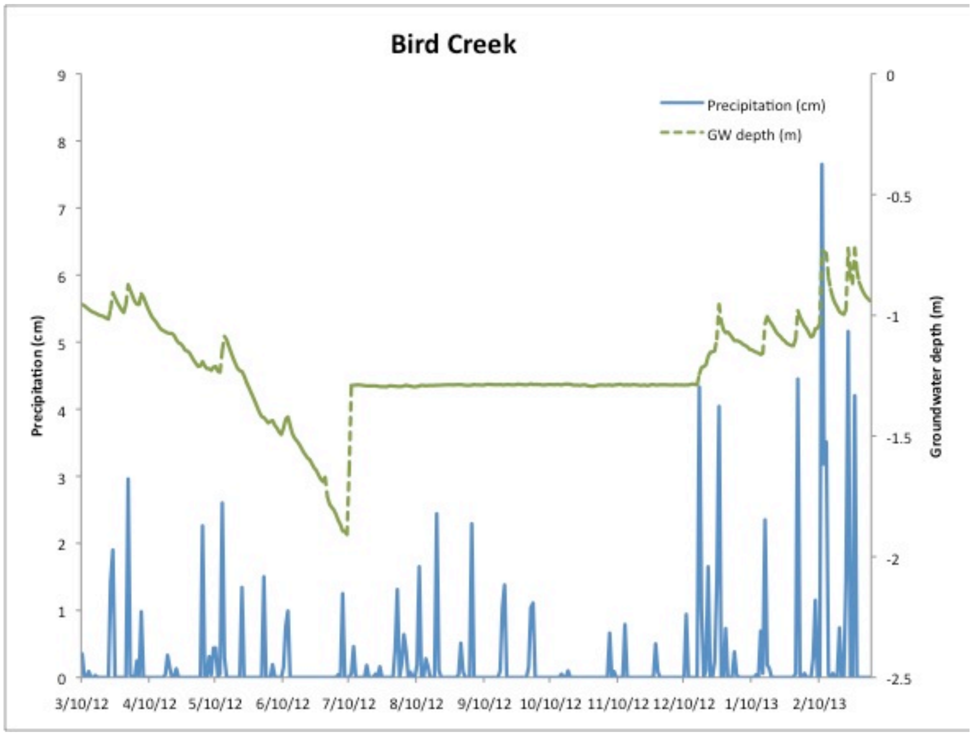

Figure 43: Groundwater values (m) and precipitation (cm) at Bird Creek for duration of study period (March 2012-March 2013)

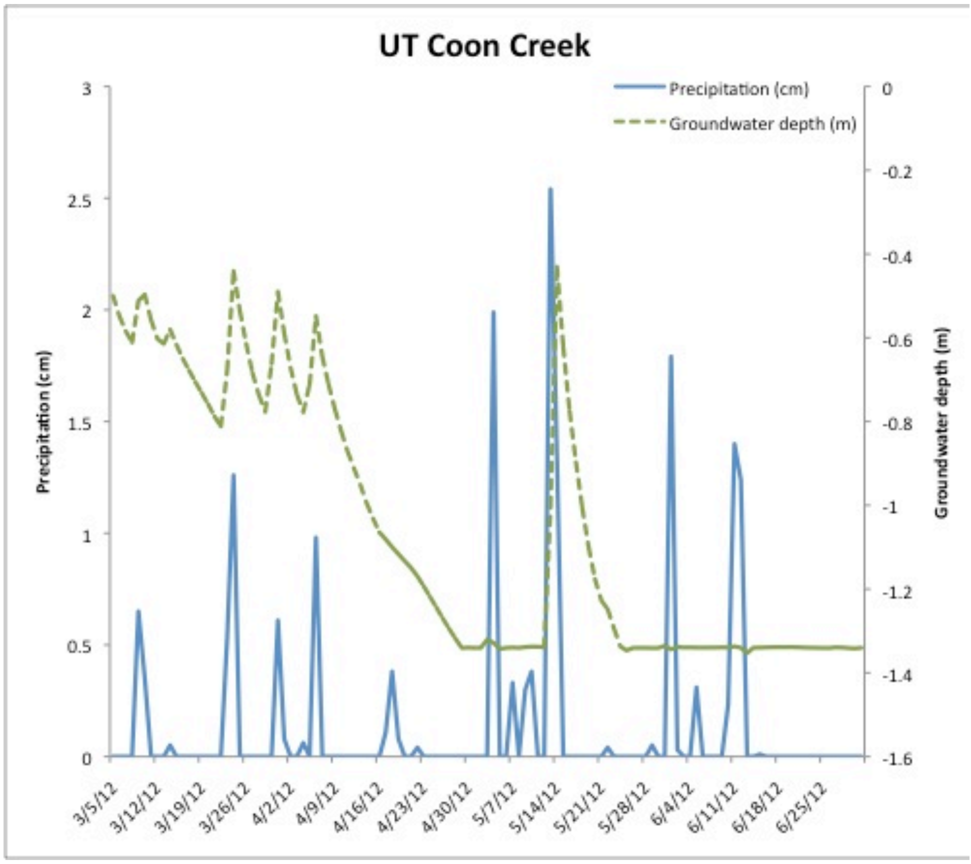

Figure 44: Groundwater values (m) and precipitation (cm) at UT Coon Creek from March 2012-July 2012; loss of data logger prevented analysis of water level data for full duration of study period

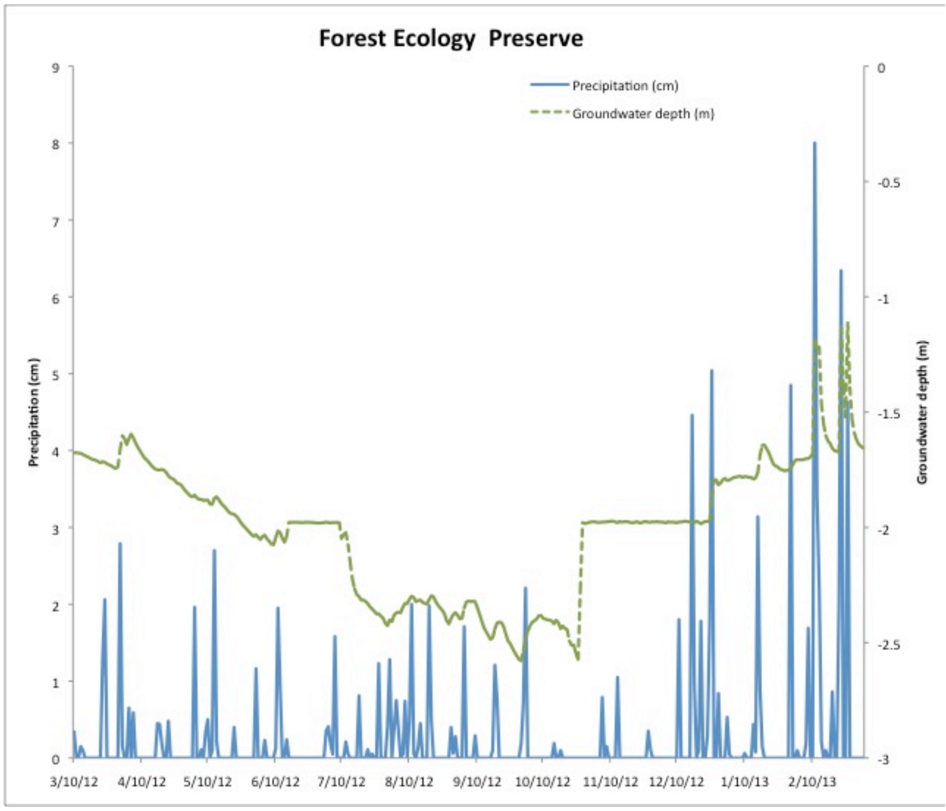

Figure 45: Groundwater values (m) and precipitation (cm) of the Forest Ecology Preserve Creek for duration of study period (March 2012-March 2013)