Evaluating the Sustainability of Forest Production When Jack Pine Stems and Logging Residues Are Used for Energy Production

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Abstract

Biological constraints on the utilization of natural jack pine (*Pinus banksiana* Lamb.) forests for energy production were examined. The amount of biomass in tree stems and logging residues was estimated for three pine stands of moderate productivity in northeastern Ontario. These data were used to estimate mean annual increments (MAI) for aboveground biomass. The environmental impacts of utilizing pine biomass for fuel were assessed by comparing MAI and nutrient removals by harvesting with estimated potential sustainable annual increment (SAI), on the basis of rate of replenishment of soil nutrients at each site. The simulation model ForSust was used to calculate SAI levels for different fire and harvesting scenarios. For whole-tree harvesting, SAI was less than MAI at all three sites.

Résumé

Nous avons examiné les contraintes biologiques rattachées à l'utilisation des forêts naturelles de pin gris (*Pinus banksiana* Lamb.) dans la production d'énergie. En estimant la biomasse contenue dans la tige des arbres et les résidus d'exploitation de trois peuplements de pin de productivité modérée dans le Nord-Est de l'Ontario, nous avons pu estimer l'accroissement annuel moyen (AAM) de la biomasse aérienne. L'impact environnemental de la valorisation énergétique de la biomasse des pins a ainsi pu être évalué à chaque site en comparant l'AAM à l'enlèvement de substances nutritives par la récolte à l'accroissement annuel soutenable (AAS) estimé d'après la vitesse de réapprovisionnement du sol en substances nutritives. À l'aide du modèle de simulation ForSust, les niveaux du AAS ont été calculés pour différents scénarios d'incendie et de récolte. Dans les 3 cas, l'AAS calculé pour la récolte par arbres entiers est inférieur à l'AAM.

Introduction

Increasing the potential supply of wood for fuel from managed or unmanaged forest stands may be accomplished several ways. Whole-tree chips can be produced in conifer stands by early thinnings, which improve stand density and enhance the growth and quality of the crop trees. Utilization of biomass during final harvesting can be increased by whole-tree harvesting. New production methods are reducing the cost of harvesting logging residues as fuel for energy production during the final harvest (Asplund 1997). Rapid early growth of the forest can be captured by shortening rotation lengths.

Operational and economic considerations, however, must be balanced with biological considerations. Whole-tree harvesting produces higher biomass yields than a stem-only harvest of the same stand (Freedman et al. 1981). The chief biological consideration is whether the additional biomass recovery will be offset by a loss of sustainability of forest production in the future. Increased biomass yields are accompanied by the removal of nutrient-rich foliage and branches. Increased biomass removal from the site, therefore, may decrease nutrient availability in the soil (Olsson et al. 1996), which in turn may result in a long-term reduction in stand growth during the next crop rotation. In the short term, increasing harvesting intensity has had a short-term positive effect on postharvest biomass production (Hendrickson 1988).

Evaluating the impacts of harvesting in biological terms is a considerable challenge. Harvesting impacts have traditionally been assessed by contrasting nutrient removals, determined by preharvest budgets, with soil nutrient contents (Foster and Morrison 1976). Soils, however, differ widely in their ability to supply nutrients necessary to sustain forest productivity. Biologically available nutrient pools in soil, furthermore, are difficult to define (Mahendrappa et al. 1986) and are spatially and temporally extremely variable.

Nutrients in the soil are replenished by weathering of primary minerals, precipitation, and decomposition of plant residues. Additional insights on harvesting impacts, therefore, can be realized by the nutrient mass balance approach that evaluates whether nutrient exports can be balanced by replenishment processes over the rotation period.

Our current state of knowledge allows only broad generalizations with respect to identifying species-site combinations that are at risk to lose future production if biomass utilization were to be increased for energy production. In response, process studies, experimental field trials, and computer simulation models need to be integral parts of any research program that examines the environmental consequences of intensive forest harvesting. For example, results from long-term experimental trials (Powers et al. 1990) are needed to quantify the magnitude and timing of any post-harvest production losses. Simulation models are useful in extending the results, from a limited number of experiments, to a greater range of species-site combinations. Process studies provide new knowledge to help explain experimental results and for the development and calibration of simulation models. The Environmental Issues Activity Group (IEA Bioenergy Task XII, Activity 4.2) has provided an international forum that promotes research in each of these areas (Dyck et al. 1996).

Part of the research integration has begun with the application of the ForSust model (Bhatti et al. 1998) to evaluate the long-term effects of harvesting and other site disturbances on potentially sustainable forest biomass production. This model can be used to judge environmental impacts by applying a long-term nutrient mass balance approach for each site. With this approach, nutrient removals by harvesting are compared with the replenishment of soil nutrients by mineral weathering and precipitation. In this paper, we extend our initial analysis with jack pine forests from across Canada and assess the biological consequences of harvesting stems and logging residues at three jack pine (*Pinus banksiana* Lamb.) stands in northeastern Ontario.

Study Area

Three mature, fire-origin jack pine stands, of average productivity (Table 1) were selected within the Algoma and Sudbury districts of northeastern Ontario. The Superior 2 and Nimitz sites were located south of the town of Chapleau, the Eddy 4 site was north of Webbwood. The sites were located in the Missinaibi-

Table 1.   General Stand Characteristics for Mature Jack Pine.

Site	Age (yrs)	Mean DBH* (cm)	Mean height (m)	Stems/ha	Basal area m²/ha
Eddy 4	71	19.2	15.9	818	23.7
Superior 2	75	20.7	17.9	814	27.4
Nimitz	68	18.4	18.2	1140	30.3

* Diameter at breast height.

Table 2. Distribution of Biomass (tonnes/ha) among Major Components of Jack Pine Stands.

Site	Biomass				
	Foliage	Branches	Bark	Bole	Total
Eddy 4	8	18	9	80	115
Superior 2	9	21	11	95	136
Nimitz	7	18	10	106	142

Table 3. Simulated SAI Values (tonnes/ha/yr) for Specific Harvesting and Forest Fire Scenarios, and Field-estimated MAI Values.

Site	Estimated MAI	Harvesting SAI Harvest type *				Forest Fire SAI % Base loss		
		WT.	BWB	SO	DB	0	50	100
Eddy 4	1.62	0.68	0.90	1.22	1.38	2.43	1.81	0.90
Superior 2	1.81	0.63	0.79	1.08	1.12	1.43	1.43	0.95
Nimitz	1.94	1.08	1.18	2.04	2.35	2.59	2.26	1.23

* WT = Whole-tree. BWB = Bole, Wood, Branches. SO = Stem-only. DB = Debarked bole.

Cabonga section of the Boreal Forest and the Temagami section of the Great Lakes St. Lawrence Forest (Rowe 1972). These jack pine stands contained a minor component of black spruce (*Picea mariana* [Mill.] B.S.P.). The soils, dystric brunisols or weakly developed humo-ferric podzols (Canada Soil Survey Committee 1978), were coarse-textured well-drained materials developed from glacial outwash or fluvial deposits. The length of the growing season, annual precipitation and mean July temperature varied between 160-175 days, 800-900 mm, and 16-17° C, respectively.

Methods

The ForSust model input is limited to annual summaries of climate, local estimates for actual evapotranspiration (AET), wet atmospheric deposition for nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg), general soil conditions (depth, clay content, soil parent material type, and soil Ca, K, Mg availabilities), and biomass and nutrient concentrations for foliage, branches, stemwood and bark. Locations for weather and atmospheric deposition information were chosen to match the jack pine site locations as closely as possible. Data sources included a climate CD-ROM (Environment Canada 1994), and the national stream water discharge rates (Environment Canada 1992).

The field-estimated mean annual increment (MAI) in tonnes/ha/yr was computed (Bhatti *et al.* 1998) for each jack pine stand, from tree diameters, heights, ages, and densities on replicated 30m × 30m plots. Stemwood, branches, bark, and foliage were obtained in 1995 from four dominant pines

at each location (four samples per tree). Soil data were collected by horizons from a single pit in each plot. Standard procedures were used in the chemical analysis of N, Ca , K, and Mg in plant and soil materials (Foster and Morrison 1976). The potential sustainable annual increment (SAI) was computed as outlined in Bhatti *et al.* (1998).

Results and Discussion

The three sites supported jack pine of moderate productivity (Table 1). Standing crops had wood volumes of 172 to 248 m^3/ha and mean annual wood increments of 2.4 to 3.6 m^3/ha/yr. The amounts of dry matter in stem wood, bark, branches, and foliage that can be harvested from these stands are listed in Table 2. Jack pine stands accumulate only moderate amounts of nutrients (Foster and Morrison 1976). The order of abundance of nutrients in the boles was Ca> N>K>Mg. Potential logging residues (branches and foliage) would yield 25 to 30 tonnes/ha of biomass for energy production. Harvesting logging residues for fuel would increase the nutrient removal considerably: removal of the entire aboveground portion of the trees would double the N and increase by 50 to 75% the amount of the other nutrients harvested.

Model estimates for potential SAI biomass are presented in Table 3 for various site-disturbance scenarios. These estimates show that model-simulated SAIs for fire-regenerated jack pine stands correspond fairly well with field-estimated MAI values as long as the proportion of bases lost during disturbance does not exceed 50% of the nutrients in the trees (i.e., SAI = MAI). The maximum amount of biomass energy would be produced if all the

aboveground dry matter in these stands were utilized (whole-tree harvesting). The ForSust calculations suggest that nutrient removals associated with whole-tree harvest would not be sustainable at current MAI levels (SAI<MAI: Table 3). At two of the sites (Eddy 4, Superior 2) the estimated rate of nutrient replenishment was not sufficient to replace the estimated rate of nutrient removal if only stemwood were extracted.

A word of caution with respect to the interpretation of model results is in order, however: the model production predictions in this paper need to be validated by assessing biomass recovery in long-term experimental trials that assess the impacts of different levels of nutrient removals associated with harvesting and site preparation. Such trials were established in 1994 at the three locations in this report, and at six additional sites, across a range of jack pine productivity (Tenhagen et al. 1996).

The sustainability of current biomass production was generally found to be unattainable with whole-tree harvesting for 17 jack pine sites from across Canada, according to ForSust model results (Bhatti et al. 1998). On most of these sites, ForSust-estimated nutrient replenishment rates would not be able to compensate for the whole-tree nutrient exports. Only in some jack pine sites was the nutrient supply judged to be sufficient to justify whole-tree harvesting. In principle, such evaluations need to be extended to additional pine sites in order to identify jack pine sites that are (or are not) at risk to lose future production with respect to intensive harvesting practices. Since jack pine stands are generally associated with with infertile sites, it is reasonable to suggest that jack pine stands are a poor choice with respect to providing wood or logging residues for energy production. Boreal stands containing mixedwood associations of white spruce (*Picea glauca* [Moench] Voss) and trembling aspen (*Populus tremuloides* Michx.) are likely suitable candidates for such use. Such stands generally produce high biomass yields, especially when found on fertile lacustrine and till soils.

Conclusions

In this case study a yield of 115 to 142 tonnes/ha of dry matter would be realized with jack pine stands if all the aboveground biomass of these stands were to be utilized for energy production. Quite moderate yields of biomass would be realized if only the logging residues from these average productivity jack pine stands were used for fuel. ForSust-simulated SAI was generally less than field-estimated MAI when stem-only and whole-tree harvesting were assessed. The results of model simulations were interpreted as demonstrating that the nutrients removed during logging would have to be replaced to avoid a loss in forest productivity in the next rotation. We suggest that site impoverishment, through depletion of nutrients by harvesting, is a concern on coarse-textured, infertile soils. The costs associated with protecting the long-term nutritional integrity of these sites must, therefore, be accounted for when assessing the commercial viability of utilizing jack pine for energy production.

Acknowledgments

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