Forest Ecology and Management 346 (2015) 65–80

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Ten-year results of seedling growth on calcareous soils in the interior of British Columbia, Canada

Charlotte E. Norris [a], Doug G. Maynard [a,*], Karen E. Hogg [a], Ross Benton [a], Brian D. Titus [a], Mike P. Curran [b,1]

[a] Natural Resources Canada, Canadian Forest Service, 506 West Burnside Road, Victoria, British Columbia V8Z 1M5 Canada
[b] British Columbia Forest Service, Nelson, British Columbia V1L 4C6 Canada

ARTICLE INFO

Article history:
Received 2 December 2014
Received in revised form 24 February 2015
Accepted 25 February 2015
Available online 16 March 2015

Keywords:
Compaction
Organic matter removal
Calcareous soil
Douglas-fir
Lodgepole pine

ABSTRACT

Impaired soil quality due to compaction and organic matter removal following forest harvesting and mechanical site preparation is of concern, especially on calcareous soils which are believed to be particularly sensitive to disturbance. This study set out to determine the effects of organic matter removal and compaction on soil quality and seedling productivity on calcareous soils of a localized disturbance landscape (2.25 m^2). Here we report ten year post-establishment results of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) seedlings across four sites in southern British Columbia, Canada with eight treatment levels incorporating different quantities of organic matter removal and soil compaction. Pine seedlings suffered high rates of mortality when planted in deposits across all sites while Douglas-fir seedling mortality was high when planted in compacted undisturbed treatments at two sites and in deposits on the remaining sites. Douglas-fir volume was greatest on the deposit treatment regardless of site but grew significantly better on the non-calcareous site. Pine seedlings outgrew Douglas-fir seedlings and, after ten years, seedlings were largest on a mildly calcareous site. Seedling growth was generally found to be negatively affected by calcareous soils and compaction; however, the specificity of results, in terms of species and site interaction and changing response as the seedlings aged, reinforced the importance of treatment effects on soil quality and forest productivity across the entire length of a stand rotation.

1. Introduction

Changing forest practises due to increased mechanization through the mid-20th century in North America led to concerns of loss of subsequent forest productivity from the effects of compaction and organic matter removal on soil quality. A review by Greacen and Sands (1980) identified the mechanics, causes and consequences of compaction, and its detrimental effect on forest soils. A review of practices and research from the 1970s and 1980s on the effects of forest harvesting and mechanical site preparation in British Columbia (BC), Canada demonstrated overall forest degradation (Utzig and Walmsley, 1988). Reports of decreases in soil quality due to increased compaction (Smith and Wass, 1976) and decreases in nutrient contents from the loss of organic matter (Smith and Wass, 1985) were also noted. However, in the application of forest harvesting and mechanical site preparation, these treatments were known to be applied heterogeneously across the landscape (Smith and Wass, 1976). By the late 1980s forest managers recognized that organic matter loss and soil compaction were harmful to soil quality but few experiments were found to systematically address their effects at the site and landscape level in BC or elsewhere in North America.

Organic matter loss and compaction are negative effects on the respective properties of soil organic matter content and soil porosity; the two properties believed to be critical to soil quality (Powers, 2006; Schoenholtz et al., 2000) and in 1989 the Long-Term Soil Productivity (LTSP) trials were initiated to address this hypothesis across a forest stand rotation in a variety of ecosystems in North America (Powers, 2006). The term soil quality is an anthropocentric statement which summarizes the abiotic and biotic conditions of the soil as they relate to a desired outcome e.g., forest productivity or biodiversity. Soil porosity is critical to soil quality as it is a key determinant of soil gas and water exchange and when a force is applied to the soil the pore structure decreases and the bulk density increases i.e., compaction (Kozlowski, 1999). Soil quality for ideal

* Corresponding author. Tel.: +1 250 298 2393 (D.G. Maynard).
E-mail addresses: cenorris@telus.net (C.E. Norris), Doug.Maynard@NRCan-RN-Can.gc.ca (D.G. Maynard).
1 Retired.

http://dx.doi.org/10.1016/j.foreco.2015.02.036
0378-1127/

growth conditions includes a variety of soil pore sizes as larger pores readily transmit water through the soil and medium sized pores provide the available water for plant growth. Loss of soil porosity by soil compaction is therefore generally referred to as unfavourable for soil quality and forest productivity.

The second property, soil organic matter, has an important role in nutrient cycling and is therefore believed to be critical in soil quality assessments (Schoenholtz et al., 2000). Effective nutrient cycling (e.g., nitrogen (N)) is the flux of nutrients within the forest floor and soil organic matter from decomposition by the soil microbial community and uptake by the growing plant roots to satisfy the plant's elemental requirements for growth. Tree growth may often be limited by the availability of organic matter nutrients e.g., N in the boreal (Maynard et al., 2014b) and interior BC forests (Brockley, 2006, 2007). Nutrient N-limitation in northern forest systems is often attributed to low rates of organic matter decomposition (e.g., Van Cleve et al., 1983) leading to greater quantities of soil organic matter and accumulation of forest floor. Decomposition rates are dependent on the quality of organic matter present, its quantity and stabilization within the soils and on climate (Schmidt et al., 2011). In contrast, other key nutrients for plant growth (e.g., potassium (K), calcium (Ca) and magnesium (Mg)) derive from the parent material and not the organic matter. Evaluating soil quality in terms of nutrient status may be done with a number of indicators including the assessment of: soil properties (e.g., total organic N), decomposition indices (e.g., litter-bag studies), and nutrient concentration in the soil available for plant use (e.g., ion exchange resin probes). Alternatively, soil quality may be assessed by the health of the trees as trees have been shown to be effectively monitored for nutrient deficiencies by elemental foliar analysis (van den Driessche, 1974).

Forest productivity, in addition to soil compaction and organic matter loss, is furthermore believed to be limited on calcareous parent material due to its low soil nutritional status (Kishchuk, 2000). In BC, forest soils in the southern Kootenay and Boundary regions were identified as potentially sensitive to disturbance due to their varying proportion of calcareous parent material (Hope, 2006; Maynard et al., 2014a). In the late 1990s work began to add research sites in southern BC to address the multiple concerns of parent material type, organic matter loss and compaction (Maynard et al., 2014a). The four sites of Mud Creek, Emily Creek, Kootenay East and Rover Creek characterized the region and, at each site, a mini-plot trial was established. Separate to the mini-plot trial but set up concurrently and adjacent at each site was a LTSP trial (Maynard et al., 2014a). The mini-plot trial was created to investigate the effects of organic matter removal and compaction on subsequent forest productivity on a localized landscape level by having plot sizes of 2.25 m^2. The objectives of this mini-plot trial were to: (1) determine the effect of site preparation (compaction and organic matter removal) on the productivity of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and pine (*Pinus contorta* var. *latifolia* Engelm.) seedlings; and (2) determine which soil quality indicators best explain seedling productivity. We hypothesize that: (1) organic matter removal and compaction will negatively affect seedling growth; (2) the sites with calcareous parent material close to the surface will negatively influence seedling growth.

2. Material and methods

2.1. Site descriptions

Four sites in the interior of British Columbia, Canada, were used to study the effects of compaction and organic matter removal on seedling establishment and growth of Douglas-fir, lodgepole pine and western white pine, hereafter called the mini-plot trial. The four sites were constructed as replicates across the landscape and established between 1999 and 2002. Detailed site information and establishment of Mud Creek (MC), Emily Creek (EC), Kootenay East (KE), and Rover Creek (RC) has been previously reported (Maynard et al., 2014a) therefore abbreviated site information follows. All four sites were established in conjunction with, and adjacent to, the LTSP sites in southeastern BC which were implemented by Ministry of Forests, Lands and Natural Resources Operations (formerly BC Forest Service) in collaboration with the larger LTSP program (Hope, 2006; Maynard et al., 2014a). Mud Creek, EC and KE sites are located within 13 km of Canal Flats (north of Cranbrook, BC) in the Interior Douglas-fir biogeoclimatic zone (Meidinger and Pojar, 1991) and all are on Orthic Eutric Brunisols (Soil Classification Working Group, 1998). Established in 1999, MC is located at an elevation of 1005 m, is of loam texture (21% clay) and has an average depth to carbonates of 22 cm. Emily Creek was established in 2000 at an elevation of 1180 m, on loam of 7% clay and with a depth to carbonates of 48 cm. Kootenay East was established in 2001 at an elevation of 1030 m, on silt loam (16% clay) and with a depth to carbonates of 24 cm. Rover Creek is located west of the other three sites, near Castlegar, BC, in the Interior Cedar-Hemlock biogeoclimatic zone, and was established in 2002 at an elevation of 625 m. The soil at RC is an Orthic Dystric Brunisol with a soil texture of loamy sand (5% clay) and has no evidence of carbonates within the top 100 cm.

2.2. Treatments

This study, the mini-plot trial, investigated the effect of differing levels of organic matter removal and varying levels of compaction on forest productivity after harvesting (Table 1). The first treatment type was undisturbed (no additional organic matter removal after harvesting) and uncompacted (UNNC). Second and third treatments were undisturbed but compacted with a light (UNLC) and heavy compaction (UNHC). Compaction was applied by an excavator with a vibrating plate where 5–10 s represented light compaction and 30 s for heavy compaction (Maynard et al., 2014a). Shallow gouge (SG) represented a mid-range disturbance with organic matter removal of the forest floor and mineral material to create a 1–20 cm depression and this disturbance was further treated with either light compaction (SGLC) or remained uncompacted (SGNC). Deep gouges (DG) were representative of more extreme mechanical site preparation conditions with holes ranging in depth from 16 to 51 cm and these either remained uncompacted (DGNC) or were treated with light compaction (DGLC). The deposit (DENC) was the final treatment and ranged in height from 9 to 69 cm. This treatment was created by the

Table 1
Treatment abbreviations and definitions for the mini-plot study.

Abbreviation	Disturbance	Compaction	Treatment
UNNC	Undisturbed	No compaction	Harvested and free of machine traffic
UNLC	Undisturbed	Light compaction	Harvested with 10 s vibration
UNHC	Undisturbed	Heavy compaction	Harvested with 30 s vibration
SGNC	Shallow gouge	No compaction	Harvested, gouge 1–20 cm
SGLC	Shallow gouge	Light compaction	Harvested, gouge 1–20 cm, 10 s vibration
DGNC	Deep gouge	No compaction	Harvested, gouge 16–51 cm
DGLC	Deep gouge	Light compaction	Harvested, gouge 16–51 cm, 10 s vibration
DENC	Deposit	No compaction	Harvested, deposit 9–69 cm