BIOGEOCHEMICAL EFFECTS OF SILVICULTURAL MANAGEMENT ON

INTERMITTENT STREAMSIDE MANAGEMENT ZONES IN

THE COASTAL PLAIN OF ALABAMA

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A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
May 10, 2008

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VITA

Christopher Gregory Colson, son of Carrie and William Colson, was born January 6, 1976, in Jacksonville, Florida. He graduated from North Allegheny Senior High School, Pittsburgh, Pennsylvania in 1994. He then attended Catawba College in Salisbury, North Carolina where he majored in Environmental Science. In 1998, he graduated with a Bachelor of Arts and later that year entered the graduate school at Auburn University, Alabama where he accepted a graduate research assistantship under Dr. B. Graeme Lockaby. In 2001, he moved to Idaho and married Karen Geissinger on October 26, 2002. Following completion of his Master's Degree, Chris plans to continue his professional career.

THESIS ABSTRACT

BIOGEOCHEMICAL EFFECTS OF SILVICULTURAL MANAGEMENT ON INTERMITTENT STREAMSIDE MANAGEMENT ZONES IN THE COASTAL PLAIN OF ALABAMA

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Master of Science, May 10, 2008
(B.A. Catawba College 1998)

115 Typed Pages

Directed by B. Graeme Lockaby

Three experimental intermittent watersheds in the Coastal Plain of Alabama were subjected to varying Streamside Management Zone (SMZ) silvicultural treatments in 2000: reference, partial cut, and clearcut. Biomass and carbon (C), nitrogen (N), and phosphorus (P) dynamics in litterfall, leaf litter decomposition, and herbaceous vegetation were measured for pre-harvest baseline values and post-harvest responses. Changes in aboveground primary productivity and herbaceous vegetation composition, regarding speciation and distribution of stratum, also were evaluated.

Pre-harvest comparisons of litterfall and mass loss rates indicated the reference SMZ exhibited the highest productivity with no significant differences between the partial cut and clearcut SMZs. General assessments of pre-harvest measurements of

nutrient dynamics across all response variables and all 3 SMZs revealed no significant differences.

Post-harvest comparisons of productivity demonstrated a significant treatment response of herbaceous vegetation in the clearcut SMZ, specifically regarding the forb and grass strata. Analysis of nutrient dynamics suggested that P was limited in all 3 SMZs. Reductions in decomposition rate among the partial cut and clearcut SMZs indicate a possible loss of P to the intermittent stream system. Observed levels of P content in the herbaceous vegetation of the treatment SMZ likely did not account for the loss of aboveground woody biomass as it relates to nutrient assimilation and storage.

My results suggest that herbaceous vegetation responses to silvicultural treatments within SMZs do not buffer adverse effects to nutrient allocation, ultimately resulting in possible nutrient loss from the site and, thus, impacting site productivity and downstream water quality. Modification of best management practices to reflect the sensitivity of intermittent watersheds to silvicultural operations would benefit site productivity and water quality.

ACKNOWLEDGEMENTS

The author would like to thank Drs. B. Graeme Lockaby, Jack W. Feminella, and Robert B. Rummer for their instruction, guidance, patience, and commitment, with special consideration to Dr. Lockaby serving as the author's major professor. The author was most appreciative of the generous support and assistance provided by Robin Governo. Significant gratitude is owed to the author's parents, William and Carrie Colson and his wife, Karen Colson, for their dedicated support and encouragement.

Style manual or journal used: Soil Science Society of America Journal

Computer software used: Microsoft Office Word 2003, Microsoft Office Excel 2003, and SAS 6.0

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INTRODUCTION

The complexity and diversity associated with forested wetlands has long been of interest among the scientific and resource management community as well as concerned citizens. The hydrology of these ecosystems is the cornerstone for the unique dynamics that define them. However, the high spatial and temporal variability of the hydrology and the interrelated biogeochemical cycles associated with these wetland forests makes them difficult to study (Lockaby and Walbridge, 1998). Forested wetlands comprise several specific types of systems including bottomland hardwood forests, cypress swamps, and pocosin and bay forest ecosystems (Walbridge, 1993). Wetlands can be classified by their source of hydrology: precipitation (headwaters), ground water (fens), and overland flow (riverine floodplains) (Brinson 1993).

Bottomland hardwood forests are of particular interest because of their close association with lotic habitats, and are typically characterized as possessing fertile soil as well as the ability to filter pollutants from streams. Highly productive flood plains with high buffering characteristics have been highly utilized by the agriculture and forest industries for their potential for high resource yield without sacrificing the integrity of water quality. Many of these desirable floodplain forests, typically eutrophic rivers originating in the Piedmont, occur within the southeastern Coastal Plain. The broad stream valleys of the Coastal Plain that house these floodplain forests were developed by past geological events that eroded away relatively young sedimentary materials (Hodges, 1997). During large rain events, stream systems exhibit overbank flooding subjecting flood plains to periods of inundation or increased soil moisture. These hydroperiod variations are often the driving force behind nutrient transformations within these systems.

Floodplain forests are often characterized as ecotones, transitional areas between adjacent ecological systems, which form the interface between the aquatic environment and terrestrial upland (Risser, 1995). Many consider the wetland ecotone the most important component of a landscape because of the nutrient transformations that occur within this area where two different ecosystems converge (Holland, 1991). Riverine floodplain forest ecotones are spatially variable. As flooding occurs, the terrestrial-aquatic interface is separated from the stream system towards the upland. As floodwaters recede, so, too, does the transitional area. Movement of such a critical area in terms of nutrient cycling makes it difficult to define the factors that most influence the dynamics of the specific floodplain system. This ecotone area between a stream channel and the floodplain can be separated into three hydrologic phases: 1) baseline channel flow generated from surface flow, groundwater input, and precipitation, 2) overbank flow during flooding events, and 3) post-flood drainage from floodplain back into stream (Brinson, 1983). The temporal extent of each phase depends upon geomorphic, climatic, and anthropogenic influences, which can be highly variable (Lockaby and Walbridge, 1998). Therefore, nutrient exchange between a flood plain and its stream may be limited to the hydrologic patterns that impact ecotone behavior among such fine spatial variability.

BEST MANAGEMENT PRACTICES

The tight cycling of nutrients and high rates of plant uptake have characterized floodplain and riparian forests as being highly effective in buffering the eutrophication of stream systems from the overloading of nutrients. In addition to floodwater storage, water quality maintenance is a well-established function of riverine wetlands (Brinson 1993). The protection of water quality has become important to the public concern over ecological and human health integrity. Stream water quality degradation has been correlated with upland disturbance or management, in the form of agricultural and silvicultural operations.

Over the past 30 years, the need to protect water quality from these sources was recognized and, as a result, Best Management Practices (BMPs) were developed. BMPs are basically land management designs that improve or sustain water quality. They are specifically defined as "a practice or combination of practices that is determined by a state, after problem assessment, examination of alternative practices, and appropriate public participation, to be the most effective and practicable means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals" (Bailey and Waddell, 1979).

To date, most studies that have evaluated the BMP effectiveness have focused on agricultural management (Moore et al. 1992, Park et al. 1994, Edwards et al. 1996, Kuhl et al. 1996). All of these studies observed decreases in runoff, sedimentation and nutrient input from nonpoint source pollution associated with agricultural practices following BMP implementation. Each study utilized different approaches to BMP implementation including, but not limited to, forested and grassland riparian buffers, no-tilling, and responsible application of fertilizers (Moore et al. 1992, Park et al. 1994, Edwards et al. 1996, Kuhl et al. 1996). These studies suggest that BMP development should be site-specific in relation to desired objectives, thus making universal assessment of BMP effectiveness difficult if not impossible.

STREAMSIDE MANAGEMENT ZONES

Silvicultural BMPs are generally designed to protect the ecological integrity of the watershed, promote regeneration, and to provide efficient access for the removal of valuable timber resources. One element of silvicultural BMPs is Streamside Management Zones (SMZs). SMZs are defined as strips of land immediately adjacent to streams where soils, organic matter, and vegetation are managed to protect the physical, chemical, and biological integrity of surface water adjacent to and downstream from disturbance operations (Alabama Forestry Commission 1993). Currently, BMPs, including SMZs, are only voluntary for silvicultural activities. In addition, only recommendations of SMZ widths are provided for intermittent streams. Buffer width is not necessarily the sole determining factor of streambank stability and streamwater quality. Factors that also affect riparian function and streamwater quality include floodplain width, soil physical parameters, and the gradient of streamside slopes (NCASI 2000). Most state guidelines establish a minimum SMZ width and residual tree recommendations (Blinn and Kilgore 2001, 2004). However, in the case of intermittent streams, little scientific data exist to support the use of specific guidelines across all sites (Blinn and Kilgore 2001, 2004).

Many studies have been conducted to examine the buffering abilities of riparian zones in low-order, headwater systems of agricultural watersheds containing intermittent and perennial streams (Peterjohn and Correll 1984, Jacobs and Gilliam 1985, Lowrance et al. 1985, Cooper et al. 1987, Lowrance et al.. 1997, Perry et al. 1999). The culmination of such work has resulted in the design of the Riparian Ecosystem Management Model (REMM) (Lowrance et al. 1998). REMM was developed primarily for the benefit of water quality maintenance in agricultural watersheds. The model divides a riparian zone into three sections. Zone 1, adjacent to the stream is unmanaged hardwood forest. Zone 2 is a managed forest typically of pine species. Zone 3 is a grass buffer adjacent to the agricultural field. Preliminary assessment of data using this model for several sites reveals that it sufficiently buffers nutrients from entering the stream while still allowing for the use of natural resources (timber removal in Zone 2) (Lowrance et al. 1998).

A generally recognized riparian model has not been developed for silvicultural operations. Silvicultural operations differ from those in agriculture because the management of a forest crop often entails a much longer harvest cycle. For this reason, a silvicultural riparian zone may not require the intensive management often expected of an agricultural riparian zone, allowing sufficient time between management for system recovery. However, management during the rotation (thinning, fertilizing, etc.) may deem the use of a managed riparian zone beneficial to water quality, so more research is needed to determine the full benefits of a riparian zone throughout a complete silvicultural rotation.

In response to the lack of specific data, Hubbard and Lowrance (1997) evaluated the effects of forested riparian management on nitrate removal. Results indicated that a selective cut or thinning of the riparian forest, increased nitrate removal to a greater extent than the control riparian forest. The authors attributed this to the mild disturbance stimulating plant uptake of nitrate. The “nutrient-retention hypothesis” would also support such an outcome (Vitousek and Reiners 1975). The nutrient-retention hypothesis states that young forests demonstrate higher accumulations of biomass and, therefore, high net ecosystem productivity, ultimately retaining more nutrients on site. Conversely, mature forests have much less biomass, resulting in lower productivity and a greater propensity for nutrient loss. Waring and Schlesinger (1985), however, found that large, widely spaced trees exhibited greater transpiration rates. Stands of low-density allow trees to maintain more open stomata and have higher air/leaf water vapor deficits (Whitehead and Jarvis 1981). In addition, higher aerial cover and resultant interception potentially increase the ability of trees to reduce the effects direct rainfall has on sedimentation as well as increasing evaporation and reducing stormwater runoff. Cumulatively, these studies might suggest that silvicultural manipulation (i.e. thinning) of riparian areas and SMZs would likely increase stand productivity. For instance, Crop Tree Management, the selection and release of desired trees by removing adjacent competing trees, could be utilized to favor trees with both high nutrient uptake and high timber quality, depending on the landowner’s objectives (Sykes et al. 1993). SMZs that are too narrow or low in stand density may not provide adequate protection to stream systems, whereas those that are too wide or provide no further buffering in relation to high stand density are viewed as an economic loss of valuable resources in silviculture (NCASI 2000).

FLOODPLAIN DYNAMICS

Hydroperiod Influences

Hydroperiod influences on flood plains control the character and magnitude of nutrient inputs moving through riparian forests via surface and subsurface flow (Lockaby and Walbridge, 1998). During a flooding event, nutrients are often deposited upon the floodplain surface by alluviation. These nutrient-rich soils may provide the means for high vegetative productivity. In response to this observation, Odum (1979) proposed the subsidy-stress model to predict productivity based upon flooding intensity. He hypothesized that the highest rates of productivity will occur in floodplain forests subjected to periodic floods of short duration where subsidies of nutrients and water are deposited, without the persistent anaerobic conditions typical of longer duration floods. Megonigal et al. (1997) tested this hypothesis by measuring aboveground net primary productivity in 2 floodplain forests in Louisiana and South Carolina. They found that the subsidy-stress hypothesis did not adequately predict productivity in relation to flooding intensity. They reasoned that that considerable natural variability was associated with differences in water quantity (intensity and duration of flooding and water and soil chemistry (nutrient content), as well as differences in the vegetation's physiological resistance to stresses. This variation made prediction and modeling difficult. Floodplain vegetation, especially tree species, is physiologically and morphologically adapted to the flooding regime at a given position along a hydrologic gradient (Sharitz and Mitsch 1993, Megonigal et al. 1997). Again, hydroperiod fluctuations have the potential to introduce variability into the associated plant communities.

Shure and Gottschalk (1985) measured litterfall, another useful index of productivity, along an environmental gradient perpendicular to the stream system of a floodplain forest in South Carolina. Their results indicated that litterfall increased from bank to upland, or as flooding intensity decreased. In contrast, litterfall increased near the bank following heavy and prolonged flooding. They attributed this result to fluvial inputs of nutrients and oxygen, increasing site productivity near the stream. Similar results were observed by Bell and Sipp (1975) in an Illinois flood plain, where the litter layer and litter cover increased with elevation and distance from the stream channel. There are obvious implications in using Bell and Sipp's (1975) data as an index of productivity in terms of possible differences in decomposition rates along the hydrologic gradient. Depth of litter layer would be influenced by the site-specific decomposition rate along the gradient. A deep litter layer in the upland may be a result of either high litterfall inputs or slow decomposition rates, or both factors. Using the litter layer as a single indicator of productivity may produce biased aboveground productivity data. With respect to litter layer depth, floodplain forests, despite being more productive than other forest ecosystems of the temperate region, generally possess a shallow litter layer resulting from high decomposition rates (Bray and Gorham 1964, Brinson et al. 1980, and Shure and Gottschalk 1985).

Decomposition

Results by Bray and Gorham (1964), Bell and Sipp (1975), Brinson et al. (1980), and Shure and Gottschalk (1985) reinforced the variability in decomposition rates associated with floodplain forests. Plant productivity is directly related to availability of vital soil nutrients, made available through rainfall, surface and subsurface flow from the upland, deposition following flooding, and cycling of nutrients through decomposition of organic matter. Physical breakdown of litter by decomposers and transport of nutrients across terrestrial and aquatic gradients characterize flood plains as some of the most complex ecosystems of the world. The decomposition of these floodplain constituents represents a critical pathway for energy flow and nutrient exchange and promotes the efficiency underlying high productivity of floodplain forests (Lockaby et al. 1996a).

The integration of 3 factors controls the decomposition process: 1) litter quality, 2) nature of the microenvironment, and 3) microbial abundance and activity (Lockaby and Walbridge 1998). Litter quality has been extensively studied as a factor affecting decomposition (McClaugherty et al. 1985, Blair et al. 1990, and Elliot et al. 1993). Litter quality affects microbial assemblages and activity. Some litter may be more resistant to microbial degradation with others representing a more desirable energy source to decomposers. Decomposition rates also exhibit variability as a result of hydroperiod along flooding gradients (Brinson 1977, Peterson and Rolfe 1982, Shure et al. 1986, Lockaby et al. 1996a, Lockaby et al. 1996b). Fluvial inputs of nutrients, the leaching of nutrients, temporal variations in soil moisture, and fluctuating soil respiration levels all are affected by hydroperiod and, thus, are capable of altering soil microbial activity.

Nutrient Cycling

Consideration of riverine wetlands as nutrient sinks or sources represents an oversimplification of the biogeochemistry of these systems. Wetlands are commonly assumed to be nutrient sinks because they are intrinsically depositional landforms (Brinson 1993). In contrast, a flood plain has the ability to export nutrient accumulations during flooding events causing them to exhibit nutrient source traits (Mitsch and Gosselink 1986). Additionally, systems that receive low-nutrient inputs, serve neither as sources nor sinks, but rather as nutrient transformers (Elder 1985). As a consequence, the fate of nutrients in floodplain systems exhibits high variability and often must be examined specifically in relation to the nutrients in question. Intrasystem cycling of nutrients may be limited by one nutrient at one site and limited by another at an adjacent site. Analyses of many response variables in relation to nutrient allocation, use, and fate (i.e. litterfall, decomposition, groundwater, streamwater, etc.) are usually required to determine nutrient dynamics of a floodplain system because of the spatial and temporal variability of these functions.

HEADWATER STREAMS

Typically, the term flood plain is associated with larger, high-order stream systems. These larger systems have received the majority of management and research attention. These systems experience flooding events of greater magnitude and consequence resulting in the potential for greater levels of nutrient transport and transformation than their low-order stream counterparts. Low-order headwaters streams have not been studied to the same degree as high-order streams; thus, disturbance impacts are not well understood (Mostaghimi et al. 1998). As stream order increases, riparian transport to the flood plain remains constant per unit of stream length and overbank transport increases because of increasing stream discharge downstream (Brinson 1993). Headwater riparian forests depend more heavily on weathering and atmospheric inputs of nutrients than large riverine flood plains with additional fluvial inputs (Brinson et al. 1980). In addition, large riverine floodplains rely on riparian transport from the uplands as well as the upstream sources for nutrient inputs. Riparian transport is considered to be a one-way linkage as materials only flow from the upland to the stream system, whereas overbank transport can flow in both directions (Lockaby and Walbridge 1998). In contrast, Pringle (1997) suggested several downstream physical disturbances (channelization, impoundments, etc) that can affect upstream systems through the lowering or raising of stream levels. It is generally accepted that as stream water flows downstream through increasing stream orders, although the variables affecting them create a continuous gradient of physical conditions that cause responses within the cycling patterns of loading, transport, utilization, and storage of organic matter (River Continuum Concept; Vannote et al. 1980). In this concept, headwater streams represent the maximum interface with the terrestrial system and, thus, are considered the primary accumulators, processors, and transporters of nutrients and materials from the landscape (Vannote et al. 1980).

INTERMITTENT STREAMS

Intermittent streams are inherent among many headwater systems. Intermittent streams can be thought of as the starting point of all nutrient transport, and are therefore crucial in the determination of the nature and dynamics of the downstream watershed. For these reasons, disturbance of upland areas adjacent to intermittent streams can produce obvious negative effects that are magnified in lower portions of catchments. Similar to flood plains, intermittent streams are driven by the hydrology of large rain events, which often result in nutrient and sediment transport from upland zones.

Several studies in the southeastern Coastal Plain have examined the effects of natural, thinned, and clearcut headwater upland sites on nutrient loss (Schreiber et al. 1976, Duffy et al. 1978, Schreiber et al. 1980, Northup et al. 1995), ephemeral streamwater quality without the use of BMPs (McClurkin et al. 1985), and groundwater quality (McClurkin et al. 1987). All studies observed a decrease in the nutrient pool following rain events. Generally, concentrations of exported nutrients were proportional to cutting intensity (i.e. a selective cut exhibited less nutrient loss than a clearcut). The results of these studies reinforce the need for increased attention on water quality maintenance in headwater systems. Nutrient functions are site dependent and variable across time and space as well as consisting of several determining factors (i.e. sources and rates of nutrient input, export, and transformations). To date, most studies do not provide an analysis of all response variables required to develop a comprehensive view of the cycling of a system. In addition, comparisons among similar experimental watersheds can be difficult due to uncontrollable environmental variations and often only provide broad correlations. This can limit the significance of differences observed between reference and treatment sites occurring in different watersheds.

HARVESTING INFLUENCES

Water Quality

Forested watersheds that have historically received minimal soil disturbance from anthropogenic activities typically display high water quality. The benefits of forest cover in an intact watershed have long been evident (Likens et al. 1970). Following a clearcut of an experimental watershed, herbicide treatment was applied for 3 years to control the re-establishment of vegetation. As expected, large inputs of sediment and nutrients were lost to the stream. In addition, it took several years after treatment for the rates of productivity to become re-established to pretreatment levels. The authors attributed the decrease in productivity to the loss of nutrients from the terrestrial system (Likens et al. 1970). Several years later, a similar experiment was conducted within the Hubbard Brook Experimental Forest (Kochenderfer and Wendel 1983). After several years of herbicide application, water yield, rates of productivity, and vegetative ground cover took 10 years to recover to pre-treatment values. The authors determined all 3 factors to be closely correlated. The loss of sediment resulting from insufficient vegetative cover resulted in reduced soil moisture retention capabilities and soil nutrient content ultimately retarding vegetation re-establishment.

The publication of the Likens et al. (1970) study led to a greater awareness of silvicultural management impacts to water quality within freshwater ecosystems (Sopper 1975). Public scrutiny and misconception of forestry practices resulted from the Likens study. Many watershed studies resulted and scrutinized silvicultural operations at the watershed scale in terms of productivity, regeneration, and most importantly, water quality. In addition, most prior studies were situated in mountainous watersheds, and many of those were situated in established experimental watersheds (e.g., Hubbard Brook Experimental Forest, New Hampshire, Fernow Experimental Forest, West Virginia, Oak Ridge National Environmental Research Park, Tennessee, and Coweeta Hydrologic Laboratory, North Carolina). A significant data gap continues to exist for the impacts of forestry on headwater systems, especially in low-gradient, coastal plain watersheds.

The use of a riparian strip in a small watershed in Fernow Experimental Forest, West Virginia, maintained water quality following a clearcut of the watershed (Aubertin and Patric 1974). Instream rates of sedimentation, dissolved solids and nitrates and phosphates exhibited only negligible increases after clearcutting. Sopper (1975) reviewed and evaluated watershed clearcutting effects on water quality in Hubbard Brook Experimental Forest, Fernow Experimental Forest, and Coweeta Hydrologic Laboratory, and concluded that nutrient losses following forested watershed clearcutting were small to negligible. All of the above studies utilized a paired experimental watershed to compare similar systems and how they respond to silvicultural disturbances. After reviewing 11 sites recently harvested throughout the United States, Mann et al. (1988) determined that terrestrial nutrient losses and associated elevated levels in streams generally occurred following harvest but returned to pretreatment levels after 3 years. A paired experimental watershed approach was used at Caspar Creek, California, to assess the recovery period of a watershed following clearcut disturbance (Thomas, 1990). Data indicated that consistent differences in control and response variables, while not significant, still existed between watersheds for turbidity and stream flow 20 years after harvest. These results suggest further study is required to determine the full impact of silvicultural disturbances at the watershed scale.

Southeastern Coastal Plain watersheds exhibit unique ecological responses to harvesting. Disturbed areas are not only subjected to precipitation but also frequently receive greater flooding than usual because of the reduction in evapotranspiration, resulting in the potential for greater nutrient transport. Increases in stream volume, typical of harvesting operations, may result in greater floods and the magnification of such processes (Smith 1997). In addition, the sandy soils typical of the southeastern Coastal Plain are more susceptible to leaching of nutrients (Havlin et al. 1993). Although, in forested bottomlands of the Southeast, clearcutting with sufficient advance regeneration is the most proven and widely used method of successfully regenerating valuable bottomland tree species (Meadows and Stanturf 1997).

Soil Physical Parameters

Variations in soil physical parameters following disturbance can be critical to soil microbial activity and vegetative net primary productivity. Typically, increased soil temperature results from a loss of vegetative cover, which often promotes increased microbial activity. Investigating a southwest Alabama forested wetland with dark organic soils, Aust and Lea (1991) measured changes in soil temperature and organic matter content across several sites to monitor ecosystem recovery following several different silvicultural applications. All sites exhibited increases in soil temperature with the greatest differences found between skidder and herbicide treatments (Aust and Lea 1991). Decreases in soil organic matter were measured across sites with the herbicide treatment being the lowest. Differences in soil temperature were also compared by Messina et al. (1997) across a clearcut, a partial cut, and reference site in a Texas bottomland. No treatment differences were observed for soil physical parameters such as soil temperature, soil respiration, and bulk density. In addition, no statistical differences were observed in stream water and ground water chemistry, possibly because SMZs were included in the measurements. This result led the authors to conclude that harvesting practices can be conducted with minimal impacts to physiochemical response variables. Perison et al. (1997) measured increased rates of decomposition on cotton strip assays on 2 harvested South Carolina bottomland sites (skidder and helicopter) as compared to an unharvested reference. They attributed the increased decomposition rate in harvested sites to increased soil temperature and resultant increase in microbial activity. High concentrations of nutrients were also observed in the groundwater in the skidder treatments. The authors determined nutrient increases coincided with high decomposition and possible potentially high mineralization rates in the skidder treatment. They observed differences in water table depth as well when comparing sites following treatments. Water table depths were generally lowest in the reference followed by the helicopter and skidder treatments, respectively (Perison et al. 1997).

Removal of riparian canopy cover not only increases soil temperature, but often increases stream temperature (Johnson and Jones 2000). However, studies have shown that stream temperature regulation can be significantly influenced by parameters other than reduced shade, such as groundwater and tributary inputs, gradient and aspect, and air temperature (Johnson 2004, Danehy et al. 2005). Nonetheless, harvesting impacts on stream temperature alteration can be significant in low-order, intermittent streams, especially when stream canopy cover is eliminated (Fritz et al. 2006). Stream temperatures of low-order streams are most regulated by the forest canopy height and density, and stream channel width and orientation (Naiman et al. 1992). Increased stream temperature, via direct insolation, can adversely affect fish and invertebrate populations and composition and also pose significant threats to the entire stream system in terms of compromised water quality (NCASI 2000).

Biogeochemistry

Several studies have been conducted that specifically evaluated biogeochemical effects of bottomlands following harvest activity. Two studies conducted by Lockaby et al. (1994, 1997a) on a southern Alabama flood plain measured no statistically different treatment effects on denitrification, and groundwater, surface water, or stream water chemistry following harvest activity. Unexpectedly, groundwater levels dropped in the harvested sites, which was in contrast to Perison et al. (1997), who found that sites harvested by skidder (i.e. receiving the most soil and vegetative disturbance) had the highest levels of groundwater compared with a reference site and helicopter-logged site. Results such as those reported by Perison et al. (1997) are typically observed. The unexpected decrease in water table depth reported by Lockaby (1994) was attributable to evaporation from dark organic soils that seemed to negate the expected loss in evapotranspiration. The decreased soil moisture caused a decrease in decomposition rate as well on harvested sites because of a moisture limitation upon microbial activity.

SMZs are considered effective buffers in terms of several essential riparian functions, including streambank stabilization, sediment reduction, chemical removal, input of coarse woody debris (CWD), particulate organic matter production, and shade production in relation to streamwater temperature (NCASI 2000). Removal of vegetation will have obvious implications to any or all of these functions. Resource managers need to be aware of these functions and how their intended management objectives can affect them and, in turn, the integrity of the watershed.

In relation to within-stream processes, removal of vegetation through timber harvest has the potential to switch streams from allochthonous to autochthonous production by simultaneous stimulation of in-stream primary production and reduction of terrestrial inputs (Bilby and Bisson 1992). Such a transition will have obvious implications to fish and invertebrate populations and composition, potentially adversely affecting whole-stream structure and function.

Another effect of timber harvesting operations is production of residual slash and the resulting CWD nutrient dynamics. Many studies have determined CWD to act as a nutrient sink following clearcutting, and is elemental in the recovery of a site following a harvest when nutrient loss is elevated (Abbott and Crossley 1982). Even in a natural, undisturbed state, forested systems rely on CWD as a nutrient sink exhibiting rapid turnover and providing a vital source of limited nutrients (Onega and Eickmeier 1991).

As previously described, floodplain decomposition within undisturbed communities of the southeastern Coastal Plain is typically not limited by moisture or temperature. The role of CWD in immobilization and mineralization patterns of periodically flooded forests will provide further evidence towards the determination of a system as a nutrient source or sink. An example of the variability associated with source-sink behavior was measured by Rice et al. (1997) in the Atchafalaya River Basin of Louisiana. Following hurricane disturbance, the role of CWD in biogeochemical transformations was different between N and P; N tended to be stored whereas P was an elemental source.

Similar to its role in nutrient retention, presence of CWD within stream systems is integral to stream habitat complexity and instream nutrient dynamics. Naiman et al. (1992) described CWD as critical in determining the characteristics of freshwater habitats in low- and mid-order forested streams. Sedell and Beschta (1991) described the roles of CWD in streams as 1) creating and maintaining pools, 2) reducing local stream velocities, thus creating foraging sites, 3) forming eddies beneficial to foraging, 4) providing shelter from predators, 5) providing shelter during major storm events, and 6) trapping and storing terrestrial organic inputs and promoting the preferred biological nutrient transformations (as cited in NCASI 2000). Several studies have shown that riparian width (McDade et al.. 1990, Van Sickle and Gregory 1990, Murphy and Koski 1989, Darling et al.. 1982) and forest density and height (Robison and Beschta 1990, Darling et al.. 1992) is directly related to CWD input to streams. Typically the tallest trees and, in general, riparian forests consisting of large trees with low density, provide the greatest input.

Herbaceous Vegetation

Stabilization of a system following a harvest operation can be dependent on re-establishment of vegetation. The maintenance of species diversity for wildlife habitat, natural regeneration of renewable resources, and proficient nutrient uptake beneficial to water quality are three primary management objectives, following silvicultural operations. The role of succession during recovery can drastically alter the composition of a stand and, therefore, the nutrient cycling governed by plant uptake (Elliot 1997). The return of nutrient uptake provided by vegetation is crucial to maintaining water quality following a harvest. The primary succession of herbaceous vegetation is expected to fill this void. Therefore, herbaceous biomass and its rate of nutrient uptake are of immediate concern. Removal of large trees and their stored nutrients represents an obvious loss to the nutrient pool. Replacing the role one tree may have represented in nutrient uptake could possibly be dependent upon large contributions of herbaceous vegetation. Vegetated buffers act as sinks through the physical removal of sediments and waterborne pollutants from surface runoff resulting in a net reduction of nutrients and pollutants entering the stream system. In addition, the establishment of vegetation will reduce the potential for the formation of channels following storm events. Water will flow slower allowing for the settling and infiltration of nutrients (NCASI 2000).

There is abundant information on herbaceous biomass dynamics following disturbance (Conde et al. 1983a and 1983b, Locasio et al. 1991, Messina 1997, NCASI 2000), but the contributions of herbaceous vegetation to nutrient cycling in forested systems is limited. Following the clearcutting of pine flatwoods on two sites in north Florida, Conde et al. (1983a, 1983b) measured increases in herbaceous biomass to be ~6- and 4x times greater than pretreatment values, respectively. Stevens and Cummins (1999) observed differences in in-stream sedimentation and invertebrate assemblages to be correlated with land use and riparian plant composition. Riparian vegetation could not be isolated from land use as the causal factor, but it should still be recognized as a possible factor affecting overall in-stream health. In the Georgia piedmont, significant increases in grass biomass were observed 4 years after a clearcut harvest of a pine plantation (Locasio et al. 1990, 1991). In addition, herbaceous roots have been found to increase streambank cohesiveness and strength (Zimmerman et al. 1967, Waldron and Dakessian 1982). Supporting these results in the former study was a greater width-to-depth ratio in forested streams than those within meadows (Zimmerman et al. 1967; as cited in NCASI 2000). The increase in ratio suggests that forested streams erode the stream bank more than meadow streams, making the stream wider in relation to its depth. The use of grasses as a riparian buffer was also illustrated by Lowrance et al. (1998). The authors attributed effectiveness of grass buffers to the higher soil cohesiveness of herbaceous roots compared with those of large woody plants.

Riparian grasses may possess additional benefits for soil stabilization. Foster et al. (1980) measured high soil nutrient losses in an old-field succession planted with ragweed (*Ambrosia* sp.) due to increased nutrient uptake presumably by the ragweed. This suggests that the establishment of grasses may provide the element of nutrient uptake lost through the removal of tree species, which would eliminate the possibility of nutrient loss due to leaching. In contrast, some grasses possess characteristics that can inhibit nitrification, thus decreasing the amount of that form of plant available nitrogen and therefore making nitrogen susceptible to nutrient loss or export from the system. Purchase (1974) observed a reduction in normal levels of nitrification in grasslands that exhibited a phosphorus deficiency. Additionally, some grasslands are known to inhibit nitrification because of root exudates from the grasses (Munro 1966). More work needs to be conducted to fully understand the contributions herbaceous vegetation make to the recovery of nutrient budgets following harvesting activity in riparian areas.

In summary, headwater riparian areas possess many of the same underlying characteristics (i.e. flooding regime, fluvial input and export of nutrients, high productivity and nutrient uptake) as the large flood plains but function uniquely in their own right and provide a valuable asset to the maintenance of water quality. Low-order intermittent stream systems are often subjected to greater management intensity and the reaction of the system to the disturbance and how it affects downstream systems is not well understood. Low-order systems need to be evaluated for the potential benefits they are capable of producing by enhancing water quality and providing a buffer from anthropogenic management, particularly that of forestry as well as producing a valuable element of renewable natural resources.

The focus of this research is in response to the lack of Alabama BMP guidelines specific to intermittent SMZs and stream systems. My research investigated the influences of silvicultural management on the nutrient dynamics of intermittent SMZs, and the degree to which those impacts affected streamwater chemistry. Development of rudimentary models of nutrient use, circulation, and loss would most accurately identify the biogeochemical parameters most affected by silvicultural management. Unfortunately, the southeast experienced a lengthy drought during the implementation and life of the study that prevented adequate response sampling of the water chemistry parameters necessary for such models. However, evaluation of terrestrial (i.e. soil and vegetation) responses to different management regimes allowed for broadly accurate interpretations of nutrient fate and likely influences on in-stream water chemistry. The objective of my study was to 1) evaluate and apply the above interpretations to management of SMZs, and 2) make determinations on BMP design and effectiveness as it relates to intermittent stream systems.

STUDY SITE

The 3 experimental watersheds are located in southwest Alabama in the Coastal Plain physiographic region near Monroeville, AL. The watersheds, 10-30 ha in area, are intermittent drainages within the Alabama River Basin (Figure 1). Each drainage flows through a Streamside Management Zone (SMZ). SMZ soils consist of Atmore silt loams and Malbis loams, range in pH from 5.0-6.1, exhibit no significant differences in nutrient content, and are characteristic to the region, and slope does not exceed 10% (USDA 1986) (Table 1). Soils are characterized as deep and poorly drained with moderately low organic matter and experiencing low to no flooding frequency. Upland soils within the experimental watersheds consist of Bama sandy loams, Malbis fine sandy loams, and Escambia very fine sandy loams. Upland slopes do not exceed 10% and soils are typically well-drained and low in organic matter. The watersheds are composed of midrotation even-aged loblolly pine plantations in the uplands and uneven-aged mixed deciduous hardwoods dominated primarily by water oak (*Quercus nigra* L.), swamp laurel oak (*Quercus laurifolia* Michx.), sweet gum (*Liquidambar styraciflua* L.), sweet bay (*Magnolia virginiana* L.), tuliptree (*Liriodendron tulipifera* L.) and loblolly pine (*Pinus taeda* L.) in the SMZs (USDA 2006). The watersheds contained SMZs approximately 15m in width (Figure 1). SMZ width determination is typically based upon slope, soil permeability, upland management disturbance, depth to water table, and rainfall (Altier et al. 1993). SMZs were of natural regeneration and consistently designed with respect to the latter considerations.

METHODOLOGY

HARVESTING MANIPULATIONS

A paired watershed approach was utilized. Three watersheds in close proximity, exhibiting similar slope, aspect, soil qualities, vegetative communities, and intermittent streams were chosen. Among 3 SMZs, situated in separate drainages, one was subjected to a clearcut, one a partial cut, and the final SMZ to remain intact as a reference. The study watersheds were assumed to be similar enough that differences can be attributed to the treatments and compared to the reference.

The reference SMZ received no harvesting activity and was used as a control. The second SMZ received a partial cut with an approximate 33% decrease in basal area chiefly determined by the removal of selected trees based upon species and size of tree (primarily large *Liriodendron tulipifera*). The third SMZ was a clearcut. The upland pine plantations received a 40% thinning across all 3 watersheds. All harvesting activities were conducted in summer 1999. No post harvest site preparation operations (i.e. fire, herbicides) were used, and cut areas were allowed to naturally regenerate.

HERBACEOUS VEGETATION SURVEY

In April and September 2000, herbaceous vegetation surveys were conducted on each study watershed. A technique similar to that used by Locasio et al. (1991) was employed. Two transects approximately 50-m long were laid parallel to each side of the stream. Five sampling areas (0.5 m^2) were established every 10 m and ~5-10 m away from the stream along each transect. All monocots were classified as grasses and all forbs and woody species were identified to species whenever possible. All vegetation was separated into grasses, forbs, and woody plants, and then weighed for biomass and analyzed for C, N, and P concentrations. C and N concentrations were measured by thermal combustion using a Perkin-Elmer 2400 CHN Analyzer for each collection period. P concentrations were determined colorimetrically using an ammonium vanadate solution on an HCl extract following dry-ashing at 400˚C for 4 hours (Jackson 1958). Concentrations of C, N, and P were then multiplied by the weight of samples for each collection period to determine C, N, and P content of the samples. Dry weight results were paired with litterfall biomass and aboveground woody biomass values to obtain a true postharvest index of aboveground net primary productivity. Nutrient analyses were combined with litterfall and decomposition values to continue to establish a rudimentary nutrient budget. Comparisons were also made in vegetation composition in terms of % frequency of species across each SMZ.

ABOVEGROUND NET PRIMARY PRODUCTIVITY

Aboveground woody biomass was estimated for both pre- and post-harvest values for each SMZ. Five 0.02-ha plots were established on each SMZ within the treatment area. Each tree > 5 cm dbh was measured for dbh and species was determined and recorded. Dry weight per tree was determined based on regression equations for each species found in Clark et al. (1985) and Clark and Taras (1976).

SOIL TEMPERATURE

Two Onset® soil temperature data loggers were placed at a 10-cm soil depth in each SMZ and soil temperature measured and recorded on an hourly basis. A deployment soil depth of 10 cm was used to account for soil temperature influences on decomposition processes while reducing the influence of air temperature on data recordings. This depth in the soil column is considered to contain the highest levels of oxygen and organic matter, providing ideal habitat for microbial populations (Bormann and Likens, 1979). Initially, the soil temperature loggers were used to verify the similarity shared by the 3 watersheds. Following harvest manipulations, loggers were used to monitor differences that were induced by the loss of canopy cover and the resulting increased solar insolation and its effects on soil temperature.

LITTER PRODUCTION AND NUTRIENT DYNAMICS

SMZ litter was collected monthly to estimate the litterfall component of annual aboveground net primary productivity (ANPP). Litter was estimated through monthly collections from ten 0.5-m^2 litter traps placed systematically within each SMZ. Traps were placed in the field 1 year prior to the harvest (September 1998). Five of the traps were placed on each side of the streams at ~10-m intervals upstream from the downstream end of the study reach. Monthly litter was collected, air-dried, and weighed. Random 5-g samples were oven-dried at 70ºC, moisture loss was determined, and then dry weight was estimated for the entire litter collection of the month for each watershed. Litter samples were then ground and analyzed for C, N, and P concentrations. oncentrations of C,N, and P were then multiplied by the ash-free weight of samples for each collection period to determine C, N, and P content of the samples. These determinations were combined with decomposition characteristics to quantify nutrient cycling rates specific to each SMZ.

The litterbag technique of Swift et al. (1979) was used to make determinations of decomposition rate and N, P, and C dynamics as they relate to decomposition. Litterbags (30.5 cm x 45.7 cm, with 6-mm and 2-mm openings on the upper and lower sides, respectively) were filled with 20 g of mixed species air-dried litter as regulated by the litterfall composition collected within each SMZ (Table 15). These litterbags were used to determine the decomposition dynamics specific to and within each SMZ. A second set of bags was assembled using 20 g of 'traded' mixed litter according to the litterfall composition common across all 3 SMZs. This litter consisted of the 5 most common species occurring across all 3 SMZs based on the specific litterbag composition of each SMZ (Table 2). Traded litter was used to eliminate litter quality as a variable when making comparisons among SMZs. There were 12 collections of litterbags in weeks 0, 2, 4, 6, 10, 18, 26, 36, 46, and 60. Three bags were collected on each collection date from each SMZ and for specific and traded litterbags.

Upon collection, litter was oven dried at 70º C, weighed, and ground to pass through a 20-mesh sieve. It was then analyzed for C, N, and P concentrations, as previously described. Concentrations of C, N, and P were then multiplied by the ash-free weight of samples for each collection period to determine sample C, N, and P content. The resulting data were compared with litterfall nutrient analyses and used to differentiate the fates of nutrients among SMZs.

STATISTICAL ANALYSIS

HERBACEOUS VEGETATION

Response variables included analysis of relative frequency of species, total biomass, woody plant biomass, forb biomass, and grass biomass. The total number of species encountered was measured for each treatment and used to determine successional differences in diversity following SMZ treatments. All biomass measurements (total, woody plants, forbs, grasses) were compared within sites among reference and treatment SMZ means using ANOVA (α=0.05). Biomass was then compared across sites using ANOVA, and Duncan's New Multiple Range Test was used to compare means (SAS 1991).

SOIL TEMPERATURE

Daily ranges of soil temperatures for each SMZ treatment, based on maximum and minimum values, were determined. Daily means for each hour of the day were initially determined. Based on these values, the hour typical of the daily maximum soil temperature (i.e. noon) and the hour typical of daily minimum temperature were chosen. Means were determined for these hours for pre- and postharvest years and also separated within seasons. Comparisons of these means were made using Duncan's New Multiple Range test and ANOVA (α=0.05) (SAS 1991).

LITTERFALL AND DECOMPOSITION

Response variables include % mass, N, and P remaining as well as mass loss rate (*k*). Based on measurements of the last collection, ANOVA for the % mass, N, and P remaining with site (reference, partial, clearcut) as the primary treatment variable were conducted. Comparisons were made with reference vs. partial cut, reference vs. clearcut, and partial cut vs. clearcut, and Duncan's New Multiple Range test ($\alpha = 0.05$) was utilized to compare means of these results. Comparisons among traded vs. specific litter were accomplished through the use of *t*-tests within a site. *k* was determined using nonlinear, negative exponential regression and compared across treatments using ANOVA, with site as the primary treatment variable (SAS 1991).

RESULTS

PRODUCTIVITY

Herbaceous Vegetation

Biomass

Means from the undisturbed reference, the April 2000, and the September 2000 sampling periods for all 3 vegetative components across all 3 SMZ treatments are listed in Table 2 and Figure 3. The only significant difference during the reference sampling period was observed in the forb component of the reference SMZ. Forbs contributed a significantly higher percentage of total herbaceous biomass in the reference versus the partial cut and clearcut SMZs.

The first post-treatment sampling in April 2000 showed significant differences in both the forb and grass components of the clearcut SMZ. The grass component of the clearcut exhibited a pulse in productivity resulting in a significantly higher biomass value (159.37 g/m^2), than the reference and partial cut, supporting a strong treatment response.

The September 2000 sampling period revealed significant responses in biomass production in the clearcut SMZ (Table 3). Significant differences in biomass were measured for all 3 vegetative components. The partial cut SMZ exhibited a decrease in woody plant biomass from the April to the September sampling periods.

Comparisons across sampling periods within SMZs showed the grasses component in the April 2000 sampling period of the reference SMZ to be significantly different (Table 3). For the partial cut SMZ, the woody plants component of the April 2000 sampling period was the only significantly different mean. For the clearcut SMZ, the September 2000 forbs was the only component to differ significantly. All 3 components of the September 2000 sampling period were significantly different from those of the reference sampling period.

In contrast, grasses in the reference SMZ increased from the reference to the April sampling periods, and then decreased in the September sampling below those initially measured in the baseline sampling of the reference (Table 3).

The clearcut SMZ exhibited consistent increases in all three vegetative components across all three sampling periods. The highest values for all components were measured in the September sampling followed by the April and reference, respectively (Table 3).

A summary of combined totals of all vegetative components for biomass are illustrated in Table 3. In terms of biomass for the reference sampling, all 3 SMZ totals were relatively close.

C, N, and P Dynamics

As expected, total C content of vegetation tracked those of biomass in the SMZ treatments (Tables 2, 3, and 4 and Figures 3 and 4). In the reference sampling period, the only statistically significant mean was that of the forbs component in the reference SMZ (Table 4 and Figure 4). Following harvests, forb and grass means for the clearcut SMZ were different from other treatment means in the April sampling period. This result was similar with results measured for biomass. In relation to the September sampling period, the clearcut exhibited significant means for all 3 vegetative classes across treatments, paralleling the trends observed with biomass. In terms of comparisons across sampling periods and within SMZ treatments, the same trends as those observed in biomass were observed for C. Unexpected decreases in C content over time in the grass component of the reference SMZ and the woody plant component of the partial cut, both of which increased during April sampling before dropping below reference baseline levels. Total C content values were higher for each successive sampling period observed over time for the clearcut SMZ, similar to those of biomass (Table 3). The same unexplained decreases in value were observed for the reference and partial cut SMZ from the April to the September sampling periods.

Nitrogen content in the forb component of the reference SMZ was the only significantly different value observed in the baseline reference sampling period (Table 5 and Figure 5). Prior to harvests, N content of forbs in the reference SMZ was higher than those measured in the partial cut and clearcut. The forb component of the reference SMZ decreased over time, as did the grass component. Following harvest, forbs and grasses in the clearcut SMZ responded to the treatments by increasing in N content; grasses N in the partial cut also exhibited an increase. Over time, significant increases in N content were observed for all 3 vegetative components in the clearcut (Table 5 and Figure 5). Unexpected decreases in N content of the woody plants in the partial cut indicate similar proportionality with biomass and C. As previously mentioned, significant decreases in the nitrogen content of grasses in the reference SMZ also were observed, whereas the resulting content of grasses in the partial cut and clearcut were significantly higher in this treatment. With respect to combined N content of herbaceous vegetation (Table 3), all SMZs increased in content over time with the exception of a decrease measured in the partial cut from the April sampling to the September sampling.

Comparisons of total P content are illustrated in Table 6 and Figure 6. Phosphorus content in forbs of the reference SMZ was the only significant value measured during the reference period. This result is consistent with biomass and total C and N content values previously discussed. Following the harvest, forb and grass components of the clearcut were significantly different from values measured in the other SMZs but were not significantly different from the baseline values in the clearcut. For woody plants, the clearcut and partial cut SMZs were significantly different from each during the September 2000 period, and the forbs component of the clearcut SMZ also was significant. The partial cut exhibited an increase in woody plant P content following the harvest but eventually recovered over time. Treatment responses in the clearcut were most evident following the September period where woody plant and forb components were significantly different both among SMZs and over time.

Total C content values (combined content of vegetative components) tracked biomass relatively closely (Table 3). Total N and P content results displayed contrasting trends with respect to C content and exhibited a strong treatment effect. Following the reference sampling, content values were similar and totals ranged from 0.72 to 0.41 g/m^2 and 0.09 to 0.06 g/m^2 for N and P, respectively.

Plant Richness

Difficulty and uncertainty in identifying seedlings and grasses to species resulted in determinations of richness based only on broad comparisons of genera. Obviously, this measure of richness is not wholly accurate because of the potential for high species richness occurring within a genus. This measurement of richness was utilized only to broadly illustrate variations in vegetative succession that resulted from the different SMZ treatments. Baseline reference sampling, conducted downstream of the study area in April 2000, indicated the highest richness in reference and partial cut SMZs, with 18 genera in each treatment (Table 10). Recorded during initial post-harvest sampling in April, the partial cut SMZ had the highest number of genera (38) followed by the clearcut (25) and reference (15) SMZs, respectively. In the September 2000 sampling period the clearcut SMZ had had the most genera followed by the partial cut and reference SMZs, respectively. In each sampling period and each SMZ treatment, the most genera were classified as woody plants followed by forbs and grasses, respectively.

Litterfall

Biomass

Nine-month means across all 3 SMZs were not significantly different during the preharvest sampling period (Table 11). The reference, partial cut, and clearcut SMZs exhibited litterfall amounts of 738.4, 544.7, and 558.6 g / m^2 / 9 mo, respectively. In contrast, postharvest biomass values were significantly different across all 3 treatments (Table 11). Significant differences were found for both the partial cut and clearcut treatments compared with the reference (Table 11 and Figure 7).

C, N, and P Dynamics

Preharvest values for total C, N, and P content were not significantly different across SMZs (Table 11). Post-harvest means were significantly different among treatment SMZs for all nutrient response variables investigated. Values for the treatment SMZs also were significantly different among pre- and post-harvest comparisons, except for total N content of the partial cut SMZ. The post-harvest content was not statistically significant from the preharvest content. One trend that developed throughout the post-harvest was that all nutrient content levels were highest in the reference SMZ, followed by the partial cut and then the clearcut SMZs (Table 11).

Litter Quality

Carbon:nitrogen (C:N), nitrogen:phosphorus (N:P), and carbon:phosphorus (C:P) ratios for all three harvesting treatments are listed in Table 11. Preharvest C:N and N:P means of litterfall exhibited no statistically different figures. The partial cut SMZ C:P resulted in a preharvest value significantly different from other SMZs. Conversely, postharvest C:P were not significantly different across treatments in contrast with clearcut SMZ C:N and N:P. N:P across treatments and within SMZs were significantly different across all three treatments. C:N and C:P were only significant with respect to the partial cut SMZ (Table 11).

ABOVEGROUND NET PRIMARY PRODUCTIVITY

Preharvest measurements of aboveground net primary productivity (ANPP) yielded values ranging from 982.7 g/m^2 in the clearcut to 1700.3 g/m^2 in the reference SMZ (Table 12). Postharvest measurements increased for the Reference SMZ, decreased for the partial cut and decreased for the clearcut SMZ (Table 12).

DECOMPOSITION

Soil Temperature and Rainfall

Monthly mean diurnal soil temperature differed between pre- and postharvest measurements across all 3 SMZs (Figure 2). As expected, the clearcut SMZ exhibited the greatest differences, followed by the partial cut and reference SMZs, respectively. The pre-harvest year, 1998, exhibited more consistent monthly means than the postharvest year, 2000. This pattern could be explained by the greatly reduced rainfall that occurred in 2000 compared with prior years of the study. The consequent decrease in soil moisture content could have increased insolation on soil temperature because of lower soil moisture content and, thus, lower resistance of soil to changes in temperature. In addition, no overbank flooding events occurred at any of the SMZ study sites.

Mass Dynamics

Temporal patterns of mass loss for traded and specific litter were modeled using an exponential decay function for each SMZ treatment (Table 14). Traded and specific litter both exhibited highest rates of mass loss in the reference SMZ followed by the partial cut and clearcut SMZ, respectively. No statistical differences in decay rates were found between litter types. Decomposition rates for the reference SMZ were fastest for the specific litter and slowest among the partial cut and clearcut SMZ. Little difference between the partial cut and clearcut SMZs were observed with the traded litter.

Comparisons of percent mass remaining for traded and specific litter at 60 weeks were consistent with trends exhibited by mass loss rates for both litter types and SMZ treatments (Table 14). Statistically significant values were exhibited by the specific litter for both the reference and clearcut SMZs. Traded litter exhibited no statistical differences across all three experimental SMZs (Table 14).

Temporal patterns of mass remaining showed similar trends of mass loss across all treatments, except for an unexpected increase in percent mass remaining at week 26 (Figure 8). Initial decomposition rates were relatively high, but generally decreased over time.

C, N, and P Dynamics

The temporal pattern of percentage of original C remaining (Figure 9) and the percentage of original C remaining at week 60 (Table 15) mirrored those of percent mass remaining.

The percentage of original C remaining in the reference SMZ at week 60 was significantly different from partial cut and clearcut SMZs (Table 15), but no statistical differences were measured between litter types (Table 15).

An overall increase in percent N remaining after 60 weeks was observed as a result of a cyclic pattern of both mineralization and immobilization with the exception of both litter types in the reference SMZ (Figure 10). Litter types exhibited similar percentages across all SMZ treatments. The reference SMZ exhibited a pattern of mineralization after week 26, with the specific litter dropping below 100 % N remaining after 60 weeks (Figure 10). The partial cut SMZ exhibited a decrease in percent N remaining at weeks 6 and 60 across both litter types (Figure 10). The clearcut SMZ exhibited trends similar to that of the partial cut SMZ except for a decrease beginning at week 26 in the clearcut SMZ specific litter treatment (Figure 10). Overall, N dynamics were dominated by patterns of immobilization as percent N generally exceeded 100 % over 60 weeks, except for the specific litter reference SMZ.

Spikes of brief P accumulation were observed at week 10 in percent P remaining followed by a return to a steady decrease by week 26 across all treatments for both litter types (Figure 11). Overall, a pattern of net P mineralization was observed. The percentage of original P remaining at week 60 exhibited no statistical differences across treatments for both litter types (Table 15).

Litter Quality

C:N of decomposed litter exhibited significant differences between litter types for all SMZs (Table 16). Initial (week = 0) ratios for traded litter and specific litter ranged from 77.3 to 82.5 and 85.8 to 130.3 across SMZs, respectively (Table 16). After 60 weeks, traded litter and specific litter ratios ranged from 26.3 to 34.3 and 34.0 to 54.8 across SMZs, respectively (Table 16). Comparisons of specific litter ratios at 0 and 60 weeks exhibited a narrowing trend over time across all 3 SMZs (Table 16). Conversely, ratios were significantly widened in the reference and clearcut SMZ and significantly narrowed in the partial cut SMZ for the traded litter (Table 16). After 60 weeks, C:N for traded litter in the reference SMZ significantly differed from other treatments within the same litter type (Table 16). Specific litter in the clearcut SMZ was also significantly different than the other treatments following 60 weeks (Table 16).

The only significant differences observed for N:P were between initial and those following 60 weeks across all SMZ treatments and for both litter types (Table 17). Initial N:P ranged from 5.1 to 5.8 and 4.4 to 5.2 across all three SMZ treatments for traded and specific litter types, respectively (Table 17). Sixty week N:P ranged from 9.1 to 9.9 and 7.6 to 8.9 across all SMZ treatments for traded and specific litter types, respectively (Table 17). Within SMZ treatments and litter types, N:P significantly widened over 60 weeks (Table 17).

DISCUSSION

PRODUCTIVITY

Herbaceous Vegetation

Biomass

One of the concerns with forest harvesting operations is that of reduced streamwater quality from transport of sediment across the riparian zone. Immediate re-establishment of vegetation following harvest can rapidly reduce erosion potential and sediment entering streams (Messina et al. 1997). Re-vegetation, particularly herbaceous vegetation and root and stump sprouting of woody plants, can provide a physical barrier during heavy rain events that maintains surface roughness and slows surface transport of sediment. In addition, rooting of such vegetation near or at the stream bank can provide a stable substrate that will reduce or prevent streambank erosion (Simon and Collison, 2002).

Woody plant and grass biomass was similar across all 3 SMZ treatments supporting the strong comparability of my study's paired watershed approach. Furthermore no differences in woody plant biomass were observed across all 3 SMZs. The greatest biomass of herbaceous vegetation occurred in the clearcut SMZ for both postharvest sampling periods followed by the partial cut and reference SMZ, respectively (Table 3). Differences among treatments could be observed in patterns of biomass change across the sampling periods (Table 2 and Figure 3). In the partial cut SMZ, April 2000 sampling period revealed only a significant difference in woody plant biomass, reflecting a probable influence of stump sprouting and germination of seeds within the seed bank. The harvest, which occurred in late summer of the previous year, most likely resulted in removal of vegetation before many of the woody species had fruited out. Therefore, any woody species that sprouted may have been the result of dormant seeds banked from previous growing seasons. The remaining trees probably shaded the SMZs and impaired the establishment of many herbaceous species, eliminating competition for woody sprouts.

In the clearcut SMZ, biomass values significantly different from the reference sampling period were not measured until the September sampling, at which time biomass of all 3 vegetative components had greatly increased. Following an entire growing season, herbaceous vegetation had become abundantly established in both treatment SMZs by September (>1 year post- harvest). The clearcut SMZ possessed ~5 times more herbaceous vegetation biomass than the partial cut and reference SMZs in September 2000 (Table 3). At that time, the clearcut SMZ exhibited biomass values approximately twice that of the previous sampling period and ~13 times that of the reference sampling; the grass component accounted for most of this biomass. As the postharvest growing season progressed, the secondary succession vegetation of the clearcut SMZ gradually became denser and contributed to increased nutrient uptake supported by increased C, N, and P content. Accumulation of the nutrients by the vegetation removes them from the soil environment ultimately reducing the content that would be subject to export via sedimentation or leaching.

The partial cut SMZ, which actually decreased slightly in biomass from April to September, increased overall approximately twice that of the reference sampling period. The unexpected decrease in biomass might be explained by a significant shift in vegetative dominance as the woody plants began to re-establish and annual grasses and forbs began to die back. In fact, a stratification of woody plant biomass occurred across all 3 SMZ s with the clearcut exhibiting the highest values followed by the reference and the partial cut, respectively. Evidence of this shift is presented as biomass values of the respective vegetative components in Table 2 and Figure 3.

No treatment was imposed on the reference SMZ, so the shift in vegetative dominance and biomass between the April and September sampling may be explained by the phenology exhibited by many of the grass species. Many of the grasses had completed their annual life cycle and were therefore absent from the September vegetation. Grasses in the treatment SMZs were likely to be early successional species capable of late season growth. Prolonged subsistence of such species would be expected to be more pronounced with the increased solar exposure and soil moisture. Regardless, the increase in herbaceous biomass for either the partial cut or clearcut SMZ is not comparable to the biomass lost with the whole tree harvest (Table 12).

The dense vegetation of the clearcut SMZ is likely to be effective as a physical sediment trap or a source of streambank stability (Lockaby et al. 2005). The early establishment of the woody plant component in the partial cut, possibly attributable to stump and root sprouts, may contribute to soil stabilization and an increase in surface roughness and nutrient uptake (Lowrance et al. 2000). However, the herbaceous vegetation in the clearcut likely serves as the most significant accumulator of sediment filtrates (Lowrance et al. 2000, Parkyn 2004).

C, N, and P Dynamics

It has been suggested that for southern forested wetland systems to retain and cycle nutrients efficiently through plant uptake periodic harvests are necessary to retain high uptake rates (Lowrance, 1984, Walbridge and Lockaby 1994). Loss of nutrients from the terrestrial system can potentially reduce stand productivity in the following years because of nutrient limitations. Transport of those nutrients into streams may cause eutrophication, a situation that typically results in an adverse shift in aquatic biota composition (Horne and Goldman 1994). However, export of C from forested watersheds is a normal and necessary function and drives productivity within aquatic food webs. A direct comparison of total biomass and total C content revealed a similar dynamics between the two indices. Rapid aggradation of C stocks were evident as herbaceous production was directly related to harvest intensity

High density of vegetation will provide the potential for high plant uptake of N. Unfortunately, N is susceptible to leaching and export from the system, thus any surplus that cannot be utilized by the plants is left to the fate of the soil system; soils saturated in N content will not be capable of absorbing available N thus leaving the nutrient unbound to soil aggragates and susceptible to leaching and off-site transport. In this case, nutrients were, in fact, susceptible to leaching and riparian transport following rain and flood events. This situation may not necessarily be unfavorable for the terrestrial system, but it represents a possibly high influx of N to the stream system.

In the April 2000 sampling period grasses assimilated the most N despite their lower biomass. However, there was no significant difference between the values associated with the 2 treatment periods. In the partial cut SMZ, woody plants assimilated the most N in April 2000 and the least in September 2000. However, all 3 vegetative components seemed to contribute evenly to N uptake, despite differences in biomass. The forbs component was the minor exception exhibiting a significant decrease that indicated a reduced N uptake; such a result could indicate N limitation in the system. This difference was observed in the reference SMZ suggesting such an outcome was a result of external environmental stimuli as opposed to a treatment effect. Overall, values for the April and September sampling resulted in an inverse relationship associated with each SMZ treatment (i.e. the greater the silvicultural impact, the higher the nutrient content levels of herbaceous vegetation).

Again, September 2000 sampling of the clearcut SMZ provided significant means for all 3 vegetative components. Interestingly, the grass component had the lowest N content despite possessing the highest biomass. Given the grass component's low assimilation capacity for N and its dominance over the other 2 components in terms of biomass, considerate is possible that N may be limited in the SMZ and that the grass component is being outcompeted for this nutrient by woody plants (Lowrance et al. 2000). The grass component may have been more useful in adding roughness and retaining sediment rather than assimilating N (Lowrance et al. 2000, Lee et al. 2003, Parkyn 2004).

In the September 2000 sampling period, the clearcut SMZ assimilated nearly 6 times more N than the reference SMZ, reinforcing the suggestion of herbaceous vegetation's ability to compensate for the loss in nutrient uptake following the harvest of trees. However the herbaceous component is unlikely to compete with rates typical of a forested system. The partial cut SMZ was approximately equal to the reference SMZ in N assimilation, suggesting a weak treatment effect. The reduced disturbance impact, relative to the clearcut, may not be sufficient to encourage a shift in nutrient allocation by the remaining and newly established vegetation. These speculations are supported by similar results observed by Lowrance and Sheridan (2005). Alternatively, if nitrogen is typically limited in the system, trees that were not harvested may have been able to accommodate the post-harvest increases in N content that may have occurred within the system (Vitousek and Reiners 1975).

P content across all 3 SMZ treatments and sampling periods were not as variable as N or C. The most significant differences among vegetative components was found in the woody plant and forb components of the clearcut SMZ from the September sampling period supporting previous trends of biomass, C, and N. The only significant difference found in the partial cut SMZ was the woody plant component of the April 2000 sampling period and the analogous value for the reference SMZ. This pattern might suggest that P was not necessarily limited as the only treatment effect was measured in the clearcut. However, the September 2000 grass component of the partial cut SMZ exhibited the highest biomass (Table 2 and Figure 3) but had the lowest P content of the vegetative components, despite any statistical significance (Table 5 and Figure 5). Such a result could indicate P consumption by residual trees, or the grass component was simply not an effective assimilator of available P. Collective results of similar studies would support this determination (Vitousek and Reiners 1975, Lee et al. 2003, and Lowrance and Sheridan 2005).

In terms of differences among vegetative components, reference SMZ values for total P content, total N content, and total biomass across all 3 sampling periods exhibited no significant differences. Such similarity suggests that any significant differences found among the partial cut and clearcut SMZs represented a treatment effect. Any significant external or environmental effects would have produced significant differences in the reference SMZ.

Throughout post-disturbance monitoring, treatment values (i.e. April and September 2000 sampling periods of the partial cut and clearcut SMZs) of the grass component exhibited the highest C:N followed by the woody plant and then the forb components, respectively (Table 7).

Plant Richness

High biological diversity functions as an element of balance in regard to ecosystem integrity and the resulting benefits to economic and social sustainability (Grime 1998, Carey et al. 1999), and consequently, maintenance or encouragement of vegetative diversity is recommended as a postharvest objective (Carey et al. 1999). In terms of ecosystem integrity, especially that of riparian areas, natural regeneration of native species can provide the qualities sought after by land managers, specifically maximum nutrient uptake and re-establishment of shade to buffer diurnal stream temperatures. In relation to wildlife habitat, vertical stratification of several types of vegetative classes will ensure habitat suitable for a variety of species in terms of shelter, cover, and food (Keyser et al. 2003).

Reference sampling across all 3 vegetative components yielded very similar stratification, in terms of relatively equal grasses, forbs, shrubs, and trees occurrence, as well as abundance, biomass, and generic richness (Table 3). These systems were determined to be relatively mature stands made evident by the age of pre-harvest trees and by the woody plant component showing the greatest diversity and abundance, followed by the forb, and then the grass components.

April 2000 sampling suggested a shift in vegetative richness. Biomass remained highest in the woody plant component, but the number of genera sampled increased relatively equally across all 3 vegetative components. In contrast, September 2000 sampling revealed a decrease in total biomass of the woody plant and forb components for the treated areas and a significant increase of the grass component. However, plant richness as a whole did not increase. Locasio et al. (1991) observed similar results, where distribution of and diversity of plants was not significantly different across silivicultural treatments. This result suggests a shift in vegetative components rather than the establishment and proliferation of seral species (Locasio et al. 1991).

Litterfall

Biomass

Preharvest values across all SMZ treatments were consistent with those found in previous studies of riparian and floodplain systems over 1 year in relation to the 9-mo collection interval of my study (Bell et al. 1978, Bray and Gorham 1964, Day 1982, Peterson and Rolfe 1982, Shure and Gottschalk 1985) (Table 11). Postharvest litterfall was consistent with harvest intensity. Comparisons of preharvest and postharvest values within the reference indicated stable litterfall mass between years. Litterfall in the partial cut decreased 34% and was consistent with the 33% decrease in basal area that occurred from the partial harvesting treatment. The litterfall in the clearcut decreased by 78% and, again, this reduction reflected a directly proportional loss in SMZ canopy and basal area.

C, N, and P Dynamics

Postharvest nutrient content was consistent with the imposed treatments and well correlated with postharvest litterfall mass. Decreases that were observed in the reference SMZ may reflect the changes in upland contributions to the SMZ following upland thinnings. Alternatively, the drought that occurred during the study may have resulted in decreased assimilation rates of N. As a result, N may have become more limited as less inorganic N was available. Preharvest litterfall N content is consistent with previous studies of wetland and floodplain forests (Brinson 1980, Peterson and Rolfe 1982). Postharvest values were also consistent with the treatments imposed upon the SMZs. Statistically significant differences were observed within the partial cut and clearcut SMZs in relation to pre- and postharvest values while no significant differences were measured in the reference SMZ (Table 11 and Figure 7). This result suggested a treatment effect that likely reflects variations with nutrient content directly associated with differences in total biomass. Variation in total P content also reflected treatment intensity and was likely a function of total litterfall biomass.

Litter Quality

Day (1982) suggested that wide C:N and low N and P concentrations could cause low decomposition rates. In relation to other studies in P-limited systems, C:N values for Day's studies (42 for mixed oak) were remarkably wide (Brinson 1977, Day 1982). The high C:N encountered in the Day (1982) study suggested the potential for immobilization as a result of N limitation (Table 11). In relation to pre- and postharvest comparisons, the reference and partial cut SMZ exhibited significant differences within SMZs (Table 11).

The initial specific litter C:N for the reference (91.32) and partial cut (85.77) decreased by 13.5 and 15.3%, respectively, following harvest treatments. However, the postharvest ratio for the clearcut was not significantly different from that of the preharvest, although the numerical difference was large (17%).

Aboveground Net Primary Productivity

ANPP measurements demonstrate the impact of the imposed silivicultural treatment on each SMZ (Table 12). Postharvest measurements increased for the reference SMZ, decreased slightly for the partial cut SMZ, and decreased dramatically for the clearcut SMZ, patterns that would be expected given the gradation of disturbance associated with each treatment. The reference SMZ, as expected, increased in woody biomass from the reference sampling to the 2000 sampling and then on to the 2001 sampling by 12.3% (from 1700.30 to 1938.69 tons/acre) and 2.6% (from 1938.69 to 1989.48 tons/acre), respectively. This result may reflect drought effects imposed on productivity made evident by reductions in the 2001 productivity rates compared to those of the 1999 and 2000. The partial cut and clearcut decreased by 7.9 and 66.2%, respectively, after the first postharvest season. But, after the third season, values increased from the second year by 5.0 and 6.8% for the partial cut and clearcut, respectively. These percent increases were greater than the reference SMZ for the same sampling season and the greatest value exhibited by the clearcut. The spike in productivity was consistent with typical vegetative responses to disturbance (Lockaby et al. 1999, Jones et al. 2000). Higher rates in the clearcut followed by the partial cut and reference, respectively, suggest productivity responses that are consistent with the disturbance levels of the treatments (see Aust and Blinn 2004).

DECOMPOSITION

Mass Dynamics

The decay coefficient for the reference SMZ resulted in values of k = 1.33 and 1.43 for the traded and specific litter, respectively. These 2 statistically similar values suggested litter quality did not limit decomposition processes within undisturbed areas and pre-treatment conditions. These rates were slightly higher than those presented by Brinson (1990) and averaged by Lockaby and Walbridge (1998) for temperate riverine forests as k = 1.01. The partial cut and clearcut decay coefficients were found in the range of 0.88 to 0.60 and were significantly different from the reference SMZ. Partial and clearcut values were not significantly different, however, higher values were observed in the traded litter for both treatments and the partial cut SMZ had higher values overall, consistent with expected treatment effects. The non-significant differences suggest that litter quality was not a limiting factor in decomposition. However, the higher rates exhibited by the traded litter, while not significant, may be explained by the generally high litter quality inherent to the species composition used in the traded litter, possibly resulting in a litter quality higher than that of site-specific litterfall. Such an outcome might suggest that litter quality is somewhat limited. But species composition differences between specific and traded litter (Table 13) only differed by 2 species (red maple, *Acer rubrum* and yellow poplar, *Liriodendron tulipifera*) of hardwood litterfall in each case. It is unlikely that differences in litter quality would be considerably significant, as demonstrated by traded litter results.

Percentage of original mass remaining (week = 60) for all 3 SMZ treatments closely correlated with those of decay coefficient rates. Values were dissimilar to those reported by Lockaby et al. (1997), who investigated harvesting influences on low-order blackwater streams in the Alabama coastal plain. Results indicated that the highest percentages of original mass remaining, 68.4 and 52.2, were found in the reference site and the treatment site, respectively. Typically, within the temperate southeastern U.S., decomposition rates can increase, decrease, or even remain consistent following harvesting activity (Lockaby et al. 1999). Often though, removal of vegetation increases soil moisture from loss of evapotranspiration and increases soil temperature from loss of shade (Lockaby et al. 1999), both of which are potentially beneficial to increased microbial activity and decomposition of organic matter. This reaction is under the assumption that soil moisture is not limiting.

Because of the widespread drought in the Southeast following the imposition of SMZ treatments, decomposition rates were likely limited by soil moisture deficits. The lack of shade left on each of the treatment SMZs increased soil temperature (Figure 2), but the lack of soil moisture possibly inhibited a quick recovery of vegetation. As a result, soils probably received greater solar input, which, in turn, increased evaporation rates beyond those of the shaded reference SMZ.

C, N, and P Dynamics

N:P at the time of treatment installation ranged from 4.4 to 5.8 across all litter types and SMZ treatments (Table 17). P is considered limited when ratios fall within the range of 10-15 (Lockaby and Walbridge 1998) suggesting P was not limited across SMZs before harvesting manipulations. Following 60 weeks, all N:P increased (7.6 – 9.9) approaching the range of potential P limitation (Table 17). No statistical differences were observed across litter types or treatments suggesting no silviculturally imposed P limitations. These ratios were lower than those reported by several studies across the southeastern US (Brinson 1977, Lockaby et al.. 1996a). Such narrow C:P and N:P, in addition to a trend of P mineralization, suggests that in all 3 systems, despite harvesting manipulations, P was available in the system (Lockaby and Waldridge, 1998). High levels of P content characterize this system as a potential P source. Silvicultural implications of a system as a nutrient source include possible inputs to stream systems that can result in poor water quality (NCASI 200). Alternatively, narrow N:P may also reflect a possible N limitation as well.

The temporal, cyclic behavior of original % N remaining over the 60–wk study exhibited generally alternating trends of immobilization and mineralization across litter types and treatments. These similarities across the different treatments and litter types suggest that N functions were driven by external environmental stimuli shared by all three treatments, most likely soil moisture determined by the lack of rainfall. It is assumed that soil moisture limited N dynamics. Changes in factors influenced by the treatments, such as treatment effects in soil temperature, litterfall abundance and quality, soil disturbance, and evapotranspiration, were masked or decreased by the lack of soil moisture. The drought, which was experienced by all 3 SMZs, was the most obvious external force. Had rainfall been typical, more pronounced differences in treatment effects among the SMZs would have been expected.

These patterns suggested that N was neither in abundance nor in short supply. Brinson (1977) reported C:N in a North Carolina alluvial swamp forest within an initial range of 34-69 gradually decreasing over time to ~15. Brinson (1977) determined that N was generally accumulated and suggested that it was not limiting. C:N of my study at the time of installation ranged from 77.3 – 82.5 and 85.8 – 130.3 for the traded and specific litter, respectively. This suggested that a slightly higher N deficiency existed among the traded litter, but a true deficiency occurs in both litter types and across treatments.

SUMMARY AND CONCLUSIONS

PRODUCTIVITY

Broadly speaking, the herbaceous vegetation survey yielded the highest levels of both biomass and species richness in the clearcut SMZ, followed by the partial cut and reference SMZs, respectively. Consistent with that trend, the highest levels of both biomass and species richness were observed in the September 2000 sampling period, followed by the April 2000 and reference sampling periods, respectively. These results are consistent with plant succession following disturbance (Miller et al. 1995) and riparian community structure (Lyon and Sagers 1998) observed in the Southeast.

In terms of nutrient accumulation, general similarities were observed for the reference SMZ across all sampling periods and for all 3 SMZ treatments during the reference sampling period. Alternatively, increases in both N and P content were observed in the treatment SMZs and generally increased over time. N content increased most dramatically, suggesting a greater abundance of plant available N as opposed to P. The rapid stabilization associated with plant biomass suggests that the treatment induced increase in herbaceous vegetation and nutrient assimilation was compensating for the functions lost with the harvested riparian timber. However, it is doubtful the transpiration rates and nutrient allocation abilities of the herbaceous vegetation could replace those of a forested riparian system in the short term.

Litterfall values among SMZs remained consistent throughout the project. No preharvest statistical differences were observed for nutrient content measurements among all 3 SMZs. Postharvest values of nutrient contents for treatment SMZs were significantly different between SMZs. Treatment differences (pre- vs. postharvest) were also observed within SMZs except for N content of the partial cut. These consistencies indicate that the removal of the riparian timber and, thus, the source of litterfall input, consequently reduced litterfall biomass and nutrient flux within these systems. The pre- and postharvest similarities of total N content in the partial cut SMZ suggests that litterfall may not have been limited by N in the system prior to the implementation of the treatments. However, the partial cut treatment may not have removed enough timber to significantly reduce N levels. Nutrient ratios support this conclusion as the treatment SMZs were significantly different with respect to C:N and N:P, and similar with respect to C:P.

DECOMPOSITION AND NUTRIENT CYCLING DYNAMICS

The rate of decay for both specific and traded litter across all 3 watersheds exhibited statistically significant treatment differences. This result was most likely produced by the reduction in shade and, therefore, increases in solar radiation in the clearcut SMZ, further reducing the soil moisture levels and thus soil decomposition functions. Based on decomposition results, a sufficient supply of N occurred in the systems, whereas P appeared to be possibly limited. The reduced rate of decomposition, exhibited by the partial cut and clearcut SMZs, was expected to further reduce the availability of inorganic P; however, numerical differences occurred but no statistical differences in P mineralization were detected.

No significant differences were observed between traded and specific litter within SMZ treatments for decomposition rate or percent mass, C, N, and P remaining. This result suggests that litter quality did not govern decomposition rates or dynamics. Typically, organic matter of high nutrient content will result in higher decomposition rates as opposed to those of lower nutrient value. As changes in decomposition rates were not measured, it is likely that decomposition rates were determined by external environmental factors such as rainfall level and soil temperature. Additionally, treatment effects were observed among SMZ treatments with no differences in litter quality within SMZs. In terms of nutrient utilization, consistent patterns were observed in C, N, and P dynamics, which reinforce the limitations and availability of the nutrients in the systems. As changes in litter quality would be expected to exaggerate these responses, no differences were observed between litter qualities.

One explanation for the lack of litter quality differences may have been the relative similarities associated between the two litter types. Of the 7 species used to select litter compositions, only 5 species were selected for each litterbag composition type. This difference broadly resulted in 3 common species among litter types and only two main contrasts. The litter bag compositions were designed to reflect the inherent litterfall qualities of each system, and coordinate the similarities shared by all 3 systems, but these differences may not have been sufficient to accentuate the contributions of litter quality to the biogeochemical dynamics of the system. Perhaps a traded litterbag composition of only one species would have provided a wider difference between litter qualities and led to detectable differences within nutrient dynamics.

The absence of an intermittent hydroperiod likely affected the rates of decomposition in the reference SMZ; however, it is unclear how additional soil moisture would influence the partial cut and clearcut SMZs. Without the stimulation of brief inundation, decomposition was most likely driven by temperature and limited by moisture. Cyclic trends of utilization, dominated by immobilization of N and the mineralization of P, appeared to be independent of rain events supporting the contributions of soil temperature as the principle driver of decomposition. It is apparent that litter quality had no influence on decomposition rates across all 3 watersheds.

Postharvest ANPP and litterfall values exhibited by the partial cut and clearcut SMZ were consistent with the treatments imposed upon the SMZs. Decreases in productivity as a result of increased levels of disturbance intensity support this conclusion. Conversely, herbaceous vegetation productivity values were generally directly proportional to levels of disturbance, as the clearcut exhibited the highest values of biomass followed by the partial cut and reference SMZs, respectively. The ability of either residual vegetation, presumably dominated by mid- to late-seral stage species (reference SMZ), early seral vegetation (clearcut SMZ), or a combination of both (partial cut SMZ) to assimilate nutrients and prevent their loss from the site, is of immediate concern following harvesting activities. Attention is often devoted to the revegetation of the site by tree species of value, but impacts to water quality, as well as decreases in site productivity, cannot be ignored.

N has been generally recognized as the most available nutrient across all 3 SMZs and P is typically most limited. Therefore, N is more likely to be found in abundance following disturbance, and most likely to move off site.

By combining values of N content for litterfall and herbaceous vegetation, several rudimentary conclusions can be extrapolated. Specifically, post-harvest comparisons between SMZs will provide an index of N storage and SMZ effectiveness. Such a presumption, however, does not consider storage of nutrients in the boles or woody tissues of mid- to late-seral woody species. However, by considering differences in woody ANPP, inferences can be drawn for nutrient-use by the system.

Pre-harvest or reference values for ANPP, litterfall, and herbaceous vegetation when combined, yielded the highest productivity estimates for the reference SMZ, followed by the partial cut and clearcut SMZs exhibiting comparable values. During the second year following the treatments the reference SMZ had reduced values of productivity, likely attributable to the reduced rainfall for the year. Therefore, post-harvest estimates of productivity, based on values of litterfall and herbaceous vegetation, can be made among SMZs to compare N use efficiencies.

By summing post-harvest N content values for litterfall and herbaceous vegetation across all 3 SMZ treatments, the clearcut SMZ assimilated the highest values followed by the reference and partial cut SMZs, respectively. Again, by disregarding the contributions to N storage by the woody tissues of mid- and late-seral species, the clearcut SMZ was able to assimilate the most N despite the intensity of watershed disturbance imposed by harvesting.

This broad conclusion simply states that the clearcut SMZ was able to retain more N than the reference and partial cut SMZ. This conclusion does not consider the stress imposed upon the system by drought or the ability of mature woody tissue to store nutrients. This conclusion does, however, demonstrate the ability of herbaceous vegetation to prevent nutrient loss in the event of intensive harvests. Land managers typically overlook this principle during site preparation of intermittent watersheds as herbaceous vegetation can outcompete seedlings and retard regeneration of sites. Promotion of herbaceous vegetation in SMZs is likely to curb nutrient loss and sustain water quality following harvesting operations. In addition, the high rate of stump sprouting observed during this study (personal observations) will likely result in rapid regeneration of the sites.

With respect to BMP guidelines, and riparian management in headwater coastal plain systems, harvesting of riparian timber could result in the drastic decrease of P content in an already limited system. This limitation, in turn, might result in a reduction in productivity and nutrient cycling, and the likely accumulation of N in the soil. N, then, would be susceptible to rain and/or flood induced leaching.

My study has generally satisfied the goals of its objective, demonstrating that silvicultural management can have direct influences on nutrient dynamics in the riparian system. Limited to the 3 silvicultural prescriptions applied to each SMZ, my study does not provide sufficient interpretation of SMZ dynamics for design of intermittent SMZs. However, the study did emphasize the need for the Alabama Forestry Commission to develop BMPs that include standards and guidelines for intermittent SMZ delineation specific to the purposes of nutrient management and protecting stream water quality during and following harvesting operations.

Table 1. SMZ pre-treatment soil analysis.

SMZ	pH	mg / kg				%	
		P	K	Mg	Ca	C	N
Reference	4.65[a]	1.38[a]	16.38[a]	29.75[a]	118.75[a]	1.23[a]	0.06[a]
Partial cut	4.80[a]	2.13[a]	11.75[a]	10.88[a]	100.00[a]	1.26[a]	0.05[a]
Clearcut	4.73[a]	2.25[a]	14.50[a]	15.00[a]	116.25[a]	1.65[a]	0.07[a]

*Means followed by the same letter are not significantly different at the $\alpha = 0.5$ level.

Figure 1. Dimensions of paired watersheds and SMZs.

	Reference	Partial cut	Clearcut
Stream length:	305.10 m	607.16 m	261.52 m
SMZ area:	2.18 ha	2.30 ha	0.92 ha
Watershed area:	14.03 ha	12.05 ha	8.19 ha
Watershed perimeter:	1489 m	1525.22 m	1318.57 m
Compactness coefficient:	1.11	1.23	1.29
Drainage density:	5.63 km/km	13.05 km/km	88.27 km/km

Reference Partial cut Clearcut

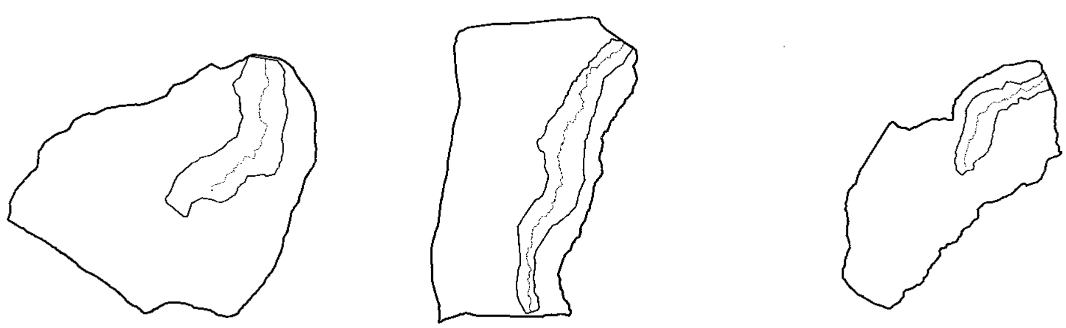


Figure 2. 1998 and 2000 diurnal temperature changes over one year.

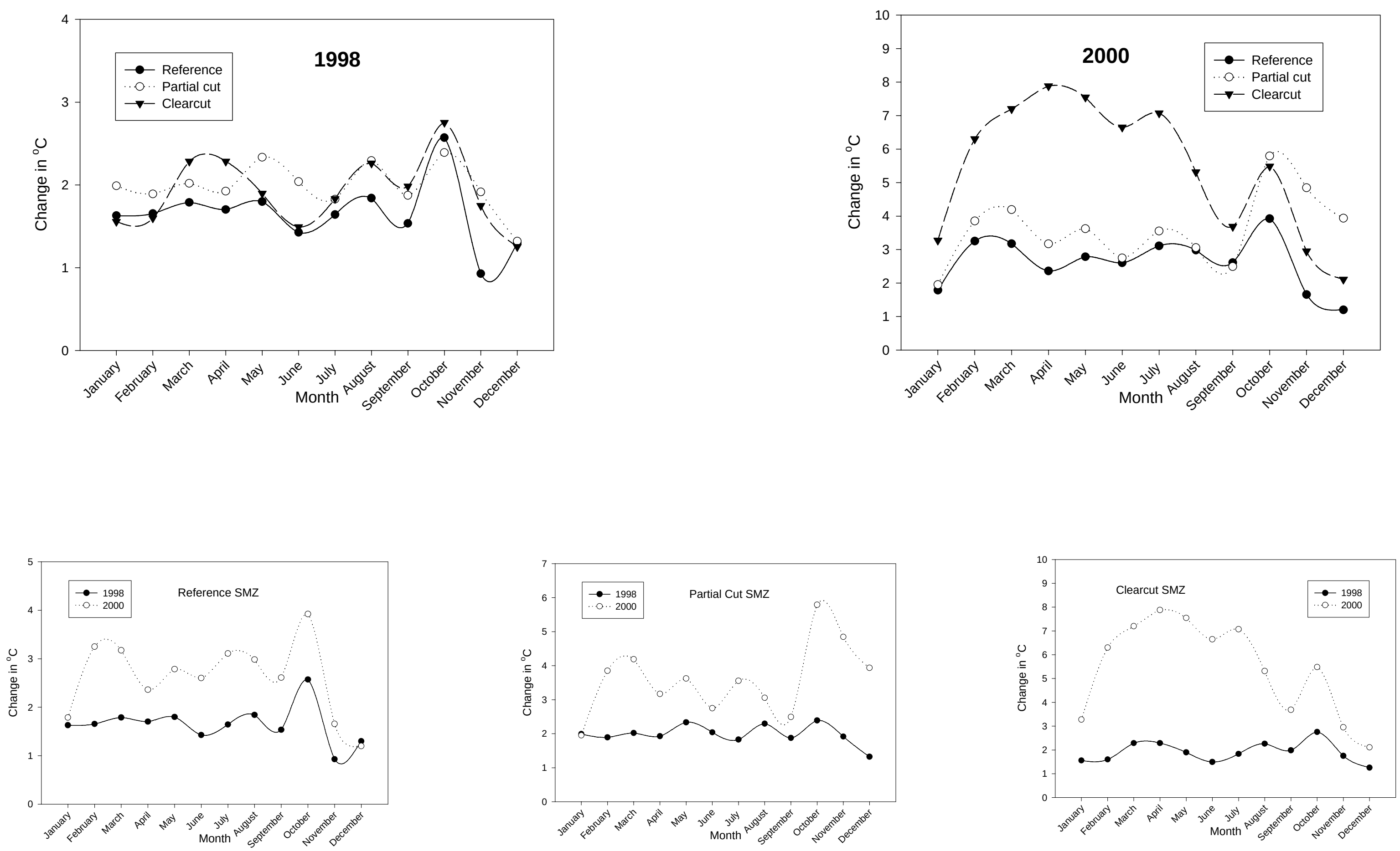


Table 2. Total biomass comparisons of herbaceous vegetation components of 3 postharvest sampling periods across 3 SMZ management treatments. All values are in g / m^2.

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
Reference Sampling			
Woody plants	25.81 A[1] a[2]	30.36 A[1] b	19.79 A[1] b
Forbs	14.12 A a	6.79 B a	1.60 B b
Grasses	4.59 A b	12.93 A a	15.89 A b
April 2000 Sampling			
Woody plants	58.30 A a[2]	93.61 A a	62.77 A ab
Forbs	5.56 A a	2.87 A a	25.10 B b
Grasses	14.20 A a	25.79 A a	159.37 B ab
Sept. 2000 Sampling			
Woody plants	57.49 AB a[2]	24.88 A b	135.97 B a
Forbs	10.71 A a	38.72 A a	156.86 B a
Grasses	2.46 A b	41.36 A a	198.43 Ba

[1]Means with the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within the same sampling periods are not compared.
[2]Means among SMZs and across the three sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within within the same SMZs are not compared.

Figure 3. Total biomass comparisons of herbaceous vegetation components of three postharvest sampling periods across three SMZ management treatments

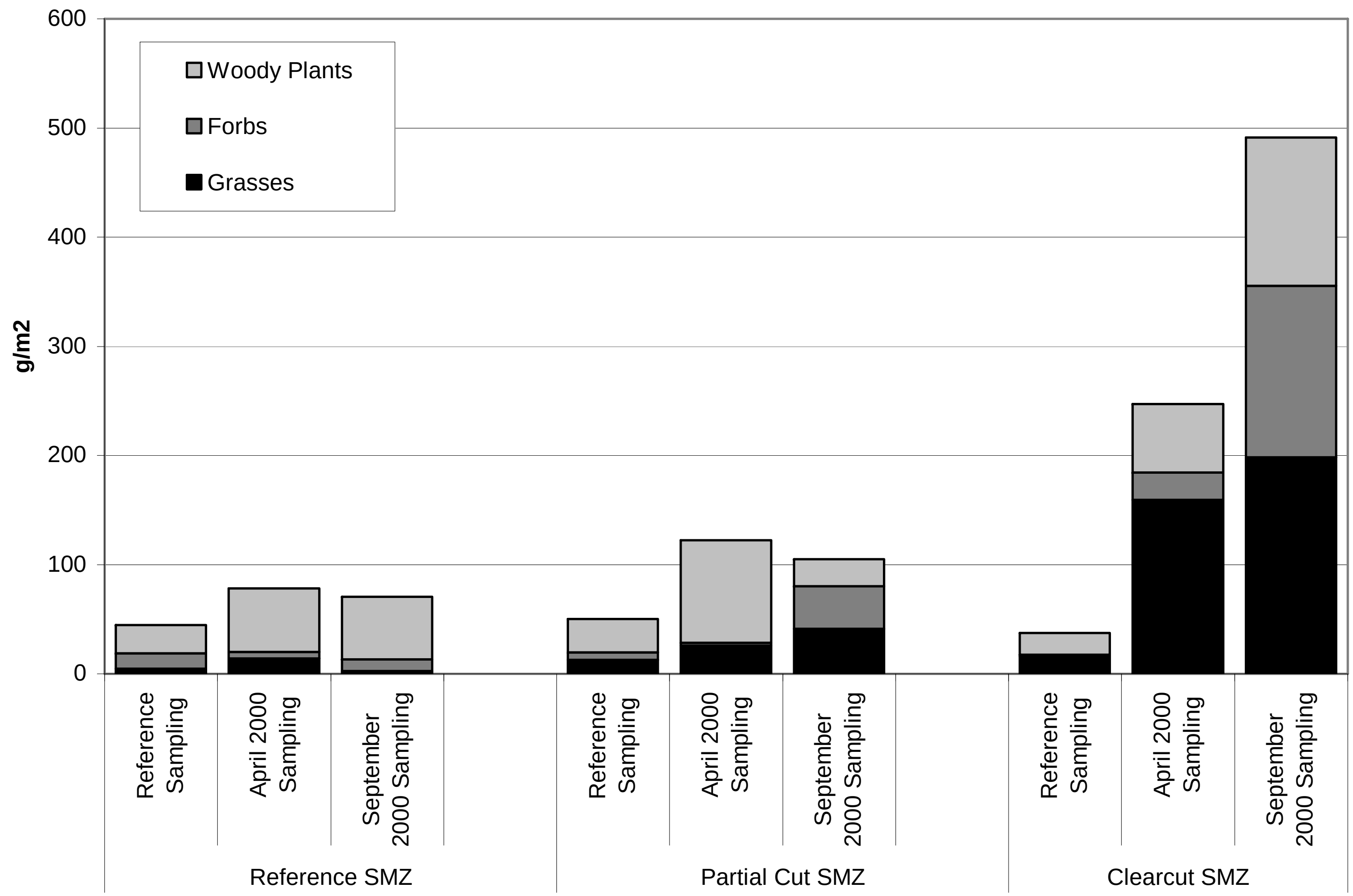


Table 3. Total biomass, and total carbon, nitrogen, and phosphorus content of all herbaceous vegetation components of three postharvest sampling periods across 3 SMZ management treatments. All values are in g / m^2.

	Biomass	Carbon	Nitrogen	Phosphorus
Reference Sampling				
Reference SMZ	44.5 A[1]	20.4 A	0.72 A	0.09 A
Partial cut SMZ	50.1 A[1]	23.2 A	0.57 A	0.08 A
Clearcut SMZ	37.3 A[1]	16.9 A	0.41 A	0.06 A
April 2000 Sampling				
Reference SMZ	78.1 A	34.3 A	1.09 A	0.21 A
Partial cut SMZ	122.3 A	54.4 A	1.54 A	0.30 A
Clearcut SMZ	247.2 B	107.7 B	2.20 B	0.48 B
Sept. 2000 Sampling				
Reference SMZ	70.7 A	32.2 A	1.21 A	0.16 A
Partial cut SMZ	105.0 A	47.9 A	1.37 A	0.16 A
Clearcut SMZ	491.3 B	234.5 B	6.40 B	1.54 B

[1]Means with the same sampling period and response variable, and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level.

Table 4. Total carbon content comparisons of herbaceous vegetation components of 3 postharvest sampling periods across three SMZ management treatments. All values are in g / m^2.

	Reference SMZ	Partial cut SMZ	Clearcut SMZ
Reference Sampling			
Woody plants	11.9 A[1] a[2]	14.3 A[1] b	9.2 A[1] b
Forbs	6.5 A a	3.2 B a	0.7 B b
Grasses	2.0 A ab	5.8 A a	7.0 A b
April 2000 Sampling			
Woody plants	26.1 A a[2]	42.0 A a	27.9 A ab
Forbs	2.3 A a	1.2 A a	10.5 B b
Grasses	5.9 A a	11.2 A a	69.3 B ab
Sept. 2000 Sampling			
Woody plants	26.4 A a[2]	11.3 A b	66.0 B a
Forbs	4.8 A a	18.1 A a	76.3 B a
Grasses	1.0 A b	18.4 A a	92.3 B a

[1]Means with the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within the same sampling periods are not compared.
[2]Means among SMZs and across the three sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within within the same SMZs are not compared.

Figure 4. Total carbon content comparisons of herbaceous vegetation components of three postharvest sampling periods across three SMZ management treatments.

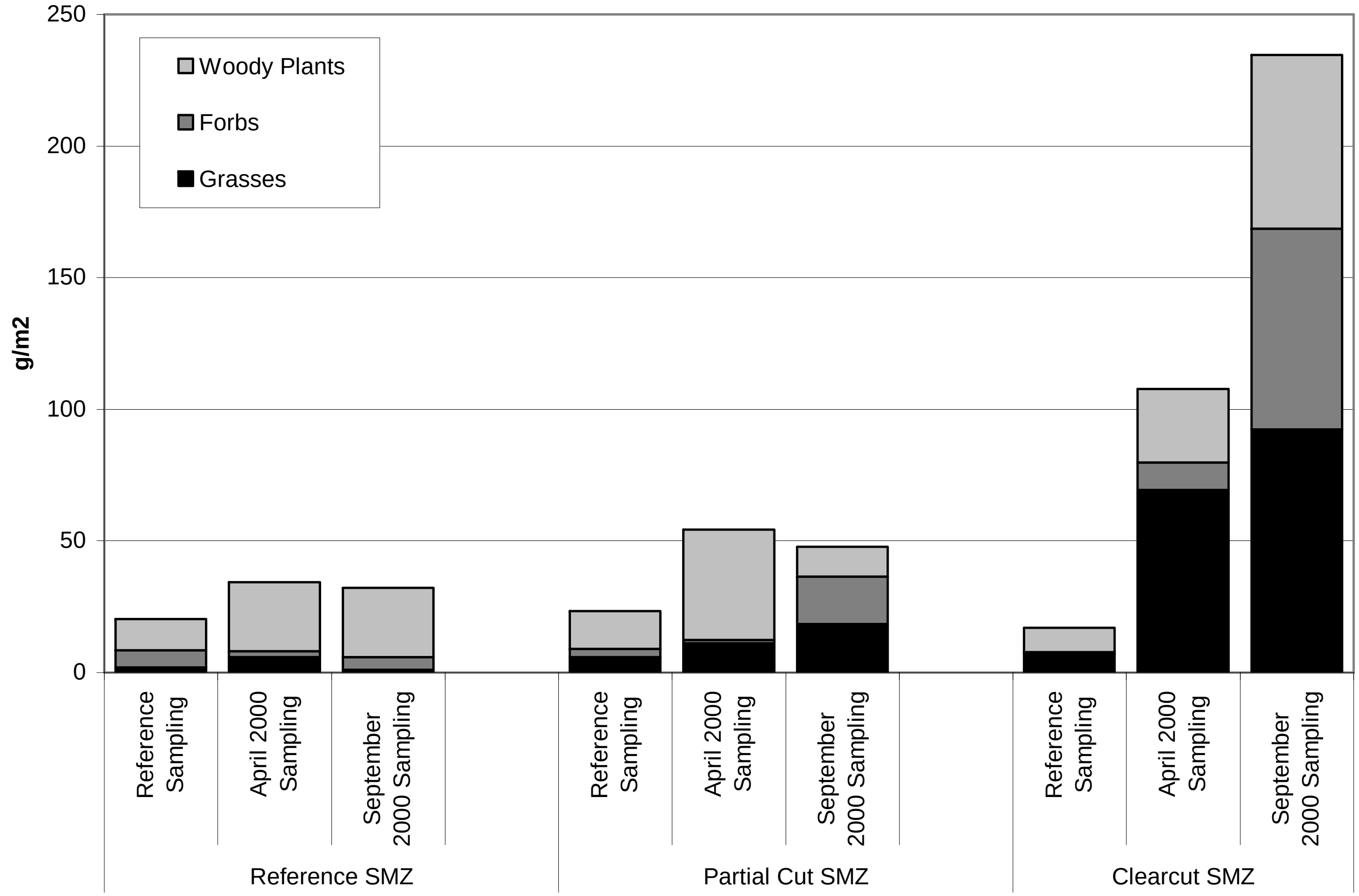


Table 5. Total nitrogen content comparisons of herbaceous vegetation components of 3 postharvest sampling periods across three SMZ management treatments. All values are in g / m^2.

	Reference SMZ	Partial cut SMZ	Clearcut SMZ
Reference Sampling			
Woody plants	0.40 A[1] a[2]	0.40 A[1] b	0.25 A[1] b
Forbs	0.26 A a	0.07 B a	0.02 B b
Grasses	0.07 A ab	0.09 A a	0.13 A b
April 2000 Sampling			
Woody plants	0.86 A a[2]	1.19 A a	0.85 A ab
Forbs	0.07 A b	0.05 A a	0.32 B b
Grasses	0.16 A a	0.29 A a	1.03 B a
Sept. 2000 Sampling			
Woody plants	1.02 AB a[2]	0.36 A b	2.09B a
Forbs	0.16 A ab	0.59 A a	2.92 B a
Grasses	0.02 A b	0.42 A a	1.39 B a

[1]Means with the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within the same sampling periods are not compared.
[2]Means among SMZs and across the three sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within within the same SMZs are not compared.

Figure 5. Total nitrogen content comparisons of herbaceous vegetation components of three postharvest sampling periods across three SMZ management treatments.

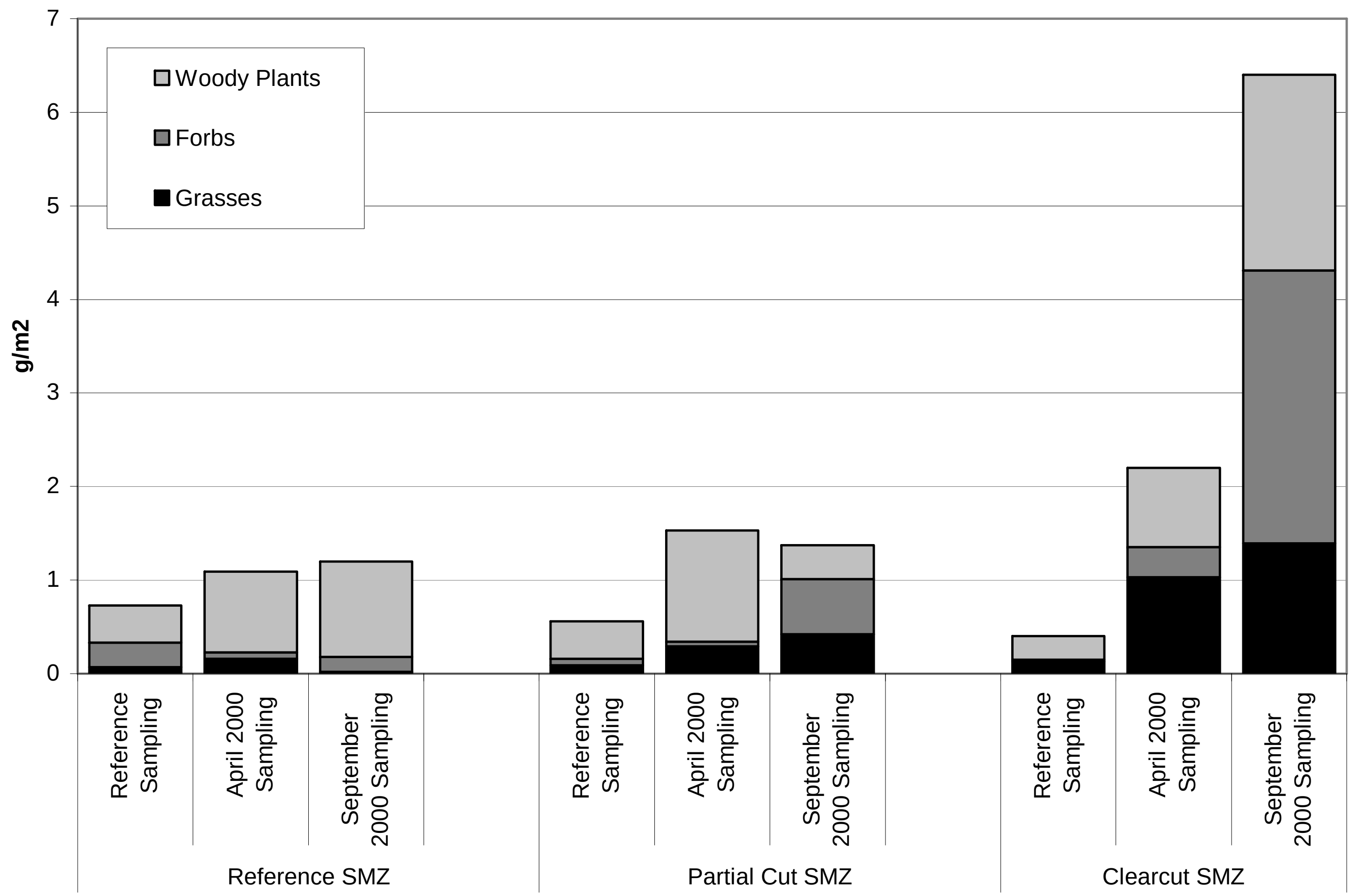


Table 6. Total phosphorus content comparisons of herbaceous vegetation components of 3 postharvest sampling periods across three SMZ management treatments. All values are in g / m^2.

	Reference SMZ	Partial cut SMZ	Clearcut SMZ
Reference Sampling			
Woody plants	0.05 A[1]a[2]	0.05 A[1] b	0.04 A[1] b
Forbs	0.03 A a	0.02 B a	0.00 B b
Grasses	0.01 A b	0.01 A a	0.02 A a
April 2000 Sampling			
Woody plants	0.16 A a[2]	0.24 A a	0.17 A ab
Forbs	0.01 A b	0.01 A a	0.07 B b
Grasses	0.04 A b	0.05 A a	0.25 B a
Sept. 2000 Sampling			
Woody plants	0.13 AB a[2]	0.05 A b	0.27 B a
Forbs	0.02 A ab	0.06 A a	0.51 B a
Grasses	0.00 A a	0.05 A a	0.76 B a

[1]Means with the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within the same sampling periods are not compared.
[2]Means among SMZs and across the three sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within within the same SMZs are not compared.

Figure 6. Total phosphorus content comparisons of herbaceous vegetation components of three postharvest sampling periods across three SMZ management treatments.

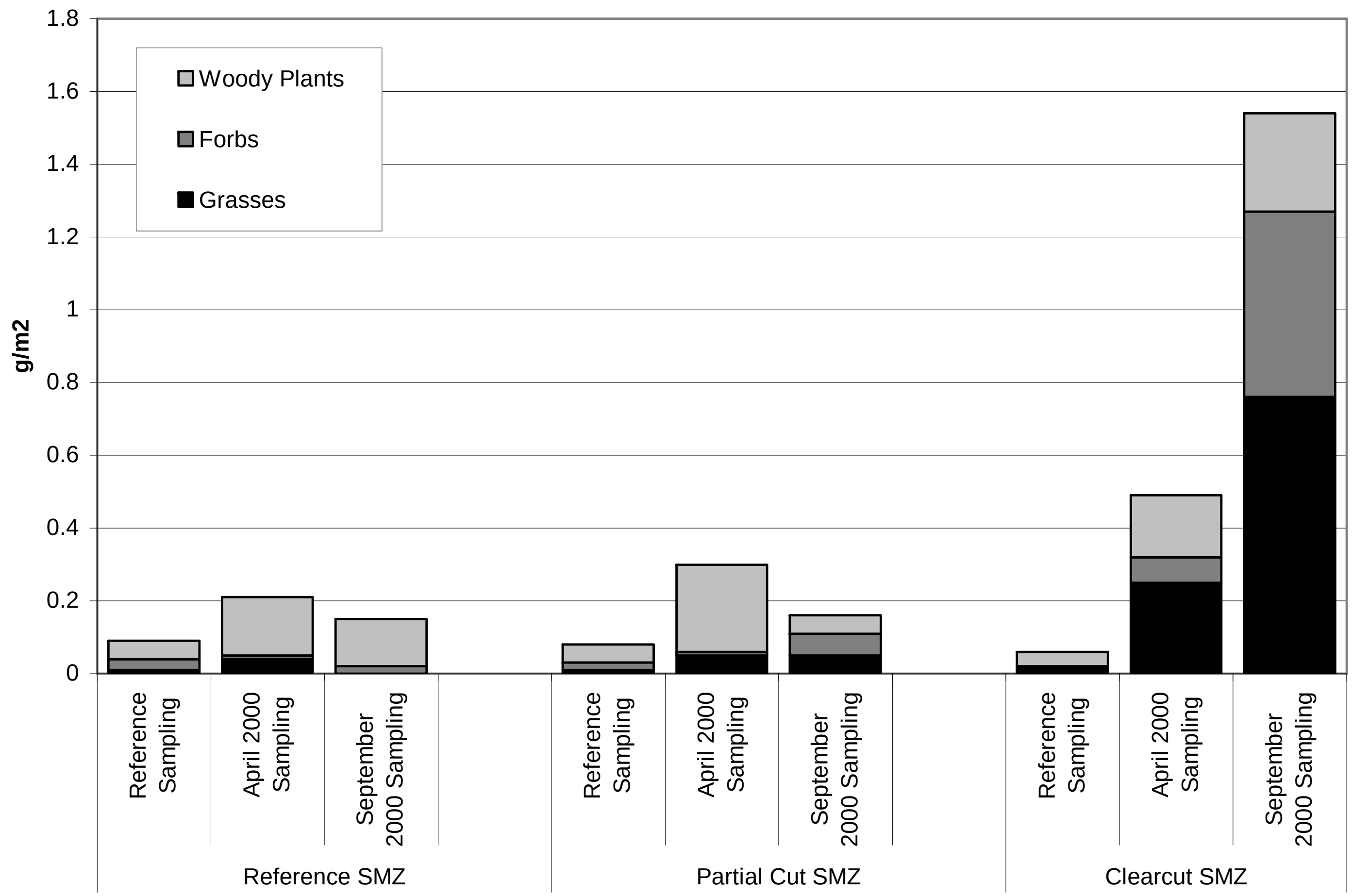


Table 7. Carbon : nitrogen comparisons of herbaceous vegetation components of 3 postharvest sampling periods across three SMZ management treatments.

	Reference SMZ	Partial cut SMZ	Clearcut SMZ
Reference Sampling			
Woody plants	34.8 A[1]a[2]	39.3 A[1]a	43.2 A[1]a
Forbs	25.6 A b	43.3 B a	33.8 AB a
Grasses	27.7 A a	59.3 B a	58.2 B a
April 2000 Sampling			
Woody plants	36.4 A a[2]	37.9 A a	39.7 A a
Forbs	52.5 A a	33.2 A ab	34.0 A a
Grasses	40.5 A a	40.7 A b	60.6 B a
Sept. 2000 Sampling			
Woody plants	31.3 A a[2]	36.3 A a	31.7 A a
Forbs	30.0 A ab	29.5 A b	30.7 A a
Grasses	39.2 A a	49.7 AB ab	59.5 B a

[1]Means with the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within the same sampling periods are not compared.
[2]Means among SMZs and across the three sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within within the same SMZs are not compared.

Table 8. Nitrogen : phosphorus comparisons of herbaceous vegetation components of 3 postharvest sampling periods across three SMZ management treatments.

	Reference SMZ	Partial cut SMZ	Clearcut SMZ
Reference Sampling			
Woody plants	8.1 A[1] a[2]	7.4 AB[1] a	6.3 B[1] b
Forbs	9.3 A a	8.5 A a	7.6 A a
Grasses	9.6 A a	6.3 A a	5.8 A a
April 2000 Sampling			
Woody plants	5.3 A b[2]	5.6 A b	5.2 A b
Forbs	5.6 A b	5.9 A b	4.9 A b
Grasses	5.2 A b	6.3 A a	5.2 A a
Sept. 2000 Sampling			
Woody plants	7.1 A a[2]	7.1 A a	7.6 A a
Forbs	8.4 A a	9.1 A a	7.2 A a
Grasses	6.7 A b	8.2 A a	6.8 A a

[1]Means with the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within the same sampling periods are not compared.
[2]Means among SMZs and across the three sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within within the same SMZs are not compared.

Table 9. Carbon : phosphorus comparisons of herbaceous vegetation components of 3 postharvest sampling periods across three SMZ management treatments.

	Reference SMZ	Partial cut SMZ	Clearcut SMZ
Reference Sampling			
Woody plants	275.6 A[1] a[2]	290.1 A[1] a	258.9 A[1] a
Forbs	227.6 A a	362.9 B a	241.9 A a
Grasses	263.0 A a	369.0 A a	327.0 A a
April 2000 Sampling			
Woody plants	188.0 A a[2]	203.0 A b	196.0 A b
Forbs	212.0 A a	190.6 A b	166.2 A b
Grasses	200.9 A a	249.8 AB b	299.5 B a
Sept. 2000 Sampling			
Woody plants	215.7 A b[2]	249.3 A ab	338.0 A ab
Forbs	246.3 A a	263.8 A b	203.9 A ab
Grasses	250.7 A a	386.4 A b	372.5 A a

[1]Means with the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within the same sampling periods are not compared.
[2]Means among SMZs and across the three sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level. Vegetative components within within the same SMZs are not compared.

Table 10. Comparisons of total biomass and generic richness of vegetative components over 3 postharvest sampling periods in three SMZ management treatments.

		Reference Sampling Period			April 2000 Sampling Period			September 2000 Sampling Period		
Vegetative Component	**Parameter**	**Reference SMZ**	**Partial Cut SMZ**	**Clearcut SMZ**	**Reference SMZ**	**Partial Cut SMZ**	**Clearcut SMZ**	**Reference SMZ**	**Partial Cut SMZ**	**Clearcut SMZ**
Woody plants	**Total # of genera**	11	11	8	9	21	12	8	11	12
	Biomass (g/m2)	25.81	30.36	19.79	58.3	93.61	62.77	57.49	24.88	135.97
Forbs	**Total # of genera**	5	4	3	1	15	9	3	5	7
	Biomass (g/m2)	14.12	6.79	1.6	5.56	2.87	25.1	10.71	38.72	156.86
Grasses	**Total # of genera**	2	3	1	1	2	4	1	2	4
	Biomass (g/m2)	4.59	12.93	15.89	14.2	25.79	159.37	2.46	41.36	198.43
Total	**Total # of genera**	18	18	12	15	38	25	12	18	23
	Biomass (g/m2)	44.52	50.08	37.28	78.06	122.27	247.24	70.66	104.96	491.26

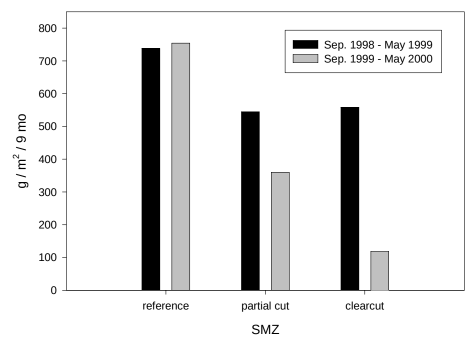
Table 11. Pre- and postharvest comparisons of total biomass, total nutrient content, and elemental ratios of total litterfall over 9-month collection periods (September – May). All content values are in g / m^2 / 9 mo. Standard errors of the means are in parentheses.

	Preharvest			Postharvest		
	Reference	Partial cut	Clearcut	Reference	Partial cut	Clearcut
Total Litterfall Biomass	738.4 A[1] a[2] (91.51)	544.7 A[1] a (53.21)	558.6 A[1] a (63.22)	754.3 A a[2] (118.63)	360.4 B b (39.86)	118.4C b (15.47)
Total Carbon Content	402.6 A a (101.72)	265.3 A a (49.76)	315.1 A a (71.40)	362.2 A a (60.46)	171.6 B b (19.00)	60.2 C b (7.93)
Total Nitrogen Content	7.465 A a (2.55)	4.347 A a (0.62)	4.259 A a (0.69)	6.134 A a (0.66)	3.347 B a (0.35)	0.931 C b (0.11)
Total Phosphorus Content	1.031 A a (0.29)	0.644 A a (0.09)	0.728 A a (0.13)	0.709 A a (0.09)	0.403 B b (0.04)	0.131 C b (0.02)
Carbon : Nitrogen	63.10 A a (4.24)	58.22 A a (4.11)	76.25 A a (9.19)	54.59 A b (1.71)	49.31 A b (1.34)	63.26 B a (2.84)
Nitrogen : Phosphorus	6.440 A b (0.23)	6.757 A b (0.28)	5.948 A b (0.34)	9.102 AB a (0.26)	9.249 A a (0.27)	8.406 B a (0.28)
Carbon : Phosphorus	403.87 A a (29.50)	391.22 B a (29.67)	409.76 A a (32.81)	492.16 A ab (19.22)	452.27 A b (16.09)	520.91A a (23.12)

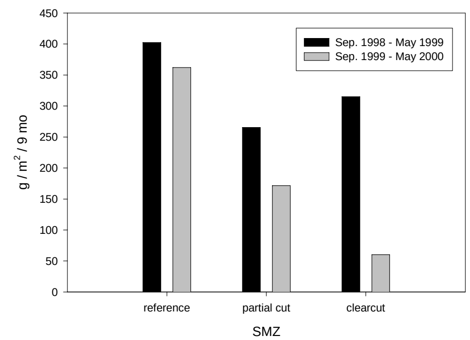
[1]Means within the same sampling period and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level.
[2]Means among SMZs and across the two sampling periods with the same lowercase letter are not significantly different at the alpha = 0.5 level.

Figure 7. SMZ management effects on litterfall over 9 months. Comparison of pre- and postharvest litterfall values of total biomass, and total carbon, nitrogen, and phosphorus content.

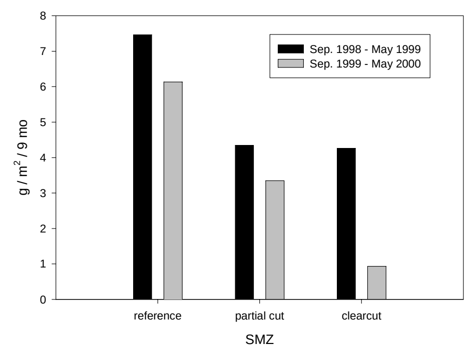
A) Total Biomass



B) Total Carbon Content



C) Total Nitrogen Content



D) Total Phosphorus Content

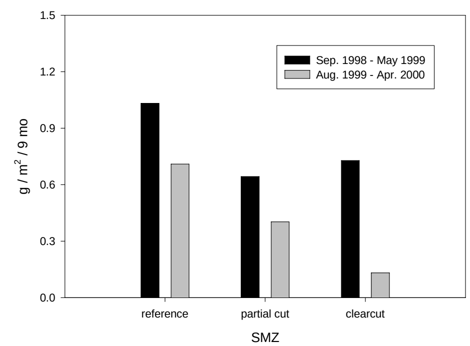


Table 12. Total woody aboveground net primary productivity for the preharvest growing season and two postharvest growing seasons. Values are in tons per acre.

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
1999 - preharvest season	1700.30	1642.53	982.73
2000 - 1st postharvest season (% change)	1938.69 (+12.30)	1513.55 (-7.85)	332.46 (-66.17)
2001 - 2nd postharvest season (% change)	1989.48 (+2.55)	1593.70 (+5.03)	356.69 (+6.79)

Table 13. Leaf litter composition of traded and specific litter of 20 g decomposition bags. Traded litter composition was determined based on litterfall collections across 3 SMZs. Specific litter composition reflects proportional species litterfall contributions within each SMZ.

Traded Litter

Acer rubrum	2.46g / 12.29%
Liquidambar styraciflua	8.27g / 41.08%
Magnolia virginiana	1.66g / 8.32%
Quercus nigra	6.06g / 30.28%
Vitis rotundifolia	1.60g/ 8.02%

Specific Litter

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
Acer rubrum	1.46g / 7.30%	n/a	3.02g / 15.08%
Liquidambar styraciflua	11.91g / 59.54%	2.20g / 10.99%	1.17g / 5.84%
Liriodendron tulipifera	n/a	3.33g / 16.64%	n/a
Magnolia virginiana	1.86g / 9.30%	n/a	n/a
Pinus taeda	3.35g / 16.75%	1.37g / 6.86%	7.20g / 36.01%
Quercus nigra	n/a	11.08g / 55.42%	6.54g / 32.72%
Vitis rotundifolia	1.42g / 7.11%	2.02g / 10.09%	2.07g / 10.34%

Table 14. Decomposition rates and percentage of mass remaining in traded and specific litter decomposition litterbags across 3 SMZ treatments after 60 weeks. Standard errors of the means are in parentheses.

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
Traded Litter			
Decay Coefficient (k)	1.332 A[1] a[2] (0.13)	0.886 B[1] a (0.01)	0.816 B[1] a (0.12)
% Mass Remaining	37.48 A a (1.96)	51.97 A a (1.44)	55.34 A a (7.75)
Specific Litter			
Decay Coefficient	1.430 A a[2] (0.06)	0.772 B a (0.08)	0.600 B a (0.06)
% Mass Remaining	37.34 A a (2.78)	53.66 AB a (4.26)	62.35 B a (9.27)

[1]Means within the same litter type and across SMZs with the same uppercase letter are not significant at the alpha = 0.5 level.
[2]Means within the same SMZ and across litter type with the same lowercase letter are not significant at the alpha = 0.5 level.

Table 15. Percentage of carbon, nitrogen, and phosphorus remaining in traded and specific litter decomposition litterbags after 60 weeks. Standard errors of the means are in parentheses.

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
% Carbon Remaining			
Traded Litter	33.53 A[1] a[2]	51.58 B[1] a	51.88 B[1] a
	(1.86)	(3.80)	(5.28)
Specific Litter	32.56 A a[2]	43.71 AB a	62.76 B a
	(4.50)	(7.73)	(9.41)
% Nitrogen Remaining			
Traded Litter	102.62 A a	127.03 B a	120.90 AB a
	(2.03)	(2.79)	(8.70)
Specific Litter	80.34 A a	107.55 AB a	143.70 B a
	(12.80)	(14.22)	(18.59)
% Phosphorus Remaining			
Traded Litter	55.14 A a	67.95 A a	71.01 A a
	(0.74)	(5.70)	(9.03)
Specific Litter	54.80 A a	59.14 A a	74.37 A a
	(8.85)	(7.62)	(12.23)

[1]Means within the same litter type and across SMZs with the same uppercase letter are not significant at the alpha = 0.5 level.
[2]Means within the same SMZ and across litter type with the same lowercase letter are not significant at the alpha = 0.5 level.

Table 16. Carbon : nitrogen ratios of traded and specific litter decomposition litterbags at time of installation and after 60 weeks. Standard errors of the means are in parentheses.

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
At time of installation			
Traded Litter	81.62 A[1] a[2] *A*[3] (1.78)	82.46 A[1] a *A* (4.19)	77.29 A[1] a *A* (4.41)
Specific Litter	91.32 A a[2] *A* (5.88)	85.77 A a *A* (6.52)	130.33 A b *A* (20.64)
After 60 weeks in field			
Traded Litter	26.26 A b *B*[3] (1.86)	32.49 B a *B* (1.38)	34.28 B b *B* (1.31)
Specific Litter	37.12 A a *A* (1.73)	34.01 A a *A* (1.61)	54.83 B a *A* (5.62)

[1]Means within the same litter types and time period, and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level.
[2]Means within SMZs and the same time period, and across litter types with the same lowercase letter are not significantly different at the alpha = 0.5 level.
[3]Means within the same litter types and SMZs, and across time periods with the same italicized uppercase letter are not significantly different at the alpha = 0.5 level.

Table 17. Nitrogen : phosphorus ratios of traded and specific litter decomposition litterbags at time of installation and after 60 weeks. Standard errors of the means are in parentheses.

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
At time of installation			
Traded Litter	5.13 A[1] a[2] *A*[3] (0.12)	5.82 A[1] a *A* (0.12)	5.07 A[1] a *A* (0.62)
Specific Litter	5.17 A a[2] *A* (0.20)	4.89 A a *A* (0.49)	4.36 A a *A* (0.54)
After 60 weeks in field			
Traded Litter	9.81 A a *B*[3] (0.29)	9.94 A a *B* (0.62)	9.09 A a *B* (0.46)
Specific Litter	7.64 A a *B* (0.79)	8.85 A a *B* (0.25)	8.58 A a *B* (0.41)

[1]Means within the same litter types and time period, and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level.
[2]Means within SMZs and the same time period, and across litter types with the same lowercase letter are not significantly different at the alpha = 0.5 level.
[3]Means within the same litter types and SMZs, and across time periods with the same italicized uppercase letter are not significantly different at the alpha = 0.5 level.

Table 18. Carbon : phosphorus ratios of traded and specific litter decomposition litterbags at time of installation and after 60 weeks. Standard errors of the means are in parentheses.

	Reference SMZ	Partial Cut SMZ	Clearcut SMZ
At time of installation			
Traded litter	418.41AB[1] b[2] *A*[3] (1.25)	478.95 A[1] a *A* (16.93)	387.13 B[1] b *A* (34.12)
Specific litter	470.31 A a[2] *A* (14.68)	414.21 B a *A* (20.91)	545.27 C a *A* (9.82)
After 60 weeks in field			
Traded litter	256.65 A a *B*[3] (11.09)	321.39 B a *B* (12.40)	310.64 B b *B* (10.75)
Specific litter	281.25 A a *B* (16.34)	300.89 A a *B* (15.75)	468.59 B a *A* (45.71)

[1]Means within the same litter types and time period, and across SMZs with the same uppercase letter are not significantly different at the alpha = 0.5 level.
[2]Means within SMZs and the same time period, and across litter types with the same lowercase letter are not significantly different at the alpha = 0.5 level.
[3]Means within the same litter types and SMZs, and across time periods with the same italicized uppercase letter are not significantly different at the alpha = 0.5 level.

Figure 8. Percent Mass remaining of 20g litter bags of traded and specific litter types among Reference, Partial Cut, and Clearcut SMZs over 60 weeks in the field.

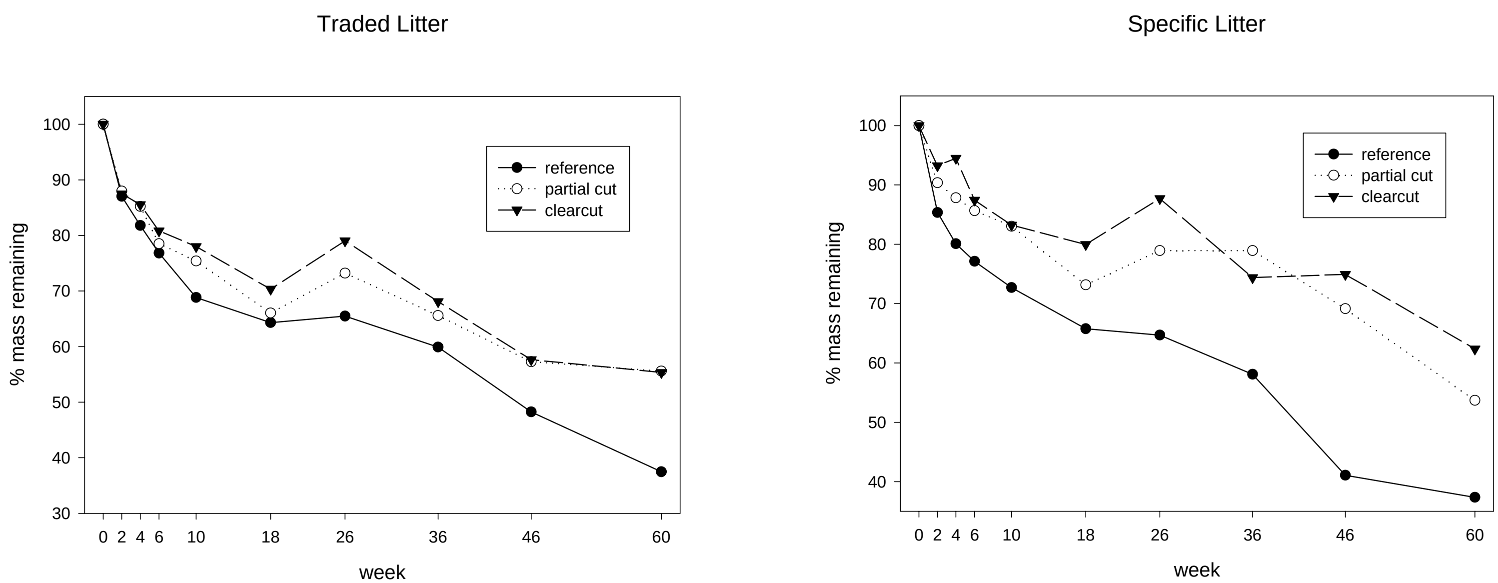
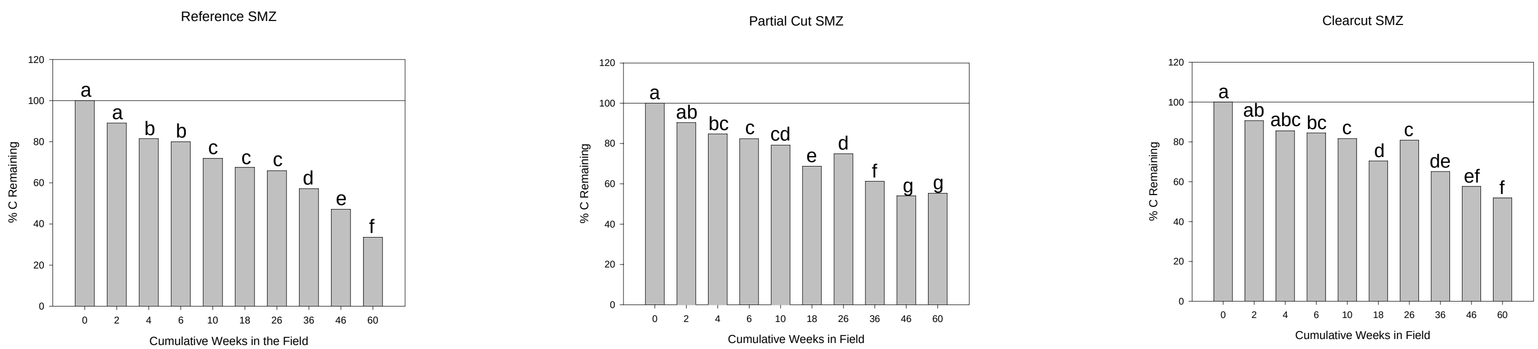


Figure 9. Percent carbon remaining of 20g litter bags of traded and specific litter types among Reference, Partial Cut, and Clearcut SMZs over 60 weeks in the field.

Traded Litter



Specific Litter

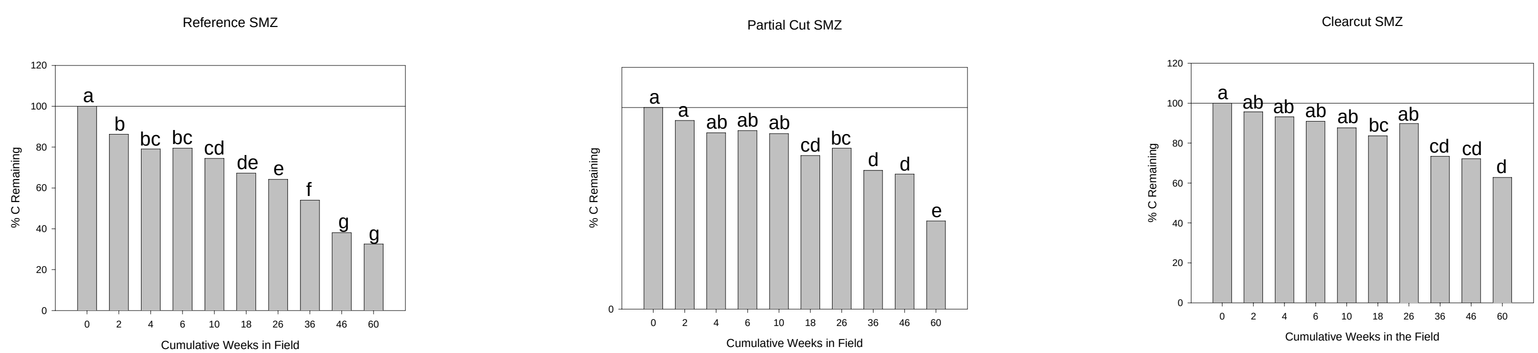
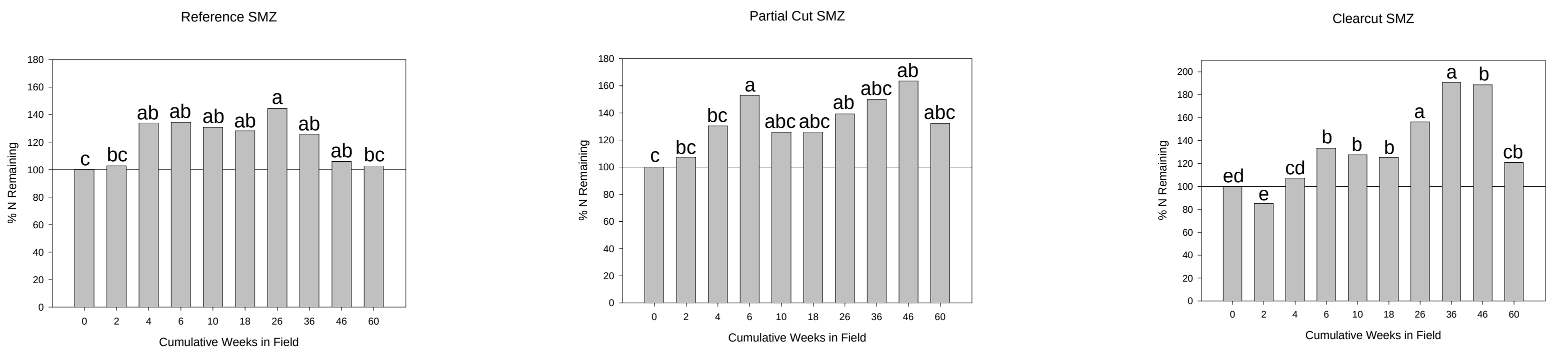


Figure 10. Percent nitrogen remaining of 20g litter bags of traded and specific litter types among Reference, Partial Cut, and Clearcut SMZs over 60 weeks in the field.

Traded Litter



Specific Litter

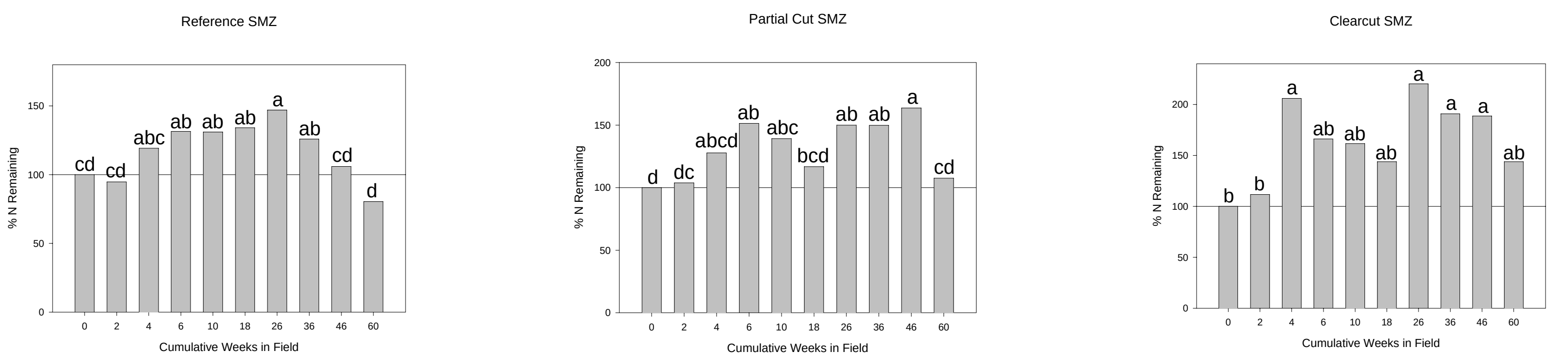
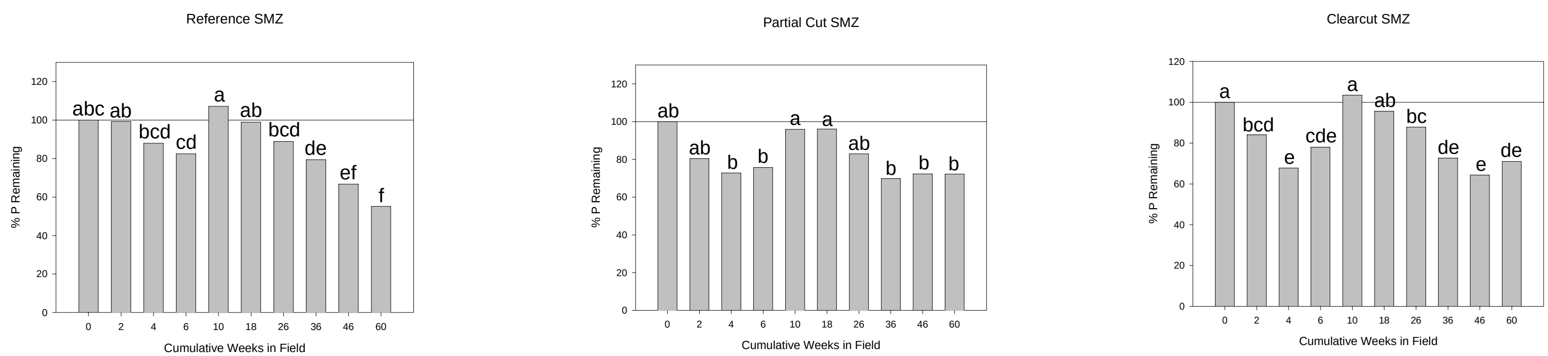
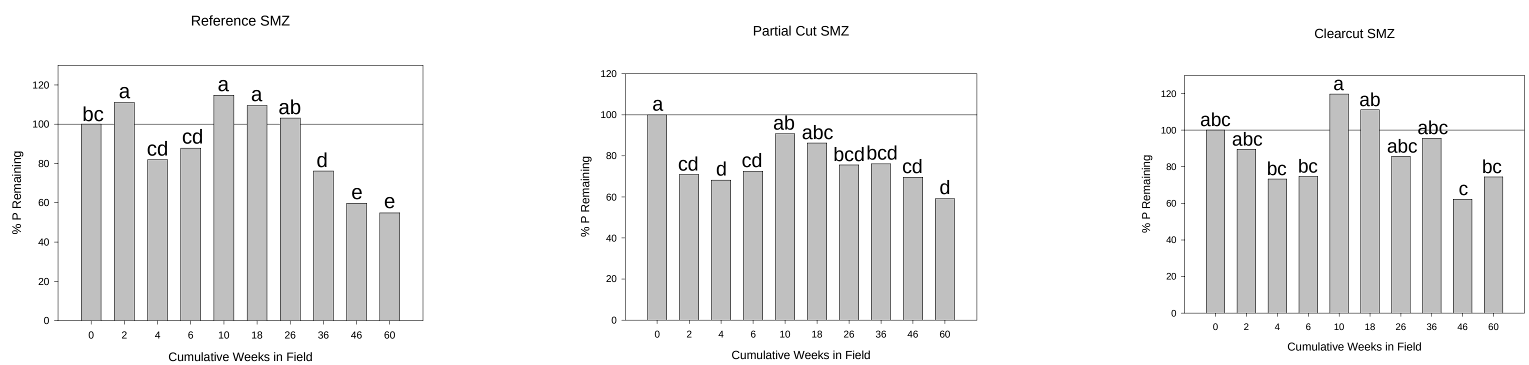


Figure 11. Percent phosphorus remaining of 20g litter bags of traded and specific litter types among Reference, Partial Cut, and Clearcut SMZs over 60 weeks in the field.

Traded Litter



Specific Litter



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Appendix. List of plant genera and species from three sampling periods across three SMZ treatments.

Reference sampling

Reference SMZ – 18 total genera @ 44.52 g/m^2

Woody plants	*Acer rubrum* L.[1]	*Parthenocissus quinquefolia* Panchon
11 genera	*Callicarpa americana* L.	*Quercus* spp. L.
25.81 g/m^2	*Cornus florida* L.	*Sebastiana ligustrina* Sprengel
	Ligustrum sinense Lour.	*Toxicodendron radicans* L.
	Lonicera japonica Thonburg	*Vitis rotundifolia* Michaux
	Morus rubra L.	
Forbs	*Mitchella repens* L.	*Smilax glauca* Walter
5 genera	*Polystichum acrostichoides* Schott	*Woodwardia areolata* Smith
14.12 g/m^2	*Rubus* spp. L.	
Grasses	*Panicum* spp. L.	*Poa* spp. L.
2 genera		
4.59 g/m^2		

Partial cut SMZ – 18 total genera @ 50.08 g/m^2

Woody plants	*Acer rubrum* L.	*Quercus* spp. L.
11 genera	*Callicarpa americana* L.	*Parthenocissus quinquefolia* Panchon
30.36 g/m^2	*Campsis radicans* Lour.	*Pinus taeda* L.
	Carya sp. Nutttall	*Sebastiana ligustrina* Sprengel
	Diospyros virginiana L.	*Vitis rotundifolia* Michaux
	Lonicera japonica Thonburg	
Forbs	*Lamium amplexcaule* L.	*Mitchella repens* L.
4 genera	*Galium* sp. L.	*Smilax glauca* Walter
6.79 g/m^2		
Grasses	*Arundinaria gigantean* Muhl.	*Poa* spp. L.
3 genera	*Panicum* spp. L.	
12.93 g/m^2		

Clearcut SMZ – 12 total genera @ 37.28 g/m^2

Woody plants	*Acer rubrum* L.	*Lonicera japonica* Thonburg
8 genera	*Asimina parviflora* Dunal	*Quercus* spp. L.
19.79 g/m^2	*Callicarpa americana* L.	*Sebastiana ligustrina* Sprengel
	Ilex opaca Aiton	*Vitis rotundifolia* Michaux
Forbs	*Mitchella repens* L.	*Smilax glauca* Walter
3 genera	*Rubus* spp. L.	
1.60 g/m^2		
Grasses	*Panicum* spp. L.	
1 genus		
15.89 g/m^2		

April 2000 Sampling

Reference SMZ – 15 total genera @ 78.06 g/m^2

Woody plants	*Acer rubrum* L.	*Morus rubra* L.
9 genera	*Callicarpa americana* L.	*Parthenocissus quinquefolia* Panchon
58.30 g/m^2	*Cornus florida* L.	*Quercus* spp. L.
	Ligustrum sinense Lour.	*Toxicodendron radicans* L.
	Lonicera japonica Thonburg	
Forbs	*Mitchella repens* L.	*Smilax glauca* Walter
1 genus	*Polystichum acrostichoides* Scott	*Woodwardia areolata* Smith
5.56 g/m^2	*Rubus* spp. L.	
Grasses	*Panicum* spp. L.	
1 genus		
14.20 g/m^2		

Partial cut SMZ – 38 total genera @ 122.27 g/m^2

Woody plants	*Acer rubrum* L.	*Ligustrum sinense* Lour.
21 genera	*Albizia julibrissin* Durazzini	*Liquidambar styraciflua* L.

93.61 g/m^2	*Ampelopsis arborea* Koehne	*Liriodendron tulipifera* L.
	Aralia spinosa L.	*Lonicera japonica* Thonburg
	Asimina parviflora Dunal	*Parthenocissus quinquefolia* Panchon
	Callicarpa americana L.	*Pinus taeda* L.
	Campsis radicans L.	*Quercus* spp. L.
	Carya sp. Nuttall	*Toxicodendron radicans* L.
	Cornus florida L.	*Vaccinium arboreum* Marshall
	Gelsemium sempervirens Aiton	*Vitis rotundifolia* Michaux
	Ilex opaca Aiton	
Forbs	*Chaerophyllum tainturieri* Hooker	*Polygala mariana* Miller
15 genera	*Dichondra carolinensis* Michaux	*Polystichum acrostichoides* Schott
2.87 g/m^2	*Duchesnea indica* Locke	*Rubus* spp. L.
	Galium sp. L.	*Rumex* sp. L.
	Helianthus radula T. & G.	*Smilax glauca* Walter
	Mitchella repens L.	*Solidago* sp. L.
	Oxalis stricta L.	*Verbena* sp. L.
	Plantago lanceolata L.	
Grasses	*Arundinaria gigantean* Muhl.	*Panicum* spp. L.
2 genera		
25.79 g/m^2		

Clearcut SMZ – 25 total genera @ 247.24 g/m^2

Woody plants	*Acer rubrum* L.	*Lonicera japonica* Thonburg
12 genera	*Aralia spinosa* L.	*Pinus taeda* L.
62.77 g/m^2	*Callicarpa americana* L.	*Rhus copallina* L.
	Campsis radicans L.	*Toxicodendron radicans* L.
	Cornus florida L.	*Vitis aestivalis* Michaux
	Ligustrum sinense Lour.	*V. rotundifolia* Michaux
Forbs	*Eupatorium capillifolium* Small	*Rubus* spp. L.
9 genera	*E. perfoliatum* L.	*Symplocos tinctoria* L'Her
25.10 g/m^2	*Gnaphalium obtusifolium* L.	*Smilax glauca* Walter
	Mitchella repens L.	*Solidago* spp. L.
	Phytolacca americana L.	
Grasses	*Arundinaria gigantean* Muhl.	*Poa* spp. L.

4 genera 159.37 g/m^2	*Panicum* spp. L.	unknown exotic

September 2000 Sampling

Reference SMZ – 12 total genera @ 70.66 g/m^2

Woody plants 8 genera 57.49 g/m^2	*Acer rubrum* L. *Callicarpa americana* L. *Carpinus caroliniana* Walter *Lonicera japonica* Thonburg	*Quercus* spp. L. *Sebastiana ligustrina* Sprengel *Toxicodendron radicans* L. *Vitis rotundifolia* Michaux
Forbs 3 genera 10.71 g/m^2	*Mitchella repens* L. *Smilax glauca* Walter	*Woodwardia areolata* Smith
Grasses 1 genus 2.46 g/m^2	*Panicum* spp. L.	

Partial cut SMZ – 18 total genera @ 104.96 g/m^2

Woody plants 11 genera 24.88 g/m^2	*Callicarpa americana* L. *Campsis radicans* L. *Cornus florida* L. *Hedera helix* L. *Ligustrum sinense* Lour. *Liriodendron tulipifera* L.	*Lonicera japonica* Thonburg *Quercus* spp. L. *Parthenocissus quinquefolia* Panchon *Pinus taeda* L. *Vitis rotundifolia* Michaux
Forbs 5 genera 38.72 g/m^2	*Mitchella repens* L. *Polystichum acrostichoides* Schott *Rubus* spp. L.	*Rumex* sp. L. *Smilax glauca* Walter
Grasses 2 genera 41.36 g/m^2	*Panicum* spp. L.	*Rumex* sp.

Clearcut SMZ – 23 total genera @ 491.26 g/m^2

Woody plants 12 genera 135.97 g/m^2	*Albizzia julibrisn* Durazzini *Aralia spinosa* L. *Callicarpa americana* L. *Campsis radicans* L. *Carpinus caroliniana* Walter *Diospyros virginiana* L.	*Lonicera japonica* Thonburg *Prunus serotina* Ehrhart *Rhus copallina* L. *Sambucus canadensis* L. *Vaccinium arboreum* Marshall *Vitis rotundifolia* Michaux
Forbs 7 genera 156.86 g/m^2	*Ambrosia artemisifolia* L. *Eupatorium capillifolium* Small *E. perfoleatum* L. *Mitchella repens* L.	*Rubus* spp. L. *Smilax glauca* Walter *Solidago* sp. L.
Grasses 4 genera 198.43 g/m^2	*Arundinaria gigantean* Muhl. *Panicum* spp. L.	*Rumex* sp. L. unknown exotic

[1] All taxonomic nomenclature according to:
Radford, A. E., H. E. Ahles, and C. R. Bell. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press, Chapel Hill, NC, 1968.