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Influence of stand thinning and repeated fertilization on plant community abundance and diversity in young lodgepole pine stands: 15-year results

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ABSTRACT

Enhanced forest productivity may provide the supply of wood fiber to keep pace with increasing global demand for wood products and the growing constraints on the harvestable land base imposed by measures to conserve biodiversity. Stand thinning and fertilization are silvicultural practices that increase forest productivity in many situations. Intensive management has debatable impacts on plant species diversity with no consistent predictions from existing models and a general lack of long-term responses to treatments. This 15-year study was designed to test four hypotheses (H), that (H_1) the application of a range of pre-commercial thinning (PCT) intensities will increase plant abundance in herb and shrub layers, (H_2) fertilization will increase abundance of all plant layers (herbs, shrubs, trees, and combined total), (H_3) PCT and fertilization treatments will decrease species and structural diversity of all plant layers, and (H_4) enhanced abundance of vegetation will result in a decline in total species diversity and structural diversity. Study areas were located in lodgepole pine (*Pinus contorta* var. *latifolia*) stands near Summerland, Kelowna, and Williams Lake in south-central British Columbia, Canada. Each study area had nine treatments: four pairs of stands thinned to densities of ~250 (very low), ~500 (low), ~1000 (medium), and ~2000 (high) stems/ha with one stand of each pair fertilized five times at 2-year intervals, and an unthinned stand.

Mean abundance (crown volume index) of herbs and shrubs were unaffected by stand density, and hence H_1 was not supported. Mean abundance of herbs and mean total abundance of the plant community were significantly higher in fertilized than unfertilized stands, and hence H_2 was only partially supported. Mean species richness of the herb, shrub, tree, and combined total layers were unaffected by density or fertilization. Mean species diversity of these layers were also unaffected by density, but fertilization reduced herb and shrub diversity, at least temporarily. Neither tree nor total species diversity were affected by fertilization. Mean structural diversity of herb and shrub layers were unaffected by stand density. Mean structural diversity of the tree layer was significantly greater in the most heavily thinned stands (250 stems/ha) than in the unthinned and lightly thinned stands (2000 stems/ha), and similar to that of the 500 and 1000 stems/ha stands. Mean structural diversity of the total plant community was significantly enhanced by fertilization. Thus, H_3 was partially supported for the fertilization-induced reduction in herb and shrub diversity, but structural diversity was unaffected or enhanced. A trend of decreasing total species diversity with increasing productivity supported H_4. The changing relationship between productivity and structural diversity indicated that structure was more related to succession than productivity, and therefore our results did not support H_4.

PCT and fertilization clearly influence plant community abundance, diversity, and structure. This is one of the first studies to document the magnitude and longevity of these changes with a replicated, large-scale, and long-term study. PCT and repeated fertilization of young lodgepole pine stands appear to be management strategies compatible with wood production and biodiversity conservation.

1. Introduction

Given the increasing global demand for wood products (Raunikar et al., 2010), concurrent with the increasing constraints on the harvestable land base imposed by measures to conserve biodiversity (Hunter and Schmiegelow, 2011; Leroux and Kerr, 2013),

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enhanced forest productivity is required if the supply of wood fiber is to keep pace with demand. This is particularly true for the forest industry throughout boreal and sub-boreal forests of North America, where management is predominantly extensive rather than intensive (Lautenschlager, 2000; Park and Wilson, 2007). The enhanced productivity possible with intensive management has been clearly demonstrated for pine (*Pinus* spp.) plantations throughout the southern United States (US), where tree improvement programs and treatments of thinning (pre-commercial and commercial) and fertilization have resulted in tree growth rates that have more than doubled and rotation lengths cut by more than 50% (Fox et al., 2007). Similar management strategies have also significantly increased silvicultural yields of pine and spruce (*Picea* spp.) stands throughout the boreal forests of Scandinavia (Nohrstedt, 2001; Saarsalmi and Mälkönen, 2001). Intensive management of second-growth forests in northern ecosystems of North America may provide similar benefits as observed in the southern US and Scandinavia, and therefore should likely be promoted to meet the demand for wood and biomass production (Brooks, 1997; Sutton, 1999). While the need for enhanced forest productivity is clear, concerns regarding potential negative impacts of intensive management on biodiversity question the wisdom and sustainability of such management (McDonald and Lane, 2004).

Forest management, because of its historic narrow focus on enhanced productivity of one or two species of crop trees, is often associated with a decrease in biodiversity; particularly plant diversity (Gilliam and Roberts, 1995). However, there is variable support for this generalization as studies have reported a range of results, from increased (Thomas et al., 1999; Battles et al., 2001; Thysell and Carey, 2001; Lindgren et al., 2006) to decreased levels of plant diversity in managed compared with unmanaged forests (Hansen et al., 1991; Elliot et al., 1997). A potential unifying mechanism that could accommodate this range of observations is the intermediate disturbance hypothesis, which suggests that moderate disturbance prevents a few plant species from dominating resources, but that severe disturbance creates a stressful environment that few species can tolerate (Battles et al., 2001). Because forest management practices (e.g., thinning) represent a type of disturbance, it follows that intensive management may decrease plant species diversity (Wang and Chen, 2010), raising concerns about the suitability of intensive management and its impact on biodiversity.

Although the form of the productivity-diversity relationship (PDR) has been debated for decades (e.g., see exchange between Adler et al. (2011), Fridley et al. (2012), Pan et al. (2012) and Grace et al. (2012)), a predominant view is that of a hump-shaped model (Waide et al., 1999; Mittelbach et al., 2001). The suggested mechanisms are that, at low productivity, increased productivity leads to increased diversity as enhanced resource availability facilitates larger populations with low rates of extirpation. At high productivity, further increases to productivity leads to decreased diversity as the heterogeneity of limiting resources decreases and competitive exclusion increases. Recently, however, studies are beginning to challenge the hump-shaped PDR, suggesting instead a positive linear relationship (Gillman and Wright, 2006; Bai et al., 2007) or no general relationship at all (Adler et al., 2011; Grace et al., 2012). The continued debate surrounding the PDR form clearly indicates that accurate predictions regarding diversity should not be expected from existing models and that decisions regarding management should be based on real data gained from context-specific monitoring.

This study was designed to address the concern over potential negative impacts of intensive management on biodiversity by monitoring long-term plant community response to incremental silviculture treatments applied to young stands of lodgepole pine (*Pinus contorta* var. *latifolia*). Lodgepole pine is the major coniferous tree species in inland areas of the Pacific Northwest where it occupies ~20 million ha in Canada (mostly in British Columbia and Alberta) and about six million ha in the western US (Cole and Koch, 1996). Lodgepole pine is a pioneer species that is perpetuated through repeated fire disturbance, and stands often occupy sites of low-N status (Brockley et al., 1992). In addition, this species often regenerates at very high densities, resulting in conditions with repressed growth rates (Blevins et al., 2005). Given the overcrowded and low nutrient conditions of young lodgepole pine stands, silvicultural treatments of pre-commercial thinning (PCT; Johnstone, 1985; Cole and Koch, 1996) and fertilization (Weetman, 1988; Brockley, 1996) have significant potential to increase crop tree productivity (Lindgren et al., 2007; Lindgren and Sullivan, in press), and therefore provide a useful model for studying the effects of intensive management on plant communities.

In this paper, we examine the impacts of PCT and repeated fertilization on plant community (herbs, shrubs, trees, and combined total) abundance, species diversity, and structural diversity as these attributes provide both direct and indirect measures of stand-level biodiversity. Not only is the plant community itself a major component of biodiversity, but it also provides much of the physical attributes of habitat types for all species of wildlife (e.g., forage, hunting grounds, cover, nesting sites) (Carey et al., 1999; Sullivan et al., 2001). It also modifies the environmental conditions of these habitats, both above (air temperature, wind speed, humidity, and shading) and below ground (soil temperature, moisture, and nutrient content) (Berch et al., 2006). An improved understanding of how plant community attributes respond to PCT and fertilization would enhance our ability to determine the suitability of these silvicultural treatments for sustainably managing our forests.

This study was designed to test four hypotheses (H), phrased as predictions, that (H_1) the application of a range of PCT intensities will increase plant abundance in herb and shrub layers, (H_2) fertilization will increase abundance of all plant layers (herbs, shrubs, trees, and combined total), (H_3) PCT and fertilization treatments will decrease species and structural diversity of all plant layers, and (H_4) enhanced abundance of vegetation will result in a decline in total species diversity.

2. Methods

2.1. Study areas

Three study areas were chosen on the basis of having candidate stands of young (12–14 year old) lodgepole pine that had relatively uniform tree cover, comparable diameter, height, and density of trees prior to stand treatments. Location, proximity (boundaries), and size of candidate stands were determined by a balance between adequate interspersion of experimental units (Hurlbert, 1984) and the logistics and access for conducting the operational-scale treatments of PCT and fertilization. In the southern interior of British Columbia, Canada, the Summerland (49°40′N; 119°53′W) and Kelowna (50°04′N; 119°34′W), study areas are located in the dry and mild subzone of the Montane Spruce biogeoclimatic zone (MS_{dm}), whereas the Cariboo (52°29′N; 121°45′W) study area is in the dry and warm subzone of the Sub-Boreal Spruce biogeoclimatic zone (SBS_{dw}; Meidinger and Pojar, 1991). Stand areas (ha) ranged from 4.4 to 11.3 (Summerland), 9.5 to 12.6 (Kelowna), and 1.5 to 4.5 (Cariboo).

Prominent herb species throughout all three study areas included yarrow (*Achillea millefolium*), rosy pussytoes (*Antennaria microphylla*), field pussytoes (*A. neglecta*), racemose pussytoes (*A. racemosa*), heart-leaved arnica (*Arnica cordifolia*), fireweed (*Epilobium angustifolium*), bunchberry (*Cornus canadensis*), wild strawberry