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Woody plant regeneration after blowdown, salvage logging, and prescribed fire in a northern Minnesota forest

Brian Palik *, Doug Kastendick

US Forest Service, Northern Research Station, 1831 Highway 169 E, Grand Rapids, MN 55744, USA

A R T I C L E I N F O

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A B S T R A C T

Salvage logging after natural disturbance has received increased scrutiny in recent years because of concerns over detrimental effects on tree regeneration and increased fine fuel levels. Most research on tree regeneration after salvage logging comes from fire-prone systems and is short-term in scope. Limited information is available on longer term responses to salvage logging after windstorms or from forests outside of fire-prone regions. We examined tree and shrub regeneration after a stand-replacing windstorm, with and without salvage logging and prescribed fire. Our study takes place in northern Minnesota, USA, a region where salvage logging impacts have received little attention. We asked the following questions: (i) does composition and abundance of woody species differ among post-disturbance treatments, including no salvage, salvage alone, and salvage with prescribed burning, 12 years after the windstorm?; (ii) is regeneration of *Populus*, the dominant pre-blowdown species, inhibited in unsalvaged treatments?; and (iii) how do early successional trajectories differ among post-blowdown treatments? Twelve years after the wind disturbance, the unsalvaged forest had distinctly different composition and abundance of trees and woody shrubs compared to the two salvage treatments, despite experiencing similar wind disturbance severities and having similar composition immediately after the blowdown. Unsalvaged forest had greater abundance of shade tolerant hardwoods and lower abundance of *Populus*, woody shrubs, and *Betula papyrifera*, compared to salvage treatments. There was some evidence that adding prescribed fire after the blowdown and salvage logging further increased disturbance severity, since the highest abundances of shrubs and early successional tree species occurred in the burning treatment. These results suggest that salvage treatments (or a lack thereof) can be used to direct compositional development of a post-blowdown forest along different trajectories, specifically, towards initial dominance by early successional *Populus* and *B. papyrifera* with salvage logging or towards early dominance by shade tolerant hardwoods, with some *Populus*, if left unsalvaged.

1. Introduction

Salvage logging has received increased scrutiny in recent years (Lindenmayer et al., 2004). Historically, salvage logging has been used to prevent economic losses following natural disturbance and is arguably successful for that purpose. It is also used to reduce post-disturbance fuel loads and for promoting forest regeneration and guiding successional development towards desired future conditions. While there is substantial evidence that salvage logging can be successful at meeting these latter goals (McIver and Starr, 2000), its appropriateness is still questioned (Lindenmayer et al., 2004; Greene et al., 2006). In fact, recent evidence suggests that salvage logging can actually increase fine fuels (Donato et al., 2006) and subsequent fire severity (Thompson et al., 2007) inhibit natural regeneration of trees (Van Nieuwstadt et al., 2001), and slow successional recovery (Lindenmayer and Ough, 2006).

Most research on tree regeneration and successional development after salvage logging has occurred in post-fire ecosystems in the western United States and Australia (McIver and Starr, 2000). Moreover, most studies examine only the short-term effects of salvage logging on ecosystem function (Lindenmayer and Noss, 2006). Much less information is available on long-term effects and feasibility after windstorms (Spurr, 1956; Sinton et al., 2000; Elliott et al., 2002; Peterson and Leach, 2008), and from forests of other regions. For instance, while relatively infrequent in time and space, meso- to large-scale windstorms are an important forest disturbance in many regions, such as the western Great Lakes region in the United States (Canham and Loucks, 1984; Reich et al., 2001; Hanson and Lorimer, 2007). Some speculate that these disturbances may be increasing in frequency as a consequence of

* Corresponding author. Tel.: +1 218 326 7116; fax: +1 218 326 7123.
E-mail address: bpalik@fs.fed.us (B. Palik).

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climate change (Schelhaas et al., 2003). With increased frequency of wind disturbance in the future there may be an increased desire to salvage log after these disturbances.

Studies of tree regeneration and successional development after a single disturbance, wind or otherwise, are common. It is the relative rapid imposition of a second disturbance (e. g. salvage logging) after the first, which is much less studied. Some hypothesize that the cumulative effects of the combined disturbances lead to conditions outside of range of natural variation for native species and ecosystem function, with potentially deleterious effects (Lindenmayer et al., 2004; Lindenmayer and Noss, 2006; Peterson and Leach, 2008). Adding a third disturbance in rapid sequence likely results in even greater complexity or uncertainty of response, as for example when wind, salvage logging, and fire interact (e.g., Kulakowski and Veblen, 2007). There is virtually no research with a longer term perspective that allows generalization about vegetation responses to wind disturbance followed by salvage logging and prescribed fire.

The overall objective of our study was to examine tree and woody shrub regeneration patterns after a stand-replacing wind disturbance, with and without salvage logging and prescribed fire. Our study takes place in northern Minnesota, USA, a region where salvage logging impacts have received little attention, but where understanding the effects of natural disturbance and salvage logging on forest regeneration has been identified as a high priority research need (Mattson and Shriner, 2001). Specifically, our study includes wind-disturbed, but unsalvaged controls, replication of treatments, and longer term data, collected over a 12-year period. We addressed the following questions: (1) does composition and abundance of woody species differ among post-disturbance treatments 12 years after the original windstorm?; (2) is aspen regeneration inhibited in unsalvaged treatments?; (3) and how do early successional trajectories differ among disturbance treatments?

2. Methods

2.1. Study area

We conducted our study in the Trout Lake Roadless Area on the Chippewa National Forest, located in north central Minnesota, USA. The Trout Lake area is approximately 2740 ha and the forest is composed predominantly by *Populus tremuloides* (trembling aspen) and some *Populus grandidentata* (bigtooth aspen), with lesser amounts of other southern boreal transition species, including *Acer saccharum* (sugar maple), *Acer rubrum* (red maple), *Quercus rubra* (northern red oak), *Betula papyrifera* (paper birch), *Pinus resinosa* (red pine), and *Pinus strobus* (eastern white pine). At the time of disturbance, the majority of the forest was 65–70 years old, having initiated following logging and wildfires early in the 20th century. Upland soils throughout most of the study area are loamy sands and sandy loams derived from glacial outwash or till.

On July 13 1995, a severe summer windstorm swept across northern Minnesota in an easterly direction. The storm damaged approximately 152 ha in the Trout Lake area. Storm damage to the Trout Lake area was concentrated in 30 discrete blowdown patches. Patches averaged 5 ($\pm$5 sd) ha in size and ranged from 2 to 18 ha (Palik and Robl, 1999).

2.2. Study design

Nine of the 30 blowdown patches were salvaged logged during the summer of 1996, approximately 12 months after the windstorm. In late spring of 1997, five of the logged patches were prescribed burned. The purpose of the burning was to create seedbed conditions conducive to establishment of native conifer species, including *P. strobus*, *P. resinosa*, and *Picea glauca*. We sampled all salvaged logged and salvaged and burned patches and randomly selected six unsalvaged patches for sampling. Our study is an unplanned experiment in that we had no control over the assignment of treatments to patches (i.e., blowdown, salvage, prescribed fire) and thus we lack random assignment of treatments to experimental units.

2.3. Vegetation sampling

In spring 1996, prior to any salvage logging, we set up a series of permanent sampling points in each selected blowdown patch for vegetation sampling. In each patch, we located an initial point by selecting a random distance and compass bearing while standing at the approximate center of the patch. Additional points were located along the long axis of a patch by pacing randomly selected distances of at least 50 m from each subsequent point. The number of sample points in each patch ranged from four to 10 depending on patch size.

At each point we used variable radius (prism) plots to sample live residual trees (dbh $\geq$10 cm) and saplings (2.5 cm $\geq$ dbh $<$ 10 cm) within each blowdown patch. We took prism samples using a 10-factor (English unit) prism for trees and a 5-factor prism for saplings. At each point, we recorded the species and diameter of all live trees and saplings in the sample. At each of the sample points, we used the point-quarter method (Mueller-Dombois and Ellenberg, 1974) to sample trees that were uprooted or snapped off by the windstorm. In each quarter, we recorded the distance from the central point to the approximate center of the original bole location of the nearest uprooted or snapped tree, as well as its species identity and diameter at 1.4 m above the ground. We sampled tree regeneration and woody shrubs in subplots located around each tree sample point. One subplot was located at plot center and four were centered on points located 5 m from the center point in cardinal compass directions (N,S,E,W). Small stems ($<$1 m tall) were sampled in 1 m^2 quadrats, while larger stems ($\geq$1 m tall and $<$2.5 cm dbh) were tallied in 3.14 m^2 circular plots.

Vegetation was first sampled in the summer of 1996, approximately 12 months after the blowdown, but before salvage logging that began in late summer of that year. This sampling was repeated in the spring of 1997, before prescribed burning, largely to document the direct physical effects of salvage logging on stand structure and regeneration. Sampling was repeated in summer 2001, four years after the prescribed burning and again in the summer 2007, 12 years after the blowdown, 11 years after salvage logging, and 10 years after prescribed fire. For most response variables, only initial post-blowdown, but pre-salvage data, and 10–12 year post-blowdown data are reported here.

2.4. Analysis

Overstory tree diameter data (stems $\geq$10 cm dbh) for both live and dead trees were summarized into species basal areas and used to reconstruct pre-blowdown forest composition (summing residual and dead basal areas by species) and immediate post-blowdown composition (residual trees). Patch-scale basal areas were used to assess disturbance severity among treatments based on changes in basal areas after blowdown and salvage logging. Similar to the approach outlined in Peterson and Leach (2008), we quantified disturbance severity among the three treatment groups (unsalvaged, salvaged, salvaged and burned) based on (1) the amount of basal area removed by the windstorm and (2) the cumulative basal area removed by the windstorm and subsequently salvaged, as well as additional live basal area lost during salvage to harvesting and mortality of residual trees.

Plot level regeneration abundance data were summarized to the blowdown patch-scale for each measurement year. Stems $<$1 m