Forest regeneration differences between whole-tree and conventional harvesting methods in northern hardwoods: a concern for sustainable bio-fuel production?

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Completion date: December, 2012

Outcomes:
No significant difference was observed in height, diameter or calculated biomass of stems > 2m in height between Whole Tree harvesting (WTH) and Conventional Harvesting (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 after 12-14 years of stand development.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

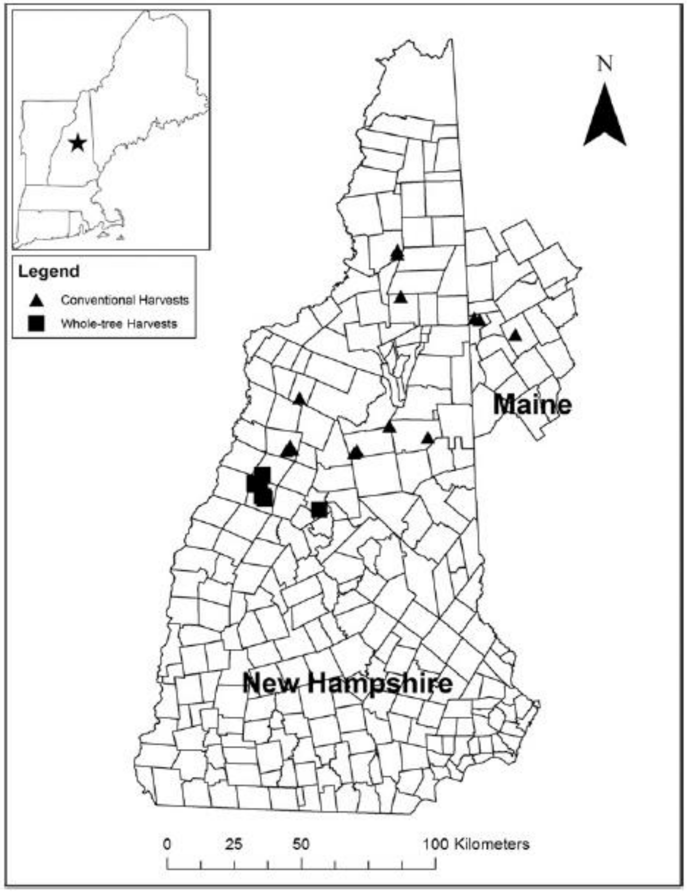

Figure 1: Locations of 14 whole-tree harvested (squares) and 15 conventionally harvested (triangles) study sites in New Hampshire and western Maine. Location within the northeastern United States is shown on the inset map.

- Whole tree harvesting is increasingly used to supply wood chips for biomass energy production. In a typical whole tree harvesting operation the trunk of the tree is used for traditional products (lumber, construction materials, etc.); branches and fine twigs are sold to a biomass energy plant. Conventional harvesting, in contrast, leaves branches and twigs on site to decompose. There has been concerns that additional removal of nutrient-rich branches and twigs by WTH might impair forest productivity – leaving a forest that regenerates trees that are slower growing and of lesser quality.

- To assess effects of harvest treatment on New England's northern hardwood forests, we conducted a regeneration survey of twenty-nine (29) small clearcuts in central New Hampshire and western Maine. 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. Conventionally harvested sites were located on public lands within the White Mountain National Forest (WMNF). Out of concern for site degradation, WTH is not currently practiced on the WMNF, so WTH sites were located on private lands. Due to the difficulty in finding sites that met our criteria, WTH sites were heavily clustered in west central New Hampshire (Fig. 1).

Project Summary (2)

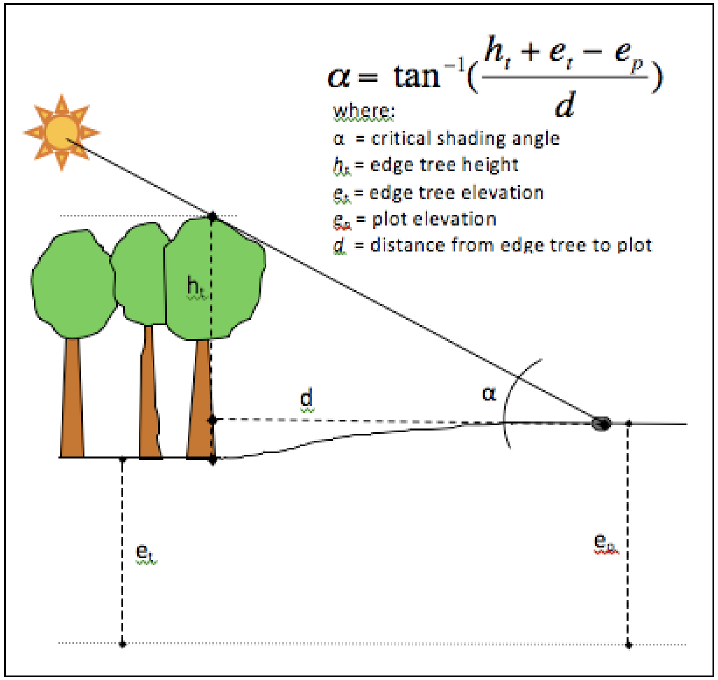

Figure 2. Diagram demonstrating calculation of the critical angle α for a given plot and a given azimuth. When the sun is above this angle, the plot receives radiation.

- Within each plot at each site, the height, diameter at breast height (DBH) and species of all trees >2 m in height within a 1 m radius were recorded. The slope and aspect of each plot were measured. Soil parent material was of glacial till origin for all sites, but was visually classified as either well-drained or moderately well-drained. The position and height of uncut edge trees surrounding the patch cut were recorded. These edge trees were used to calculate the patch cut size and to develop a spatial solar radiation model to determine the amount of sunlight each sample plot received during the growing season (Fig. 2). 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. Our study found no evidence of productivity decrease 10-14 years following single whole-tree harvesting in comparison with conventional bole-only methods. Mixed effects models and quantile regressions both showed that choice of harvest treatment had no significant effect on biomass, height or diameter of regenerating stems. Our results are limited by several factors: the extent of moose browsing, the restriction of WTH to private forest lands, as well as the development stage of the measured stands. Further, our analysis examined only a limited set of timber productivity measures and did not address broader questions of ecological productivity.

Background and Justification

Woody bio-fuels are becoming increasingly important as New England and the US move toward a more self-sufficient, sustainable energy economy. In the Northern Forest and at its periphery, existing facilities for wood-based energy production draw their raw material supplies from land-clearings, wood waste and forest stand harvesting. Expansions of existing facilities and new facilities will require additional volumes of woody biomass.

Whole-tree harvesting is increasingly used to meet the demand for biomass. In whole-tree harvesting operations, the bole of the tree is used for traditional products while the branches and fine twigs are sold to a biomass energy plant. In conventional harvesting, those branches and fine materials are left on the forest floor. In whole-tree operations, the landowner can earn more money per unit of land harvested and contribute to renewable energy generation.

Background and Justification (2)

- Concerns exist that the additional removal of nutrient-rich branches and twigs may impair forest productivity, leaving a forest that regenerates trees slower and which are shorter or of lesser quality (Malkonen 1976, Boyle 1976, Kimmins 1977, Carey 1980). Short-term gains from the sale of extra biomass may be offset by long-term financial reductions due to lowered productivity. Existing literature on the impacts of whole-tree harvesting examines questions of soil fertility. These studies compare nutrient losses across harvest treatments and link sizeable losses with reductions in productivity.

- Boyle, J.R., 1976. System for evaluating potential impacts of whole-tree harvesting on site quality. Tappi. 59 (7): 79-81.
- Carey, L.M., 1980. Whole tree harvesting in Sitka spruce: possibilities and implications. Irish Forestry. 37: 48-63.
- Kimmins, J.P., 1977. Evaluation of consequences for future tree productivity of loss of nutrients in whole-tree harvesting. Forest Ecology and Management. 1: 169-183.
- Malkonen, E., 1976. Effect of whole-tree harvesting on soil fertility. Silva Fennica. 10: 157-164.

Background and Justification (3)

- Studies that directly measure the performance of trees regenerated after a harvesting event focus on coniferous plantations (Walmsley et al. 2009, Proe et al. 1996, Dyck et al. 1991, Compton and Cole 1991, Lundkvist 1988). There is virtually no published research on the response to different harvest treatments by naturally regenerated northern hardwoods, a critical component of the Northern Forest.
- Therefore, there is a need to evaluate the differences in ecological and economic impacts, if any, that whole-tree and conventional harvesting have on the future productivity of northern hardwood stands. That productivity and its economic dimensions will affect the sustainability of wood supply to the bio-fuels sector and to the entire wood-based economy of the Northern Forest.

- Compton, J.E., Cole, D.W., 1991. Impact of harvest intensity on growth and nutrition of successive rotations of Douglas-fir. In: Dyck, W.J., Mees, C.A. (Eds.), Long-term Field Trials to Assess Environmental Impacts of Harvesting. FRI Bull. 161, Forest Research Institute, Rotorua, New Zealand, pp. 151–161.
- Dyck, W.J., Hodgkiss, P.D., Oliver, G.R., Mees, C.A., 1991. Harvesting sand–dune forests: impacts on second-rotation productivity. In: Dyck, W.J., Mees, C.A. (Eds.), Long-term Field Trials to Assess Environmental Impacts of Harvesting. FRI Bull. 161, Forest Research Institute, Rotorua, New Zealand, pp. 163–176.
- Lundkvist, H., 1988. Ecological effects of whole-tree harvesting – some results from Swedish field experiments. In: T.M. Williams and C.A. Gresham (Editors), Predicting consequences of intensive forest harvesting on long-term productivity by site classification. Proc IEA/BE Project CPC-10 Workshop, Baruch Forest Science Institute of Clemson University, Georgetown, SC, USA. Pp. 131-140.
- Proe, M.F., Cameron, A.D., Dutch, J., Christodoulou, X.C., 1996. The effect of whole-tree harvesting on the growth of second rotation Sitka spruce. Forestry. 69: 389-401.
- Walmsley, J.D. et al., 2009. Whole tree harvesting can reduce second rotation forest productivity. Forest Ecology and Management. 257: 1104-1111.

Methods

- 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.
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- Height and diameter of all trees > 2m in height were measured within 1m-radius plots. Biomass was calculated using species-specific regression equations based on measured diameter.

Figure 4. Typical sample 12-14 year old northern hardwood stand

Results

- We measured 3,471 trees above 2m in height across 815 plots within our 29 study sites. Within 277 of the plots, vegetation was either severely browsed, non-forest (field, swamp, stream, road) or clearly of advanced regeneration origin; these plots were excluded from our analysis. 45% of plots within WTH sites and 27% within CH sites were excluded. The unequal distribution of these plots across harvest treatment contributed significant off-treatment variation prior to their exclusion.

- The remaining 538 plots containing 2,951 trees were characterized by non-browsed forest regeneration that began its growth following harvest. Tree height averaged 4.3m with a maximum of 11.1m. Diameters ranged from 1.0 to 13.2 cm at breast height with an average of 2.5cm. Plot basal area averaged 12.5m^2/ha (54.4 ft^2/acre) and varied greatly from 0 to 71.7 m^2/ha (0 to 312.3 ft^2/acre) due to our small plot size. Aboveground biomass estimates per site ranged from 10.3 to 61.6 metric tons per hectare (4.6 to 27.5 tons per acre). Tree density ranged from 8,600 to 30,000 trees per hectare (3,500 to 12,000 trees per acre).

Results (2)

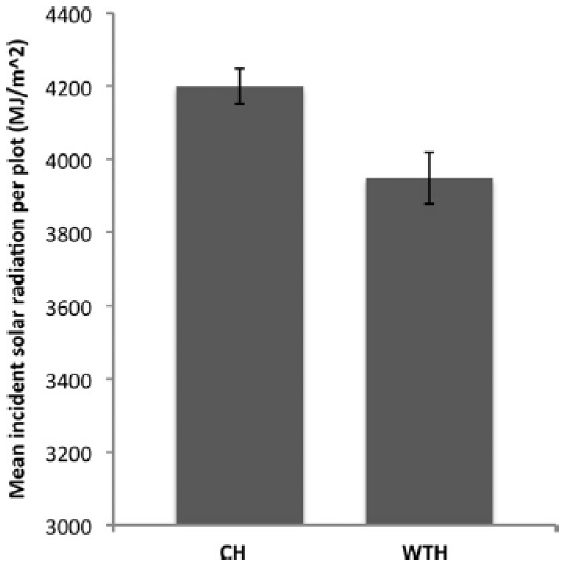

Figure 5: Estimated solar radiation per plot by harvest treatment. Error bars represent standard error of the mean. Radiation values calculated using a spatial solar radiation model created in ArcView 3.3 and ArcGIS 10.0.

- Conventionally harvested plots on average received a higher level of solar radiation, as estimated by the spatial radiation model (t-test: $t = 3.0$, 520 d.f., $p = 0.003$, Figure 5).

Results (3)

- A mixed effects model showed that harvest treatment did not have a strong effect on plot biomass (R2 = 0.10, p = 0.39, 19 d.f.; Figure 6, Table 1). Due to the very low R-squared value, the ability of this model to predict productivity using the measured environmental and harvest variables was not strong. High uncertainty in parameter estimates meant that effects on plot biomass of whole-tree harvesting could range from a decrease of 10% to an increase of 26% when compared with the biomass of conventionally harvested plots (using two standard errors as our uncertainty).

- Models using mean tree height, mean tree DBH and tallest tree height as the productivity measure, yielded similar results (Figure 6, Tables 2-4); none showed that harvest treatment had a significant effect on productivity. Additionally, none of the additional six environmental variables – clearcut age, clearcut size, solar radiation intensity, soil, plot slope and plot aspect – had a significant effect on any productivity variable. Residual variance was primarily due to variability between plots within a clearcut site, with only six to nine percent of the variability due to site-to-site differences.

Results (3)

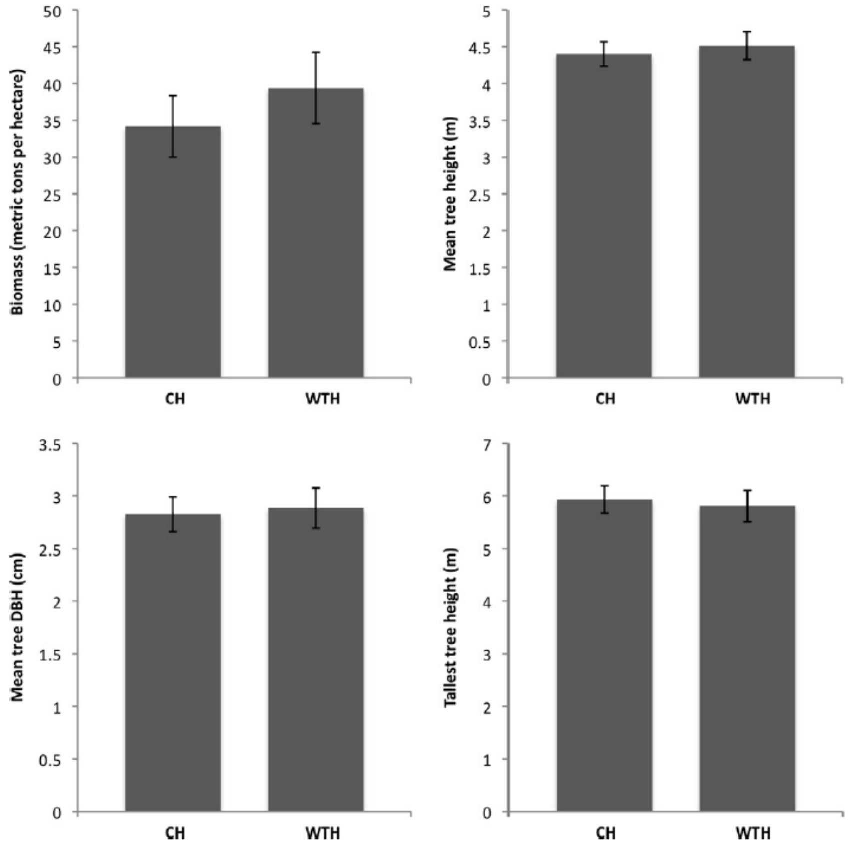

Figure 6: Productivity measures compared across harvest treatment. Error bars represent the standard error of the mean. Data from twenty-nine northern hardwood sites in central New Hampshire and western Maine.

Results (4)

Table 1
Parameter estimates for the mixed effects model on mean tree height. Positive parameter estimates indicate an increase in fixed effect is correlated with in increase in tree height. Harvest treatment and soil type were treated categorically and the effects on tree height of conventional harvesting (CH) and moderately well-drained till (MWDT) are reported as compared with whole-tree harvesting and well-drained till respectively.

	Parameter estimate	Standard error	d.f.	t-Ratio	$p > \|t\|$
Fixed effects					
Harvest treatment [CH]	−815.91	938.97	22.0	−0.87	0.39
Solar radiation	0.34	0.49	503.6	0.69	0.49
Plot slope	−91.19	113.90	312.0	−0.80	0.42
Plot aspect	−8.63	4.64	247.8	−1.86	0.06
Soil type [MWDT]	1511.35	1102.01	23.7	1.37	0.18
Clearcut age	583.82	610.42	16.1	0.96	0.35
Clearcut size	29.56	256.01	21.7	0.12	0.91
Random effects	% variance				
Clearcut ID	6.6				
Residual error	93.4				

Table 2
Parameter estimates for the mixed effects model on plot biomass. Positive parameter estimates indicate an increase in fixed effect is correlated within increase in plot biomass. Harvest treatment and soil type were treated categorically and the effects on plot biomass of conventional harvesting (CH) and moderately well-drained till (MWDT) are reported as compared with whole-tree harvesting and well-drained till respectively.

	Parameter estimate	Standard error	d.f.	t-Ratio	$p > \|t\|$
Fixed effects					
Harvest treatment [CH]	−0.05604	0.11743	20.7	−0.48	0.64
Solar radiation	−0.00007	0.00006	505.8	−1.12	0.27
Plot slope	0.01870	0.01394	323.1	1.34	0.18
Plot aspect	−0.00063	0.00057	255.7	−1.11	0.27
Soil type [MWDT]	0.12708	0.13778	22.3	0.92	0.37
Clearcut age	0.09655	0.07663	15.3	1.26	0.23
Clearcut size	0.01461	0.03203	20.5	0.46	0.65
Random effects	% variance				
Clearcut ID	7.2				
Residual error	92.8				

Results (5)

Table 3
Parameter estimates for the mixed effects model on mean tree DBH. Positive parameter estimates indicate an increase in fixed effect is correlated with in increase in tree DBH. Harvest treatment and soil type were treated categorically and the effects on tree DBH of conventional harvesting (CH) and moderately well-drained till (MWDT) are reported as compared with whole-tree harvesting and well-drained till respectively.

	Parameter estimate	Standard error	d.f.	*t*-Ratio	$p > \|t\|$
Fixed effects					
Harvest treatment [CH]	−0.02915	0.11833	25.5	−0.25	0.81
Solar radiation	−0.00004	0.00006	505.0	−0.72	0.47
Plot slope	0.00044	0.01371	358.1	0.03	0.97
Plot aspect	−0.00089	0.00056	300.1	−1.59	0.11
Soil type [MWDT]	0.21856	0.13857	27.4	1.58	0.13
Clearcut age	0.04235	0.07760	19.2	0.55	0.59
Clearcut size	−0.02494	0.03226	25.4	−0.77	0.45
Random effects	% variance				
Clearcut ID	8.0				
Residual error	92.0				

Table 4
Parameter estimates for the mixed effects model on tallest tree height. Positive parameter estimates indicate an increase in fixed effect is correlated with in increase in tree height. Harvest treatment and soil type were treated categorically and the effects on plot biomass of conventional harvesting (CH) and moderately well-drained till (MWDT) are reported as compared with whole-tree harvesting and well-drained till respectively.

	Parameter estimate	Standard error	d.f.	*t*-Ratio	$p > \|t\|$
Fixed effects					
Harvest treatment [CH]	0.06077	0.18657	21.4	0.33	0.75
Solar radiation	−0.00004	0.00009	504.9	−0.43	0.67
Plot slope	0.01109	0.02082	362.7	0.53	0.59
Plot aspect	−0.00032	0.00085	307.0	−0.38	0.70
Soil type [MWDT]	0.20092	0.21815	22.9	0.92	0.37
Clearcut age	0.05310	0.12317	16.5	0.43	0.67
Clearcut size	0.01037	0.05086	21.3	0.20	0.84
Random effects	% variance				
Clearcut ID	9.2				
Residual error	90.8				

Results (6)

- Two quantile regression equations were generated for each measure of productivity: one containing the six environmental variables and the second containing harvest treatment (WTH or CH) in addition to these six. If a pair of these equations was significantly different in predictive power, it suggested that harvest treatment has a significant effect on productivity independent of the other six environmental variables.

- The two equations were found to be not significantly different for biomass, mean height, tallest tree per plot height, or mean DBH (ANOVA; plot biomass: $F=0.62$, d.f.=503, $p=0.43$, mean height: $F=0.45$, d.f.=505, tallest tree per plot height: $F=0.50$, d.f.=504, $p=0.48$, $p=0.50$, mean DBH: $F=0.91$, 504 d.f., $p=0.34$).

Outreach

- Results of this project have been published in *Forest Ecology and Management*, a high impact, refereed scientific journal.
- Results have also been presented at the 2012 ECANUSA Conference and at a workshop sponsored by UNH Cooperative Extension and the New Hampshire Timberland Owners Association.
- Preliminary results were presented at the 2011 University of New Hampshire's Graduate Research Conference.

Implications and Applications in the Northern Forest Region

- Forest managers have some re-assurance that whole-tree harvesting does not appear to reduce the timber productivity of northern hardwood stands in the early years of stand development.

- The findings of this report may help inform policy debates about whole-tree harvesting as a means for supply feedstock for renewable energy generation

- Because there were no significant differences between treatments after 10-14 years of stand development, there were no significant differences in financial performance.

Future directions

- Possible future work will address the limited scope of sampling by expanding the sampling to additional WTH and CH sites in the Northern Forest region.

- This study focused on the early development of naturally regenerated northern hardwood stands. Additional future research should address whether the lack of significant difference between treatments after 12-14 years of development persists after two decades of development.

- Although this research did not find significant differences in tree species composition, additional research on the comparative impacts of WTH and CH on the broader dimensions of forest ecology is needed.

List of Products

Peer Reviewed:

- Roxby, G. and T. Howard. 2013. Whole-tree harvesting and site productivity: twenty-nine northern hardwood sites in central New Hampshire and western Maine. Forest Ecology and Management 293:114-121.

Other:

- Roxby, G. and T. Howard. 2012. Whole Tree Conventional Harvesting: Assessing Productivity Differences. 2012 ECANUSA Forest Science Conference. Durham, NH. Nov 1-3.

- Roxby, Gabriel. 2012. Effects of Whole-Tree Harvesting on Site Productivity and Species Composition in Northern Hardwood Forests. M.S. Thesis. University of New Hampshire. 112 pages.

- Roxby, Gabriel. 2012. Effect of Whole Tree Harvesting on Site Productivity. Presentation at Biomass Harvesting - What is left behind? NHTOA and UNH Cooperative Extension Workshop. Bridgewater, NH. July 26, 2012.

- Roxby, Gabriel. 2011. Evaluating the Sustainability of Whole-Tree Harvesting. University of New Hampshire Graduate Research Conference. April, 2011. Durham, NH.