Forest Ecology and Management 256 (2008) 2110–2120

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Spatial impacts of soil disturbance and residual overstory on density and growth of regenerating aspen

Klaus J. Puettmann [a], Anthony W. D'Amato [b,*], Melissa Arikian [c], John C. Zasada [d]

[a] Department of Forest Science, Oregon State University, Corvallis, OR 97331, USA
[b] Department of Forest Resources, University of Minnesota, St. Paul, MN 55108, USA
[c] Emmons and Olivier Resources, 651 Hale Avenue. N., Oakdale, MN, 55128, USA
[d] Northern Research Station, USDA Forest Service, Forestry Sciences Laboratory, Grand Rapids, MN 55744, USA

ARTICLE INFO

Article history:
Received 27 February 2008
Received in revised form 31 July 2008
Accepted 31 July 2008

Keywords:
Tree regeneration
Populus tremuloides
Soil disturbance
Residual overstory
Harvesting effects

ABSTRACT

We examined spatial aspects of harvesting impacts on aspen regeneration at 25 sites in northern Minnesota. These sites had been clearcut or partially harvested 4–11 years ago. At each site, residual overstory, which was composed of trees other than aspen, soil disturbance, and tree regeneration were determined along transects leading away from skid trails into the neighboring stand. We characterized spatial extent of soil disturbance as soil strength using an Eijkelkamp soil cone penetrometer. Soil disturbance dropped off very quickly at the edge of skid trails, suggesting that the impact of harvesting traffic on areas adjacent to skid trails is minor. On skid trails, disturbance levels were higher on sites harvested in summer than on sites harvested in winter. Even after adjustment for differences in soil disturbance, stands harvested in winter had higher regeneration densities and greater aspen height growth than stands harvested in summer, suggesting that aspen regeneration was more sensitive to a given level of soil disturbance on summer-harvested sites versus on winter-harvested sites. Soil disturbance and residual overstory interactively reduced aspen regeneration densities and height growth, indicating that avoidance of soil disturbance is even more critical in partially harvested stands. Predictions based in the spatial patterns of impact found in this study indicated that harvesting conditions may have a great impact in future productivity of a site.

1. Introduction

Forests in the Great Lakes region of the United States once contained vast expanses of forests dominated by white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Aiton.), jack pine (*Pinus banksiana* Lambert.), and northern hardwood species (Curtis, 1959; Ahlgren and Ahlgren, 1983). While these forests still constitute important components of the landscape, widespread logging and intense slash fires in this region during the mid-1800s to early 1900s resulted in an increase in aspen species (*Populus* spp.) in many areas previously dominated by these forest types (Graham et al., 1963; Schulte et al., 2007). Notably, aspen species were able to take advantage of and regenerate in disturbed areas created by natural disturbances and forest harvesting (Schier, 1976; Bates et al., 1989), despite management practices designed to encourage the establishment of other species, particularly conifers (Peterson and Peterson, 1992).

Forests dominated by trembling (*Populus tremuloides* Michx.) and bigtooth (*Populus grandidentata* Michx.) aspen now comprise roughly one-third of Minnesota's timberland, totaling almost 2.0 million hectares in 2006 with 46% of stands being older than 40 years (Domke et al., 2008). As the commercial importance of aspen has increased, forest managers have clearcut aspen stands, a strategy that takes advantage of the species' rapid reproduction from root suckers (Stoeckeler and Macon, 1956; Farmer, 1962; Steneker, 1974; Schier and Smith, 1979; Raile and Hahn, 1982; Bella, 1986). However, recent trends in forest management include leaving reserve trees, single or clumped, in clearcut areas (Kohm and Franklin, 1997, Puettmann and Ek, 1999). This strategy changes conditions for the regeneration niche of aspen, as a residual overstory left after a harvest has been shown to reduce aspen regeneration (Stoeckeler and Macon, 1956; Schier and Smith, 1979; Hove et al., 1990; Ffolliott and Gottfried, 1991; Palik et al., 2003).

Aspen regeneration by suckering is especially sensitive to soil disturbance (Stone and Elioff, 2000; Smidt and Blinn, 2002; Frey et al., 2003). Soil conditions after harvest are determined by site factors such as soil texture and moisture content, as well as logging

* Corresponding author. Tel.: +1 612 625 3733; fax: +1 612 625 5212.
E-mail address: damato@umn.edu (A.W. D'Amato).

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2008.07.037

equipment used, operator skills, and harvesting intensity (Dyrness, 1965; Froehlich, 1973). Harvesting traffic that decreases soil aeration and/or damages roots (Hatchell et al., 1970; Shetron et al., 1988) decreases the growth potential of roots and the ability of aspen to sucker (Youngberg, 1959; Hatchell et al., 1970; Stone and Elioff, 1998; Smidt and Blinn, 2002).

The impact of leaving residual trees after harvest varies by forest ecosystem and recent studies suggest that the presence of residuals may negatively influence regeneration in systems dominated by light demanding species such as aspen (Zenner et al., 1998; Palik et al., 2003). For proper evaluation, the tradeoffs associated with leaving residuals need to be quantified and put in perspective with other factors that influence tree regeneration. For example, harvesting impacts on soils are part of any ground-based harvesting operation, i.e., they occur in or near all areas in which residual overstory trees influence regeneration. Because aspen is a very light demanding species that regenerates through suckering (Perala, 1990) it may be especially sensitive to the combined effects of soil disturbance and the presence of a residual overstory. Specifically, aspen suckers simultaneously draw resources from the parent root system, which can be affected through harvesting traffic, and from photosynthesis, which can be affected by competition from residual overstory trees. To date, however, studies that investigated the impacts of soil disturbance on tree regeneration have not considered the impacts of residual overstory (e.g., Froehlich, 1979; Schier et al., 1985; Bates et al., 1990; Navratil, 1991; Shepperd, 1993; Smidt and Blinn, 2002; Zenner et al., 2007; Mundell et al., 2008). Similarly, studies quantifying the impacts of residual overstory on aspen regeneration have not incorporated the effects of soil disturbance (e.g., Stoeckeler and Macon, 1956; Perala, 1977; DeByle and Winokur, 1985; Huffman et al., 1999; Palik et al., 2003). By combining these two aspects, our study investigates a basic question about the drivers of ecosystem structure and places plant responses to competition, stress, and disturbances in a broader context. Moreover, it provides an investigation into the basic role of competition (Grace and Tilman, 1990; Grime, 2001), specifically whether and how the plant response to competition (from overstory trees) varies with different levels of stress and disturbances (through soil impacts, cf. Campbell and Grime, 1992; Turkington et al., 1993).

In many parts of the Lake States, harvesting is restricted in summer months as a result of access problems due to high water tables and about half of the harvesting operations in Minnesota occur during winter months (Puettmann and Ek, 1999). Thus, an additional consideration in assessing the influence of overstory residuals and soil disturbance on aspen regeneration is the effect of season of harvest on regeneration patterns. In particular, aspen suckering response has been shown to vary by season of harvest (Zehngraff, 1946, 1947; Stoeckeler, 1947; Stoeckeler and Macon, 1956; Smidt and Blinn, 2002; Frey et al., 2003) and this phenomenon has been attributed to a combination of lower aspen root carbohydrate stores in spring and early summer after leaf flushing (Schier and Zasada, 1973; Schier, 1981) and less site disturbance during winter harvests (Mace, 1971; Zasada et al., 1987; Berger et al., 2004; Mundell et al., 2008). As such, seasonal effects must be considered in an evaluation of aspen regeneration dynamics after harvesting.

In our study, we investigated the interactions of these three factors influencing post-harvest aspen regeneration. In particular, we were interested in characterizing the spatial aspects of the impacts of harvesting traffic and residual trees on aspen regeneration as influenced by gradients in traffic patterns and residual overstory tree densities. Correspondingly, the first set of objectives was to develop predictive equations that spatially quantified gradients in soil disturbance along a transect moving from skid trails to side areas (objective 1a) and whether or not summer harvests result in higher soil disturbance levels than winter harvests (objective 1b). We recognize that previous work has demonstrated that soil disturbance levels are often greater on skid trails and following summer harvests (e.g., Brais and Camiré, 1998; Berger et al., 2004); but the spatial extend of such impacts has not been documented. Also, the development of these predictive equations was necessary for addressing subsequent objectives exploring impacts of harvesting traffic on tree regeneration. In particular, the second set of objectives addressed whether and at what spatial scale harvesting traffic decreases tree regeneration density and growth through disturbance of the soil (objective 2a) and whether or not this relationship differs between sites harvested in winter and those harvested in summer (objective 2b). Objective 3 incorporated effects of residual overstory into the relationships established under objectives 1 and 2. It investigated whether the influence of harvesting traffic on regeneration density and height growth was also influenced by the presence of a residual overstory, and if so, at what spatial scale. To address objectives 2 and 3 we developed two-stage regression equations (Borders, 1989) that allowed for the prediction of spatial impacts of harvesting traffic on aspen regeneration without actually measuring soil disturbance on a site.

2. Methods

2.1. Study area and site selection

This study included 25 stands, located within 6 northeastern Minnesota counties (Fig. 1), that were dominated by trembling aspen (*Populus tremuloides* Michx.) and, to a lesser extent, bigtooth aspen (*Populus grandidentata* Michx.). All stands had been clearcut or partially harvested between 1988 and 1994 and were measured in the summers of 1997 and 1998, 4–11 (average 6) growing seasons after harvest. Sites were selected to assure a range of harvest regimes and fairly homogeneous within-site characteristics. Harvest regimes included summer and winter aspen clearcuts, aspen clearcuts with low hardwood residual basal area ($<3\ m^2/ha$), and aspen cuts with heavy hardwood residual basal area (average $12\ m^2/ha$). None of the selected sites had incurred major disturbances or management activity following harvest. Table 1 provides more detailed site descriptions.

The overall mean annual temperature for the study region ranges from 3.8 to 5.6 °C, and the overall mean annual precipitation ranges from 66 to 76 cm (Anderson et al., 1996). All sites were fairly level, with an average slope of 8% and soil parent materials in these areas were mainly dominated by glacial tills (Anderson et al., 1996). Soil textural data collected from all field sites indicated they were located on similar classes of sandy loams and silt loams.

All sites were considered aspen harvests; that is, aspen was the main species cut. Based on harvesting records, the amount of aspen volume removed indicated that the pre-harvest densities of aspen were substantially higher than the densities considered minimum (20 trees/ha) for successful establishment of a fully stocked aspen stand (Perala, 1977). Northern hardwoods, including sugar and red maple (*Acer saccharum* Marsh. and *Acer rubrum* L.), basswood (*Tilia americana* L.), northern red oak (*Quercus rubra* L.), and paper birch (*Betula papyrifera* Marsh.), were the most common of the 22 tree species other than aspen in the residual stands. Thus, since harvesting focused on aspen, the other species collectively comprised 82% of the residual overstory basal area. Consequently, trembling and, to a lesser extent, bigtooth aspen were the most common species regenerating, comprising 97% of regenerating stems on all aspen sites. The most common of the 11 regenerating