Predicting Differences in Forest Stand Nutrient Uptake and Removal: Potential Effects of Increased Biomass Removals for Energy on Long-Term Site Sustainability

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BACKGROUND

Accelerated global energy demand coupled with rising fossil fuel costs has escalated efforts to utilize alternative, renewable energy sources. Forest biomass harvesting represents a way to access and utilize unmerchantable harvest residues as a fuel source, maximizing the utilization of biomass resources from sustainably harvested sites. This is in contrast to conventional harvesting, where merchantable timber is removed and unmerchantable biomass is left on-site (MFS and ENE 2006).

Compared with conventional harvesting operations, biomass for energy harvests would draw on site nutrient pools more intensively, increasing the potential of compromising site sustainability. Few long-term studies on the effects of biomass for energy harvesting on site nutrient pools exist (Tennenbaum 2005, Pimental et al.1984). Further, site characteristics such as drainage, parent material, ecosystem diversity, and topography can affect nutrient pool response to biomass for energy harvesting (Federer et al. 1989), making site-specific predictions difficult.

A multi-parameter approach is necessary to accurately predict the effects of biomass energy harvests on forest nutrient pool dynamics. Given the scarcity of long-term in-situ investigations, modeling the nutrient consequences for a forest ecosystem of increased harvest intensity is a promising approach. Utilizing this approach will foster a better understanding of nutrient dynamics across different sites in order to maximize biomass for energy harvesting efficiency while preserving or improving the long-term sustainability of managed forests.

OBJECTIVES:

- To assess the utility of the model REMSS (Ducey and Allen 2001) for predicting biomass accumulation, nutrient uptake, and nutrient removal with harvest among different intensities of silviculture in an even-aged balsam fir forest.
- To assess the consequences of biomass harvesting of silvicultural residues for energy and other bioproducts on soil nutrient availability and long-term forest sustainability.

Table 1: Silvicultural Treatments Considered for Differences in Harvest Nutrient Removals

Treatment	Abbreviation
No management control	CTR
Pre-commercial thinning only at dominant height of 3.1 m to a residual of 1675 trees per hectare (t ha^{-1}),	PCT
Commercial thinning only at a dominant height of 12.4 m as 40% of stand basal area removal	CT
Pre-commercial thinning at dominant height of 3.1 m to a residual of 1675 t ha^{-1}, followed by commercial thinning at a dominant height of 12.4 m of 40% of stand basal area	PC
PC as described above, followed by a clearcut at age 100	PCC
A 25 percent increase in removal over each of the thinning treatments in the PC scenario, followed by a clearcut at age 100 (representative of a biomass for energy harvest)(MFS 2008)	BPCC

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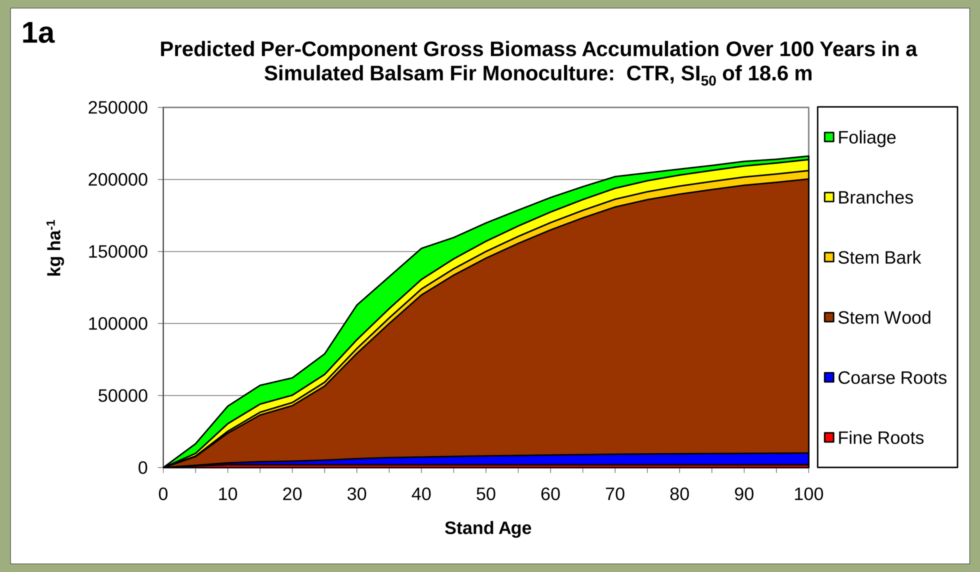
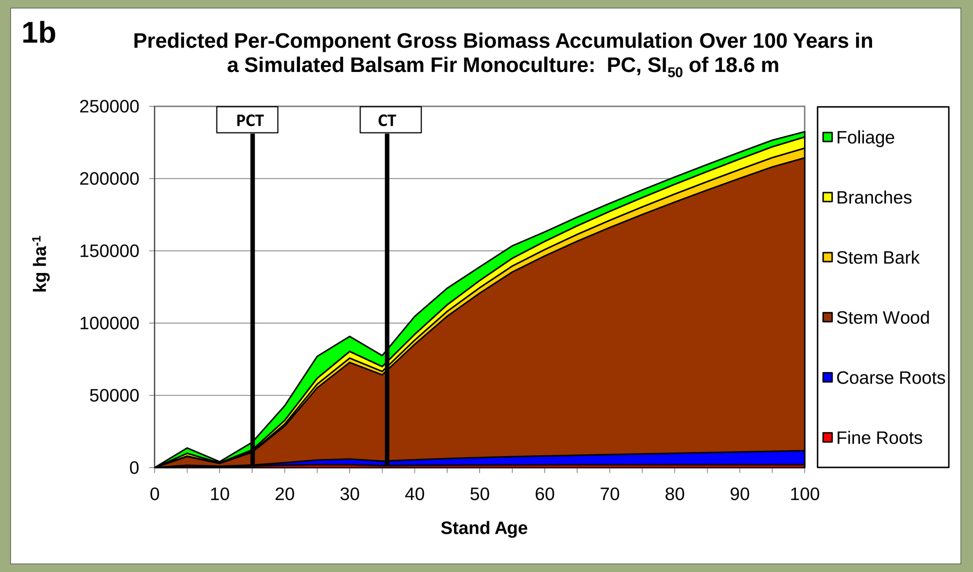
METHODS

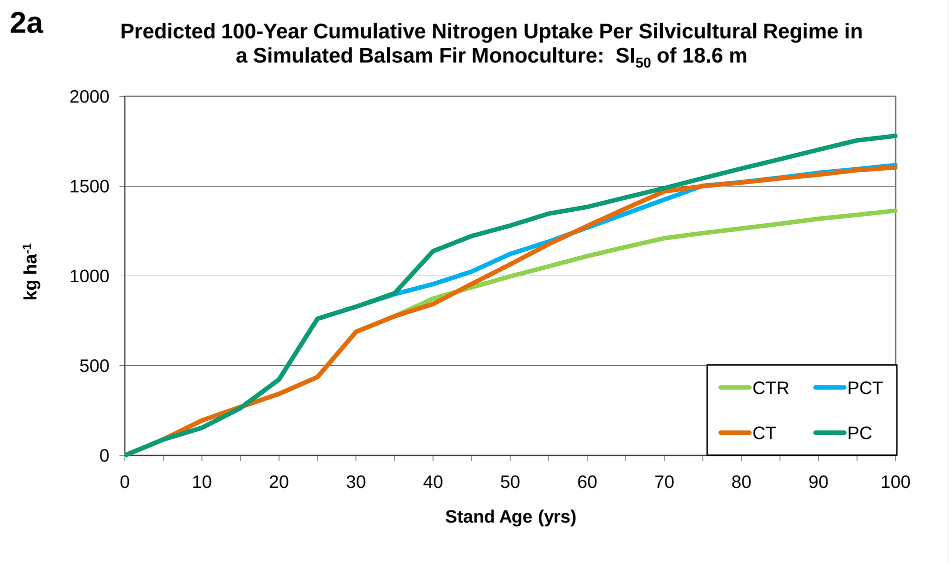
1. Simulated balsam fir monocultures with three different site indices$_{50}$ (SI_{50}) for a 100-year rotation using the Recalibrated Northeast Variant of the Forest Vegetation Simulator (NE-FVS) (Saunders 2008).
2. Ran a sensitivity analysis on the nutrient uptake and removal model D-Fir REMSS (Ducey and Allen 2001) to determine relative importance of parameters.
3. Parameterized D-Fir REMSS with balsam fir data from the northeastern United States and southeastern Canada.
4. Used the balsam fir monocultures generated by NE-FVS as input data for B-Fir REMSS.
5. Ran B-Fir REMSS for a 100-year rotation of five different silvicultural regimes selected from the NE-FVS database (Table 1)
6. Estimated additional removals in biomass for energy operations by using a factor of 25% over the PCC scenario (MFS 2008) (Table 1).
7. Compared primary literature estimates of nitrogen, phosphorus, potassium, calcium, and magnesium pools in northeastern spruce-fir forests to B-Fir REMSS nutrient removal estimates to assess the potential for nutrient depletion with increased harvest intensity.

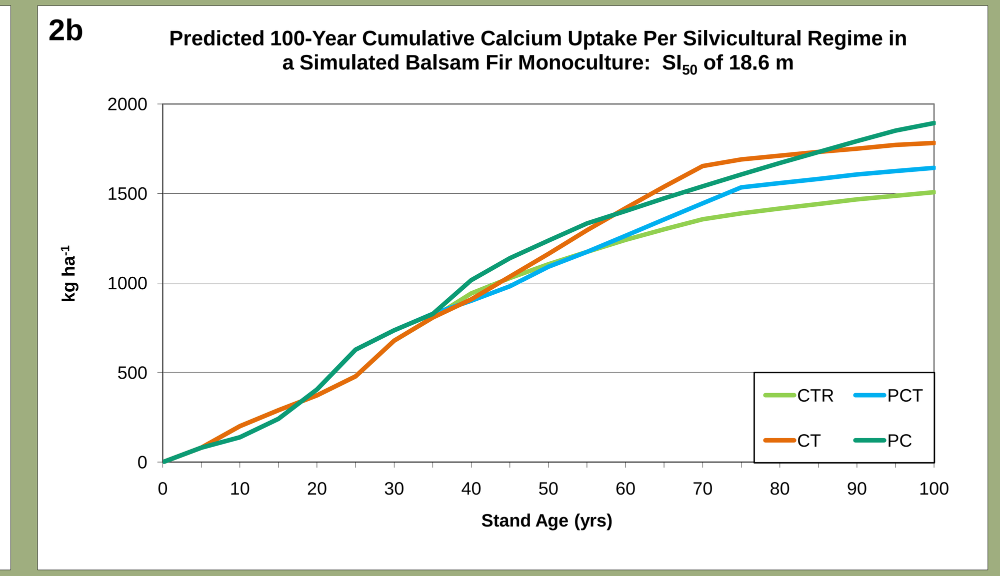
RESULTS

Figures 1a and 1b compare gross cumulative biomass accumulation per tree component between the CTR and PC scenarios. In both scenarios, stemwood was the largest component of cumulative biomass accumulation, followed by coarse roots. The PC scenario had a higher gross cumulative biomass accumulation at age 100 than the CTR, PCT, or CT scenarios. Thus, it appears that more intensive thinning leads to a greater cumulative biomass accumulation over time.









To date, this study has focused primarily on nitrogen and calcium as nutrients of concern. Figures 2a and 2b show differences in gross cumulative nitrogen and calcium uptake per silvicultural scenario. The most intensively thinned scenario in REMSS (PC) resulted in the highest cumulative uptake for all macronutrients, and the highest SI_{50} (i.e., 24.8 m) had the highest cumulative uptake for all macronutrients. Thus, intensively managed forests with higher SI_{50} take up more nutrients than those with lower SI_{50}.

Table 2 shows primary literature estimates of biomass and nutrient removals with whole-tree clear-cut harvests in mature northeastern spruce-fir forests. This level of harvest is similar to the BPCC scenario predicted by B-Fir REMSS.

Table 2: Representative Biomass and Nutrient Removals (kg ha^{-1}) with Whole-Tree Harvest in Mature Northeastern Spruce-Fir Forests

Biomass	N	P	K	Ca	Mg	Source
210467	410	59	245	537	57	Smith et al. 1986
182000	336	40	176	--	--	Hendrickson et al. 1987
119856	387	52	159	413	36	Weetman and Webber 1972
282388	346	65	158	448	--	Norton and Young 1976
136000	310	38	144	360	39	Freedman et al. 1981

Table 3 estimates end-of-rotation nutrient removals predicted by B-Fir REMSS for each treatment scenario. It is apparent that a biomass for energy (BPCC) treatment results in the largest cumulative removal of nutrients. The literature estimates presented in Table 2 generally fall between the B-Fir REMSS estimates for SI_{50} 12.4 m and 18.6 m. Many spruce-fir sites in the northeastern United States and southeastern Canada are characterized by minimal to moderate SI_{50} values due to poor site drainage and marginal site quality. Thus, the fact that literature estimates lie within the low-to moderate SI_{50} classes of B-Fir REMSS predictions lends support to the efficacy of the model.

Table 3. REMSS Predicted Cumulative Biomass and Nutrient Removals with Harvest (kg ha^{-1})

	Biomass	N	P	K	Ca	Mg
SI_{50} of 12.4 m						
CTR	n/a	n/a	n/a	n/a	n/a	n/a
PCT	20753	93	21	67	90	12
CT	37720	49	12	50	152	8
PCC	40589	133	30	99	158	17
PCC	135213	273	69	213	446	36
BPCC	169016	341	86	267	557	45
SI_{50} of 18.6 m						
CTR	n/a	n/a	n/a	n/a	n/a	n/a
PCT	19902	90	20	65	87	11
CT	39248	123	25	88	155	15
PC	50973	188	30	106	180	18
PCC	271696	478	109	331	821	53
BPCC	339620	597	136	413	1027	66
SI_{50} of 24.8 m						
CTR	n/a	n/a	n/a	n/a	n/a	n/a
PCT	16102	76	16	55	73	10
CT	33768	170	43	95	129	17
PC	62120	276	47	162	260	29
PCC	313744	549	131	398	975	65
BPCC	392180	686	164	498	1219	81

When compared with literature estimates, B-Fir REMSS was found to overestimate phosphorus, and to a lesser extent, calcium removal with harvest. The reason for this overestimation in the model is under investigation.

Comparison of REMSS nutrient removal estimates to literature estimates of nutrient pools and fluxes for comparable forest types indicate the greatest concern for nutrient availability due to management may be with calcium. Under the highest removal rates in REMSS for nitrogen, there would be no net change in nitrogen pools after 100 years, and it is likely total nitrogen pools would continue to increase even with biomass energy harvesting. For calcium, a representative value for current exchangeable calcium pools in regional spruce-fir forests is ≈975 kg ha^{-1} . Cumulative estimated calcium removal with a biomass for energy harvest (BPCC) in a SI_{50} of 24.8 m spruce-fir stand is 1219 kg ha^{-1} (Table 3). Pool estimates are for exchangeable calcium only, and neglect critical calcium fluxes that occur in forests. Nevertheless, the magnitude of the harvesting removals compared to the available pool for this nutrient suggests there is cause for a critical examination of the implications of biomass energy harvesting for long-term forest sustainability on some sites. The availability of calcium in forest soils is not only a concern related to forest harvesting intensity, but has been well documented as a concern due to the effects of acid deposition (Weetman and Webber 1972, Smith et al. 1986, Federer et. al 1989, Hornbeck et al. 1990, Watmough et al. 2005). Further research into the magnitude of leaching losses, dry deposition, and weathering rates of calcium is warranted to gain a better understanding of the magnitude of risk of depletion from forest soils and the characteristics of soils subject to these concerns.

CONCLUSIONS

The model REMSS, parameterized for balsam fir, is a useful tool for predicting nutrient uptake and removal in managed forest ecosystems. The ability to parameterize the model to various species and site conditions allows model application to a broad range of forested ecosystems. In the absence of suitable empirical field studies encompassing the appropriate forest types and site conditions, REMSS offers a simulation tool to address comparisons of silvicultural options in managed forests *in silico*. As there is increasing pressure on the utilization of forest resources, there is an increased need to provide forest managers with practical guidelines to take full advantage of new market opportunities while maintaining forest ecosystem services and sustainability. This study is being carried out to evaluate a modeling tool that could help address uncertainty, identify research priorities, and provide an indication of risk deserving of further attention in forest management decisions.

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