REGENERATION RESPONSE TO TORNADO AND SALVAGE HARVESTING IN A BOTTOMLAND FOREST

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Abstract—A direct hit from an F4 tornado on May 2003, followed by a partial salvage logging operation at Mermet Lake State Conservation Area on the Ohio River bottoms of southern IL have provided a rare opportunity to assess the responses of a bottomland hardwood forest to severe wind and soil disturbances. The study area encompasses 700 acres and is representative of many bottomland forests within the Mississippi Alluvial Valley in the influence of past agricultural clearing and present hydrologic management for waterfowl habitat on forest composition. Assessment of regeneration recovery was conducted during the first three growing seasons following salvage logging across a range of wind and logging-related soil disturbances. Regeneration density and percent stocking increased with wind disturbance intensity. No differences were found in stem densities between areas severely disturbed by wind, with and without harvesting.

INTRODUCTION

Natural and anthropogenic disturbances, such as wind and harvesting, need to be considered when formulating forest restoration and management strategies for bottomland forests. Accordingly, there is growing documentation regarding the effects of these on regeneration development (Aust and others 2006, Battaglia and Sharitz 2005). The present study considers the interaction of these two disturbances when they occur in rapid succession.

Wind frequently disturbs forests of the Middle Mississippi River Valley and is recognized as a driver of forest succession and composition (Peterson and Pickett 1995). In this region, tornadoes and linear winds are the dominant types of windstorms, frequently resulting in damage to a high percent of the canopy trees and creating large gaps. The vegetative response to wind disturbance is a function of wind intensity and gap size. Small gaps tend to release advance regeneration, often of shade-tolerant species. In larger gaps associated with severe disturbance, more shade intolerant species become established (Battaglia and others 1999, Battaglia and Sharitz 2005, Conner and Sharitz 2005, Webb 1989). Sprouts, originating from the bole or root collar of damaged individuals, also contribute to regeneration following severe wind disturbance (Peterson and Pickett 1991, Peterson and Rebertus 1997). Battaglia and Sharitz (2005) found that in forests with some level of disturbance, species from all categories of shade tolerance were present, contributing to higher species richness on disturbed sites.

Harvesting has been a major source of disturbance in bottomland forests since European settlement (King and others 2005, Whitney 1994). The effects of harvesting on bottomland forest regeneration are similar to wind disturbance, as density and species richness often increase with disturbance intensity (Aust and others 1992, Jansson and Johansson 1998, Reisinger and others 1988). A number of studies following clearcutting with skidder removal or simulation, indicated regeneration of preferred commercial species were favored (Aust and others 2006, Hassan and Roise 1998, Jones and others 2000).

Regenerated stands were similar in composition to both pre-wind and pre-harvesting-disturbed communities(Aust and others 2006, Battaglia and others 1999, Peterson and Pickett 1995). Aust and others (1997) and Hassan and Roise (1998) found that following harvesting on bottomland sites, regeneration was adequate in skidded areas, and stump sprouting contributed significantly to regeneration (Aust and others 2006, Hassan and Roise 1998, Jones and others 2000, Perison and others 1997).

The objectives of this study were to assess the regeneration response of a bottomland forest to 1) wind disturbance intensity, with and without salvage logging; and 2) soil disturbance intensity associated with salvage logging within wind-disturbed sites.

STUDY SITE

The study area was located within the Mermet Lake State Conservation Area in Massac County, IL, (37°15’ 25”N, 88°50’30”W), near the northern limit of the Mississippi Embayment. The General Land Office survey of 1807 characterized this area as a cypress 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 subject to drainage and conversion to row cropping, which led to increased fire frequency. Partial hydrologic restoration occurred in 1957, and the site has been managed as a wildlife area since that time. Fire and timber harvesting had been absent since the onset of state ownership and disturbance other than seasonal flooding limited until approximately 400 acres of forested land was severely damaged by an F4 tornado on May 6, 2003. A salvage harvesting operation intended to remove merchantable material and restore access to hunters occurred from October 2003 to April 2004. Prior to May 2003, the study area supported a 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.*

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alata Michx., *Fraxinus pennsylvanica* Marsh., *Liquidambar styraciflua* L., and *Nyssa aquatica* L.

METHODS

In the summer of 2004, sampling was conducted at 96 plots located in a grid pattern across approximately 140 acres of the study site. The site treatment classified was as follows: 1) undisturbed (Undisturbed)—areas that appeared free of structural tornado damage and containing a closed canopy overstory ≥ 60 years old; 2) transitional wind damage (Transitional)—areas located at the edge of the tornado swath that sustained some wind damage but where a partial overstory remained; 3) wind damaged (Wind)—areas that received a direct hit from the tornado and sustained nearly complete overstory removed; and 4) wind damaged with salvage harvesting (Harvested)—areas that sustained the same damage as Wind, but where salvage harvesting occurred.

Each plot contained four 1/1,000 ac (0.0004047 ha) circular regeneration sub-plots located at each of the four primary compass points and centered eight feet from the plot center. In each sub-plot, all regenerating woody species > 2 ft in height and less than 2 inches d.b.h. were identified annually during May-June from 2004 through 2006 (first through third growing seasons).

Within the harvested treatment, intensity of soil disturbance was characterized for each sub-plot according to Aust and others (1998) and recorded 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 < 8.0 inches; Class 3—soil was rutted (as evidenced by puddled soil) and rut depth ≥ 8.0 inches; and Class 4—soil was obviously churned and puddled with indication of liquid soil movement.

One way analysis of variance (ANOVA) of expected mean squares was used to examine stem density variations between treatments. Changes over time were analyzed using repeated measures ANOVA, with an unstructured correlation structure used, to determine effects of treatment, time, and treatment*time interactions. Tukey's HSD method was used for pairwise comparisons of means. A stocking rate of at least 50 percent of sub-plots within a treatment containing at least one stem of an overstory species was considered adequate.

RESULTS

Effects of Disturbance on Woody Regeneration

During the third growing season, woody stem regeneration densities were 4,590 stems/acre for the entire site, with potential overstory species comprising 58 percent of all stems. Treatment (DF = 3, 91; F = 9.86; $p < 0.0001$), time (DF = 2, 91; F = 11.47; $p < 0.0001$), and a treatment*time interaction (DF = 6, 91; F = 3.08; $p < 0.0086$) were significant effects on woody species regeneration densities. The interaction resulted from a greater increase in the mean stem densities in the Wind and Harvested treatments compared to the Undisturbed and Transition treatments (fig. 1) in the third year mean stem densities (DF = 3, 89; F = 8.36; $p < 0.0001$)

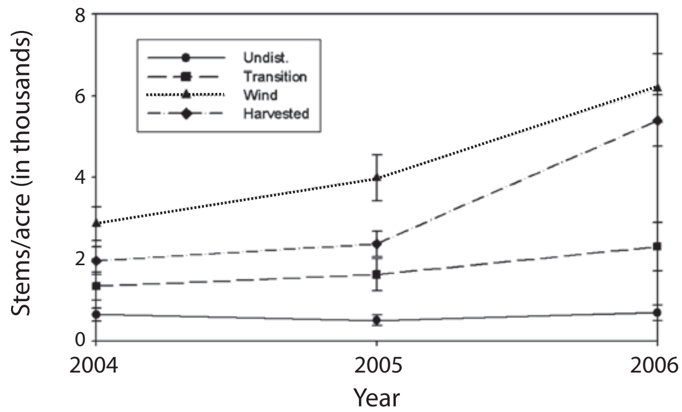

Figure 1—Stems per acre of all woody stems over first three years, by disturbance type.

(table 1). No difference in mean stem densities were detected between soil disturbance classes within the Harvested treatment (DF = 4, 46; F = 0.98; p = 0.4289).

Stem densities of overstory species regeneration increased with severity of wind disturbance (table 1). The Wind and Harvested treatments did not differ from one another but within the Harvested treatment, potential overstory stem density differed only between soil disturbance Classes 3 and 4. During the study period, regeneration of 36 potential overstory species was recorded, with green ash and red maple combined comprising nearly 50 percent of potential overstory species stems in the third year (table 2).

During the third growing season, 62 percent of all plots were stocked with at least 1 stem of a potential overstory species. Stocking levels increased with wind disturbance (table 3). Within the Harvested treatment, only soil

Table 1—Woody and overstory species regeneration stem densities during third growing season following salvage logging as a function of disturbance type

Disturbance type	Woody regeneration density (stems/acre)	Overstory species regeneration Density (stems/acre)
Undisturbed	687.5 a	625 a
Transition	2312.5 ab	1406 ab
Wind	6176.5 b	3309 b
Harvested	5394.2 b	3288 b

Means followed by the same letter within a column do not differ at 0.05 level.

Table 2— Species constituting ≥ 1% of overstory regeneration during the third growing season following salvage logging

Species	Percentage of stems (2006)
Acer negundo	3
Acer rubrum	26
Acer saccharum	3
Carya spp.	2
Celtis occidentalis	2
Diospyros virginiana	3
Fraxinus pennsylvanica	24
Liquidambar sturaciflua	7
Liriodendron tulipifera	3
Quercus spp.	3
Robinia psudoacacia	1
Sassafras albidum	4
Salix nigra	9
Ulmus spp.	6

Table 3—Percentage of sub-plots containing at least 1 seedling during the third growing season following salvage logging by disturbance type and soil disturbance class

Variable	Level	Percentage of plots
Disturbance type	Undisturbed	33
	Transition	50
	Wind	75
	Harvested	69
Soil disturbance class	0	85
	1	85
	2	71
	3	46
	4	65

disturbance Classes 3 and 4 had stocking levels lower than Wind. Considering 50 percent stocking adequate, the only treatments not adequately stocked were the Undisturbed and soil disturbance class 3 within the Harvested treatment (table 3). Within stocked plots, nineteen different species served as the dominant stem, with F. pennsylvanica or A. rubrum the dominant stem in 47 percent of the plots (table 4).

Table 4—Dominant stem composition of stocked sub-plots during the third growing season following salvage logging

Species	All Plots with 1 stem (n=224)
Acer negundo	4%
Acer rubrum	19%
Acer saccharum	4%
Carya spp.	2%
Diospyros virginiana	4%
Fraxinus pennsylvanica	28%
Liquidambar sturaciflua	9%
Liriodendron tulipifera	6%
Nyssa aquatica	1%
Populus heterophylla	1%
Quercus spp.	5%
Robinia psudoacacia	1%
Sassafras albidum	4%
Salix nigra	7%
Taxodium distichum	1%
Ulmus spp.	6%
Total	102% *

* Total greater than 100% result of co-dominant stems in 9 plots

DISCUSSION

Vegetation response was strongly related to disturbance intensity. These results are similar to those reported for other bottomland sites disturbed by wind or harvesting, where stem densities increased following disturbance (Aust and others 2006, Battaglia and others 1999, Battaglia and Sharitz 2005, Hassan and Roise 1998). Increased stem densities were also accompanied by an increase in diversity, with the number of species present increasing from Undisturbed to Harvested. This increase can be attributed to a reduction in competition and a shift from shade tolerant to shade intolerant species positively associated with an increase in disturbance intensity. The increases in total stem densities, species richness, and a shift toward more shade intolerant species is consistent with other studies of large gap formation (Battaglia and others 1999, Battaglia and Sharitz 2005, Hassan and Roise 1998, Peterson and Pickett 1995).

Early differences in stem densities between the Wind and Harvested treatments appear to be short-term. Rapid regeneration of the Harvested treatment was consistent with other research on bottomland sites (Aust and others 2006, Hassan and Roise 1998), as was the positive association between both stem density and diversity with disturbance intensity (Aust and others 2006, Battaglia and others 1999, Battaglia and Sharitz 2005, Hassan and Roise 1998, Peterson and Pickett 1995).

Within the Harvested treatment, tree regeneration density did not differ across soil disturbance classes. Further, the lack of a difference in stem densities between Harvested and Wind by the third growing season suggests that recovery from harvesting soil disturbance was occurring rapidly. This too is consistent with other studies on bottomland sites (Aust and others 2006, Hassan and Roise 1998).

During the third growing season, potential overstory species stem densities still differed between Classes 3 and 4, with Class 3 the only category where densities were not similar to or greater than those of the Wind treatment. An unexpected finding was that Class 4 not only had greater densities than the Wind area, but supported the highest densities of potential overstory species of any class. This area was associated with the most visually dramatic disturbance, as churning and liquid soil movement were associated with areas of nearly total devegetation. However, this high intensity of soil disturbance was associated with the establishment of high stem density, but lower diversity than all other treatments. Regeneration in Class 4 was dominated by light-seeded, moisture-tolerant species that benefit from wet, highly disturbed soil with little to no competition during their establishment period.

In the Harvested treatment, only Class 3 was considered to be inadequately stocked by overstory tree species. This is most likely due to extensive rutting (> 8 inches in depth) and compaction associated with extended periods of standing water throughout the year and limited establishment by even the most hydric species. However, even the severely impacted classes had relatively large increases in stocking by the second and third growing season, relative to the other soil disturbance classes. If this trend continues, the variations in stocking and stem densities between soil disturbance classes will continue to decrease, with Class 3 reaching adequate stocking in year 4.

CONCLUSION

Regeneration of overstory tree species occurred across the range of wind and salvage logging disturbance classes at Mermet Lake State Conservation Area. Variations in stem density and stocking levels among disturbance classes were observed during the first two growing season, but had diminished or were absent during the third growing season, suggesting these differences were transitory. Further analyses will address differences in species composition across the wind and harvesting disturbance gradients. Continued monitoring will be needed to determine how the regeneration cohort that has established following wind and soil disturbance responds to the post-agricultural hydrologic and fire regimes. The increasing presence of invasive species, such as Japanese stilt grass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), and multiflora rose (*Rosa multiflora*) also appears to impact regeneration of native woody species in some areas and should be subject to continued monitoring.

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