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Are shallow-soiled sites sensitive to increased biomass removals? An operational, paired-wise comparison approach

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ABSTRACT

Although commonly cited as being particularly sensitive to biomass/nutrient removals via full-tree harvesting (i.e., entire aboveground portion of the tree is removed and processed at roadside), there have been no long-term experimental trials installed or reported on to date that specifically target shallow-soiled (<20 cm) sites common in strongly glaciated boreal landscapes. This study reports on ten year results examining the effects (i.e., regeneration potential, tree growth, soil N availability, and foliar nutrition) of operational full-tree harvesting compared to operational stem only harvesting (i.e., individual stems delimbed and topped at the stump) on replicated, shallow-soiled sites with contrasting soil textures (i.e., sand versus loam) and dominant commercial tree species (i.e., jack pine – *Pinus banksiana* Lamb. versus black spruce – *Picea mariana* (Mill.) B.S.P.). The operational harvests at the seven study sites were all conducted during the fall prior to freeze up.

In terms of tree regeneration metrics, the harvest treatments only had a significant effect on free-to-grow (>1 m) crop tree (jack pine or black spruce) density. Despite the removal of cone-bearing branch material to roadside, the FT harvest treatment blocks had significantly higher densities compared to the SO blocks likely the result of increased mineral soil exposure, improved seedbed receptivity, and warmer soil surface temperatures during the growing season. Initially (5th year), jack pine height growth was better on the FT treatment blocks, but by year 10 this significant effect on total height was gone and the 5-year growth increment was better on the SO treatments. In contrast, black spruce height growth was better on the SO blocks in both year 5 and 10, although the 5-year increment was not significantly different between harvest treatments. Although soil N pools were higher in the SO treatments in year 10, the difference was only reflected in jack pine foliar N, suggesting black spruce may be less sensitive/responsive to declines in soil N pools.

The 10-year results would suggest that no additional biomass retention restrictions are necessary for full-tree harvesting operations that are targeting traditional wood products (sawlogs and/or pulp & paper) on these shallow-soiled sites. However, some of the noted shifts in some of the measured parameters between year 5 and 10 would suggest longer-term monitoring of these sites will be necessary to provide more conclusive empirical evidence as to the long-term effects of full-tree harvesting on shallow soils within the boreal forest region.

1. Introduction

Increased removal of biomass (woody residues) has the potential to influence tree growth by altering resource availability and microclimate immediately after harvest, modifying seedbed conditions, and causing changes in soil nutrient pools important to long-term productivity (Slesak et al., 2016). In particular, fine logging residues (i.e., live branches and foliage) tend to be high in N (Blanco et al., 2005; Palviainen and Finér, 2010). Since N is generally known to be an important growth limiting nutrient in boreal forest systems (Merilä et al., 2014; Maynard et al., 2014; Paré and Thiffault, 2016), the sustainability of intensive harvest regimes that remove excessive amounts of this crown material from the site continues to be brought into question (Jacobson et al., 2000; Lattimore et al., 2009; Hesselink, 2010; Helmisaari et al., 2011).

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In contrast to harvesting operations conducted solely for traditional wood products (i.e., sawlogs and pulpwood), biomass harvesting also removes non-merchantable trees (i.e., non-target species, undersized or defective trees), effectively reducing the amount of woody biomass retained on a given site (Ewel et al., 1987; Marshall, 2000; Wall, 2012; Webster et al., 2016). This increasing demand for forest biomass, and related pressure on forest ecosystems, has resulted in the resurgence of the debate on the sustainable production of biomass and the resiliency of forest sites to increased removal of logging residues, especially during clearcut, biomass harvesting (Lamers et al., 2013; Berger et al., 2013). In response to these concerns, a number of jurisdictions and certification systems have developed guidance in the form of regulations, best management practices, or recommendations for ensuring that soil productivity is maintained when removing harvest residues (Stupak et al., 2007; Abbas et al., 2011; Titus et al., 2013; Evans et al., 2012). These guidelines commonly classify sites according to their suitability for biomass harvesting (e.g., Rauland-Rasmussen et al., 2007), and regulate harvesting on some sites (Stupak et al., 2008; Evans and Perschel, 2009).

The ecological effects of harvesting, particularly full-tree harvesting (i.e., entire aboveground portion of the tree is removed and processed at roadside), on soil quality and site productivity has been the subject of much research and review (Johnson and Curtis, 2001; Powers et al., 2005; Walmsley and Godbold, 2010; Thiffault et al., 2011; Quideau et al., 2013). When negative effects have been observed, they generally have occurred on inherently nutrient-poor sites (O'Hehir and Nambiar, 2010), where more intensive practices were employed (Egnell and Valinger, 2003; Smith et al., 2000), or in colder climates (Morris and Miller, 1994). Sites commonly referred to being sensitive to increased biomass removals are shallow-to-bedrock soils (<20 cm) or dry, coarse-textured outwash sands (Bhatti et al., 1998; Paré et al., 2002; Abbas et al., 2011; Roach, 2012) due to their limited soil nutrient reserves, having a relatively high proportion of ecosystem nutrients residing in aboveground tree biomass (Green and Grigal, 1980; Foster et al., 1995; Morris, 1997), low cation exchange capacity (Hazlett et al., 2014), and having a high potential for available nutrients to be leached from the system (Evans and Perschel, 2009; Wilhelm et al., 2013). For the most part, the sensitivity of these sites has been based on nutrient budgets and resultant expert opinion, as opposed to empirical evidence based on long-term experimental trials (Titus et al., 2012). Only recently, have results regarding the effects of increased organic matter removals on dry, outwash sandy sites emerged (Kurth et al., 2014; Fleming et al., 2014; Hazlett et al., 2014). In contrast, there have been no long-term experimental trials installed or reported on to date that specifically target shallow-soiled sites common in strongly glaciated boreal landscapes (Rowe, 1972). Even within the expansive (i.e., over 100 installations) North American Long-term Soil Productivity (LTSP) network, there are no specific/targeted sets of installations that are designed to examine the effects of increased biomass removals on shallow-soiled sites.

This study reports on ten year results examining the effects (i.e., regeneration potential, tree growth, soil N availability, and foliar nutrition) of operational full-tree harvesting (i.e., entire aboveground portion of the tree is removed and processed at roadside) compared to operational stem only harvesting (i.e., individual stems delimbed and topped at the stump) on replicated, shallow-soiled sites (organic + mineral soil depth <20 cm over bedrock) with contrasting soil textures (i.e., sand versus loam) and dominant commercial tree species (i.e., jack pine – *Pinus banksiana* Lamb. versus black spruce – *Picea mariana* (Mill.) B.S.P.). Specific research questions addressed included: (1) *Does the reduced amounts of logging residues retained on site following operational full-tree harvesting when compared to stem only harvesting influence soil quality and or stand development and growth parameters?,* (2) *Are impoverished, sandy sites more sensitive to this increased biomass/nutrient removal compared to more nutrient-rich, loamy sites?*, and (3) *Is there a differential tree species response between harvest treatments and or soil types?*

We hypothesized that reductions in fine, cone-bearing logging residues on the full-tree harvest blocks would reduce tree regeneration (e.g., seedling density and stocking) due to limited ingress of natural pine and spruce seedlings, thereby altering species composition (greater hardwood component) across all sites. In addition, we expect reductions in soil N availability on the full-tree treatment blocks due to a reduction in labile N pools associated with the nutrient rich fine slash (foliage and twigs), but significant harvest treatment effects would only occur on the coarse-textured, sandy sites due to small soil N reserves and higher leaching potential. This reduction, in turn, would result in lower foliar N content, but only detectable in the faster-growing, intolerant jack pine seedlings. Finally, we do not expect significant tree and stand growth metrics as a result of harvest treatment as these young stands have yet to reach crown closure, the point in stand development where N demand may exceed soil N supply.

2. Material and methods

2.1. Study site descriptions

Seven mature (60–140 years), fire-origin stands growing on very shallow (<20 cm) to bedrock, glacial tills (dystric brunisols) were selected in 2001 to represent two broad soil textural classes: coarse-textured sands versus medium-textured loams. Bedrock type was either granite (igneous rock comprised mainly of quartz and feldspar with minor amounts of mica, hornblende, biotite, and muscovite) or greenstone (metabasalt – form during the late Archean period, and is a low-grade mafic metavolcanic rock with preserved evidence of its original basaltic character). Soils derived from the weathering of greenstone tend to be higher in base cations (Green and Grigal, 1980). The stands were either dominated by jack pine (4 sites) or black spruce (3 sites) (Table 1). Originally, eight sites were included in the study to provide a balanced design (4 jack pine sites: 2 sand - PjS, 2 loam - PjL and 4 black spruce sites: 2 sand - SbS, 2 loam - SbL) (Fig. 1). After harvest, one of the SbL sites had a near equal mixture of black spruce and jack pine regeneration, so both species were measured and sampled for nutrient content, adding a third block for the jack pine loam sites (Table 1). Although pre-harvest measurements were completed, the eighth site (2nd replicate for the black spruce - loam site) was never harvested due to local mill closures. Although these sites are classified as the same ecosite (ES12: black spruce – jack pine: very shallow soils) in Ontario's Forest Ecosystem Classification (FEC) system (Racey et al., 1996), they represent a broad range in soil moisture regime (dry to moderately moist), drainage patterns (very rapid to moderately well), stand densities (1028–4130 stems ha^{-1}), and levels of stand productivity (SI_{50}, site index (height in metres at breast height age 50), jack pine: 12.2–16.7 m; black spruce: 9.4–15.9 m; and gross total volume (GTV) 66.5–184.8 m^3 ha^{-1}).

The study sites were well dispersed across northwestern Ontario, spanning three boreal shield ecoregions (Lake of the Woods – 2 sites, Lac Seul Upland – 4 sites, Big Trout Lake – 2 sites). The two SbS sites are the most easterly sites located north of Nakina, ON (50°35′N, 86°54′W) within the Big Trout Lake ecoregion over to the western portion of the northwestern Ontario for the two PjS located north of Kenora, ON (50°25′N 94°6′W) situated in the Lac Seul Upland ecoregion (Ecoregion Working Group, 1989). Using Environment Canada's (2014) nearby weather station data mean