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Whole-tree harvesting and site productivity: Twenty-nine northern hardwood sites in central New Hampshire and western Maine

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ABSTRACT

Whole-tree harvesting is widely used in the northeastern United States to supply biomass energy plants with fuel, but questions remain regarding its long-term sustainability. To assess its effects on the northern hardwood forests that make up a significant portion of northern New England, we conducted a regeneration survey of twenty-nine (29) small clearcuts in central New Hampshire and western Maine in 2011. We measured fourteen (14) whole-tree harvested (WTH) and fifteen (15) conventionally harvested (CH) sites and compared the productivity of the 10–14 year old regeneration. Height and diameter of all trees >2 m in height were measured within 1 m-radius plots. Biomass was calculated using species-specific regression equations based on measured diameter. No significant difference was observed in height, diameter or calculated biomass of stems >2 m in height between WTH and CH treatments. We conclude that no significant effects of residue removal on site productivity from whole-tree harvesting are observed within our sample of northern hardwood sites as this point in their stand development.

1. Introduction

The burning of woody biomass to produce energy is a source of local, renewable power in northern New England. Whole-tree harvesting provides a source of wood chips to supply these biomass plants. In a whole-tree harvesting (WTH) operation, traditionally unmarketable treetops and branches can be chipped and sold. This additional income can be important to a landowner and help supply a growing renewable energy sector. However, concerns have been raised over the sustainability of whole-tree harvesting, as it removes nutrient-rich twigs, tops and low-grade woody material that would remain on site in a conventional (bole-only) harvesting (CH) operation. This additional drain on site nutrient reserves could have detrimental effects on site productivity, which may offset the benefits derived by this practice in our forests. There is a need to evaluate the potential effects of whole-tree harvesting on the future productivity of northern hardwood forests.

Concerns over long-term productivity effects of whole-tree harvesting have existed since the 1970s (Boyle, 1976; Kimmins, 1977; Anderson, 1985) when the practice first began being widely used. Early research on nutrient impacts of harvesting methods focused on comparing the amount of nutrients removed during harvest with the site's nutrient reserves. If removals are large enough, the practice of WTH could be harmful to the site and would likely impair its ability to grow trees quickly. Several studies have found cause for concern on nutrient poor sites or sites that are harvested on short rotations (Weetman and Webber, 1972; White, 1974; Carey, 1980), while others have concluded that WTH might be sustainable on richer sites (e.g. Boyle and Ek, 1972). Johnson et al. (1982) pointed to calcium as the nutrient most likely to become limiting in an upland mixed-oak forest in Tennessee. Studies such as these that estimate system inputs and outputs may overestimate outputs by assuming that all or even most of the available residue material is removed from the site. Several studies have shown that it is not operationally possible to remove all biomass during harvest, with Briedis et al. (2011) recently finding that 15% of all harvested material (45% of residue material) generated during whole-tree harvesting operations in central Maine remained on site. A previous study of a wider variety of sites across New England measured that 4–10% of all harvested material remained on site (Pierce et al., 1993).

More recently, studies have looked to soil fertility for evidence of site depletion. As preferentially more nutrients are removed during whole-tree harvesting than in conventional harvesting, soil in WTH sites could become depleted over time. We might expect this effect to occur quicker in sites with nutrient poor soils. As a deficiency in one or more nutrients becomes limiting, the site's ability to grow trees will decline. Goulding and Stevens (1988) found WTH led to a short-term potassium deficiency, while Olsson et al. (1996a) showed a decrease in exchangeable K, Ca, Mg, Mn, and Zn cations. In other studies, no differences in soil nutrient content were observed. Johnson et al. (1991) found no preferential

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decrease in exchangeable base cations from WTH, and Olsson et al. (1996b) found no treatment effect on C and N soil content. In a meta-analysis, Johnson and Curtis (2001) suggested that harvest effects on carbon and nitrogen varied greatly by site, and that WTH was more harmful on coniferous sites than on deciduous ones. The fact that some of these studies measured exchangeable nutrient fractions while others measured total nutrient concentration may have also played some role in the discrepancy of their results.

Productivity can also be measured directly in the form of tree height, diameter or biomass. Studies of softwood plantations in Europe and the southeastern United States have found evidence of decreased second stand productivity resulting from residue removal during WTH when compared with CH (Proe et al., 1994, 1996; Egnell and Leijon, 1999; Egnell and Valinger, 2003; Scott and Dean, 2006; Walmsley et al., 2009). However, other studies have showed residue removal does not exert a significant effect on second stand productivity (Hendrickson, 1988; Dyck and Skinner, 1990; Smethurst and Nambiar, 1990; Sanchez et al., 2006; Tan et al., 2009; Saarsalmi et al., 2010). Once again the effect of residue removal does not seem to be universal; some sites seem to be more resilient to the removal of additional nutrients than others. It is worth noting that these studies, in addition to those that measured soil fertility discussed above, were experimental manipulations. In most, WTH and CH treatments were simulated within a single harvest opening 0.5–4 ha (1–10 acre) in size. The plots were typically 20 × 20 m in size separated by a 10 m buffer strip and either contained harvest residues (simulating CH) or were left devoid of residues (WTH).

Our previous study of four patch cuts in a northern hardwood forest in the Bartlett Experimental Forest (BEF) in the White Mountains of New Hampshire showed forest productivity 12 years following harvest did not vary significantly by treatment. While initial results from that study suggested that whole-tree harvesting had weak positive effects of second stand productivity, we believe these results to be due to non-treatment factors. WTH plots contained less severely browsed regeneration than CH plots, and tended to receive more sunlight simply due to their size, shape and orientation. After removing heavily browsed sample plots across both treatments, mixed effects models showed that while higher radiation intensity predicted more productive regeneration, harvest treatment had no appreciable effect. Thus, 12 years following patch cutting in a northern hardwood forest, it appears residue removal in northern hardwood stands had no detectable effect on forest productivity.

With its ample forest resources and well established forest products industry, New England represents an ideal spot for the development of a biomass industry (Benjamin et al., 2009). Is widespread use of whole-tree harvesting to supply wood chips to such an industry justified or will it leave our forests depleted of nutrients and unable to grow trees at desired rates? Are the results obtained in the Bartlett Experimental Forest indicative of forest response across the northern hardwood forest of northern New England? Our previous study could not address this question due to its low level of replication (two sites per treatment) and narrow geographical sampling.

The goal of the current study was to determine whether productivity differences exist between northern hardwood sites that have been whole-tree harvested and comparable sites that were conventionally harvested. Our objectives were to (1) determine if productivity of regenerating trees is correlated with residue retention or removal and (2) determine if any correlations observed could be due to other site factors – radiation intensity, site age, clearcut size, soil type, slope and aspect. A comparison of our results with those found in the BEF gives a better picture of the effects of WTH as compared with CH as practiced in the northeastern United States.

2. Methods

2.1. Site selection

Patch cut sites were selected based on their similarity to the four 12-year old patch cuts studied in 2010 in the BEF. Each site was cut using whole-tree or conventional harvesting between the years of 1997 and 2001, giving each an age of between 10 and 14 years when measured in the summer of 2011. The sites were all classified as northern hardwoods – sites with a significant softwood component were excluded. Overall species composition was similar on WTH and CH sites, with American beech (*Fagus grandifolia*), yellow birch (*Betula allegheniensis*), paper birch (*Betula papyrifera*), striped maple (*Acer pensylvanicum*), red maple (*Acer rubrum*), pin cherry (*Prunus pensylvanica*) and bigtooth aspen (*Populus grandidentata*) the most common species encountered. We tried to limit the size of the patch cuts to between 0.8 and 4 ha (2–10 acres) during selection. However, when each cut was actually measured, several fell outside this range and were still included in our analyses. These factors were partially practical, but were also a way to minimize site variability due to factors other than harvest treatment. With each site as similar to the rest as possible, we hoped to be able to detect any productivity differences due to harvest treatment if they existed. We measured 29 sites in New Hampshire and western Maine (15 conventionally harvested and 14 whole-tree harvested) that fit our criteria.

2.2. Site descriptions

Several site parameters varied significantly between WTH and CH treatments. Whole tree harvested areas averaged 1.8 ± 1.1 ha in size and 11.5 ± 0.9 years in age. Canopy openings in conventionally harvested sites tended to be larger and older (*t*-test; size: $t = 3.5$, 27 d.f., $p = 0.002$; age: $t = 2.9$, 27 d.f., $p = 0.007$), averaging 3.3 ± 1.2 ha and 12.7 ± 1.3 years. Sites were located between 250 and 650 m in elevation on soils derived from glacial till parent material and classified as either well drained or moderately well drained. Bedrock underlying clearcut sites was primarily igneous, with WTH sites primarily dominated by Bethlehem Granodiorite and Ammonoosuc Volcanic Formations and CH sites containing a more heterogeneous mix of Bethlehem Granodiorite, Granite and Littleton Formations among others (Lyons et al., 1997). Plot slope averaged 6° and did not vary significantly over harvest treatment (*t*-test; $t = 0.5$, 520 d.f., $p = 0.62$). Detailed information on the land-use history of each site was not available, but prior to harvest most of the sites were second growth forest and were likely cleared for agriculture or timber harvesting in the late 1800s or early 1900s (Belcher, 1980; Foster, 1992).

Conventionally harvested sites were located on public lands within the White Mountain National Forest (WMNF) and were managed by the US Forest Service. However, out of concern for site degradation whole-tree harvesting is not currently practiced on the WMNF, so WTH sites were located on privately managed lands. Due to the difficulty in finding sites that met our criteria, WTH sites were heavily clustered in west central New Hampshire (Fig. 1). Distance between farthest WTH sites was 26 km, as compared with the more widely dispersed CH sites (96 km separating the farthest two).

2.3. Conceptual model

Within this paper, we hypothesize that environmental and treatment variables (measured and unmeasured) have an effect