Forest Ecology and Management 296 (2013) 41–52

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

Variation in logging debris cover influences competitor abundance, resource availability, and early growth of planted Douglas-fir

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ARTICLE INFO

Article history:
Received 9 November 2012
Received in revised form 8 January 2013
Accepted 21 January 2013
Available online 6 March 2013

Keywords:
Vegetation management
Soil productivity
Microclimate

ABSTRACT

Logging debris remaining after timber harvest can modify the microclimate and growing conditions for forest regeneration. Debris also can influence tree seedlings indirectly through its effects on development of competing vegetation, although the mechanisms are poorly understood. At two sites in Washington and Oregon (USA) that differed in availability of soil water and nutrients, mechanisms were studied by which logging debris and competing vegetation interacted to influence performance of planted Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) seedlings. In a split-plot design, two levels of competing vegetation (presence and absence) and three covers of logging debris (0%, 40%, and 80%) were replicated eight times at each site on 2 × 2-m areas centered on individual Douglas-fir seedlings. Vegetation abundance, seedling growth, and resource availability were monitored for 4 years (2005–2008). Soil water depletion was lower and Douglas-fir water potential and foliar nitrogen were higher in the absence of competing vegetation, resulting in increased seedling growth. The highest seedling growth rates and foliar nitrogen contents occurred where absence of vegetation was combined with 80% debris cover. Where competing vegetation was present, 40% debris cover was associated with decreases in herb cover and soil water depletion and increases in seedling growth relative to 0% or 80% debris covers. At the Washington site where soil quality was lower, the combination of presence of vegetation and 80% debris cover was associated with a 2.4 °C average reduction in summer soil temperatures at 15 cm depth, reduced foliar nitrogen content, and the slowest rates of seedling growth. Potential effects of logging debris, such as mulching (i.e., reduced evaporation of soil water) and interception loss (i.e., reduced precipitation inputs), were minor to non-detectable from sensors buried at 20–40 cm soil depth. Results of the research suggest that retention of moderate levels of logging debris (i.e., 40% cover) after forest harvesting in the Pacific Northwest is likely to increase early growth of Douglas-fir by increasing soil water availability through reduced herb abundance. Where intensive vegetation control is practiced, retention of higher debris levels (i.e., 80% cover) may provide further benefits to seedling growth.

Published by Elsevier B.V.

1. Introduction

Management of competing vegetation is a primary silvicultural strategy for focusing productivity of forest sites on the desired tree species (Balandier et al., 2006). Limited site resources are channeled effectively to the crop, accelerating production of biomass and shortening the period until economic and other values can be realized (Walstad and Kuch, 1987). Observations of significant benefits from competing vegetation control to survival and growth of tree seedlings are consistent throughout North America (Fleming et al., 2006) and other areas of commercial forest production in the world (Wagner et al., 2006). During the early years of forest development, vegetation control increases availability of growth-limiting soil resources, especially water and nutrients (Harrington and Tappeiner, 1991; Zutter et al., 1999; Dinger and Rose, 2009). Thus, an understanding of the mechanisms by which competing vegetation limits performance of tree seedlings is critical to the efficient practice of forest vegetation management.

Forest productivity research has identified interactions between competing vegetation and logging debris that occur soon after forest harvesting. In general, retention of logging debris in temperate zone forests inhibits development of herbaceous, and sometimes woody, species. This finding has been reported for a wide range of forest ecosystems including mixed stands of balsam fir (*Abies*

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0378-1127/$ - see front matter Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.foreco.2013.01.033

balsamea (L.) Mill.) and paper birch (*Betula papyrifera* Marshall) in northern Minnesota (USA) (Outcault and White, 1981), loblolly pine (*Pinus taeda* L.) plantations in the southeastern USA (Cox and Van Lear, 1985), trembling aspen (*Populus tremuloides* Michx.) in central Ontario, Canada (Hendrickson, 1988), and Sitka spruce (*Picea sitchensis* (Bong.) Carrièr) in North Wales, UK (Fahey et al., 1991). Retention of logging debris in the Pacific Northwest (USA) has been shown to inhibit development of common plant competitors including Scotch broom (*Cytisus scoparius* (L.) Link) (Harrington and Schoenholtz, 2010) and various non-native herbaceous species (Peter and Harrington, 2012), thereby facilitating increased survival and growth of coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) seedlings. Retention of logging debris also has been associated with mulching effects – increased conservation of soil water, usually near the soil surface (O'Connell et al., 2004; Roberts et al., 2005) – attributed to reductions in evaporation and soil temperature (Devine and Harrington, 2007). In nitrogen deficient forest ecosystems of Europe, productivities of Sitka spruce through 23 years after planting (Walmsley et al., 2009) and Norway spruce (*Picea abies* (L.) Karst) through 31 years after planting (Egnell, 2011) were greater after stem-only harvesting than after whole-tree harvesting – a response attributed to greater retention of nitrogen and other nutrients. Thus, logging debris has the potential to increase survival and growth of tree seedlings and saplings (e.g., in droughty or nitrogen deficient soils), thereby contributing to long-term sustainability of forest productivity. However, identification of applicable site characteristics and elucidation of the underlying mechanisms by which competing vegetation and logging debris interact to control forest productivity remain as important knowledge gaps.

Logging debris effects have traditionally been studied by subsampling vegetation and soil responses within experimentally treated plots, scaling the responses to the stand level, and identifying potential relationships (Scherer et al., 2000; Zabowski et al., 2000; Roberts et al., 2005; Ares et al., 2007). Although commonly used in forestry research, these approaches may be unsuitable for detecting fine-scale effects of logging debris and underlying mechanisms because debris cover can vary considerably at the plot level (>0.01 ha), especially given operational conditions (Eisenbies et al., 2005; Slesak et al., 2011a). Slesak et al. (2010) applied fixed levels of logging debris (0%, 40%, and 80% covers) around individual Douglas-fir seedlings, with and without competing vegetation, to study 2-year changes in soil nitrogen, carbon, water, and temperature. Using the same seedling-centered study, we expand on the results of Slesak et al. (2010) by identifying how the treatments influenced growth of Douglas-fir seedlings through analyses that increased the sample size, extended the period of assessment to 4 years, and interpreted responses of additional variables (i.e., vegetation abundance, seedling growth, seedling water potential, and relativized components of seedling foliar nitrogen). We hypothesized that logging debris would influence Douglas-fir growth primarily through its effects on soil water availability via three potential mechanisms: (1) changes in water consumption via altered abundance of competitor species, (2) reduced evaporation via mulching effects, and (3) reduced precipitation inputs via interception losses. We also hypothesized that (4) logging debris would influence soil nitrogen availability to Douglas-fir as indicated by changes in foliar nitrogen concentration and content.

2. Methods

2.1. Study sites

The research was conducted on two sites affiliated with the North American Long-Term Soil Productivity (LTSP) study (Harrington and Schoenholtz, 2010; Powers et al., 2005) that differed in availability of soil water and nutrients (Table 1). The Matlock, Washington (USA) site has a very gravelly loamy sand of the Grove series (Dystric Xerorthent) formed in glacial outwash and averaging 1.5 m in depth (USDA NRCS, 2012). The Molalla, Oregon (USA) site has a cobbly loam of the Kinney soil series (Andic Dystrudept) averaging 1.4 m in depth (USDA NRCS, 2012). The Matlock and Molalla sites have almost three-fold differences in soil water holding capacities, as well as contrasting pool sizes for soil nitrogen and other nutrients (Devine et al., 2011).

The regional climate is characterized as Mediterranean with cool, wet winters and warm, dry summers having a prolonged period of drought (Franklin and Dyrness, 1973). Potential natural vegetation includes the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)/salal (*Gaultheria shallon* Pursh) plant association at Matlock (Henderson et al., 1989) and the western hemlock/Oregon-grape (*Mahonia nervosa* (Pursh) Nutt.)/swordfern (*Polystichum munitum* (Kaulf.) Presl) and western hemlock/Oregon grape-salal plant associations at Molalla (Halverson et al., 1986).

2.2. Experimental design and treatments

At each site, 48 Douglas-fir seedlings were selected for study within buffer areas separating plots of the existing LTSP study design. Details regarding methods of forest harvesting, conifer regeneration, and vegetation control were described in Harrington and Schoenholtz (2010). When this individual-seedling study was initiated (March 2005), the Douglas-fir seedlings had completed their first growing season after being planted at a 3 × 3-m spacing. The experimental design at each site was a randomized complete block, split plot with two levels of competing vegetation (presence and absence) as main plots and three levels of logging debris (0%, 40%, and 80% cover) as split plots. The experimental unit was the 2 × 2-m growing space of an individual Douglas-fir. At each site eight seedlings were assigned to each of the six treatments.

Debris cover treatments were implemented by centering a 2 × 2-m PVC frame on a given seedling with frame sides parallel to the rows of adjacent planted seedlings and then covering the ground surface with logging debris 5.0–12.5 cm in diameter to create the assigned projected cover of debris (nearest 10%) as determined by visual estimation. Existing woody logging debris, free of needles and adjacent to the experimental plots at each site, was cut to lengths ⩽3 m and applied randomly around assigned seedlings such that total depth did not exceed 30 cm to avoid shading of seedlings. The size distribution of debris was kept approximately the same for each level of debris cover. For seedlings assigned 0% debris cover, all logging debris was removed from the 2 × 2-m growing space. To avoid soil disturbance, no attempt was made to remove legacy wood (i.e., surficial old-growth logs at various stages of decomposition present within the growing space of approximately 5% of the assigned seedlings).

Annual herbicide treatments were applied to the main plots of the existing LTSP study assigned to receive vegetation control (Harrington and Schoenholtz, 2010). To accomplish complete removal of vegetation within the growing space of designated seedlings, a supplemental non-soil-active herbicide treatment was applied annually with a backpack sprayer in May of 2005–2008 to the 2 × 2-m area. The treatment consisted of a hooded nozzle application of glyphosate (Accord® Concentrate[3]), triclopyr ester (Garlon®4), and non-ionic surfactant (X-77®) in water at product concentrations of 1%, 0.5%, and 0.5%, respectively. Herbicide expo-

[3] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the US Department of Agriculture of any product or service.