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Acceleration of old-growth structural attributes in lodgepole pine forest: Tree growth and stand structure 25 years after thinning

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ABSTRACT

Acceleration of forest succession to develop late-seral structural characteristics in younger stands may be achieved by silvicultural practices such as pre-commercial thinning (PCT). Young second-growth stands of lodgepole pine (*Pinus contorta*) range across several million ha of the inland Pacific Northwest of North America and respond positively to various stand treatments. Objectives of this project were that large-scale stand thinning to a wide range of densities, at a 25-year period after PCT, would enhance: (1) productivity and structural features (diameter and height growth, and crown volume and dimensions of crop trees; (2) merchantable volume of crop trees; and (3) development of old-growth structural attributes. Three stands thinned to densities of ~500 (low), ~1000 (medium), and ~2000 (high) stems/ha at age 17 years, with an unthinned young pine and old-growth pine stand for comparison, were located near Penticton in south-central British Columbia.

Lodgepole pine grew faster in mean diameter (cm) in the low- (13.89) than either of the medium- (10.2) or high-density (9.2) stands, but mean height growth increment (8.8–9.7 m) was similar over the 25-year period since PCT. Mean diameter was 2.2 times greater in the low-density stand than unthinned stand. The medium- and high-density stands also tended to have large diameters (1.7–1.9 times that of the unthinned stand) and crowns, but still with mean heights 5–6 m less than trees in the pine component of the old-growth stand. Mean merchantable stand volume (m^3/ha) was 1.7–1.9 times higher in the medium- (231) and high-density (257) stands than low-density (137) stand, and comparable to the old-growth pine (225). Mean crown volume (m^3) of crop trees was substantially greater in the low- (88) than in the medium- (27) and high-density (31), unthinned (4), or old-growth stands (4 pine only). Mean structural diversity of five layers of coniferous trees was highest in the low- and medium-density stands, with declining diversity from the high-density to unthinned to old-growth stands. In terms of old-growth structural attributes, large dominant trees with substantial crowns, multi-layered canopies of conifers, some canopy gaps, and understory patchiness of herbs and shrubs appeared in the heavily thinned (⩽1000 stems/ha) stands at 25 years post-thinning. These stands were 42 years old at this re-measurement, and hence were not considered “old-growth” but the heavily thinned stands seemed to have some old-growth structural attributes. Silvicultural trade-off of stand volume gain vs. old-growth attributes may be necessary for low-density stands.

1. Introduction

Coniferous forests are a dominant feature of temperate and boreal ecological zones in North America and Eurasia. Relatively undisturbed conifer forests were recently widespread but now are among some of the most intensively altered habitats (Norse, 1990; Rosencranz and Scott, 1992; Lindenmayer and Franklin, 2002). For example, in the Pacific Northwest (PNW) of North America only 14% in Washington and Oregon, U.S.A. and less than 30% in coastal British Columbia, Canada, of the original old-growth forest remains (Strittholt et al., 2006; Bunnell and Dunsworth, 2009). Unmanaged second-growth forests tend to have rotation ages of less than 100 years and may not necessarily develop attributes of mature or old-growth conifer forests. As harvesting of old-growth forests continues, there is a crucial need for the development of old-forest structural attributes in second-growth forests. Acceleration of forest succession to develop late-seral structural characteristics in younger stands has been discussed by several authors (McComb et al., 1993; Hayes et al., 1997;

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Bauhus et al., 2009) and at least partly demonstrated by others via the silvicultural practices of pre-commercial thinning (PCT) and fertilization (Schmidt and Seidel, 1988; Sullivan et al., 2001, 2006; Homyack et al., 2004; Lindgren et al., 2007; Lindgren and Sullivan, 2013a). Innovative stand thinning operations can include a range of stand densities or variable-density thinning (Carey et al., 1999; Bauhus et al., 2009).

Old-growth structural attributes are well defined and include: (1) large dominant trees with substantial crowns, (2) multi-layered canopies of coniferous trees, (3) snags, (4) an abundance of coarse woody debris (CWD), (5) canopy gaps, and (6) understory patchiness with some herb and shrub development (Franklin and Spies, 1991; Kneeshaw and Burton, 1998; Wells et al., 1998; Franklin et al., 2002). In landscapes dominated by young regenerating stands that have developed after clearcut harvesting and wildfire, often just attributes 1, 2, 5, and 6 can be achieved by PCT and commercial thinning (CT). However, it is likely that some dead standing trees (snags) and dead fallen trees (CWD on forest floor) may, in fact, develop over time, particularly decades after thinning. These silvicultural interventions are designed to develop complex stand structure, both vertically and horizontally, and late-seral structural features over decades, rather than centuries (Carey and Wilson, 2001; Sullivan et al., 2013). A major assumption of this approach is that the occurrence of many wildlife species in late-successional forests is linked to specific structural (ecological) characteristics than to just age of the forest (Gibbons and Lindenmayer, 1996; Lonsdale et al., 2008).

Young second-growth stands of lodgepole pine (*Pinus contorta*) range across a vast area (several million ha) of the inland PNW of North America (Koch, 1996a). These pine stands and those of other species (e.g., Douglas-fir, (*Pseudotsuga menziesii*)) are structurally simple, usually with a single canopy layer, few tree species, sparse understory vegetation, and often few, if any, standing or fallen dead trees (Hayes et al., 1997; Wilson and Puettmann, 2007). Lodgepole pine responds positively to various silvicultural practices designed to enhance growth rates of crop trees and structural diversity of stands (Johnstone, 1985; Koch, 1996a,b; Cochran and Dahms, 1998; Sullivan et al., 2001, 2006; Lindgren et al., 2007). It is the responses of crop trees to PCT, in terms of diameter and height growth, as well as crown architecture that create the desirable structural attributes. As noted by Schmidt and Seidel (1988), crowns are the production factory of a tree, and hence they reflect the degree of vigor and growth in the stand, but not necessarily stand growth efficiency (Smith and Long, 1989).

An array of wood products and structural diversity could be produced from a range of thinning densities, particularly lodgepole pine and Douglas-fir (Koch, 1996b; Barbour et al., 1997; Lippke and Fretwell, 1997; Sullivan et al., 2001; Busing and Garman, 2002). Heavily thinned stands may have reduced total wood volume, but could produce large-diameter timber and quality products, whereas higher volumes and dimensional wood products would be produced from higher density stands (Jozsa and Middleton, 1994; Barbour et al., 1997). The actual merchantable volume at harvest from a range of stand densities is a key question driving silvicultural practices such as PCT in young second-growth stands. Thus, at what point in time, or successional development, do younger thinned stands provide sufficient merchantable volume *and* "structural complexity" of late seral forests?

Sullivan et al. (2013) discussed the three limitations of studies that were essential to our understanding of how wildlife habitats develop in managed forests: (1) real-world scale of treatments, (2) several decades of time to monitor responses, and (3) the testing of extreme treatments. Few, if any, studies have investigated the growth responses of crop trees and coniferous stand structure to PCT in young lodgepole pine forests at a spatial scale relevant to wildlife and over a relatively long-term (25 years since thinning) period. In BC, young lodgepole pine stands have historically been thinned to within a very narrow range of stand densities, typically 1600–2000 stems/ha, with very few stands <1000 stems/ha (Johnstone, 1985). This study was designed to test the hypotheses (H) that large-scale stand thinning to a wide range of densities, at a 25-year period after PCT, would enhance (H_1) productivity and structural features (diameter and height growth; tree crown volume and dimensions) of crop trees (those dominant trees destined for harvest); (H_2) merchantable volume of crop trees; and (H_3) development of old-growth structural attributes. This paper is one of several periodic publications reporting on long-term responses of tree growth and stand structure to these thinning treatments (Sullivan et al., 1996, 2001, 2006).

2. Materials and methods

2.1. Study area and experimental design

There were originally five lodgepole pine stands located at each of three replicate study areas in south-central British Columbia (BC), Canada: Penticton Creek, Kamloops, and Prince George. Unfortunately, the Kamloops and Prince George study areas were devastated by the mountain pine beetle (*Dendroctonus ponderosae*) in 2005. The Penticton area was unaffected and forms the basis of this current investigation. The Penticton Creek study area was located 15 km northeast of Penticton (49°34′N; 119°27′W). All stands were located in the Interior Douglas-fir (IDF_{dk}) biogeoclimatic zone (Meidinger and Pojar, 1991). Elevation of stands ranged from 1340 to 1500 m. Topography in the area is hilly with sandy loam soil, southeast aspect, and an average slope of 10%. This area (several thousand ha) was burned by wildfire in 1970, salvage logged in 1971, and planted with lodgepole pine in 1972. Density of pine from natural regeneration ranged from 18,500 to 30,000 stems/ha. Dominant coniferous species in these stands included lodgepole pine with a minor component of Douglas-fir, interior spruce (*Picea engelmannii x P. glauca*), and western larch (*Larix occidentalis*). Dominant understory vegetation included willow (*Salix* spp.), Sitka alder (*Alnus sinuata*), grouseberry (*Vaccinium scoparium*), fireweed (*Epilobium angustifolium*), pine grass (*Calamogrostis rubescens*), and Arctic lupine (*Lupinus arcticus*).

The area was selected on the basis of having several thousand hectares of young lodgepole pine forest. Stands within these tracts of young forest had relatively uniform tree cover and comparable diameter, height, and density of lodgepole pine trees prior to PCT. In 1988, there were four 17-year-old second-growth lodgepole pine stands: stand A was low density, target 500 stems/ha; stand B was medium density, target 1000 stems/ha; stand C was high density, target 2000 stands/ha; Stand D was unthinned at 5000 stems/ha. In 2013, density in stems/ha of these stands was 550 (A), 1190 (B), 1670 (C), 5070 (D), and stand E was old growth with 790 stems/ha of lodgepole pine and 1150 stems/ha of all tree species (Fig. 1). The second-growth stands had very few remnant trees and snags remaining from previous stands. The old-growth stand was dominated by lodgepole pine with a relative abundance of 64% followed by subalpine fir (28%), and spruce (8%) for overstory trees. Tree ages were 120–140 years for lodgepole pine, 143 years for subalpine fir, and 167 years for spruce. Mean heights of overstory trees ranged from 21.0 m to 24.2 m.

Operational thinning with chainsaws was conducted after the growing season in fall 1988. Trees in the low-density stand were pruned to a 2.8-m lift (above ground level) in October 1992. This range of stand densities and scale of treatment, after PCT, was considered large enough to allow detection of 25-year changes in productivity of crop trees and coniferous stand structure. The relatively broad range of densities was considered sufficient to