Forest Ecology and Management 417 (2018) 31–39

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Logging debris and herbicide treatments improve growing conditions for planted Douglas-fir on a droughty forest site invaded by Scotch broom

Timothy B. Harrington[a,*], David H. Peter[a], Robert A. Slesak[b]

[a] Pacific Northwest Research Station, USDA Forest Service, 3625 93rd Avenue Southwest, Olympia, WA 98512-1101, USA
[b] Department of Forest Resources, University of Minnesota, St. Paul, MN 55108, USA

ARTICLE INFO

Keywords:
Coarse woody debris
Microclimate
Competition threshold
Douglas-fir
Scotch broom

ABSTRACT

Logging debris has the potential to benefit forest regeneration by increasing resource availability, modifying microclimate, and altering plant community structure. To understand potential mechanisms driving these benefits, we initiated research at a forested site on the Olympic Peninsula, WA that contained the invasive, nonnative competitor, Scotch broom (*Cytisus scoparius*). Immediately after harvesting the stand of mature coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) in late 2011, two levels of logging debris retention were created on replicated plots: 18.9 and 9.0 Mg ha^{-1}, with debris depths averaging 32 and 17 cm, respectively. Within each plot, three herbicide treatments (aminopyralid (A), triclopyr ester (T), and A + T) and a non-sprayed control were applied to split plots in August 2012. Douglas-fir seedlings were planted in early 2013, and microclimate and seedling performance were monitored through 2016. During the growing seasons of 2012–2014, soil water content was greater and soil temperature was lower under heavy debris than under light debris. Survival of planted Douglas-fir seedlings declined an average of 45 and 11 percentage points after intense summer droughts in 2015 and 2016, respectively, but it averaged 7–10 percentage points greater in heavy debris than in light debris during this period. Douglas-fir stem diameter growth was consistently greater in heavy debris than in light debris, with the exception of treatment A + T where diameter did not differ between debris treatments. A reciprocal regression model (R^2 = 0.55) predicted that total stem volume of Douglas-fir increased from 19 to 84 dm^3 ha^{-1} as Scotch broom cover decreased from 20% to 0% as a result of the logging debris and herbicide treatments. There were limited treatment effects on mineral soil chemical and physical properties, but forest floor mass and nutrient content were increased in the heavy debris treatment. Five years after forest harvesting (2016), logging debris mass in heavy debris differed little from that in light debris at study initiation, indicating a substantial reduction in fuels and the potential for severe wildfire. Results suggest that, on gravelly soils and possibly other droughty forest ecosystems in the Pacific Northwest, heavy debris will benefit planted Douglas-fir by improving growing conditions and by limiting abundance of nonnative competitors, such as Scotch broom.

1. Introduction

During forest harvesting and site preparation, machine traffic, logging debris treatments, and herbicide treatments are important vectors of disturbance that redistribute growth-limiting site resources (i.e., soil water and nutrients) among crop and non-crop species (Fig. 1). These vectors can be managed to limit abundance and manipulate species composition of competing vegetation. If vegetation abundance is managed at low levels (e.g., < 20% cover; Dinger and Rose, 2009), or if it is less competitive because of the species composition, additional resources can become available to the crop species (Davis et al., 1998). Site factors including soil texture and annual precipitation regulate how these resources are made available to existing vegetation and whether available resources are sufficient to maintain survival and increase growth of planted tree seedlings. Thus, vegetation management treatments are particularly critical on forest sites in the Pacific Northwest that are encumbered by annual summer droughts, as well as those with coarse-textured soils, because soil water is often the primary resource limiting early growth of planted conifers (Newton and Preest, 1988).

Controlling competing vegetation with herbicides or other treatments during forest regeneration provides a direct and rapid method for channeling resources to planted tree seedlings (Walstad and Kuch, 1987). Because of the assumed cost-effectiveness of vegetation control, treatments are often prescribed routinely and independent of the

Abbreviation: A + T, combination of aminopyralid and triclopyr herbicides in a single treatment

* Corresponding author.
E-mail addresses: tharrington@fs.fed.us (T.B. Harrington), dpeter@fs.fed.us (D.H. Peter), raslesak@umn.edu (R.A. Slesak).

https://doi.org/10.1016/j.foreco.2018.02.042
Received 4 December 2017; Received in revised form 21 February 2018; Accepted 26 February 2018
0378-1127/ Published by Elsevier B.V.

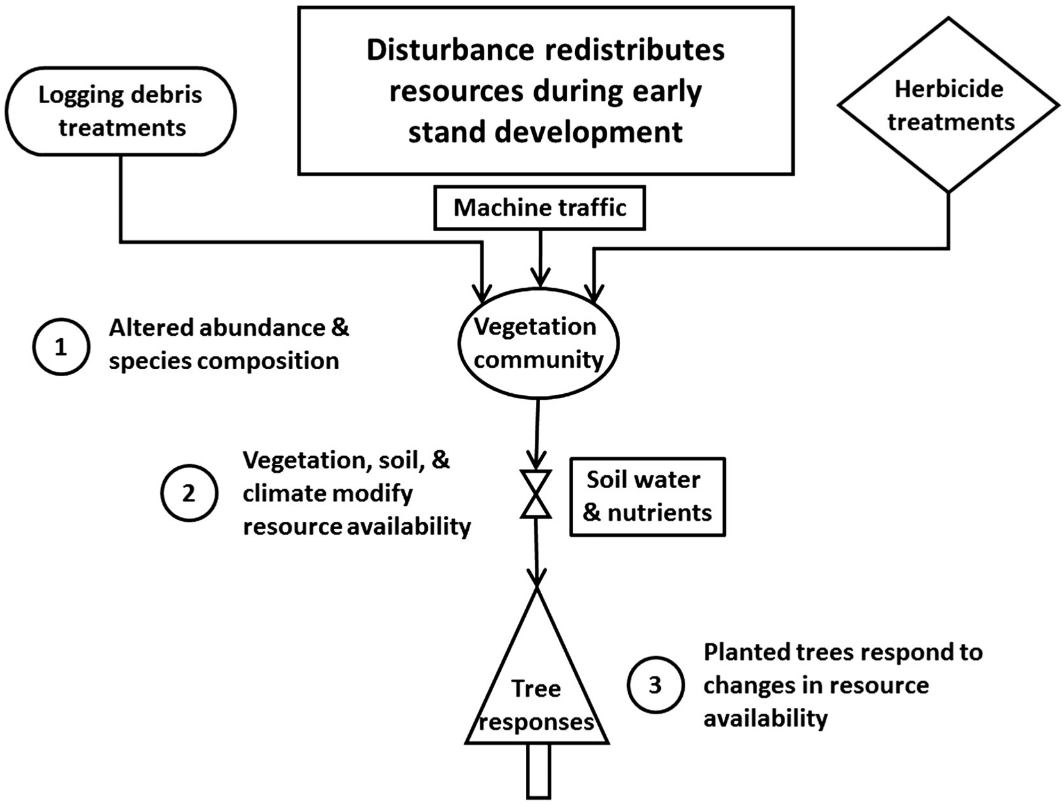

Fig. 1. Conceptual model of how disturbance redistributes growth-limiting resources to vegetation during early stand development. (1) Logging debris treatments, machine traffic, and herbicide treatments are common vectors of disturbance during forest harvesting and site preparation that can be managed to limit abundance and manipulate species composition of competing vegetation. (2) Site factors of soil texture and annual precipitation regulate how additional resources, especially soil water, are made available to planted conifers, (3) potentially enabling them to maintain their survival and increase their growth.

methods in which the previous stand was harvested. Yet the method and intensity of forest harvesting can have important consequences on subsequent development of the early seral plant community, depending on intensity and spatial extent of soil disturbance and the amount and configuration of residual logging debris. For example, removal of logging debris, and the soil disturbance associated with this activity, can stimulate invasions of nonnative plants, such as Scotch broom (*Cytisus scoparius* (L.) Link), oxeye daisy (*Leucanthemum vulgare* Lam.), and sweet vernalgrass (*Anthoxanthum odoratum* L.) (Harrington and Schoenholtz, 2010; Peter and Harrington, 2012; Peter and Harrington, 2018). These species, found throughout western Washington and Oregon, are both highly competitive and difficult to control because of their prolific regeneration. Therefore, the cost of effective vegetation control will likely depend on specific harvesting methods and their influence on the recalcitrance of the post-harvest plant community. An integrated approach is needed that jointly considers the objectives of forest harvesting and forest regeneration in a similar context to accomplish both activities without exacerbating costs of one activity over those of the other.

Retention of logging debris in a dispersed pattern during harvesting has the potential to limit harvesting and site preparation costs, reduce vegetation control costs, and improve forest productivity. For example, cut-to-length harvesting systems de-limb and process the logs at the stump, leaving behind the non-merchantable debris. Compared to conventional whole-tree harvesting via shovel logging (10–15 Mg ha^{-1} of logging debris mass), retention of logging debris by stem-only harvesting (20–25 Mg ha^{-1}) has been shown to decrease cover of herbaceous species and Scotch broom, increase soil water content, and increase accretion of soil carbon and nitrogen in western Washington and Oregon (Roberts et al., 2005; Harrington and Schoenholtz, 2010; Slesak et al., 2011; Harrington et al., 2013). These short-term changes in plant community structure and soil resource availability following logging debris retention have been associated with longer-term increases in forest productivity, including greater volume growth of coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) during the first 10–15 years after planting (Ares et al., 2007; Holub et al., 2013; Slesak et al., 2016; S. Holub, personal communication). In addition, logging debris tends to be a more significant source of organic matter for coarse textured soils (Wan et al., 2018) and wetter and cooler climates (Thiffault et al., 2011) than for the converse conditions. However, there are some potential real or perceived drawbacks to logging debris retention. In the North American Long-Term Soil Productivity (LTSP) study, retention of logging debris was associated with small decreases in tree survival attributable to increased difficulty of planting (Fleming et al., 2006). Retention of logging debris could also be less desirable to forest managers if it increases the cost of vegetation control treatments, provides habitat for small mammals that cause damage to planted tree seedlings (Sullivan and Sullivan, 2014), or increases risk of wildfire for a period after harvesting (Stephens et al., 2012). Quantifying the above benefits and drawbacks would be useful to determine if and when logging debris retention is an effective practice to decrease management costs and improve overall stand productivity.

To expand the knowledge base of our conceptual model (Fig. 1), we initiated research in 2011 to compare efficacy of logging debris and herbicide treatments for controlling competing vegetation and to determine if synergisms exist to increase regeneration performance when these treatments are combined. We selected a study site likely to be invaded by Scotch broom soon after forest harvesting to create a suitable test environment for our experimental treatments. The research had the following objectives: (1) quantify treatment effects on soil water, soil chemistry, and soil temperature, (2) compare performance of planted Douglas-fir among treatments, (3) describe competitive relationships between Douglas-fir performance and abundance of the primary competitor species, and (4) assess changes in plant community