Silvicultural Management Within Streamside Management Zones of Intermittent Streams: Effects on Decomposition, Productivity, Nutrient Cycling, and Channel Vegetation

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ABSTRACT: *The purpose of this watershed study on three intermittent streams was to evaluate responses of riparian processes to three streamside management zone (SMZ) treatments; no harvest, clearcut, and partial harvest (50% basal area removal). Riparian response variables measured included litterfall, leaf litter decomposition, understory vegetation, soil temperature and water chemistry. However, due to drought conditions, insufficient water chemistry data were collected to support quantitative assessment of treatment effects. Comparisons of mass loss rates (k) indicated that decomposition on the control treatment was the most rapid. Understory vegetation surveys showed statistically greater mass of forbs and grasses within the clearcut SMZ. Results suggest that no harvest or a partial harvest within SMZs along intermittent streams are preferable because these treatments maintain carbon inputs to streams. South. J. Appl. For. 28(4): 211–224.*

Key Words: Carbon, nitrogen, phosphorus, streamside management zone.

Environmental awareness has increased as a result of media coverage and much attention continues to be focused on possible impacts of silvicultural activities. Because some Southern forests are intensively managed and account for as much as 60% of the United States production of timber (Prestemon and Abt 2002), it is imperative that forest managers are able to balance the need to maximize productivity with maintenance of the ecological integrity and long-term sustainability of the landscape (Sharitz et al. 1992).

Land management operations such as forestry and agriculture have the potential to impair water quality if excess sediment is allowed to enter streams (Binkley and Brown 1993, Lowrance et al. 1983). To assist forest managers, best management practices (BMP) were created to provide guidelines to maintain water quality (Alabama Forestry Commission 1993). Streamside management zones (SMZs) are one of the most important components of BMP guidelines. The United States Environmental Protection Agency defines SMZs as "buffer strips of a width specified in state BMPs, consisting of the existing native vegetation communities along the stream corridor" (USEPA, www.epa.gov/watertrain/forestry/subb1.htm, July 22, 2004). The intention of an SMZ is to maintain a range of critical ecological functions including filtration of overland flow, stabilization of steambanks, water temperature moderation, input of coarse woody debris, wildlife habitat, and nutrient cycling. Some states prohibit all timber harvest within SMZs whereas most states allow some thinning of trees. Alabama has nonregulatory BMP that suggest a 10.66-m or wider SMZ measured from a definable bank. However, "permanent residual tree cover is not required along intermittent streams as long as other vegetation and organic debris are left to protect the forest floor during regeneration." (Alabama Forestry Commission 1993).

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In Southern bottomland forests, the clearcutting method is a widely used method to regenerate bottomland oak (Meadows and Stanturf 1997). Partial cuts are used to prepare stands for regeneration to a desired species (Meadows and Stanturf 1997). Because vegetation responses differ with harvest techniques and forest types, it is important to document responses for management policies which emphasize an ecosystem approach (Gilliam 2002).

The purpose of this research is to address the question of how harvests within the SMZ of intermittent streams affects nutrient cycling. Intermittent channels were selected for study because of their critical locations as headwaters within watersheds and their hydrologic responsiveness to brief, intense rainfall events which may cause the majority of nonpoint source pollutant movement. In addition, considerable variation exists regarding silvicultural guidelines for protection of intermittent streams (Alabama Forestry Commission 1993, Florida Department of Agriculture and Consumer Services 1992, Mississippi Forestry Commission 2000) and, consequently, additional information regarding responses of these streams is warranted. We examined litterfall, decomposition rates, understory vegetation response and water chemistry within three sites varying in intensity of silvicultural operations (clearcut, partial harvest and control). The first objective was to compare litterfall, litter decomposition rates, and litter nutrient dynamics among treatments. The second objective was to assess species composition, biomass, and nutrient content within the understory vegetation component of the riparian zone and the third objective was to analyze stream water to determine if harvesting altered sediment and nutrients within streamflow.

Methods

Study Area

The three study streams were located in Monroe County, (lat. 31°, 34′ N, long. 87°, 25′ W) within the Lower Coastal Plain Physiographic Region of southwestern Alabama. The site was chosen based on presence of intermittent streams, land available for research, and similarity of vegetation cover and soils (Figure 1). Each intermittent stream drained a 10- to 15-ha watershed with a mean discharge of 0.01 to 0.08 $m^3\ s^{-1}$. The shallow (0.03 m), small (0.7-m width) intermittent streams were low gradient runs (approx. 0.03%; Fritz (2003)) that flow into a tributary of Big Flat Creek within the Lower Alabama hydrologic unit (USDA SCS 1994).

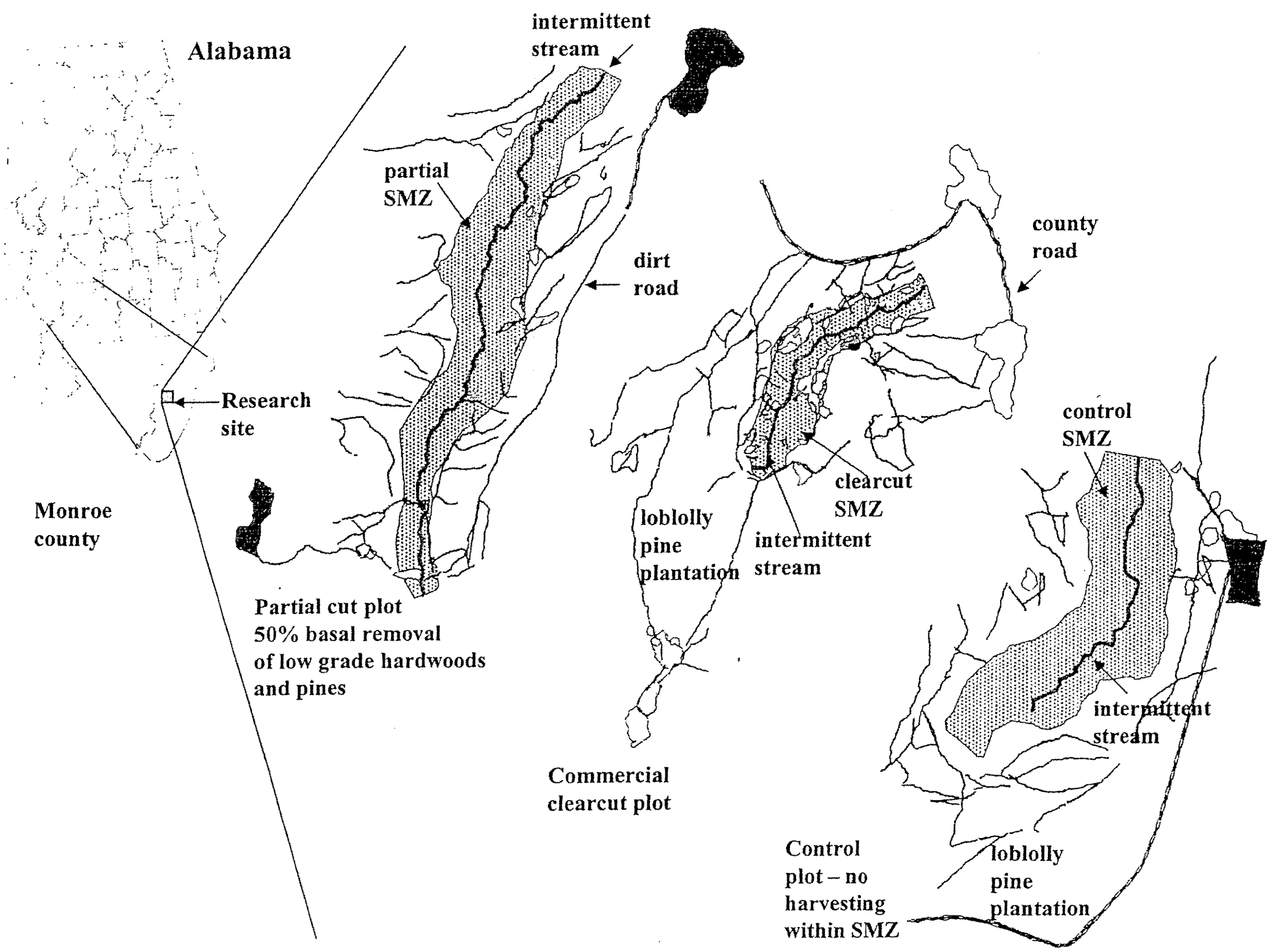

Figure 1. Map of treatment plots within streamside management zones in Monroe County, AL.

In 1998, preharvest vegetation and soil inventories were conducted prior to treatment installation. Within three watersheds, the upland overstory vegetation consisted of 15- to 20-year loblolly pine (*Pinus taeda* L.) plantations with deciduous species growing along the intermittent streams. Deciduous overstory vegetation was dominated by an uneven-aged mixture of red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.), sweetbay (*Magnolia virginiana* L.), swamp tupelo (*Nyssa sylvatica* Marshall), and water oak (*Quercus nigra* L.).

Soils on the study site were of the Iuka, Mantachie, and Atmore soil series (USDA Soil Conservation Service 1986). All treatment plots had strongly acidic soils as expected for the Iuka, Mantachie, and Atmore soil series (USDA Soil Conservation Service 1986). As slope increased, Aquic Udifluvents were observed on the partial treatment, whereas Plinthic Paleaquults were found on clearcut and control plots. Soils on the upland loblolly pine plantations above all SMZ treatment plots were Typic Paleudults.

Experimental Design

In July 1999, research treatments were created within each 15-m SMZ with one treatment being applied to each watershed. These SMZ treatments consisted of: (1) a partial harvest with 50% basal removal of low-grade hardwoods and pines; (2) a commercial clearcut followed by coppice regeneration of hardwoods; and (3) no cut control (Figure 1). Harvesting was conducted using rubber-tired, feller-buncher, and grappleskidders (Stokes et al. 1992). Trees were not felled across the stream and pulled across the channel. Harvest operations on the partial treatment were allowed to have a ford to access land on the back of the tract and equipment in the clearcut treatment operated down to the channel but not in the drain.

Two years following the SMZ treatment installations, the loblolly pine plantations outside each 15-m treatment SMZ were clearcut in 2001 using the same equipment. Streamside management zone treatment plots and loblolly pine plantations were harvested at separate times to: (1) harvest all SMZ plots within the same month; (2) allow researchers to examine effects of a harvest alone on SMZ functions; and (3) to comply with the timber company's harvest schedule.

Soil Chemistry

Five soil samples were collected using an auger to a depth of 15 cm on four 0.5-ha plots within each treatment. The soil samples within each 0.5-ha plot were then composited into one bulk soil sample for chemical analysis. Soil samples were air-dried and then analyzed for extractable phosphorus (P), exchangeable potassium (K), magnesium (Mg), calcium (Ca), total nitrogen (N), total carbon (C), and pH (Auburn University Soil Testing Laboratory 1986, Johnson et al.1984). No significant differences were observed from soil samples taken among the three treatment sites prior to treatment installation for extractable P, exchangeable K, Mg, Ca, total C, total N, or pH (Table 1).

Litterfall

To determine litterfall biomass on the SMZ, litterfall was collected using ten 0.25-m^2 traps per watershed. Litterfall traps were located on both sides of each intermittent stream. To determine monthly litterfall biomass entering streams, two 0.5-m^2 hanging screen baskets (mesh 10 × 10 holes per 2.54 cm) were suspended over each treatment stream channel. Monthly biomass falling within the SMZ and within the stream was recorded for 8 months preharvest. Total annual litterfall for litter falling on the SMZ and within the stream was calculated for 1 year postharvest from Aug.1999 through July 2000. All litterfall collected was oven-dried at 70° C until a constant mass was obtained, weighed, ground in a Wiley mill to pass a 20-mesh sieve (Lockaby et al. 1995), and analyzed for phosphorus (P) (Jackson 1958), carbon (C), and nitrogen (N) (Nelson and Sommers 1996).

Decomposition

To compare leaf litter decomposition rates, foliar litterfall was collected from Sept. 1998 through Feb. 1999 for each watershed. Foliar litterfall was air-dried, separated by species, and weighed. Litterbags were constructed of 30.5- by 45.7-cm nylon mesh with 2- and 5-mm openings on the under and upper sides, respectively. One hundred eighty litterbags were filled with 20 g of air-dried abscised foliage based on the percentage of each species type collected in 0.25-m^2 litterfall traps.

Two sets of litterbags were created: a "common" and a "specific" litterbag. The "common" set of litterbags used litterfall collected from across all watershed streamside

Table 1. Soil chemistry, to a depth of 15-cm, prior to harvesting on research sites located in Monroe Co., AL.

SMZ[a] treatment comparison	P	K	Mg	Ca	C	N	pH
	($mg\ kg^{-1}$)				($g\ kg^{-1}$)		
Partial vs	1.38	16.4	29.8	118.8	1.23	0.055	4.65
Clearcut	2.13	11.8	10.9	100.0	1.26	0.053	4.80
Prob > |T|	0.1428	0.2237	0.2586	0.7753	0.9445	0.8345	0.3559
Partial vs	1.38	16.4	29.8	118.8	1.23	0.055	4.65
Control	2.25	14.5	15.0	116.3	1.64	0.068	4.72
Prob > |T|	0.1002	0.7159	0.3672	0.9793	0.3162	0.4575	0.7080
Clearcut vs	2.13	11.8	10.9	100.0	1.26	0.053	4.80
Control	2.25	14.5	15.0	116.3	1.64	0.068	4.72
Prob > |T|	0.8439	0.5284	0.5835	0.8432	0.3153	0.3250	0.5891

[a] SMZ, Streamside management zone.

management zones. These "common" litterbags were placed on all treatments. The "specific" litterbags were created from litter specific to each watershed. Each treatment had a set of "specific" litterbags that were particular to that watershed. The purpose of the "common" and "specific" litter types was to allow separation of effects related to changes in microenvironment versus those driven by litter quality.

The "common" set of litterbags was composed of 42% sweetgum, 30% water oak, 12% red maple, 8% sweetbay, and 8% muscadine. The "specific" litterbags for the partial harvest treatment contained 55% water oak, 17% yellow-poplar, 11% sweetgum, 10% muscadine, and 7% loblolly pine; the clearcut treatment contained 36% loblolly pine, 33% water oak, 15% red maple, 10% muscadine, and 6% sweetgum; and the control treatment was created from 60% sweetgum, 17% loblolly pine, 9% sweetbay, 7% red maple, and 7% muscadine.

Litterbags were set in field plots during Aug. 1999. Thirty "common" litterbags and 30 "specific" litterbags were randomly placed in subplots on each of the partial, clearcut, and control treatment plots. Three "specific" and "common" litterbags were collected on each treatment plot at time 0 (to estimate handling loss), and 2-, 4-, 6-, 10-, 18-, 26-, 36-, 46-, and 60-week intervals. On collection, all remaining litter was removed from litterbags. Soil was removed by gently brushing decomposing leaves with a soft bristled artist brush. Litter was then oven-dried at 70° C until a constant mass was obtained, weighed, ground to pass a 20-mesh sieve, and analyzed for P, C, and N.

Understory Vegetation Survey

In each treatment, two 50-m transects were installed on each side of each intermittent stream. Five 1-m^2 plots were spaced every 10 m along each transect. During Apr. and Sept. 2000, 9 and 14 months postharvest, respectively, all vegetation <3 m in height was clipped. The clipped vegetation was separated into grasses, forbs, and woody plants in the field to ensure correct species identification. Following identification, all understory vegetation was transported to the laboratory, oven-dried at 70° C until a constant mass was obtained, weighed, ground to pass a 20-mesh sieve, and analyzed for P, C, and N.

Temperature

StowAway soil temperature recorders (model STEB02-Onset Computer Corporation, Pocasset, MA) were used to record temperature hourly. Two soil temperature recorders were located within the top 15 cm of soil and covered with leaf litter consistent with the surrounding forest floor. Soil temperatures were recorded daily from Jan. 1998 through Dec. 2000. However, the soil temperature loggers were removed from plots from July 1999 through Dec. 1999 during harvesting and reinstalled afterward.

Surface Water

Storm event samples were collected from Jan. through Apr. 1998, 1999, 2000, and 2001 using ISCO 3,700 portable samplers that sampled 1 liter of water (ISCO, Lincoln, NE). Stormwater samples were collected every 30 minutes for the first 6 hours during a storm event and then every 90 minutes for a total of 24 samples during a 24-hour time period. Following the storm event, surface water samples were transported to the laboratory and refrigerated. Water was analyzed for chloride (Cl), nitrate (NO_3), phosphorus (P), sulfate (SO_4), sodium (Na), ammonium (NH_4), potassium (K), dissolved organic carbon (DOC), total suspended solids (TSS), and total dissolved solids (TDS).

Laboratory

Soil extractable phosphorus (P) was analyzed using Mehlich 1 (double acid) solution. Atomic absorption spectroscopy was used to determine exchangeable potassium (K) in a soil extract, while calcium (Ca) and magnesium (Mg) were determined using a C_2H_2 air flame in lanthanum (La) solution (Auburn University Soil Testing Laboratory 1986). Total N on soil was determined using combustion (LECO CHN-600; LECO Corporation, Street Joseph, MI) (Nelson and Sommers 1996, Auburn University Soil Testing Laboratory 1986).

Litterfall, decomposition, and vegetation samples were dry-ashed, extracted using the vanadomolybdate method (Jackson 1958), and extracts were assessed on a Spectronic 501 spectrophotometer (Milton Roy Company, Rochester, NY) for total P. Total C and N were determined using thermal combustion (Perkin-Elmer 2,400 series II CHNS/O analyzer; Perkin-Elmer Corporation, Norwalk, CT)-(Nelson and Sommers 1996).

Surface water was analyzed using methodology described in Clescerl et al. (1999). Anion and cation water samples were run on a dual column ion chromatograph (DX-120 AS14 anion column; CS12A cation column; Dionex Corporation, Atlanta, GA). Dissolved organic carbon was determined by persulfate oxidation using a Rosemount-Dohrmann DC-80 analyzer (Rosemount-Dohrmann Analytical Inc., Santa Clara, CA). Total dissolved solids were determined using an Accumet AB30 conductivity meter (Fisher Scientific, Pittsburgh, PA). The American Society for Testing and Materials (1997) described methodology used to calculate total suspended solids (TSS).

Statistical Analysis

Because each treatment had only one replicate, data were analyzed using *t*-tests (Zar 1984, Statistical Analysis System Institute Inc. 2000). Soil chemistry variables (pH, P, K, Mg, Ca, total C, and total N), soil temperature (mean and range), litterfall variables (mass, P, C, N, C/N, and N/P), decomposition variables (mass, C, N and P-remaining, C/N, and N/P ratios), and understory vegetation (dry weight, total P, total N, and total C) were compared between the partial versus clearcut, the partial versus control, and the clearcut versus control. Decomposition mass loss rates (k) were estimated using nonlinear regressions. For all analyses, significant differences are reported at the 0.05 probability level. Surface water analytes were not statistically compared because of insufficient sample size caused by dry conditions.

Results

Precipitation

Precipitation during the study period was lower than the 1961–1990 average (Karl Harker, Agricultural Weather Information Service, Inc., Aug. 2002). In 1999, precipitation was lower by 467 mm and for 2000 by 796.5 mm (Figure 2).

Litterfall

Litterfall Within SMZ

As expected, the greatest postharvest litterfall mass was collected from the control followed by the partial and clearcut treatments (Figure 3a). Significant differences were noted throughout the year except for Jan., Feb., and Sept. 2000 for the partial versus clearcut comparison; Mar., June, July, Sept., and Dec. 2000 for the partial versus control comparison; June and July 2000 for the clearcut versus control comparison.

Posttreatment annual total litterfall biomass within the SMZ was calculated using data from Aug. 1999 through July 2000 (Table 2). Annual foliar litterfall biomass for the partial, clearcut and control sites, respectively, was 377, 125, and 640 g m^{-2} y^{-1}. Nutrient content of foliar litterfall followed the same pattern as biomass with statistical differences among the three treatments observed at the 0.05 level.

The litterfall N:P and C:N ratios within the SMZ were 9.2, 8.2, 8.7 and 52.0, 65.1, 56.4 on the partial, clearcut, and control plots, respectively. The C:N ratios differed between the partial versus clearcut plots, whereas N:P ratios differed between the partial versus control plots.

Litterfall Inputs Into Streams

Litterfall entering the streams was most similar between the partial and control treatments with only Oct. 1999 and Dec. 2000 litterfall mass differing statistically (Figure 3b). This contrasts with the partial versus clearcut and clearcut versus control comparisons, which displayed significant differences throughout most of the postharvest collections.

Annual foliar litterfall biomass inputs to stream channels for the partial, clearcut and control sites, respectively, were 814, 124, and 1,097 g m^{-2} y^{-1} (Table 2). Total litterfall biomass and nutrient content were significantly different when comparing the partial versus clearcut, and clearcut versus control. No significant differences in biomass, C, N, or P content were observed for the partial versus control comparison.

For litterfall entering the stream, N:P ratios were 9.4, 7.6, and 8.5 for the partial, clearcut and control plots, respectively. Significant differences were observed for all treatment comparisons. The C:N ratios for the partial, clearcut, and control plots were 48.7, 49.6, and 44.8. Treatment comparisons were not significant.

Decomposition

At 60 weeks, percent mass remaining of decomposing leaves in the "common" set of litterbags (litterfall collected across all watersheds), and the "specific" set of litterbags (litter specific to each watershed), were compared among treatments (Table 3). Mass loss rates (k) indicated that decomposition in the control was most rapid for both types

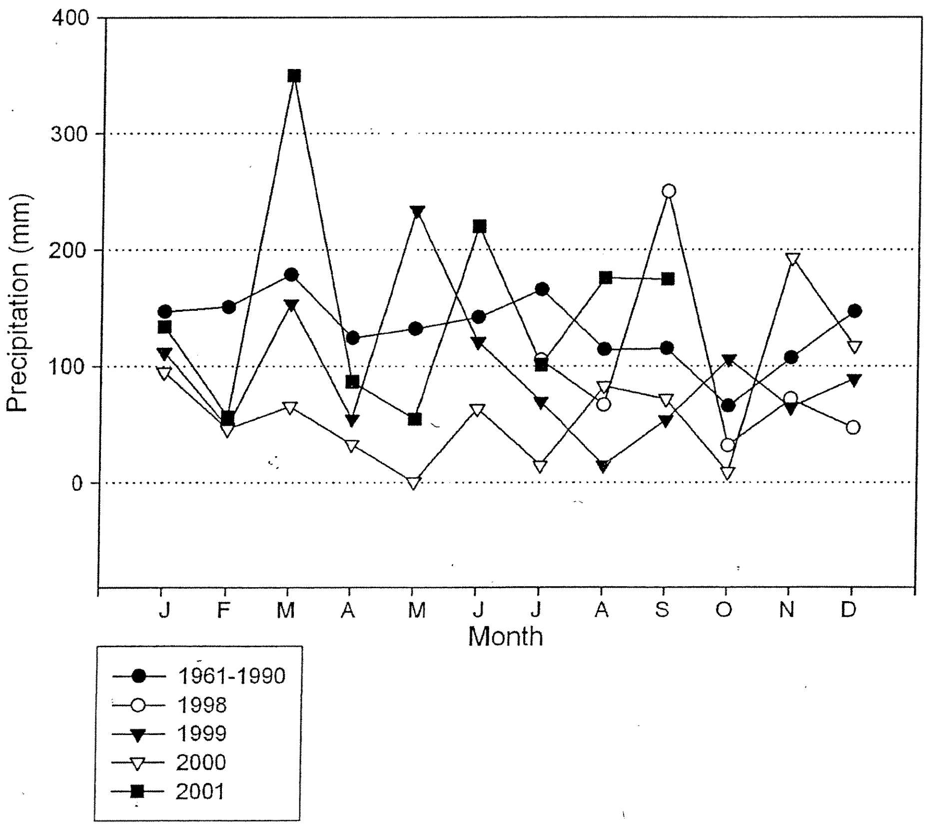

Figure 2. Precipitation (mm) by year from July 1998 through Sept. 2001 and the average long-term normal precipitation (1961–1990) for Evergreen, AL.

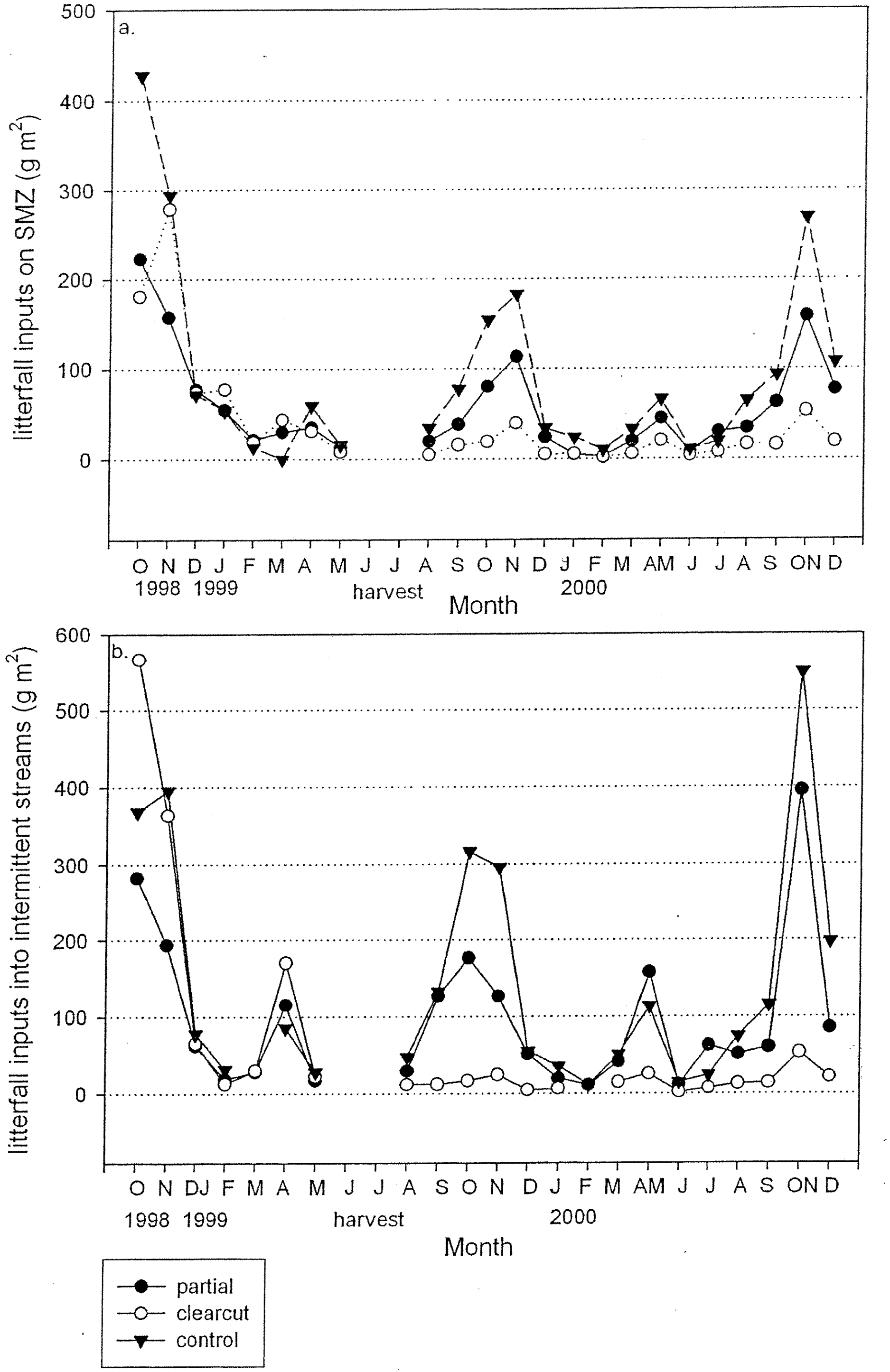

Figure 3. Litterfall inputs into (a) treatment plots within the streamside management zone (SMZ) and (b) intermittent streams in Monroe County, AL.

of litter. Estimated litter turnover times ($1/k$) for the "common" litter were 10 years on the partial, 12 years on the clearcut, and 8 years for the control. For "specific" litter, turnover times for the partial, clearcut and control, respectively, were 14, 16, and 8 years. Turnover times for "common" litter were compared to "specific" litter for each treatment. Turnover times were significantly higher for the "specific" litter in both the partial and clearcut treatments.

Carbon loss followed the pattern of mass loss with the most rapid losses in the control for both litter types. Similarly, percent P remaining was higher in the partial > clearcut > control for both types (Table 3). Percent P remaining for the partial versus control treatment was significantly greater on the partial plot for the "common" litter. Percent N remaining ranked as partial > clearcut > control within the "common" litter, but clearcut > partial > control

Table 2. Litterfall mass and nutrients falling within streamside management zones (SMZ) and in the stream during the post-harvest period (Aug. 1999–July 2000) in Monroe Co., AL.

SMZ treatment comparison	Mass	C	N	P	C/N	N/P
	(g m^{-2})					
Post-harvest on SMZ						
Partial vs	377	47.20	0.91	0.1082	52.0	9.2
Clearcut	125	15.95	0.25	0.0307	65.1	8.2
Prob > |T|	0.0001[a]	0.0001[a]	0.0001[a]	0.0001[a]	0.0297[a]	0.0551
Partial vs	377	47.20	0.91	0.1082	52.0	9.2
Control	640	80.38	1.47	0.1662	56.4	8.7
Prob > |T|	0.0001[a]	0.0001[a]	0.0001[a]	0.0001[a]	0.4011	0.0386[a]
Clearcut vs	125	15.95	0.25	0.0307	65.1	8.2
Control	640	80.38	1.47	0.1662	56.4	8.7
Prob > |T|	0.0001[a]	0.0001[a]	0.0001[a]	0.0001[a]	0.1767	0.3735
Post-harvest in stream						
Partial vs	814	101.7	2.08	0.2375	48.7	9.4
Clearcut	124	15.65	0.34	0.0450	49.6	7.6
Prob > |T|	0.0005[a]	0.0009	0.0315[a]	0.0420[a]	0.8909	0.0181[a]
Partial vs	814	101.7	2.08	0.2375	48.7	9.4
Control	1097	136.5	2.75	0.3019	44.8	8.5
Prob > |T|	0.0866	0.0951	0.2807	0.2579	0.6176	0.0320[a]
Clearcut vs	124	15.65	0.34	0.0450	49.6	7.6
Control	1097	136.5	2.75	0.3019	44.8	8.5
Prob > |T|	0.0082[a]	0.0087[a]	0.0004[a]	0.0027[a]	0.4303	0.0461[a]

[a] Significant at alpha = 0.05.

Table 3. Percentage of mass, C, N, P remaining, C/N, N/P ratios, and decomposition (k) rates associated with litterbags placed on intermittent streams in Monroe Co., AL after 60 weeks in the field.

SMZ[1] treatment comparison	Mass	C	N	P	C/N	N/P	k
	(%)						
Common litter							
Partial vs	58.4	58.2	146.8	86.7	32.5	9.9	0.0962
Clearcut	65.6	61.4	136.8	75.9	34.3	9.1	0.0846
Prob > |T|	0.5785	0.7390	0.5395	0.4712	0.3989	0.3331	0.1913
Partial vs	58.4	58.2	146.8	86.7	32.5	9.9	0.0962
Control	46.1	41.1	127.9	66.9	26.3	9.8	0.1273
Prob > |T|	0.0697	0.0172[b]	0.0655	0.0390[b]	0.0547	0.8658	0.0006
Clearcut vs	65.6	61.4	136.8	75.9	34.3	9.1	0.0846
Control	46.1	41.1	127.9	66.9	26.3	9.8	0.1273
Prob > |T|	0.1825	0.0835	0.6098	0.5169	0.0244[b]	0.2519	0.0001
Specific litter							
Partial vs	73.7	58.4	145.7	80.1	34.0	8.9	0.0703
Clearcut	66.9	67.3	155.3	79.8	54.8	8.6	0.0622
Prob > |T|	0.5686	0.4504	0.6663	0.9875	0.0600	0.6092	0.4351
Partial vs	73.7	58.4	145.7	80.1	34.0	8.9	0.0703
Control	52.7	44.7	109.2	75.3	37.1	7.6	0.1251
Prob > |T|	0.0416	0.0130[b]	0.0027[b]	0.4782	0.2585	0.2189	0.0000
Clearcut vs	66.9	67.3	155.3	79.8	54.8	8.6	0.0622
Control	52.7	44.7	109.2	75.3	37.1	7.6	0.1251
Prob > |T|	0.2869	0.0927	0.0889	0.7718	0.0396[b]	0.3526	0.0000

[a] SMZ, Streamside management zone.
[b] Significant at alpha = 0.05.

within the "specific" litter. Percent N remaining for the partial versus control comparison was significantly greater on the partial plot within the "specific" litter. After 60 weeks, treatments exhibited variation in C:N ratios. The clearcut plot had the highest C:N ratio for both litter types. For comparisons of clearcut versus control for both the "common" and "specific" litter, respectively, C:N ratios were significantly greater on clearcut plots. No significant variation was observed within either litter type for N:P ratios.

When immobilization/mineralization patterns were compared among treatment and litter types, differences between treatments in N and P dynamics were observed. Phosphorus in "common" litter on all treatments displayed an early mineralization trend with an immobilization phase during week 10 followed by a second mineralization phase (Figure 4). Early immobilization was suggested during week 2 on the control site. Percent P remaining was significantly higher for the common litter on the partial plots at weeks 6, 10, and 18, but was higher for the specific litter for the clearcut at week 4, and control plots on weeks 18 and 26.

As would be expected on N deficient sites, nitrogen dynamics were generally characterized by immobilization

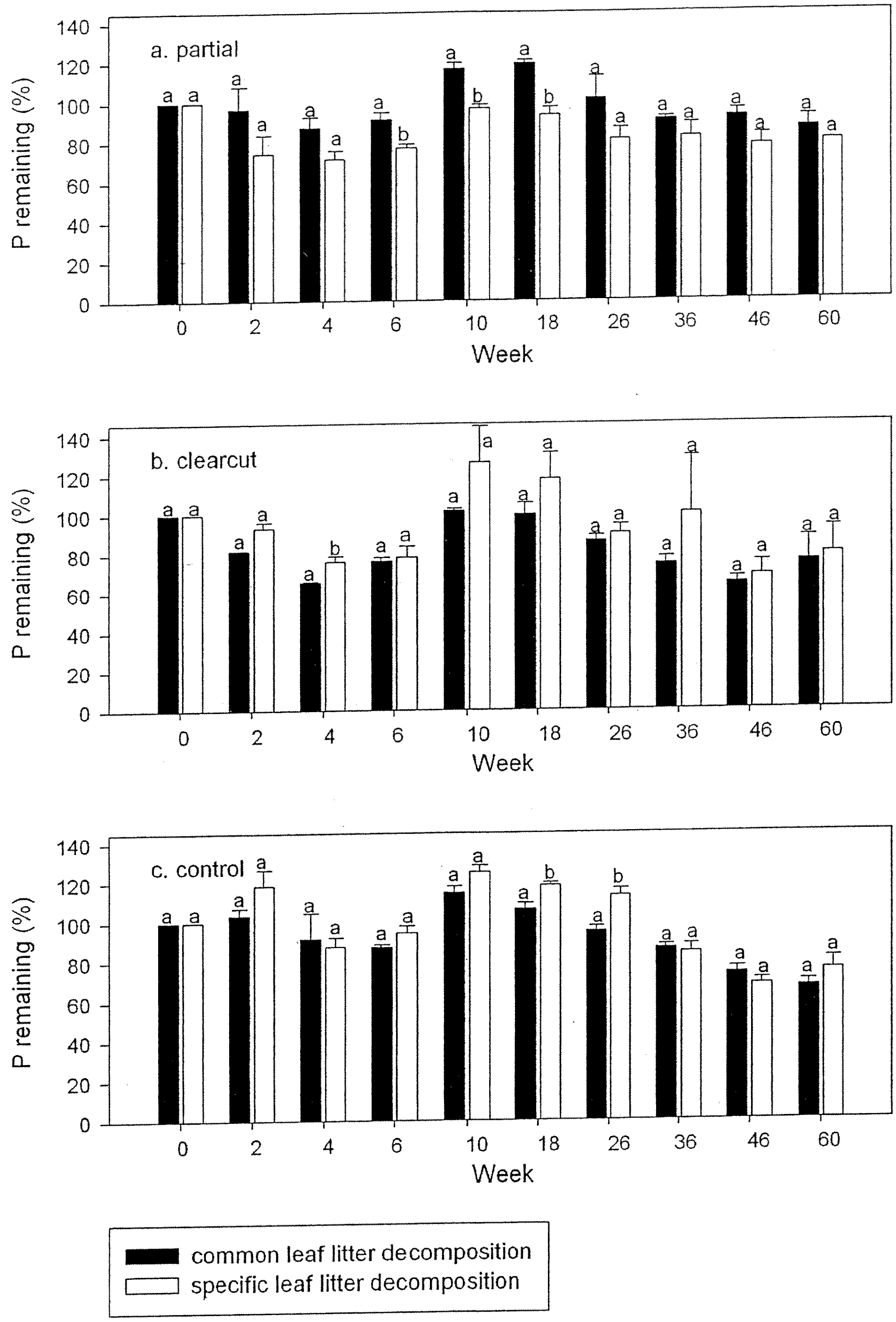

Figure 4. P immobilization/mineralization patterns for "common" and "specific" decomposing leaf litter on (a) partial, (b) clearcut, and (c) control treatment plots within the streamside management zone (SMZ) of intermittent streams in Monroe County, AL. Means with same letter are not significantly different at the $\alpha = 0.05$ level. Vertical bars represent standard error of the mean.

throughout the entire study period except for "common" litter on the clearcut at week 2 and "specific" litter on the control at week 60 (Figure 5). N immobilization on the partial and clearcut treatments was greater than that of the control for both litter types. Percent N remaining was significantly higher for the common litter on the partial plot at week 18 and on the control at week 46, but was higher for the specific litter on the clearcut at week 2.

Understory Vegetation Survey

During the Apr. 2000 (9 months postharvest) survey, distribution percentages of grass, forbs and woody vegetation were variable among treatments (Table 4). However, during the Sept. 2000 (14 months postharvest) survey, percent distribution within each treatment was more evenly distributed except for the control. During the Apr. 2000 survey, 38 genera were detected on the partial

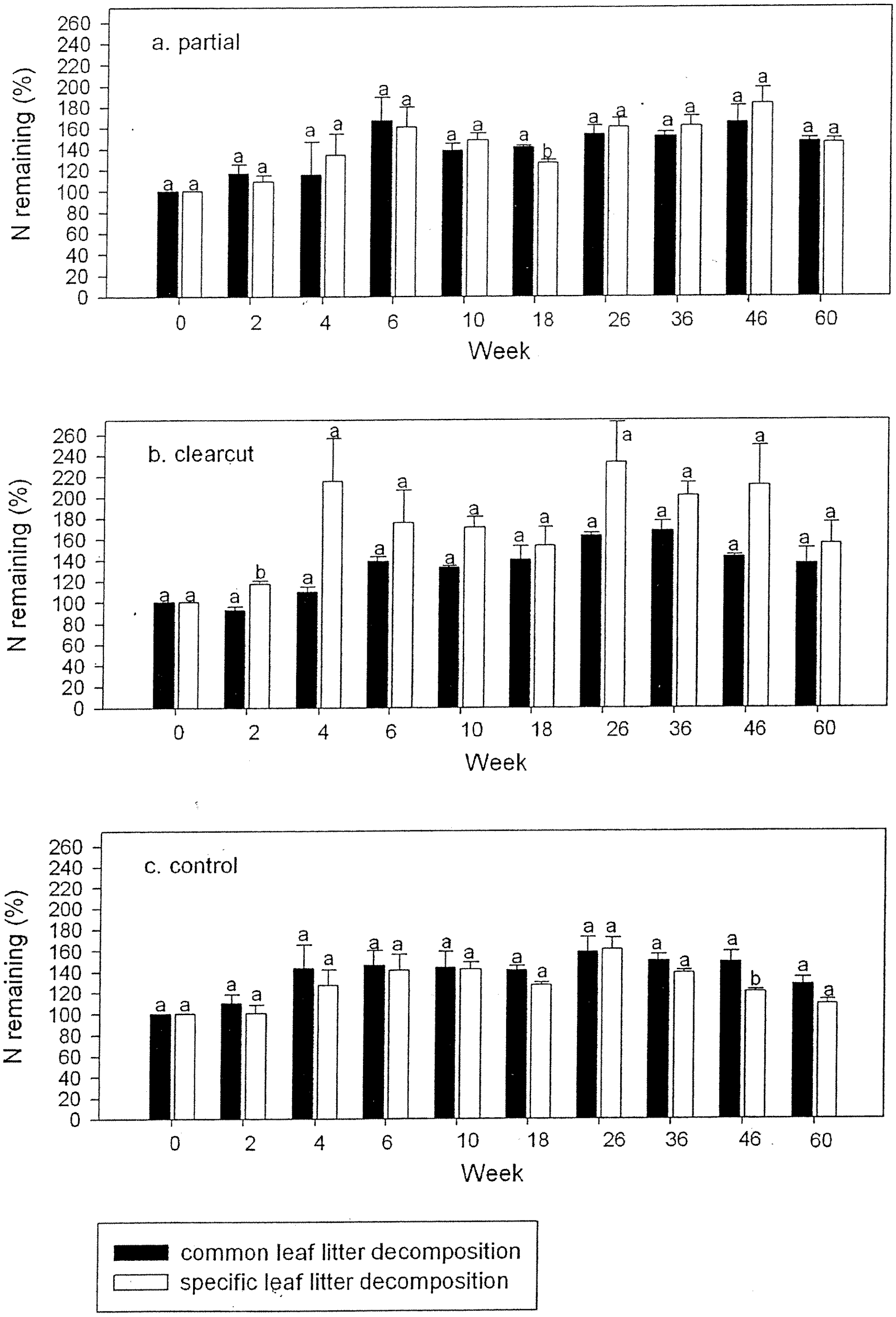

Figure 5. N immobilization/mineralization patterns for "common" and "specific" decomposing leaf litter on (a) partial, (b) clearcut, and (c) control treatment plots within the streamside management zone (SMZ) of intermittent streams in Monroe County, AL. Means with same letter are not significantly different at the $\alpha = 0.05$ level. Vertical bars represent standard error of the mean.

cut, 25 genera on the clearcut, and 15 genera on the control (Table 4). The partial cut exceeded the other treatments in both the number of forbs and woody genera growing on site. During the Sept. 2000 survey, the partial cut had 17 genera, the clearcut 23 genera, and control 12 genera. The fewest total genera were identified on the control for both surveys.

Understory vegetation species identified only on the clearcut area included: ragweed (*Ambrosia artemisifolia* L.), persimmon (*Diospyros virginiana* L.), dog-fennel (*Eupatorium capillifolium* (Lam.) Small), boneset (*Eupatorium perfoliatum* L.), rabbit tobacco (*Gnaphalium obtusifolium* L.), black cherry (*Prunus serotina* Ehrhart), dwarf sumac (*Rhus copallina* L.), sweet leaf (*Symplocos tinctoria* (L.)

Table 4. Distribution percentages and number of genera of grass, forbs, and woody vegetation from understory vegetation surveys conducted in Monroe Co., AL during April and Sept. 2000, 9 and 14 months post-harvest.

Vegetation	April 2000			Sept. 2000		
	Partial	Clearcut	Control	Partial	Clearcut	Control
	(%)			(%)		
Forbs	2	10	7	37	32	15
Grass	21	65	18	39	40	4
Woody	77	25	75	24	28	81
	(number of genera)			(number of genera)		
Forbs	15	9	5	5	8	3
Grass	2	4	1	1	3	1
Woody	21	12	9	11	12	8

L'Her.), summer grape (*Vitis aestivalis* Michaux) and an unknown exotic grass (Table 5). Species found only on the partial treatment included: pepper-vine (*Ampelopsis arborea* (L.) Koehne), hickory (*Carya* Nuttall), indian strawberry (*Duchesnea indica* (Andrz.) Focke), bedstraw (*Galium* L.), yellow jessamine (*Gelsemium sempervirens* (L.) Aiton f.). sunflower *Helianthus radula* (Pursh) T. & G.), holly (*Ilex opaca* Aiton), sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.), wood sorrel (*Oxalis stricta* L.), polygala (*Polygala mariana* Miller), and verbena (*Verbena* L.). The control treatment had the following species that were not found on the harvested treatments: red mulberry (*Morus rubra* L.), *Sebastiania ligustrina* (Michaux) Muell-Arg., and netted chainfern (*Woodwardia areolata* (L.) Moore).

For Apr. and Sept. understory vegetation surveys, total vegetation biomass was greater on the clearcut > partial > control. Nutrient content for total vegetation also followed the same pattern as biomass for both surveys. When the clearcut was compared to the control in terms of biomass and nutrients, the clearcut was statistically greater than the control for both (Table 6).

Soil Temperature

Average soil temperatures were similar on all plots prior to and postharvest. Temperature range was calculated as the difference between soil temperature at 3:00 p.m. and 3:00 a.m., which were approximately the warmest and coolest times of the day, respectively. Prior to the harvest, no patterns were observed in temperature ranges among treatments. Following harvest, a strong trend was observed with soil temperature ranges being wider on the clearcut from Jan. through Sept. 2000 and wider on the partial cut during Oct. through Dec. 2000 (Figure 6). We were particularly interested in temperature ranges because range may be a better indicator of impact to vegetation and decomposition rates than absolute temperatures.

Surface Water

When water chemistry data were analyzed, results indicated there were differences in chemical concentrations among the three treatments prior to harvest. Following harvest, below normal precipitation limited sample collections. We felt that we had insufficient water chemistry data following harvest to support quantitative analysis. Therefore, only descriptive water chemistry data for 1999 preharvest and 2001 postharvest water samples are presented in Table 7.

Discussion

Mass of total annual postharvest litterfall on the control SMZ was similar to values reported for other temperate riparian forests (Brinson 1990, Clawson et al. 2001, Conner and Day 1976, Lockaby and Conner 1999). In terms of litterfall inputs to the intermittent channels, the postharvest litterfall mass and nutrients for the partial treatment were similar to the control catchment. This similarity is probably accounted for by the recommendation in the Alabama BMP that trees near stream banks or on steep slopes leading down to streams remain uncut (Alabama Forestry Commission 1993). Consequently, those trees that overtopped the stream continued to provide detrital inputs directly to the channel. The quantity of P in the litterfall that fell in the partial and control treatment streams postharvest were within ranges reported by Schlesinger (1978) and Brinson et al. (1980), but below for the clearcut treatment. Nitrogen in the litter that fell within the streams followed the same pattern as P and was similar to the data of Schlesinger (1978) on the partial and control treatments. Postharvest nitrogen content in the litterfall that fell in the clearcut stream was reduced accordingly.

Litter decomposition rates are influenced by moisture and temperature (Barbour et al. 1987, Lockaby et al. 1999). Piatek and Allen (1999) noted that unharvested control plots in the North Carolina Piedmont had lower soil temperatures throughout the growing season but higher soil temperatures in Nov. than plots that had been harvested, site prepared, and regenerated.

This general trend was also observed in this study with the exception of 3 p.m. temperature mean for Nov. Reductions in leaf litter decomposition rates observed within the two harvested catchments are probably the result of drier soil surface conditions. Brinson (1977) and Shure et al. (1986) also noted that moisture influenced decomposition rate. "Common" and "specific" leaf litter decomposition rates responded similarly to treatments suggesting that preharvest litter quality was generally similar across all catchments.

Table 5. Species found growing within clip plots during understory vegetation surveys conducted in April and Sept. 2000, 9 and 14 months post-harvest, on partial, clearcut and control plots in Monroe Co., AL.

	April 2000			Sept. 2000		
Vegetation	Partial	Clearcut	Control	Partial	Clearcut	Control
Acer rubrum L.	+[a]	+	+	·	·	+
Albizia julibrissin Durazzini	+	·	·	·	+	·
Ambrosia artemisiifolia L.	·	·	·	·	+	·
Ampelopsis arborea (L.) Koehne	+	·	·	·	·	·
Aralia spinosa L.	+	+	·	·	+	·
Arundinaria gigantea (Walter) Muhl.	+	+	·	·	+	·
Asimina parviflora (Michaux) Dunal	+	·	·	·	·	·
Callicarpa americana L.	+	+	+	+	+	+
Campsis radicans (L.) Seemann	+	+	·	+	+	·
Carpinus caroliniana Walter	·	·	·	·	+	+
Carya Nuttall	+	·	·	·	·	·
Chaerophyllum tainturieri Hooker	+	·	·	·	·	·
Cornus florida L.	+	+	+	+	·	·
Dichondra carolinensis Michaux	+	·	·	·	·	·
Diospyros virginiana L.	·	·	·	·	+	·
Duchesnea indica (Andrz.) Focke	+	·	·	·	·	·
Eupatorium capillifolium (Lam.) Small	·	+	·	·	+	·
Eupatorium perfolium L.	·	+	·	·	+	·
Galium L.	+	·	·	·	·	·
Gelsemium sempervirens (L.) Aiton f.	+	·	·	·	·	·
Gnaphalium obtusifolium L.	·	+	·	·	·	·
Hedera helix L.	·	·	·	+	·	·
Helianthus radula (Pursh) T.&G.	+	·	·	·	·	·
Ilex opaca Aiton	+	·	·	·	·	·
Ligustrum sinense Lour.	+	+	+	+	·	·
Liquidambar styraciflua L.	+	·	·	·	·	·
Liriodendron tulipifera L.	+	·	·	+	·	·
Lonicera japonica Thunberg	+	+	+	+	+	+
Mitchella repens L.	+	+	+	+	+	+
Morus rubra L.	·	·	+	·	·	·
Oxalis stricta L.	+	·	·	·	·	·
Panicum L.	+	+	+	+	+	+
Parthenocissus quinquefolia (L.) Planchon	+	·	+	+	·	·
Phytolacca americana L.	·	+	·	·	·	·
Pinus taeda L.	+	+	·	+	·	·
Plantago lanceolata L.	+	·	·	·	·	·
Poa L.	·	+	·	·	·	·
Polygala mariana Miller	+	·	·	·	·	·
Polystichum acrostichoides (Michaux) Schott	+	·	+	+	·	·
Prunus serotina Ehrhart	·	·	·	·	+	·
Quercus L.	+	·	+	+	·	+
Rhus copallina L.	·	+	·	·	+	·
Rubus L.	+	+	+	+	+	·
Rumex L.	+	·	·	+	+	·
Sambucus canadensis L.	·	·	·	·	+	·
Sebastiania ligustrina (Michaux) Muell-Arg	·	·	·	·	·	+
Smilax glauca Walter	+	+	+	+	+	+
Solidago L.	+	+	·	·	+	·
Symplocos tinctoria (L.) L'Her.	·	+	·	·	·	·
Toxicodendron radicans L.	+	+	+	·	·	+
Vaccinium arboreum Marshall	+	·	·	·	+	·
Verbena L.	+	·	·	·	·	·
Vitis aestivalis Michaux	·	+	·	·	·	·
Vitis rotundifolia Michaux	+	+	·	+	+	+
Woodwardia areolata (L.) Moore	·	·	+	·	·	+
Exotic grass specie	·	+	·	·	+	·

[a] + indicates presence of species on treatment plots.

Peterson and Rolfe (1982) suggested that leaf litter may be a temporary N sink after noting N retention in decomposing leaf litter Illinois. Although, Peterson and Rolfe (1982) did not observe a net gain in N, an accumulation of N in decomposing leaves has been reported by Brinson (1977). In the present study, N content of leaf litter generally increased during the decomposition period on all treatments. Trends toward immobilization in litter are often observed for elements that may be deficient on particular sites (Lockaby et al. 1999), while

Table 6. Understory vegetation survey results for dry wt, total phosphorus, total nitrogen, and total carbon for research sites located in Monroe Co., AL during April and Sept. 2000, 9 and 14 months post-harvest.

SMZ[a] treatment comparison	Dry wt	Total P	Total N	Total C
	(g m^{-2})			
April				
Partial vs	44.97	0.0578	0.2656	9.44
Clearcut	82.41	0.0845	0.3848	18.81
Prob < |T|	0.1580	0.3489	0.3225	0.1164
Partial vs	44.97	0.0578	0.2656	9.44
Control	26.02	0.0363	0.1906	5.98
Prob < |T|	0.2281	0.3464	0.4617	0.3099
Clearcut vs	82.41	0.0845	0.3848	18.81
Control	26.02	0.0363	0.1906	5.98
Prob < |T|	0.0196[b]	0.0336[b]	0.0536	0.0202[b]
September				
Partial vs	34.99	0.0282	0.2385	8.35
Clearcut	163.75	0.2657	1.132	41.24
Prob < |T|	0.0002[b]	0.0325[b]	0.0005[b]	0.0002[b]
Partial vs	34.99	0.0282	0.2385	8.35
Control	23.55	0.0272	0.2126	5.66
Prob < |T|	0.2764	0.9282	0.7907	0.2913
Clearcut vs	163.75	0.2657	1.132	41.24
Control	23.55	0.0272	0.2126	5.66
Prob < |T|	0.0001[b]	0.0322[b]	0.0005[b]	0.0001[b]

[a] SMZ: Streamside management zone.
[b] Significant at alpha = 0.05.

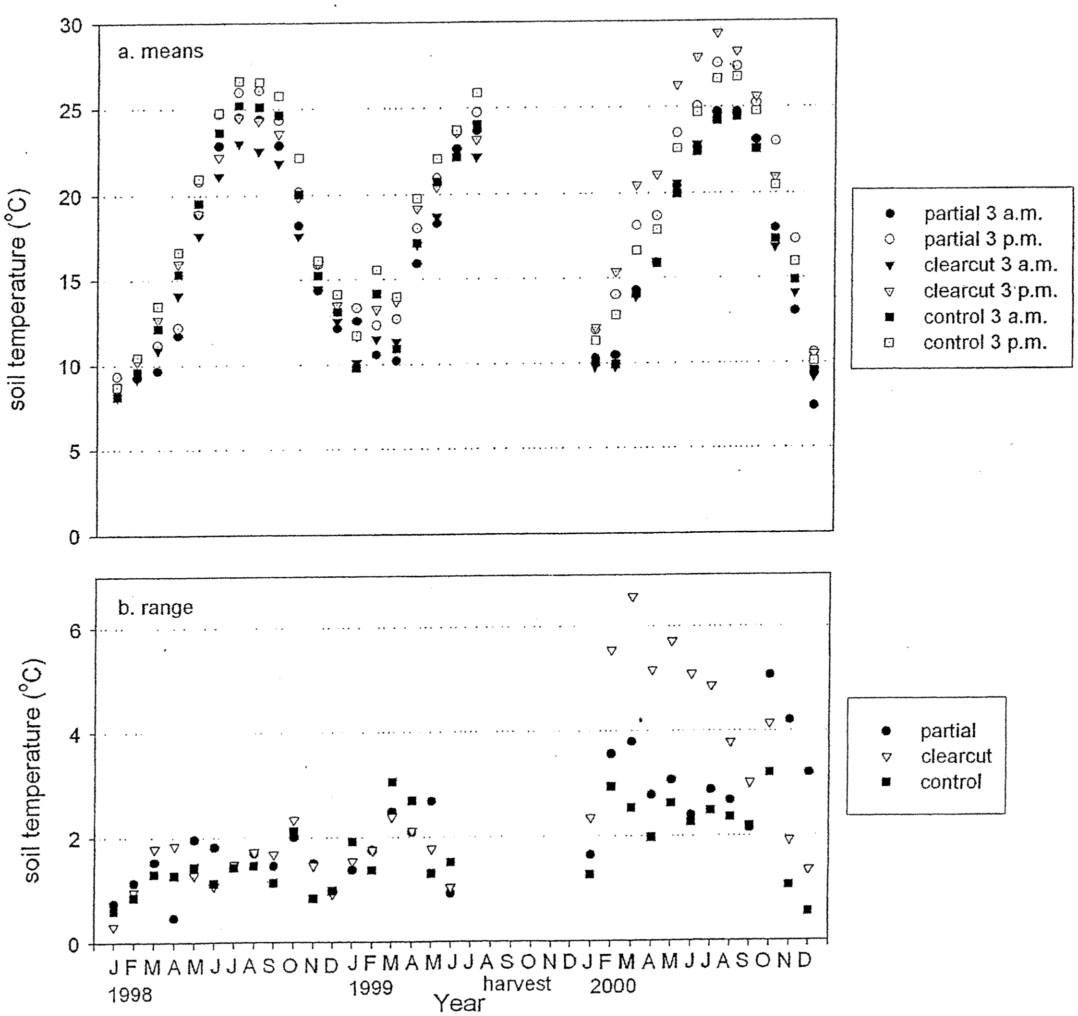

Figure 6. Soil temperature at 0–15 cm (a) mean and (b) range at 3:00 p.m. and 3:00 a.m. compared on partial, clearcut and control research plots in Monroe County, AL.

Table 7. Surface water analytes (mg/l) in intermittent streams by year for partial, clearcut and control treatments in Monroe Co., AL.

Analyte	Year	Partial	Clearcut	Control
		(mg/l)		
TDS	1999[a]	12.69	12.15	11.38
	2001	17.44	14.72	24.37
TSS	1999	14.4	7.31	57.9
	2001	4.13	8.02	10.9
Cl	1999	2.04	2.31	2.11
	2001	2.81	1.83	3.90
NO_3	1999	0.315	0.352	0.264
	2001	0.038	0.108	0.114
P	1999	0.087	0.082	0.068
	2001	0.054	0.059	0.075
SO_4	1999	1.45	1.48	1.37
	2001	5.01	3.42	8.01
Na	1999	1.48	1.49	1.44
	2001	2.04	1.38	2.82
NH_4	1999	0.035	0.025	0.027
	2001	0.019	0.007	0.032
K	1999	0.329	0.174	0.246
	2001	0.348	1.40	0.332
DOC	1999	5.56	2.62	3.20
	2001	3.24	8.21	3.77

[a], 1999, pre-harvest; 2001, second year post-harvest.

mineralization–immobilization cycles or mineralization alone may prevail with elements that are less deficient (e.g., phosphorus in this case).

Phosphorus in the decomposing leaf litter did not follow the N pattern of immobilization. Phosphorus displayed early mineralization, with a brief immobilization period at 10 to 18 weeks on all treatments followed by mineralization. This trend is consistent with Lockaby et al. (1996) observations on the Ogeechee River floodplain, Georgia. Leaf litter N and P behavior in this study was also similar to that observed in pine plantations in Alabama by Lockaby et al. (1995). In both cases, N was likely the primary nutritional deficiency. The retention of N in litter represents one mechanism through which short-term losses following disturbance in these systems would be minimized (Lockaby et al. 1999). Another relatively short-term mechanism would be the assimilation of N in herbaceous vegetation and woody regeneration that proliferated following the harvest treatments.

Grasses and other opportunistic herbaceous vegetation were stimulated by canopy removal. Herbaceous vegetation identified only on the clearcut were those typically found in fields, pastures, and roadsides whereas those species found only on the control treatment were those that grow in alluvial woods, along rivers and wet pineland (Radford et al. 1968). Schilling et al. (1999) also noted rapid colonization of herbaceous and woody vegetation on partial and clearcut sites on the Pearl River floodplain, Mississippi, following harvest. Mader et al. (1989) documented rapid regrowth following harvest in a water tupelo-bald cypress swamp in Alabama. On their harvested research sites, the 60 species of herbaceous vegetation detected comprised a large percentage of the first-year productivity (Mader et al. 1989). Roberts and Zhu (2002) reported that forest floor disturbance caused by clearcutting with mechanical site preparation and planting caused more dramatic changes in herbaceous species diversity and composition than did clearcutting with natural regeneration. Examining various types of mechanical site preparation in pine plantations in Georgia, Locascio et al. (1990) documented that grass and forb biomass was greatest on the most intensive treatment (shear, rake, burn, and disk), whereas woody biomass and vines were greatest on the moderate treatments (shear and chop; residuals 2.54 cm > dbh felled). The trend observed by Locascio et al. (1990) was also evident in this study. The abundance of herbaceous vegetation that occurred following the clearcut would have added considerably to the filtration and nutrient stabilization potentials of the SMZs. Aust et al. (1997) noted that low vegetation and postharvest debris from recent harvests augmented sediment detention.

Conclusions

Results of this study showed that nitrogen on the harvested treatments was retained in both leaf litter decomposition and herbaceous vegetation, indicating conservative nitrogen cycling on a nitrogen deficient site. Rapid colonization on the harvested treatments by herbaceous vegetation was advantageous for both the assimilation and retention of nutrients on the site. A partial harvest retaining residual tree cover along the banks of intermittent streams is advantageous in maintaining litterfall inputs into the intermittent streams.

Literature Cited

Alabama Forestry Commission. 1993. Alabama's best management practices for forestry 1993. Montgomery, AL. 30 p.

American Society for Testing and Materials. 1997. Standard test methods for determining sediment concentration in water samples. D 3977-97. American Society for Testing and Materials, West Conshohocken, PA. 6 p.

Auburn University Soil Testing Laboratory. 1986. Procedures used for soil and plant analysis by the Auburn University Soil Testing Laboratory. Alabama Agricultural Experiment Station Departmental Series No. 106. Auburn, AL. 31 p.

Aust, W.M., S.H. Schoenholtz, T.W. Zaebst, and B.A. Szabo. 1997. Recovery status of tupelo-cypress wetland seven years after disturbance: silvicultural implications. For. Ecol. Manage. 90(2,3):161–169.

Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial plant ecology. The Benjamin/Cummings Publishing Co., Inc., Menlo Park, CA. 634 p.

Binkley, D., and T.C. Brown. 1993. Forest practices as nonpoint sources of pollution in North America. Water Resources Bull. 29(5):729–740.

Brinson, M.M. 1990. Riverine forests. P. 87–141 *in* Ecosystems of the world, Vol. 15, Forested wetlands, Lugo, A.E., M. Brinson, and S. Brown (eds.). Elsevier, Amsterdam, The Netherlands. 527 p.

Brinson, M.M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology 58(3):601–609.

Brinson, M.M., H.D. Bradshaw, R.N. Holmes, and J.B. Elkins, Jr. 1980. Litterfall, stemflow, and throughfall nutrient fluxes in an alluvial swamp forest. Ecology 61(4):827–835.

Clawson, R.G., B.G. Lockaby, and B. Rummer. 2001. Changes in production and nutrient cycling across a wetness gradient within a floodplain forest. Ecosystems 4(2):126–138.

Clescerl, L.S., A.E. Greenberg, and A.D. Eaton. 1999. Standard methods for the examination of water and wastewater. 20th Ed. American Public Health Association, Washington, DC. 1,325 p.

Conner, W.H., and J.W. Day, Jr. 1976. Productivity and composition of a baldcypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. Am. J. Bot. 63(10):1354–1364.

Florida Department of Agriculture and Consumer Services. 1992. Silviculture best management practices. Tallahassee, FL. 94 p.

Fritz, K.M. 2003. The roles of aquatic and riparian vegetation at the aquatic-terrestrial interface of southeastern streams. Ph.D. dissertation. Auburn University, Auburn, AL. 260 p.

Gilliam, F.S. 2002. Effects of harvesting on herbaceous layer diversity of a central Appalachian hardwood forest in West Virginia, USA. For. Ecol. Manage. 155(1–3):33–43.

Jackson, M.L. II 1958. Soil chemical analysis. Prentice Hall, Englewood Cliffs, NJ. 498 p.

Johnson, G.V., R.A. Isaac, S.J. Donohue, M.R. Tucker, and J.R. Woodruff. 1984. Procedures used by state soil testing laboratories in the southern region of the United States. Southern Cooperative Series. Bulletin No. 190. Agricultural Experiment Station, Oklahoma State University, Stillwater, OK. 16 p.

Locascio, C.G., B.G. Lockaby, J.P. Caulfield, M.B. Edwards, and M.K. Causey. 1990. Influence of mechanical site preparation on deer forage in the Georgia Piedmont. South. J. Appl. For. 14(2):77–80.

Lockaby, B.G., C.C. Trettin, and S.H. Schoenholtz. 1999. Effects of silvicultural activities on wetland biogeochemistry. J. Environ. Quality. 28(6):1687–1698.

Lockaby, B.G., and W.H. Conner. 1999. N:P balance in wetland forests: Productivity across a biogeochemical continuum. Bot. Rev. 65(2):171–185.

Lockaby, B.G., A.L. Murphy, and G.L. Somers. 1996. Hydroperiod influences on nutrient dynamics in decomposing litter of a floodplain forest. Soil Sci. Soc. Am. J. 60(4):1267–1272.

Lockaby, B.G., J.H. Miller, and R.G. Clawson. 1995. Influences of community composition on biogeochemistry of Loblolly pine (*Pinus taeda*) systems. Am. Midl. Natur. 134(1):176–184.

Lowrance, R.R., R.L. Todd, and L.E. Asmussen. 1983. Waterborne nutrient budgets for the riparian zone of an agricultural watershed. Agric. Ecosys. Environ. 10(4):371–384.

Mader, S.F., W.M. Aust, and R. Lea. 1989. Changes in net primary productivity and cellulose decomposition rates in a water tupelo-bald cypress swamp following timber harvest. P. 539–543 *in* Proc. of the Fifth Biennial Southern Silvicultural Research Conference, Miller, J.H. (ed.). USDA For. Serv. Gen. Tech. Rep. SO-74.

Meadows, J.S., and J.A. Stanturf. 1997. Silvicultural systems for southern bottomland hardwood forests. For. Ecol. Manage. 90(2,3):127–140.

Mississippi Forestry Commission. 2000. Mississippi's best management practices, 3rd Ed. Publication 107. Jackson, MS. 24 p.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. P. 961–1010 *in* Methods of soil analysis, part 3: Chemical methods. Bigham, J.M., J.M. Bartels, D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, and M.E. Sumner (eds.). Soil Science Society of America, Inc., Madison, WI. 1,390 p.

Peterson, D.L., and G.L. Rolfe. 1982. Nutrient dynamics and decomposition of litterfall in floodplain and upland forests of central Illinois. For. Sci. 28(4):667–681.

Piatek, K.B., and H.L. Allen. 1999. Nitrogen mineralization in a pine plantation fifteen years after harvesting and site preparation. Soil Sci. Soc. Am. J. 63(4):990–998.

Prestemon, J.P., and R.C. Abt. 2002. The southern timber market to 2040. J. For. 100(7):16–22.

Radford, A.E., H.E. Ahles, and C.R. Bell. 1968. Manual of the vascular flora of the Carolinas. The University of North Carolina Press, Chapel Hill, NC. 1183 p.

Roberts, M.R., and L. Zhu. 2002. Early response of the herbaceous layer to harvesting in a mixed coniferous-deciduous forest in New Brunswick, Canada. For. Ecol. Manage. 155(1–3):17–31.

Schlesinger, W.H. 1978. Community structure, dynamics and nutrient cycling in the Okefenokee cypress swamp-forest. Ecol. Monogr. 48(1):43–65.

Schilling, E.B., B.G. Lockaby, and R. Rummer. 1999. Belowground nutrient dynamics following three harvest intensities on the Pearl River floodplain, Mississippi. Soil Sci. Soc. Am. J. 63(6):1856–1868.

Sharitz, R.R., L.R. Boring, D.H. Van Lear, and J.E. Pinder III. 1992. Integrating ecological concepts with natural resource management of southern forests. Ecol. Applic. 2(3):226–237.

Shure, D.J., M.R. Gottschalk, and K.A. Parsons. 1986. Litter decomposition processes in a floodplain forest. Am. Midl. Natur. 115(2):314–327.

Statistical Analysis System Institute Inc. 2000. SAS/STAT User's Guide, Version 8. SAS Publishing, Cary, NC. 3,884 p.

Stokes, B.J., C. Ashmore, C.L. Rawlins, and D.L. Sirois. 1992. Glossary of terms used in timber harvesting and forest engineering. USDA. For. Serv. Gen. Tech. Rep. SO-73. 33 p.

USDA Soil Conservation Service. 1986. Soil survey of Monroe County, Alabama. L.A. Dungan (ed.). US Government Printing Office. 138 p.

USDA Soil Conservation Service. 1994. State of Alabama hydrologic unit map with drainage areas by counties and sub-watersheds. Auburn, AL. 133 p.

Zar, J.H. 1984. Biostatistical Analysis. Prentice Hall, Englewood Cliffs, NJ. 718 p.

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