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Bottomland hardwood forest recovery following tornado disturbance and salvage logging

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ABSTRACT

Catastrophic wind events, including tornado, hurricane, and linear winds, are significant disturbances in temperate forested wetlands. Information is lacking on how post-disturbance salvage logging may impact short and long-term objectives in conservation areas where natural stands are typically managed passively. Woody regeneration and herbaceous cover were assessed for three years in a bottomland hardwood forest across a gradient of damage from an F4 tornado, with and without subsequent salvage logging. Soil disturbance intensity and recovery associated with salvage logging within wind-disturbed sites were also assessed. Woody stem density and proportion of potential overstory species (species with the potential to occupy a position in the canopy) increased as a function of wind disturbance intensity. Stem density, proportion of overstory trees, or species diversity did not differ between wind + salvage and wind-disturbed-only plots. Significant dissimilarity occurred among soil disturbance classes within salvaged sites. By the third growing season, vegetation in soil disturbance classes in wind + salvage areas was converging toward undisturbed conditions and bottomland hardwood forest recovery was underway in all vegetation disturbance types and soil disturbance classes. Post-tornado salvage logging, applied judiciously, may contribute to microsite and vegetation diversity.

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1. Introduction

Publicly-owned conservation areas of the Midwestern and Midsouthern United States typically occupy low-lying areas and maintain some semblance of the pre-settlement hydrologic regime in this largely privately-owned and agriculture-dominated landscape. Therefore, these remnant tracts play a rare, important, and widely-recognized role in providing biological conservation values and recreational opportunities. Following decades of highly variable hydrologic conditions, fire, and agriculture-related practices, these areas are typically dominated by several decades-old stands of mixed species bottomland hardwood forests (Nelson et al., submitted for publication). Uncontrollable natural disturbance on these typically passively managed sites, such as wind events, can drastically alter stand structure and create rare opportunities for the development of a new regeneration cohort (King and Allen, 1996). Following such disturbances managers must determine appropriate course of action to ensure that conservation and public access management objectives are satisfied (Meadows and Stanturf, 1997). These activities, especially partial salvage logging, often represent a departure from decades of typically passive management.

Presently, the most relevant literature to guide management decision making under these circumstances is sparse, associated with conventional commodity harvests, and focused on timber values. Wind disturbance creates variable canopy openness conditions in forests, depending on swath and intensity of the storm event, to which vegetation responds (Peterson and Pickett, 1991; Foster and Boose, 1992). Tornadoes can produce an array of stand conditions, ranging from undisturbed canopy to release of shade-tolerant advance reproduction in small gaps to total overstory removal with production of a new cohort of shade-intolerant species, all on a very fine spatial scale (Webb, 1989; Battaglia et al., 1999; Battaglia and Sharitz, 2005; Conner and Sharitz, 2005). Downed material can alter soil microsites through organic matter accumulation and debris dam formation. Further, downed and hanging material can make wind impacted sites inaccessible for public use and therefore incompatible with typical bottomland hardwood forest management objectives.

The effects of harvesting on bottomland forest regeneration are similar to wind disturbance in that density, species richness, and

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regeneration of desired tree species increase as a function of disturbance intensity (Reisinger et al., 1988; Aust et al., 1992; Jansson and Johansson, 1998). Across a range of sites, regenerated stands were similar in composition to those occupying the site prior to wind or harvesting disturbance (Peterson and Pickett, 1995; Battaglia et al., 1999; Aust et al., 2006). Aust et al. (1997) and Hassan and Roise (1998) found that following harvesting on bottomland sites, regeneration was adequate in skidded areas. Although salvage operations superficially resemble conventional regeneration harvests, often there is variation in traffic patterns and skidding intensity between these types of harvesting operations, and therefore resulting regeneration and soil recovery may differ.

An F4 tornado in May 2003 damaged a large swath of bottomland hardwood forest managed as a wetlands wildlife conservation area in southern Illinois, USA. Some of the disturbed areas were subjected to partial salvage logging of downed trees, resulting in a wide range of disturbances to canopy and soils. The primary objectives of this study were to assess vegetation regeneration response and determine whether early recovery trajectories differed among undisturbed, wind-disturbed, and wind + salvage areas.

2. Methods

2.1. Study site

The study area is within the Mermet Lake State Conservation Area in Massac County, Illinois (37°15′25″N, 88°50′30″W). The climate is considered continental with a 190-day growing season. The site is on the historic floodplain of the Ohio River and within the Mississippi embayment. Soils are predominantly Cape (fine, smectitic, acid, mesic, Vertic Endoaquepts) and Karnak (fine, smectitic, non-acid, mesic, Vertic Endoaquepts) and Ginat (fine-silty, mixed, active, mesic, Typic Endoaqualfs) series. Cape and Karnak series are classified as very poorly drained and Ginat as poorly drained (USDA, 2007). The General Land Office survey of 1807 characterized the study area as a baldcypress (*Taxodium distichium* (L.) L.C. Rich.) pond prior to Euro-American settlement (Illinois Archives, Land Records, *Illinois survey field notes*, 1849. Located in Southern Illinois University Carbondale Morris Library [microfilm]). During the early 1900s, the site was drained and land use converted to row cropping, which led to increased fire frequency (Nelson et al., submitted for publication).

Since the mid-20th century, management and disturbance regimes on the site have been typical of publicly-owned wetland wildlife conservation areas in mid-continental North America. The state of Illinois assumed ownership in 1949 and began management through their Department of Natural Resources as a wildlife area. Partial hydrologic restoration occurred in 1957 and fire has been excluded since 1965. Levees were constructed to contain Mermet Lake in the early 1960s. Since the onset of state ownership, anthropogenic disturbance, other than seasonal flooding, has been limited to road maintenance for hunter access. The seasonal flooding occurs from late September to late March, with water pumped from Mermet Lake.

An F4 tornado on May 6, 2003 severely damaged approximately 162 ha of forested land within the conservation area. A partial salvage operation intended to remove merchantable logs and restore access for hunters occurred between October 2003 and April 2004 on ~32 ha of the most heavily impacted portion of the stand, i.e., where crown removal was virtually complete. This operation employed rubber tired and tracked grapple skidders and removed only wind-damaged or down stems. Salvage harvesting was limited to portions of the area damaged by the tornado. Approximately 4800 bdf/ha of saw logs were removed from salvaged areas, with 69% *Quercus* and 27% *Liriodendron tulipifera*. No other species accounted for ≥5%. Researchers had no control over area salvaged. Salvage activity in the Southwest corner of the conservation area was terminated by early November to prevent disruption of Indiana bat (*Myotis sodalist*) hibernation. The East area was salvaged in the spring of 2004 and was limited to areas not inundated. Where possible, ~30 snags ha^{-1}, with one snag ha^{-1} ≥ 35.5 cm dbh, were retained for Indiana bat habitat. Slash was left in place except to clear or stabilize skid trails. At the time of the tornado, the entire study area was comprised of a 60+ years old, closed canopy bottomland hardwood forest dominated by *Quercus palustris* Muenchh. and *Q. phellos* L. Other important canopy species included *Acer saccharum* Marsh., *Carya ovata* (Mill.) K. Koch, *A. rubrum* L., *Ulmus rubra* Muhl., *U. americana* L., *U. alata* Michx., *Fraxinus pennsylvanica* Marsh., *Liquidambar styraciflua* L., and *Nyssa aquatica* L. (Nelson et al., in press). Data from the pre-tornado stand were unavailable. However, in the adjacent undisturbed stand, *Quercus* spp. comprised 41% of stems >5.1 cm, and over 90% of dominant or co-dominant stems. *Acer* spp. represented 37% of stems >5.1 cm and 7% of dominant or co-dominant stems. The only other overstory taxa with more than 5% of stems >5.1 cm was *Ulmus* spp. with 17%, but no dominant or co-dominant stems.

2.2. Study design and data collection

The study area encompassed approximately 57 ha of the study site, including virtually all of the salvage operation area (Fig. 1). During summer 2004, 48 points were located in a 100-m Universal Transverse Mercator grid pattern across the study site. Two vegetation plots were established in random directions 7.6 m from each point ($n = 96$). Each plot was classified into a disturbance category as follows: (1) undisturbed – areas that appeared free of structural tornado damage and contained a closed canopy overstory ≥60 years old; (2) transition – areas located at the edge of the tornado swath that sustained some wind damage but where a partial overstory remained; (3) wind – areas that sustained nearly complete overstory removal due to wind damage with no subsequent disturbance; and (4) wind + salvage – areas that sustained nearly complete overstory removal due to wind damage and were salvage harvested to remove merchantable woody material.

In the wind + salvage area, soil disturbance intensity was characterized for each sub-plot during each vegetation sampling

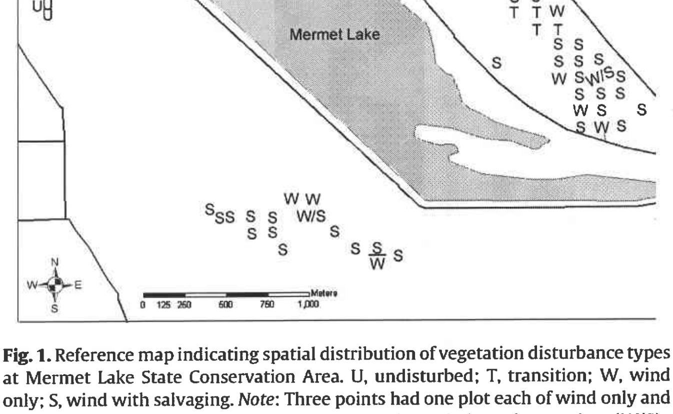

Fig. 1. Reference map indicating spatial distribution of vegetation disturbance types at Mermet Lake State Conservation Area. U, undisturbed; T, transition; W, wind only; S, wind with salvaging. *Note*: Three points had one plot each of wind only and wind with salvaging and are indicated with both symbols at those points (W/S).

Table 1
Mean density (stems ha^{-1}) of all woody stem regeneration and potential overstory species regeneration with percent overstory stems for first and third years by vegetation disturbance types

Disturbance type	Year 1		Year 3	
	All stems	Potential overstory species (% of total)	All stems	Potential overstory stems (% of total)
Undisturbed	1544 a	1196 a (77)	1700 a	1544 a (91)
Transition	3244 ab	1312 a (40)	5716 ab	3474 ab (61)
Wind	5960 c	3561 b (60)	15264 b	8177 b (54)
Wind + salvage	3741 b	2617 ab (70)	13329 b	8125 b (61)

Different letters within a column indicate difference at $\alpha = 0.05$ level.

following methods used by Aust et al. (1998). Soil disturbance intensities were categorized as follows: class 0 – soil appeared to be undisturbed by traffic; class 1 – soil was obviously compressed by vehicular traffic but no ruts were formed; class 2 – soil was rutted (as evidenced by puddled soil) and rut depth <20 cm; class 3 – soil was rutted (as evidenced by puddled soil) and rut depth ≥20 cm; and class 4 – soil was obviously churned and puddled with indication of liquid soil movement.

Each plot contained four, 4-m^2 circular regeneration sub-plots ($n = 384$) located at each of the four cardinal directions and centered 2.44 m from the plot center. Initially, 61 points were located in the study area. Of these 61 points, points were skipped (13) or displaced 50 m along a cardinal direction (8) and plots moved in a random direction (2) to avoid sampling areas that were inaccessible due to hazardous hanging tops, located on log landings, located in patches of young early successional forest originating prior to the tornado, or visually influenced by adjoining roads, railroads, row-cropped fields and developed portions of the conservation area. One wind + salvage point was disturbed over the course of the study and deleted from the dataset. Thus, at the end of the study, data had been collected for 94 plots at 47 points.

During May and June of 2004 through 2006 (years 1–3), all woody stems >61 cm tall and <5.1-cm dbh in each sub-plot were identified to species and tallied. These size criteria were used to capture potentially dominant individuals in the disturbed areas, including survivors of the tornado, regeneration of post-tornado origin, and the corresponding subcanopy cohort in undisturbed plots. Any sub-plot containing a tallied stem of a potential overstory tree species (species with the potential to occupy a position in the canopy) was considered stocked.

2.3. Statistical analysis

One-way analysis of variance (ANOVA) of expected least square means was used to separately examine stem density differences between vegetation disturbance types and soil disturbance classes. Changes through time were analyzed using repeated measures ANOVA with an unstructured correlation structure to determine effects of disturbance, time, and disturbance × time interactions. One-way ANOVA of expected least square means was used to test for differences in Shannon's H (Magurran, 1988) between vegetation disturbance types and soil disturbance classes of regenerating woody species and herbaceous vegetation for year 3 data.

Trends in overall plant community composition were explored using ordination. A presence/absence data matrix was constructed for year 3 data and analyzed using ordination by nonmetric multidimensional scaling (NMDS). Analysis of similarity (ANOSIM) comparisons (Clarke, 1993) using the Bray–Curtis dissimilarities were used to test for differences in community composition for each of the vegetation disturbance types listed above (Battaglia et al., 1999).

All ANOVAs were conducted using SAS statistical software (SAS, 2002–2003). Tukey's HSD method was applied to ANOVA comparisons to correct experimental error rate (EER) for an overall $\alpha = 0.05$. NMDS and dissimilarity indices were conducted using DECODA statistical software (Minchin, 2005). To control EER in dissimilarity comparisons in the ANOSIM the Bonferroni method was applied to correct for an overall $\alpha = 0.05$.

3. Results

Total stem density increased through the study period for all vegetation disturbance types except in undisturbed areas, and density of potential overstory species increased in all vegetation disturbance types (Table 1). Total woody stem density was positively associated with disturbance intensity. Stem densities were significantly higher in the wind areas than all other disturbance types, and densities in wind + salvage areas were significantly higher than the undisturbed area in year 1. By year 3, differences between wind and wind + salvage had disappeared. Among potential overstory species, higher densities were positively associated with increased disturbance for all but eight species. *Acer rubrum*, *F. pennsylvanica*, *Salix nigra* Marsh., *L. styraciflua*, and *Ulmus* spp. had the highest densities and together accounted for approximately 72% of stems during year 3 (Table 2). Although dominating the pre-disturbance stand, *Quercus* spp.

Table 2
Overstory species regeneration stem densities during the three year study period and percent of stems in 2006 by species

Species	Density (stems ha^{-1})			Relative density (year 3) (%)
	Year 1	Year 2	Year 3	
Acer negundo	64	121	210	3.18
Acer rubrum	301	497	1742	26.32
Acer saccharum	64	297	210	3.18
Acer saccharinum	0	7	47	0.70
Carya spp.	148	109	138	2.04
Celtis occidentalis	20	57	126	1.89
Diospyros virginiana	25	109	178	2.68
Fraxinus pennsylvanica	638	914	1557	23.54
Gleditsia triacanthos	0	7	20	0.30
Halesia carolina	7	12	20	0.30
Liquidambar styraciflua	168	301	435	6.55
Liriodendron tulipifera	116	188	217	3.28
Morus alba	20	7	20	0.30
Nyssa aquatica	84	84	59	0.89
Populus deltoides	7	7	0	0.00
Populus heterophylla	64	116	52	0.79
Prunus serotina	7	7	12	0.20
Quercus spp.	64	121	190	2.88
Robinia pseudoacacia	57	20	72	1.09
Sassafras albidum	413	329	257	3.87
Salix nigra	20	141	605	9.14
Taxodium distichum	25	25	32	0.50
Ulmus spp.	128	269	420	6.36
Total	2440	3745	6619	100.00

Table 3
Trees ha^{-1} and relative densities of overstory and shrub-understory perennial species by vegetation disturbance type during year 3 following disturbance

Species	Undisturbed		Transition		Wind		Wind + salvage	
	Stems ha^{-1}	Relative density (%)	Stems ha^{-1}	Relative density (%)	Stems ha^{-1}	Relative density (%)	Stems ha^{-1}	Relative density (%)
Overstory								
Acer negundo	0	0.00	0	0.00	326	4.00	267	3.30
Acer rubrum	193	12.50	1853	53.33	2108	25.78	2076	25.50
Acer saccharum	578	37.50	0	0.00	618	7.56	0	0.00
Acer saccharinum	0	0.00	0	0.00	0	0.00	82	1.00
Carya spp.	0	0.00	232	6.67	183	2.22	151	1.86
Celtis occidentalis	40	2.50	0	0.00	217	2.67	141	1.72
Diospyros virginiana	0	0.00	541	15.56	255	3.11	151	1.86
Fraxinus pennsylvanica	193	12.50	385	11.11	1962	24.00	2016	24.79
Gleditsia triacanthos	0	0.00	0	0.00	37	0.44	22	0.29
Halesia carolina	0	0.00	0	0.00	37	0.44	22	0.29
Liquidambar styraciflua	77	5.00	309	8.89	72	0.89	677	8.31
Liriodendron tulipifera	0	0.00	0	0.00	255	3.11	304	3.72
Morus alba	0	0.00	0	0.00	0	0.00	35	0.43
Nyssa aquatica	0	0.00	0	0.00	146	1.78	59	0.72
Populus heterophylla	0	0.00	0	0.00	292	3.56	0	0.00
Prunus serotina	40	2.50	0	0.00	0	0.00	22	0.28
Quercus spp.	116	7.50	77	2.22	400	4.89	163	2.01
Robinia pseudoacacia	116	7.50	0	0.00	0	0.00	94	1.15
Sassafras albidum	0	0.00	0	0.00	400	4.89	326	4.01
Salix nigra	0	0.00	0	0.00	217	2.67	1003	12.32
Taxodium distichum	0	0.00	77	2.22	109	1.33	12	0.14
Ulmus spp.	193	12.50	0	0.00	546	6.67	514	6.30
Shrub-understory perennial								
Aralia spinosa	0	0.00	0	0.00	109	1.70	304	6.19
Cercis canadensis	0	0.00	0	0.00	72	1.14	141	2.86
Corylus americana	0	0.00	0	0.00	0	0.00	420	8.57
Cornus obliqua	77	50.00	0	0.00	326	5.11	385	7.86
Cephalanthus occidentalis	40	25.00	2239	100.00	2179	34.09	558	11.43
Ilex decidua	40	25.00	0	0.00	0	0.00	0	0.00
Lindera benzoin	0	0.00	0	0.00	2763	43.18	2681	54.76
Lonicera spp.	0	0.00	0	0.00	0	0.00	12	0.24
Malus spp.	0	0.00	0	0.00	109	1.70	0	0.00
Prunus virginiana	0	0.00	0	0.00	0	0.00	22	0.48
Sambucus canadensis	0	0.00	0	0.00	764	11.93	351	7.14

represented <3% relative density across the study area during year 3, even though *Quercus* spp. densities increased nearly 300% from year 1 to year 3.

Response to vegetation disturbance type varied by species, with *S. nigra* and *F. pennsylvanica* being the most responsive to disturbance (Table 3). Relative density of *F. pennsylvanica* was greater in wind-damaged sites than in transition and undisturbed areas, with no further increase associated with salvage operations. In contrast, *S. nigra* had a substantial increase associated with wind + salvage versus any other vegetation disturbance type. Highest relative densities for *A. rubrum*, *Carya* spp. and *Diospyros virginiana* L. occurred in transition areas, while *A. saccharum* relative density was highest in undisturbed areas (Table 3). Midstory and understory densities in disturbed areas were greater than in undisturbed areas. The increase was driven by *Cephalanthus occidentalis* L. in all tornado-impacted vegetation disturbance types with the addition of *Lindera benzoin* (L.) Blume and *Sambucus canadensis* L. in wind and wind + salvage areas. *Aralia spinosa* L. and *Cornus obliqua* Raf. had significant presence in at least one soil disturbance class in wind + salvage areas (Table 3).

Stocking increased from year 1 to year 3 and was positively correlated with vegetation disturbance intensity (year 1: $\chi^2 = 12.72$, d.f. = 3, $P = 0.005$; year 3: $\chi^2 = 31.38$, d.f. = 3, $P < 0.0001$) (Fig. 2). Stocking differences between wind and wind + salvage areas diminished between years 1 and 3, indicating a decreasing effect of disturbance intensity through time with no effect by year 3 (year 1: $\chi^2 = 5.13$, d.f. = 1, $P = 0.024$; year 3: $\chi^2 = 0.93$, d.f. = 1, $P = 0.337$). In wind + salvage areas, stocked status was negatively correlated with soil disturbance intensity (Fig. 3). Stocking differences among soil disturbance intensity classes in year 1 had decreased by year 3 due primarily to large increases in class 4, where soil churning and liquid movement occurred.

Herbaceous cover was positively associated with vegetation disturbance intensity (Table 4). Herbaceous cover became

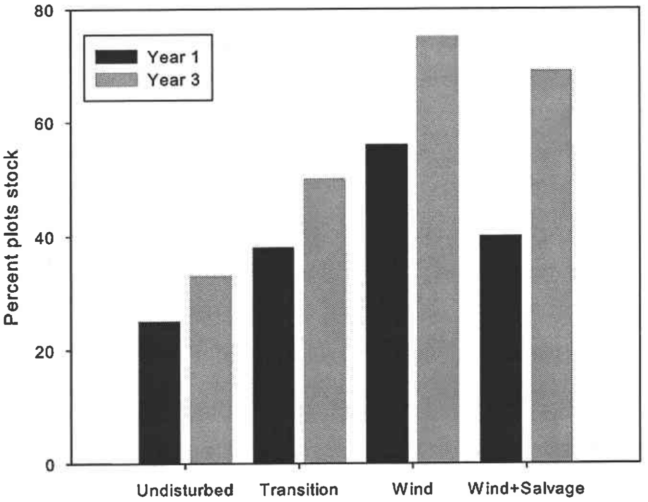

Fig. 2. Percent of plots stocked with a tree species capable of maintaining overstory status by vegetation disturbance type in years 1 and 3.

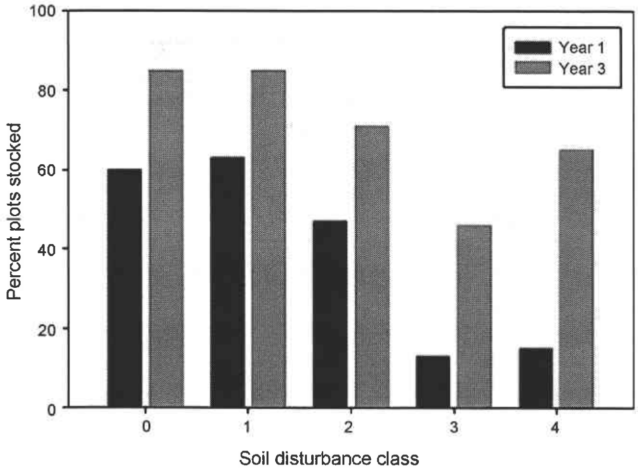

Fig. 3. Percent of wind + salvage plots stocked with an overstory tree species by soil disturbance class in years 1 and 3.

Table 4
Mean percent herbaceous cover by vegetation disturbance type and soil disturbance class for first three years following disturbance

	Year 1	Year 2	Year 3
Disturbance type			
Undisturbed	55 a	54 a	54 a
Transition	44 a	45 a	45 a
Wind	78 b	73 b	72 b
Wind + salvage	81 b	89 c	82 c
Wind + salvage soil disturbance classes			
0	94 a	90 ab	76 ab
1	92 a	93 a	85 a
2	87 a	90 ab	86 a
3	60 b	86 ab	84 a
4	66 b	80 b	66 b

Different letters within column and disturbance type/class indicate difference at $\alpha = 0.05$ level.

established rapidly in all disturbance types, and remained remarkably stable in light of dramatic increases in overstory stem density. In wind + salvage areas, the highest herbaceous cover initially occurred in the lowest severity soil disturbance class, but these differences were less pronounced by year 3, with class 4 having a lower percent cover due to the prevalence of standing water through much of the growing season.

Species diversity (Shannon's H) generally increased as a function of disturbance intensity with no significant differences between wind and wind + salvage areas (Table 5). Wind and transition vegetation disturbance types were associated with significant year 3 vegetation composition dissimilarity (Table 6). Significant dissimilarity occurred among soil disturbance classes but wind + salvage areas were not dissimilar from any of the wind disturbance types (Table 7).

Approximately 90% of the wind + salvage sub-plots were classified as having visible soil disturbance during year 1 (Table 8). Visual impacts of soil disturbance from the salvage operation typically diminished during the course of the study. By year 3, soil disturbance severity class decreased in 71% of sub-plots (Table 8). In year 3, 43% of all classes 1–4 plots, including 94% of class 1 plots, were categorized as class 0, with no plots remaining in class 4.

Table 5
Shannon's H for woody species regeneration and herbaceous and woody vine vegetation during year 3 by vegetation disturbance type

Disturbance type	Woody species regeneration	Herbaceous/vine vegetation
Undisturbed	0.3609 a	0.9197 a
Transition	0.7614 ab	1.0802 ab
Wind	1.0162 b	1.4670 bc
Wind + salvage	0.8929 b	1.7159 c

Values within a column followed by the same letter are not significantly different at $\alpha = 0.05$ level.

Table 6
Dissimilarity comparison for vegetation composition by vegetation disturbance types

Disturbance type	Undisturbed	Transition	Wind
Transition	<0.001**		
Wind	<0.001**	0.011*	
Wind + salvage	0.165	0.029	0.082

Overall ANOSIM $R = 0.0522$, $p = 0.021$. Based on Bonferroni corrections for multiple pairwise tests, * indicates $p \leq 0.05$ (significant), and ** indicates $p \leq 0.01$ (highly significant).

Table 7
Dissimilarity comparisons of vegetation composition by soil disturbance classes

Soil disturbance classes	0	1	2	3
1	<0.001**			
2	<0.001**	0.0240		
3	0.050	<0.001**	0.0010**	
4	<0.001**	<0.001**	<0.001**	0.024

Overall ANOSIM $R = 0.1364$, $p < 0.001$. Based on Bonferroni corrections for multiple pairwise tests, * indicates $p \leq 0.05$ (significant), and ** indicates $p \leq 0.01$ (highly significant).

Table 8
Percent of sub-plots with a decrease in soil disturbance classification during the first three years, by soil disturbance class (total number of wind + salvage sub-plots 220)

Initial soil disturbance class (year 1)	Final disturbance class (year 3)					
	# plots	0 (%)	1 (%)	2 (%)	3 (%)	4 (%)
1	36	94	6			
2	86	45	13	43		
3	50	20	9	39	32	
4	20	0	5	45	50	0

4. Discussion

The tornado and salvage logging represented a drastic and rapid departure from previous decades of uninterrupted low intensity disturbance and associated forest dynamics. Three years after these events, the developing stand was dominated by a diverse, fully stocked mosaic of bottomland species and stand structures varying as a function of disturbance intensity and damage (Battaglia et al., 1999; Battaglia and Sharitz, 2005). The degree of canopy removal, ranging from undisturbed through transition to wind, was correlated with release of advance reproduction of shade-tolerant species as well as reproduction of shade-intolerant species (Peterson and Rebertus, 1997; Battaglia et al., 1999). In transition areas, partial canopy removal released advance reproduction of primarily shade-tolerant species. Wind areas consisted of a combination of released shade-tolerant advance reproduction plus newly established shade-intolerant species in response to nearly complete canopy removal. This shift was even more pronounced in wind + salvage areas as harvesting operations physically removed or damaged advance reproduction presumably dominated by shade-tolerant species as well as stimulated further establishment of shade-intolerant species through soil disturbance beyond that produced by uprooting alone in wind areas (Zaczek, 2002; Lhotka and Zaczek, 2003; (Jacaranda) van Rheenen et al., 2004). The understory of undisturbed areas continued to be dominated by shade-tolerant individuals present prior to disturbance.

Overstory tree species regeneration was dominated by bottomland generalist species (*A. rubrum* and *F. pennsylvanica*) with more specialist bottomland species (*N. aquatica*, *Populus* spp. and *T. distichum*) having a limited presence. The pre-disturbance importance of oak (*Quercus* spp.), has decreased in the regenerating stand. This shift in composition may be attributable to changes in the hydrologic regime, land usage, and fire regime that occurred since the establishment of the previous stand (Aust et al., 1985; Casey and Ewel, 2006; Nelson et al., submitted for publication).

Although the developing stand is characteristic of current site conditions and reflects changes in disturbance regime during the last four decades, the low density of dominant pre-settlement species and oaks may pose a concern for management, considering the emphasis on wildlife management in this and similar mixed bottomland hardwood forests of the region. Concern regarding low oak densities may, however, be premature as low densities of oaks early in stand development may not necessarily translate into a small oak component later in stand development. Oaks can remain competitive and capture dominant status as short lived, early successional species die out or outcompete longer lived species (Bowling and Kellison, 1983; Hodges, 1997). Assessment of oak regeneration is typically delayed beyond the timeframe of this study due to accumulation during the first several years of stand development (Kruse and Groninger, 2003; Collins and Battaglia, 2008).

At least some of the disturbance conditions associated with this study appeared to increase the presence of important pre-settlement taxa such as *Nyssa* spp., *Populus* spp., *S. nigra*, and *T. distichum*. In most cases, lower densities of these species were associated with wind + salvage areas versus wind areas, a result that presents a conundrum to managers: Post-tornado salvage may decrease already low densities of key bottomland tree species. However, this disturbance and the destruction of shade-tolerant advance reproduction would be expected to facilitate establishment of shade-intolerant species. Operationally, salvage logging permitted access and provided financial resources for enhancement planting of already rare wetland tree species.

Salvage logging also represents a form of soil disturbance absent from these stands since agricultural abandonment. Indeed, site conditions in wind + salvage areas were similar to those associated with areas of severe flooding where newly formed land occurs, and consequently promoted development of pioneer species such as *S. nigra* (Hosner and Minckler, 1963; Hodges, 1997; Aust et al., 2006). This species was especially prevalent in ruts and churned soil of the more severely impacted soil disturbance classes. In particular, class 4 was characterized by low levels of herbaceous cover and dense seedling growth of *S. nigra*, a species whose regeneration success depends upon the removal of accumulated forest leaf litter (Hosner and Minckler, 1960).

Density and proportion of overstory and shrub-understory woody species increased in response to disturbance. The latter is especially noteworthy and represents a significant contribution to the structural complexity of the pre-disturbance forest. The reduced relative density of *A. saccharum* in all vegetation disturbance types is noteworthy considering the increasing dominance of this species in all canopy strata of highly productive stands throughout this region (Zaczek et al., 2002; Ozier et al., 2006). Fluctuating *A. saccharum* density in undisturbed areas during the course of the study likely resulted from favorable low moisture conditions producing in-growth followed by dieback due to flooding during the following year.

Through the first three years, overstory species composition and stocking did not appear to be adversely affected by increased density of midstory and understory species. Areas with an obstructed ground layer, whether from downed debris or a vigorous layer of mid- and understory species, may be protected from the potentially strong influence of white-tailed deer (*Odocoileus virginianus*) herbivory. High-density *Cephalanthus occidentalis* development in frequently flooded portions of wind areas may be attributable to this phenomenon and represents a significant improvement in wetlands habitat conservation value of the study site (Dale et al., 2007).

The lack of dissimilarity in woody vegetation between harvested and other vegetation disturbance types results from heterogeneity within wind + salvage areas that span the other vegetation disturbance types. The increasing similarity of woody regeneration stem densities, stocking, and diversity within the wind and harvested areas during this study, suggests that differences observed during year 1 may be transitory. Dissimilarities in woody and herbaceous vegetation have decreased among vegetation disturbance types during the study period. This rapid recovery from disturbance and the increase in stem density and diversity in wind and wind + salvage areas were noted in other bottomlands following similar disturbances (Peterson and Pickett, 1995; Hassan and Roise, 1998; Battaglia et al., 1999; Battaglia and Sharitz, 2005; Aust et al., 2006).

The absence of large differences in herbaceous cover between wind and wind + salvage areas and among the soil disturbance classes suggests that the herbaceous community had minimal influence in shaping the regeneration status of this site (Romagosa and Robison, 2003; Schuler and Robison, 2006). Scarcity of post-agricultural herbaceous competitors and abundant tree growing stock both contributed to a favorable competitive environment for tree species relative to the more typical bottomland forest recovery scenarios in this region (Kruse and Groninger, 2003; Baer and Groninger, 2004; Groninger et al., 2004). Significantly less herbaceous cover in undisturbed and transition areas versus wind and wind + salvage areas likely resulted from the uninterrupted presence of at least partial canopy cover in the former. Large inter-annual variation in mean percent herbaceous cover among soil disturbance classes appeared to result from microsite alteration; including creation of ruts, berms, pits, and mounds; and consequently greater variation in moisture availability on a very fine spatial scale. Subsequent to year 3, herbaceous cover declined rapidly in association with canopy closure across all disturbance classifications.

When assessing forest vegetation recovery, distribution as well as density of stems needs to be considered. Stocking levels were adequate to regenerate this stand (Sander et al., 1984). The significant changes observed during the three years of this study suggest assessment of recovery should be delayed until year 3. Vegetation response differences between years 2 and 3 were most pronounced within the most severely impacted soil disturbance classes. Movement through these typically dense young stands became prohibitively difficult during the fourth growing season, underscoring the appropriateness of assessment during year 3.

Woody vegetation recovery occurred rapidly across the site with the exception of soil disturbance class 3. This was attributed to limited seedling establishment resulting from increased soil compaction and increased standing water in deep ruts. Aust et al. (1998) cautioned that visual assessment of harvesting-related soil disturbance was a poor predictor of potential post-logging productivity decline, a factor that is not a primary concern on this study site (Lockaby et al., 1997). Furthermore, we found these classes to be related to stem density and herbaceous cover response and also provided a useful benchmark to track soil recovery over time. The latter consideration is valuable in this public use area where stakeholders voiced concerns regarding the esthetic impacts of salvage logging.

Although visually disruptive, rut–berm complexes provide a variety of moisture conditions and therefore vegetation regeneration niches (Aust et al., 2006). Reliance on natural rut recovery maintains habitat for amphibians in the form of ephemeral pools. These conservation values should be considered in this primarily agricultural landscape where much presettlement microtopography has been removed by grading and plowing (Battaglia and Sharitz, 2005; Fredrickson, 2005). Where ruts are incompatible with other management objectives, grading should be restricted to the first growing season to minimize disruption of vegetation recovery as well as reducing management inputs (Roy, 1956).

5. Conclusion

A diverse mosaic of site and vegetation conditions characterized this post-tornado bottomland landscape. Varying levels of wind damage appear likely to produce lasting impacts on overstory composition. On the wind + salvage areas, visual impacts of logging operations were converging toward soil disturbance class 0 during the course of the study. Although not definitive, key bottomland hardwood tree and shrub species regeneration appeared to respond differentially to salvage logging. Post-tornado salvage logging of limited scope may contribute to landscape-scale microtopography and vegetation diversity in large river floodplain forests. Managers may consider this practice where maintenance of a broad range of bottomland communities is desired.

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References

Aust, W.M., Burger, J.A., Carter, E.A., Preston, D.P., Patterson, S.C., 1998. Visually determined soil disturbance classes used as indices of forest harvesting disturbance. Southern Journal of Applied Forestry 22, 245–250.

Aust, W.M., Fristoe, T.C., Gellerstedt, P.A., Giese, L.A.B., Miwa, M., 2006. Long-term effects of helicopter and ground-based skidding on site properties and stand growth in a tupelo-cypress wetland. Forest Ecology and Management 226, 72–79.

Aust, W.M., Hodges, J.D., Johnson, R.L., 1985. The origin, growth and development of natural, pure, even-aged stands of bottomwood oak. In: Shoulders, E. (Ed.), Third Biennial Southern Silvicultural Research Conference. Southern Forest Experiment Station, Atlanta, Georgia, pp. 163–170.

Aust, W.M., Reisinger, T.W., Stokes, B.J., Burger, J.A., 1992. Tire performance as a function of width and number of passes on soil bulk density and porosity in a minor stream bottom. In: Brissette, J.C. (Ed.), Seventh Biennial Southern Silvicultural Research Confrence. Southern Forest Experiment Station, Mobile, Alabama, pp. 137–141.

Aust, W.M., Schoenholtz, S.H., Zaebst, T.W., Szabo, B.A., 1997. Recovery status of a tupelo-cypress wetland seven years after disturbance: silvicultural implications. Forest Ecology and Management 90, 161–169.

Baer, S.G., Groninger, J.W., 2004. Herbicide and tillage effects on volunteer vegetation composition and diversity during reforestation. Restoration Ecology 12, 258–267.

Battaglia, L.L., Sharitz, R.R., 2005. Effects of natural disturbance on bottomland hardwood regeneration. In: Fredrickson, L.H., King, S.L., Kaminski, R.M. (Eds.), Ecology and Management of Bottomland Hardwood Ecosystems: The State of Our Understanding. University of Missouri, Columbia, (Gaylord Memorial Laboratory Special Publication No. 10, Puxico), pp. 121–136.

Battaglia, L.L., Sharitz, R.R., Minchin, P.R., 1999. Patterns of seedling and overstory composition along a gradient of hurricane disturbance in an old-growth hardwood community. Canadian Journal of Forest Research 29, 144–156.

Bowling, D.R., Kellison, R.C., 1983. Bottomland hardwood stand development following clearcutting. Southern Journal of Applied Forestry 7, 110–116.

Casey, W.P., Ewel, K.C., 2006. Patterns of succession in forested depressional wetlands in north Florida, USA. Wetlands 26, 147–160.

Clarke, K.R., 1993. Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18, 117–143.

Collins, B., Battaglia, L.L., 2008. Oak regeneration in bottomland hardwood forest. Forest Ecology and Management 255, 3026–3034.

Conner, W.H., Sharitz, R.R., 2005. Forest communities of bottomlands. In: Fredrickson, L.H., King, S.L., Kaminski, R.M. (Eds.), Ecology and Management of Bottomland Hardwood Ecosystems: The State of Our Understanding. University of Missouri, Columbia, (Gaylord Memorial Laboratory Special Publication No. 10, Puxico), pp. 93–120.

Dale, E.E.J., Ware, S., Waitman, B., 2007. Ordination and classification of bottomland forests in the lower Mississippi alluvial plain. Castanea 72, 105–115.

Foster, D.R., Boose, E.R., 1992. Patterns of forest damage resulting from catastrophic wind in Central New England, USA. Ecology 80, 79–98.

Fredrickson, L.H., 2005. Contemporary bottomland hardwood systems: structure, function and hydrologic condition resulting from two centuries of anthropogenic activities. In: Fredrickson, L.H., King, S.L., Kaminski, R.M. (Eds.), Ecology and Management of Bottomland Hardwood Ecosystems: The State of Our Understanding. University of Missouri, Columbia, (Gaylord Memorial Laboratory Special Publication No. 10, Puxico), pp. 19–35.

Groninger, J.W., Baer, S.G., Babassana, D.-A., Allen, D.H., 2004. Planted green ash (*Fraxinus pennsylvanica* Marsh.) and herbaceous vegetation responses to initial competition control during the first 3 years of afforestation. Forest Ecology and Management 189, 161–170.

Hassan, A.E., Roise, J.P., 1998. Soil bulk density, soil strength, and regeneration of a bottomland hardwood site one year after harvest. Transactions of the ASAE 41, 1501–1508.

Hodges, J.D., 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management 90, 117–125.

Hosner, J.F., Minckler, L.S., 1960. Hardwood reproduction in the river bottoms of southern Illinois. Forest Science 6, 67–77.

Hosner, J.F., Minckler, L.S., 1963. Bottomland hardwood forests of southern Illinois—regeneration and succession. Ecology 44, 29–41.

(Jacaranda) van Rheenen, H.M.P.J.B., Boot, R.G.A., Werger, M.J.A., Ulloa Ulloa, M., 2004. Regeneration of timber trees in a logged tropical forest in North Bolivia. Forest Ecology and Management 200, 39–48.

Jansson, K.-J., Johansson, J., 1998. Soil changes after traffic with a tracked and a wheeled forest machine: a case study on a silt loam in Sweden. Forestry 71, 57–66.

King, S.L., Allen, J.A., 1996. Plant succession and greentree reservoir management: implications for management and restoration of bottomland hardwood wetlands. Wetlands 16, 503–511.

Kruse, B.S., Groninger, J.W., 2003. Vegetative characteristics of recently reforested bottomlands in the Lower Cache River watershed, Illinois, USA. Restoration Ecology 11, 273–280.

Lhotka, J.M., Zaczek, J.J., 2003. Soil scarification effects on oak reproduction in two mixed-oak bottomland stands of Southern Illinois. Southern Journal of Applied Forestry 27, 164–171.

Lockaby, B.G., Stanturf, J.A., Messina, M.G., 1997. Effects of silvicultural activity on ecological processes in floodplain forests of the southern United States: a review of existing reports. Forest Ecology and Management 90, 93–100.

Magurran, A.E., 1988. Ecological Diversity and its Measurement. Princeton University Press, Princeton, NJ, p. 179.

Meadows, J.S., Stanturf, J.A., 1997. Silvicultural systems for southern bottomland hardwood forests. Forest Ecology and Management 90, 127–140.

Minchin, P.R., 2005. DECODA Statistical Software 3.0. Southern Illinois University,, Edwardsville.

Nelson, J.L., Groninger, J.W., Battaglia, L.L., Ruffner, C.M., in press. Regeneration response to a tornado and salvage harvesting in a bottomland forest. In: 14th Biennial Southern Silvicultural Research Conference, Athens, Georgia.

Nelson, J.L., Ruffner, C.M., Groninger, J.W., submitted for publication. Drainage and agricultural impacts on fire frequency in a southern Illinois forested wetland. Canadian Journal of Forest Research.

Ozier, T.B., Groninger, J.W., Ruffner, C.M., 2006. Community composition and structural changes in a managed Illinois Ozark Hills forest. American Midland Naturalist 155, 253–269.

Peterson, C.J., Pickett, S.T.A., 1991. Treefall and resprouting following catastrophic windthrow in an oldgrowth hemlock-hardwoods forest. Forest Ecology and Management 42, 205–217.

Peterson, C.J., Pickett, S.T.A., 1995. Forest reorganization: a case study in an old-growth forest catastrophic blowdown. Ecology 76, 763–774.

Peterson, C.J., Rebertus, A.J., 1997. Tornado damage and initial recovery in three adjacent, lowland, temperate forests in Missouri. Journal of Vegetation Science 8, 559–564.

Reisinger, T.W., Simmons, G.L., Pope, P.E., 1988. The impact of timber harvesting on soil properties and seedling growth in the south. Southern Journal of Applied Forestry 12, 58–67.

Romagosa, M.A., Robison, D.J., 2003. Biological constraints on the growth of hardwood regeneration in upland Piedmont forests. Forest Ecology and Management 175, 545–561.

Roy, D.F., 1956. Salvage logging may destroy Douglas-fir reproduction. USDA Forest Service Research Note 107, 5.

Sander, I.L., Johnson, P.S., Rogers, R., 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Research Paper NC-251. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.

SAS, 2002–2003. SAS/STAT software 9.1 SAS Institute Inc., Cary, NC.

Schuler, J.L., Robison, D.J., 2006. Stand development and growth responses of 1- and 3-year-old natural upland hardwoods to silvicultural treatments. Forest Ecology and Management 232, 124–134.

USDA, 2007. Web soil survey. Available on line at: http://websoilsurvey.nrcs.usda.gov/app/accessed, November 26. Natural Resources Conservation Service.

Webb, S.L., 1989. Contrasting windstorm consequences in two forests, Itasca State Park, Minnesota. Ecology 70, 1167–1180.

Zaczek, J.J., 2002. Composition, diversity, and height of tree regeneration, 3 years after soil scarification in a mixed-oak shelterwood. Forest Ecology and Management 163, 205–215.

Zaczek, J.J., Groninger, J.W., Van Sambeek, J.W., 2002. Stand dynamics in an old-growth hardwood forest of southern Illinois, USA. Natural Areas Journal 22, 211–219.