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## Influences of harvesting on functions of floodplain forests associated with low-order, blackwater streams

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### Abstract

The influence of both aerial and ground-based harvesting on functions of forested floodplains of low-order streams was studied during a two-year period. The study sites were associated with low-order, blackwater streams with infertile and primarily organic soils. Responses to harvesting were assessed in relation to water quality, denitrification, hydrology, regeneration, and decomposition. Water quality indices included nitrate, phosphate, total and dissolved solids, and biological oxygen demand (BOD). All were unaffected by harvesting with the exception of BOD which rose once to undesirable levels. Denitrification was highly variable and also showed no significant harvest effect. Hydrologic parameters included groundwater table depths which, unexpectedly, indicated lowered water tables within harvested areas during the first growing season. Early regeneration responses were strongly linked to harvest system with primarily seed-origin species favored by ground-based activity whereas sprout-origin species dominated on aerial system plots. Owing to inherent soil wetness, decomposition responded slowly to harvest disturbance. However, after one year, decomposition was more rapid on harvested plots than in undisturbed areas.

*Keywords:* Wetland forests; Silviculture; Impacts

### 1. Introduction

Bottomland hardwood forests in the southern United States are a highly valued resource for multiple reasons (Sharitz and Mitsch, 1993). Recently, increased demand for hardwood timber (McWilliams, 1992) has focused attention on these ecosystems regarding environmental impacts of harvesting on maintenance of site productivity or sustainability (Rennie, 1990). However, substantially more research is focused on environmental and sustainability

questions in upland forest ecosystems than in floodplain forests.

The environmental variable most often studied in regard to harvesting is water quality, with data from forested wetlands only very recently available. Shepard (1994) concluded that properly designed silvicultural operations posed little threat to wetland water quality as defined by current standards. This conclusion seems particularly appropriate in 'relation to the low potential for harvested wetland sites to act as non-point sources of inorganic chemicals (Shepard, 1994). The potential for sediment generation is less clear but is generally considered low without site

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preparation, such as during **natural** regeneration (Scott et al., 1990).

Although harvest-induced changes in growth, species composition, and other site characteristics related to sustainability continue to be debated in upland forests (Powers et al., 1990; Haywood, 1994), far fewer studies have evaluated such changes in floodplain systems (Aust and Lea, 1992). Productivity and plant community dynamics in floodplains are critically linked to hydrology (Conner and Day, 1992; Day and Megonigal, 1993), therefore, silvicultural operations which alter hydroperiod are likely to affect both species composition and productivity (Conner, 1994). However, harvest operations which promote natural regeneration with minimal soil disturbance are capable of stimulating adequate restocking of desirable tree species (McKelvin, 1992) without lasting hydrologic changes (Walbridge and Lockaby, 1994).

Because little information exists for forested wetlands, especially at the initiation of this study, our objectives were to test the following hypotheses:

1. that indices of water quality would be measurably altered by disturbances associated with harvests;
2. that the rate of surface litter decomposition would be increased within harvested zones owing to increased soil temperatures;
3. that denitrification would be stimulated by harvests as a result of a nitrification pulse brought on by higher soil temperatures;
4. that subsidence would occur in the histic epipedon owing to increased oxidation at the surface;
5. that harvesting and its associated reduction in evapotranspiration would cause an elevation of the soil water table and a decreased depth of oxidized conditions;
6. that helicopter-based harvests would result in greater density of desirable regeneration than would ground-based harvests owing to the reduced ground disturbance associated with the former.

## 2. Methods

### 2.1. Study sites

The study sites are located in the upper-coastal plain of southern Alabama, USA, approximately

100 km north of Mobile. Average precipitation is 152 cm (almost entirely as rain) with a growing season from late February until November. The landscape is moderately rolling with natural forests of longleaf pine (*Pinus palustris* Mill.) and pine plantations (*Pinus taeda* L. and *P. elliotii* Engelm.) occupying the uplands which are dissected by numerous narrow floodplains, the latter being occupied by naturally regenerated, broadleaved forests.

Three floodplain forests, within 2 km of each other, were selected for study. The floodplains were associated with low-order, blackwater streams of small watersheds (approximately 100–200 ha). A typical hydrograph representing a short-term response to individual rain events is presented in Fig. 1. These forests were approximately 50–60 years old and were dominated by swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), sweetbay (*Magnolia virginiana* L.), red maple (*Acer rubrum* L.) and other commercial and non-commercial tree and shrub species. Two of the most abundant non-commercial species were buckwheat tree (*Cliftonia monophylla* (Lam.) Britton ex. Sarg.) and swamp cyrilla (*Cyrilla*

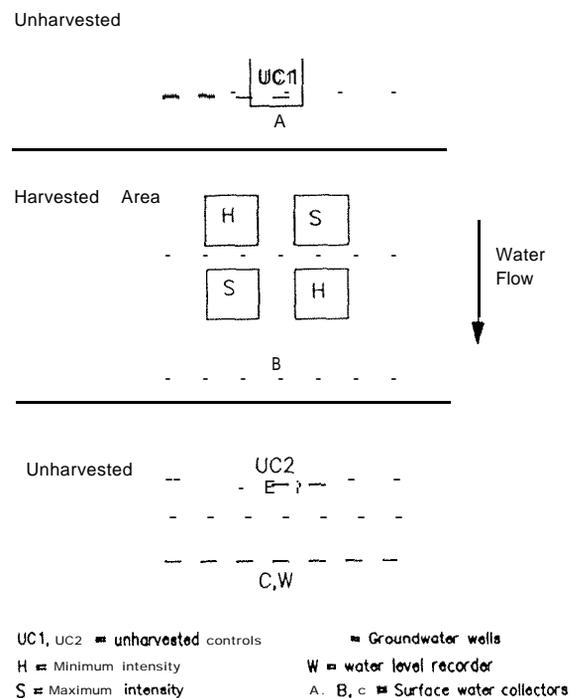


Fig. 1 A typical hydrograph representing a short-term response of a low-order, blackwater stream to rain events in March 1992.

*racemiflora* L.), both of which are evergreen, capable of reproducing by root sprouts, and potentially important competitors of the more desired species. Soils on the floodplain margins were Inceptisols while those within the floodplain were Histosols. The water table remained within 30cm of the surface for much of the year and microrelief variation was pronounced. As is typical of blackwater systems, the sites are particularly deficient in P as indicated by Bray-2 extractable P levels in surface soils of 2–3 mg l<sup>-1</sup>.

## 2.2. Experimental design and treatment installation

A randomized complete block design was utilized with the three floodplain sites serving as blocks. The three treatments consisted of (1) unharvested controls, (2) handfelling of all woody stems greater than 11.4 cm DBH (i.e. clearcut) followed by helicopter log removal (minimum intensity), and (3) clearcut with feller-buncher on mats combined with skidder log removal (maximum intensity). Within each floodplain block, a 4ha area was clearcut using a feller-buncher on mats over 80% of that area (Fig. 2). Two 0.4 ha plots represented the remaining 20% and those were handfelled. Stems were removed

from the entire 4ha with the use of helicopters. After operational stem removal, two additional 0.4 ha plots were delineated and subjected to simulated skidder activity (i.e. a rubber-tired skidder with a typical log load was driven in a fashion that mimicked operational skidder use). Two 0.4 ha control plots were also identified with one being located upstream and one downstream from the 4 ha cut. In this manner, each treatment was duplicated twice per block. Treatments were installed in March, 1991.

## 2.3. Field and laboratory approaches

Methodologies for water sampling and analysis, denitrification, and hydrologic assessments are described in detail by Lockaby et al. (1994). Those approaches, along with methods used for investigations of decomposition dynamics and regeneration, are summarized below.

Surface water sampling was initiated following treatment by the use of automated samplers which were located in three positions per block. Within a block, one sampler was located in the upstream control to sample water prior to contact with the harvested zone, another was located at the downstream edge of the harvest to sample water after contact, and the last was located 30m into the downstream control (Fig. 2). Automated samplers drew a 50 ml sample every 3 h until a weekly composite sample was removed. Owing to the highly tortuous nature of the surface water flow, efforts were not made to separate the effects of the two types of harvests. Surface water was analyzed for total suspended solids (TSS), Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>-3</sup>.

Groundwater wells 1 m deep and 15 m apart were installed in lines perpendicular to the flow within each floodplain. Lines of wells occurred at the following locations: upstream control; mid-harvest zone; downstream edge of harvest zone; and 15, 30, and 45 m into the downstream control. These wells were sampled monthly by measuring the depth to the water table, purging, allowing them to refill, and then removing a 250 ml sample. As was the case with the surface water, we did not attempt to separate effects of the two harvest methods.

Mass and nutrient dynamics associated with foliar litter decomposition were assessed using litterbags.

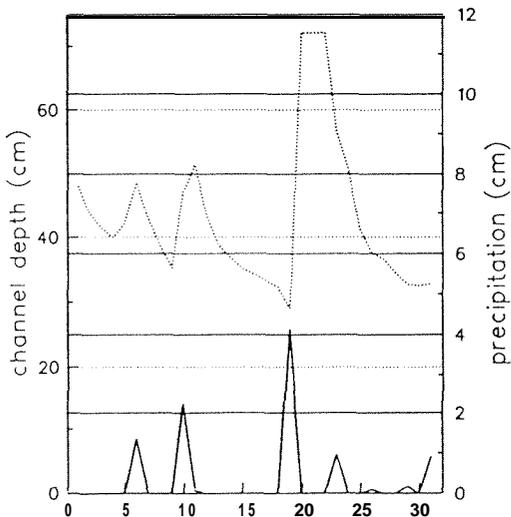


Fig. 2. General pattern of experimental plots and data sampling locations used in the three floodplains.

Litterfall was sampled within each floodplain during the autumn prior to treatment implementation. The collected litter was air-dried, separated and weighed by species, and then reconstituted into 10 g samples to match mean species composition. Each sample was allocated to nylon mesh bags composed of two sizes of mesh: 5 and 2mm on the upper and lower sides, respectively. Sets of 12 bags were placed on each of three microsites (concave, level, and convex) on three treatment plots (i.e. only one plot per treatment was used in the decomposition facet) per block. Bags were sampled at the following intervals: time of placement (to estimate handling loss); 2; 4; 8; 12; 16; 20; 28; 36; 44; 56; and 68 weeks. Litter remaining in bags was oven-dried at 70°C to constant weight, weighed, ground to pass through a 20-mesh sieve, and analyzed for C, N, and P.

Owing to the labor necessary for denitrification analyses, those investigations were conducted on only one block. Four subplots were established 36m from treatment plot centers along the four cardinal directions. Three soil cores (10 cm deep) were taken from each subplot on each of four sampling dates during the first growing season following harvest. Denitrification was estimated using the acetylene inhibition method and intact soil cores (Robertson and Tiedje, 1984). Denitrification potential was estimated from sixteen cores from each subplot during October 1991 (Lockaby et al., 1994).

We had hypothesized that subsidence might occur in association with the organic soils within the harvest zones. To assess this possibility, steel welding rods (Bridgham et al., 1991) were placed in association with all groundwater wells. These were installed to the same depth (0.9 m) in April 1991 with a notch cut at the point of contact with the pre-harvest soil surface. These rods were extracted in December 1991 and were measured at that time to ascertain changes in the position of the soil surface. The depth of oxidation (i.e. rust) was also measured as an indicator of water table depth.

Because helicopter-based logging would likely result in less damage to seedlings and rootstocks than would skidder-based systems, we predicted greater density of regeneration in helicopter plots. To test this, we tallied all woody stems by species in one 40m<sup>2</sup> subplot near the center of each 0.4ha treatment plot. Counts were made prior to harvest and at

the end of the second post-harvest growing season. Data from these plots were used to estimate relative shifts in species abundance as influenced by harvest treatment. To determine if species shifts were related to harvest impacts on rootstock survival, 60 rootstocks for each of seven major species (30 per harvest treatment) were randomly chosen and tagged before harvest and then reinventoried for survival (i.e. stump sprouting) at the end of the second growing season after harvest.

### 3. Results and discussion

The results of the surface and groundwater quality, denitrification, and hydrologic assessments have been described in detail by Lockaby et al. (1994) and will be summarized here. There was little change in water chemistry (whether surface or ground) or TSS in surface samples owing to harvests (Table 1). At no time during the first post-harvest year, did any chemical or physical water quality index exhibit a statistically significant ( $P < 0.05$ ) change in comparisons between non-harvested zones and harvested zones. This is similar to results summarized by Shepard (1994) with regard to a lack of inorganic chemistry changes following harvests: The lack of change in water chemistry and TSS data probably resulted from (1) the low-nutrient status of the black-water floodplain systems, (2) the high degree of floodplain “roughness”, and (3) the minimal surface disturbance associated with helicopter log removal (which occurred over 80% of the harvested zones).

Denitrification results were highly variable and, therefore, any treatment induced effects were likely masked. As was the case with water chemistry, no statistically significant ( $P < 0.05$ ) effects were observed. On an annual basis, we estimated 15 kg ha<sup>-1</sup>

Table I  
Total suspended solids (mg l<sup>-1</sup>) in surface water samples

Location	1991			1992
	May	July	October	July
Upstream	1.67 <sup>a</sup>	0.25	3.33	1.50
Harvested	8.67	1.33	7.83	2.50
Downstream	3.00	3.83	4.00	0.00

<sup>a</sup> Column means do not differ at  $P = 0.05$  level.

of elemental N being processed via denitrification. That estimate is similar to the general value of  $10 \text{ kg ha}^{-1}$  per year noted by Davidson and Swank (1987) for temperate forests. On the basis of the denitrification potential assay which used amendments of C, N, and C + N to indicate substrate limitations for denitrification, nitrate availability was shown to be the limiting factor for denitrification. This interpretation was based on much greater stimulation of denitrification following nitrate amendments than occurred after carbon additions.

There was no change in the level of the soil surface as measured by welding rod notches. The lack of oxidation of the soil surface was probably due to maintenance of generally moist conditions at the surface. The hydrologic responses to harvests were unanticipated. During the first growing season following harvests, water table depths were significantly ( $P < 0.05$ ) lower in wells located within harvested zones than in wells located upstream or downstream from harvested areas (Table 2). This effect was consistent until the early part of the second growing season when it dissipated as the vegetation canopy was re-established. Depths of oxidation on steel welding rods also indicated drier conditions within harvested zones (Table 2). A third indicator of lowered water tables was  $\text{Cl}^-$  analysis of groundwater samples, the latter being a useful indicator of changes in water volumes.  $\text{Cl}^-$  concentrations consistently were higher in samples taken from harvest zone well lines (Table 2). This may indicate a smaller amount of soil water in those areas.

That removal of forest cover stimulates soil wetness owing to reduced evapotranspiration has long been considered dogma in forestry literature (Kit-

tridge, 1948). However, it is apparent that, under conditions associated with these treatments and this study period, the floodplain systems described behaved differently. Changes in hydrologic regimes can be assessed from concurrent examinations of groundwater table measurements, steel welding rod data, and  $\text{Cl}^-$  concentrations in groundwater. Each of these sets of data indicate the same effect, i.e. the soil water was lowered during the first year following harvests. We suggest that the effect may be associated with (1) solar-heating of exposed, dark-colored organic soils during periods with no vegetation canopy and (2) increased windspeed across harvest zones. There is precedence for such an effect in newly harvested Florida pondcypress (*Taxodium distichum* var. *nutans* (Ait.) Sweet) domes (Ewel and Smith, 1992) which also often have histic epipedons.

Decomposition of foliar litter on soil surfaces was less responsive to harvests than had been hypothesized. Prior to week 48, there was no statistically significant ( $P < 0.05$ ) difference among the three treatments in mass loss in spite of differences among microsites within the three floodplains. The lack of decomposition response that was initially observed likely resulted from the inherent wetness of the sites. However, by week 68, mass loss was more rapid on the two harvest treatments than on the control plots (Table 3).

Similarly, immobilization of both N and P was more evident on control plots as opposed to on harvest treatment plots which exhibited net mineralization of both elements (Table 3). In the case of P, white immobilization was strongest under control conditions. The helicopter plots also displayed indications of immobilization. In contrast, net mineralization was apparent on the skidder plots.

Table 2  
Hydrologic responses during first year after harvest.

Measurements	Harvested				Unharvested							
	Middle		Lower		Upstream		Downstream					
							15 m	30 m	45 m			
Groundwater $\text{Cl}^-$ ( $\text{mg l}^{-1}$ ):	3.53	b	3.51	b	2.41	a	2.44	a	2.51	a	2.69	a
Depth to water table (m): July	0.42	b	0.43	b	0.21	a	0.19	a	0.25	a	0.29	ab
Depth to water table (m): September	0.47	a	0.44	a	0.36	ab	0.26	b	0.29	b	0.28	b
Depth of oxidation (cm)	17	a			11	b						

Row means followed by the same letter are not significantly different at the  $P < 0.05$  level.

**Table 3**  
Mass, nitrogen, and phosphorus remaining at week 68 in litterbags

Location	Mass (%)	N (%)	P (%)
Control	68.38	108.21	132.05
Helicopter	54.04	83.88	106.41
Skidder	52.18	76.81	86.71

Column means followed by the same letter are not significantly different at the  $P < 0.05$  level.

There is a lack of data regarding decomposition responses of native litter to canopy removal in forested wetlands. Most of what is known about these responses stems from studies in upland forests. Those studies indicate that, depending on soil moisture availability, the nature of the response can be bi-directional (i.e. either increases or decreases in mass loss). In some cases, surface soil temperature increases owing to increased irradiation coupled with increased moisture resulting from the absence of canopy interception may stimulate mass loss (Stone et al., 1978). However, in other cases, moisture increases may be insufficient to compensate for increased moisture demand by microbes (owing to higher temperatures) and mass loss rates can decrease (Will et al., 1983). In the present case, in spite of midday summer surface soil temperature increases

of 20°C, the inherently high moisture availability on these sites continued to depress the decomposition process and, consequently, little change in mass loss was noted during the first year following treatments.

As predicted, total regeneration density was greater on helicopter than on skidder plots, largely because of smaller post-harvest declines in density on the former (Table 4). The difference between the two methods may be explained by better survival of advance regeneration in the helicopter plots. Two-year post-harvest survival of tagged stumps was significantly greater in helicopter plots ( $\chi^2 = 7.3$ ,  $df = 1$ ,  $P = 0.007$ ) than in skidder plots (84.3 versus 60.3%). However, despite differences in survival and post-harvest densities, both harvest methods resulted in adequate stocking of commercial species (i.e. in excess of 9000 stems per hectare) and in relatively high total stem densities (Table 4).

The choice of harvest method will have an impact on future species composition. For two of the most common commercial species, (*Nyssa sylvatica* var. *biflora* and *Liriodendron tulipifera* L.), density substantially increased after harvest on skidder plots but not on helicopter plots (Table 4). Apparently, skidding stimulated germination or enhanced survival of new germinants in these two species. For two other

**Table 4**  
Mean rootstock density on six 40 m<sup>2</sup> plots per harvest treatment prior to harvest (1990) and two years post harvest (1992)

Species category	Year	Mean root stock density for each harvest method (stems per hectare)	
		Helicopter	Skidder
<b>Common commercial:</b>			
<i>Acer rubrum</i>	1990	14437	11120
	1992	3583	1730
<i>Liriodendron tulipifera</i>	1990	1030	907
	1992	1278	3107
<i>Magnolia virginiana</i>	1990	3336	1525
	1992	2760	1194
<i>Nyssa sylvatica</i> var. <i>biflora</i>	1990	1483	946
	1992	1441	2471
Total common commercial:	1990	20386	14498
	1992	9062	9102
Others:	1990	62389	92498
	1992	46074	32617
<b>TOTAL:</b>	1990	82775	106996
	1992	55136	41719

Significant method effects on proportional changes in stem density occurred for all species categories ( $P < 0.025$ ) except for *M. virginiana* ( $P = 0.854$ ) according to  $\chi^2$  tests.

commercial species (*Acer rubrum* and *Magnolia virginiana*), harvest effects were not significant ( $P < 0.05$ ) or were relatively minor. Yet in the remaining species, most of which were non-commercial, skidding had a greater negative impact on post-harvest density. Thus, although skidding does have negative impacts on survival of advance regeneration, it may have positive long-term effects through stimulation of seed germination in desirable species coupled with a reduction in density of non-commercial competitors.

In summary, clearcutting did have measurable impacts on structure and function of the sampled floodplain ecosystems. Some ecosystem responses agreed with our predictions made on the basis of other studies (mostly conducted in uplands). Some responses, most notably water table level, were unexpected. We found that microsite variability influenced litter decomposition and nutrient cycling, and thus, if major changes in microsite occur as a result of logging, changes in nutrient cycling and water quality may be greater than observed in this study. However, in the present study where harvest-induced soil and microsite disturbances were relatively minor, the measured indicators of ecosystem value, such as water quality and regeneration stocking, fell within acceptable levels.

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