



# Frontline

*Forestry Research Applications*

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## COMPUTER MODEL PREDICTS DIMINISHED PRODUCTIVITY OF TOLERANT HARDWOOD FOREST FOLLOWING FULL-TREE HARVESTING

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**CATEGORY:** Forest environment

**KEY WORDS:** Modeling, productivity, hardwood forest, harvesting

### INTRODUCTION

An understanding of the impacts of various harvesting systems on future site productivity is important to the development of plans and practices for sustainable forestry. Forest managers need reasonable indications as to how today's practices will affect growth over successive rotations. It is not acceptable to wait decades, even centuries, for the results of studies on the growth response of forests following harvest. Even then, results would only apply narrowly to the specific site conditions under study.

Short of empirical studies, there are three basic approaches for evaluating the impact of different harvesting methods on forest ecosystem nutrient reserves. These provide researchers and managers with estimations that are useful in planning future activities. The first involves static comparisons of site nutrient capital with nutrients that would be removed through different harvesting methods. The second approach adds to the first by considering nutrient inputs such as precipitation, lateral water flow, and mineral weathering and outputs such as leaching, erosion, and harvesting (Smith et al. 1986, Mann et al. 1988, Olsson et al. 1993). The third approach uses information synthesized from the first two approaches to develop simulation models that predict possible changes in site productivity under different harvesting scenarios.

Although long-term experiments will provide the ultimate answer, modeling can be of help to researchers and forest managers in the short term. This technical note describes a simulation model that incorporates knowledge from years of scientific work into fundamental ecosystem processes. It can be used to predict the long-term effects of today's management choices on forest growth.

### THE MODELING APPROACH

Simulation modeling has become integral to research on the effects of environmental factors on forest growth, soil properties, and water quality. Models can provide a framework to integrate research results, develop scientific hypotheses, and project a forest's response to disturbance. Thus, they can aid managers in decision-making processes concerning harvesting choices and renewal prescriptions.

To be a reliable tool, a model is first calibrated to local site conditions. *Calibration* involves the development of mathematical relationships that describe what is taking place in the local system, for example, the relationship of calcium (Ca) leaching to other factors, such as soil solution chemistry, cation exchange capacity, and root uptake. Calibration requires baseline data from field collections (e.g., lysimeter readings, soil physical and chemical properties, forest biomass, forest growth rates). Once the model provides what appear to be reasonable estimations, it is then *validated* with additional data that was not used in the calibration.



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This note describes the use of a model called ForSVA (Forest Soil Vegetation Atmospheric Model),<sup>1,2</sup> which has been calibrated and validated for the Turkey Lakes watershed based on over 10 years of field data (Nicolson 1988, Morrison 1990, Foster et al. 1992). The result is a reasonable estimate of water, heat, ion fluxes, and net primary production in an undisturbed tolerant hardwood ecosystem.

## ABOUT ForSVA

The model, which contains some empirical relationships, describes different forest ecosystem processes using a series of differential equations. The major processes used in the model include: water flux in vegetation and soil, dry deposition, foliar leaching, nutrient uptake, nutrient translocation, litterfall, decomposition, mineralization of organic matter, cation exchange, anion adsorption, mineral weathering, and root respiration (Fig. 1).

uses an interactive, simple, high-level programming language called STELLA II on Macintosh and PC computers (STELLA 1994).

ForSVA can be used to predict the long-term effects of harvesting practices on individual upland forest stands and soils. Forests obtain nutrients from precipitation, organic matter decomposition, and mineral weathering. If nutrients are not removed by harvesting, all stand compartmental contents (biomass, nutrients in foliage, wood, fine roots, soil solution, and exchange sites) are repeated in a sequence of natural cycles. The model assumes that natural rotations of stand growth and decay follow a fairly reproducible cyclical pattern, at least over the course of a few centuries. Harvesting causes a break in nutrient cycling by removing mineral elements essential for plant growth and by disturbing the hydrological, geological, and biogeochemical components of the ecosystem.

## APPLICATION TO TURKEY LAKES WATERSHED

The Turkey Lakes watershed (located approximately 50 km north of Sault Ste. Marie, Ontario) consists of old-growth tolerant hardwood stands dominated by sugar maple (*Acer saccharum* Marsh.). The site is located on moderately steep terrain at an elevation of 350 m to 400 m. The soil parent material consists of a stony, silty loam ablation till over a compacted basal till at a depth of 0.5 m.

Input requirements for ForSVA are limited to: i) stand initialization (initial biomass and nutrient pools per stand compartment), ii) specified annual atmospheric deposition rates for all major ions ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{H}^+$ ,  $\text{NH}_4^+$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{HCO}_3^-$ ), and iii) numerical values for the various process parameters, such as decomposition, mineralization, respiration, and soil weathering. Values for most of the parameters can be obtained from biophysical data sets of biomass and nutrient distribution of mature forest stands. Data needed to run

the model were obtained from Nicolson (1988), Morrison (1990), and Foster et al. (1992).

Two harvesting scenarios were evaluated: i) stem-only cutting with 50 percent of all the wood removed along with 10 percent of the foliage biomass removed once every 100 years, and ii) full-tree, referred to in scientific literature as whole-tree (e.g., aboveground removal of tree components), clear-cutting with 80 percent of the wood and foliage removed once every 100 years.

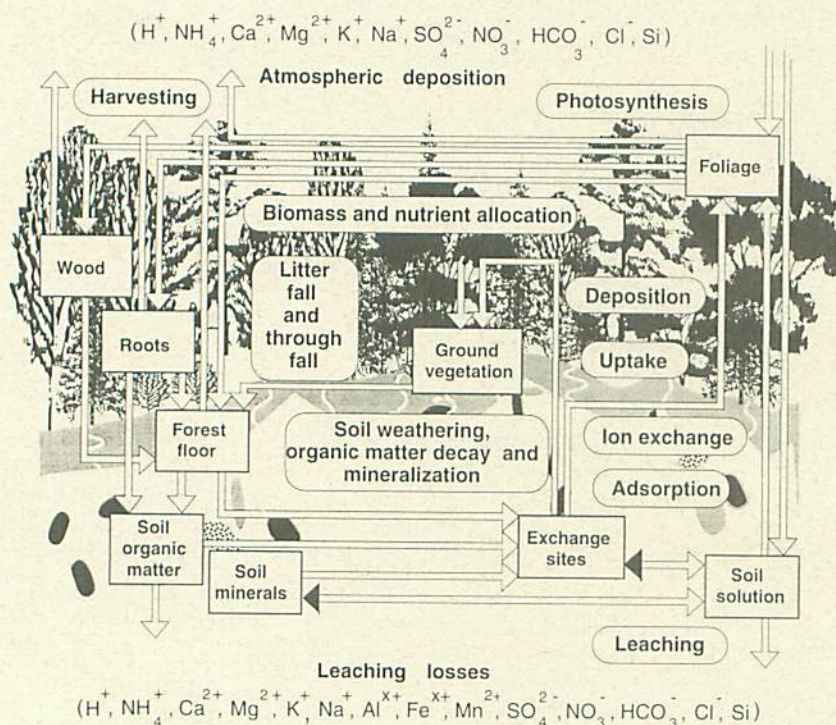


Figure 1. Schematic diagram of the ForSVA modeling environment: stand compartments and processes.

ForSVA carries out dynamic simulations that consider variations in time. The model is based on rate processes, which are driven by time variables. At present, the model runs on an annual time step. Primary productivity and nutrient cycling are simulated for the entire forest production cycle over many rotations. The end of a natural cycle occurs when the net productivity of the stand turns negative. To account for uncertainty, ForSVA can be run for many sets of input parameters to represent the variability in nature. ForSVA

<sup>1</sup>Arp, P.A.; Oja, T. A forest soil vegetation atmospheric model (ForSVA). I. Concepts. Ecol. Modell. (In press)

<sup>2</sup>Arp, P.A.; Oja, T. A forest soil vegetation atmospheric model (ForSVA). II. Application to northern tolerant hardwoods. Ecol. Modell. (In press)



Model simulation results for the Turkey Lakes tolerant hardwood forest are presented in Figures 2 and 3. Biomass in the forest floor, fine roots, wood, and foliage show an accelerated decline over five rotations with full-tree clear-cutting (Fig. 2). There was no significant influence on biomass production under a stem-only clear-cutting treatment. The effect of harvesting on cumulative leaching rates of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{K}^+$  from the rooting zone are presented in Figure 3. These simulations show that with full-tree harvesting there was relatively high leaching of exchangeable bases from the system. Nonrecoverable rates of base cation removal with harvesting and enhanced leaching rates resulted in forest growth decline. Using a mass balance approach, Johnson et al. (1991) and Likens et al. (1994) compared and contrasted the effect of clear-cutting patterns of tolerant hardwood forest at the Hubbard Brook Experimental Forest (HBEF) on soil exchangeable base cations. They observed that the greatest loss of cations was associated with biomass removal by full-tree harvesting. There was also a significant depletion of these base cations in the surface layers with retention in the Bh and Bs horizons in HBEF Spodosols. Results from the tolerant hardwood forest at the HBEF forest (Johnson et al. 1991, Likens et al. 1994), however, were reported after 10 years of harvesting. Simulation results for the Turkey Lakes tolerant hardwood forest (Figs. 2 and 3) are over five rotations.

The model simulations (Figs. 2 and 3) are based on the assumption that all model parameters remain fixed throughout stand development and during subsequent rotations. However, site process parameters (e. g., water flux in vegetation and soil, nutrient reserve) and productivity parameters (e.g., atmospheric  $\text{CO}_2$  concentrations and carbon allocation to wood, roots, and foliage) are likely to vary with changing forest structure, inputs, and environmental conditions. Relationships are highly variable from site to site, even within a single species such as sugar maple (Ouimet and Fortin 1992). Hence the model should be calibrated and validated at each site.

The model may not produce highly accurate predictions, but it does suggest that full-tree clear-cutting is a less sustainable

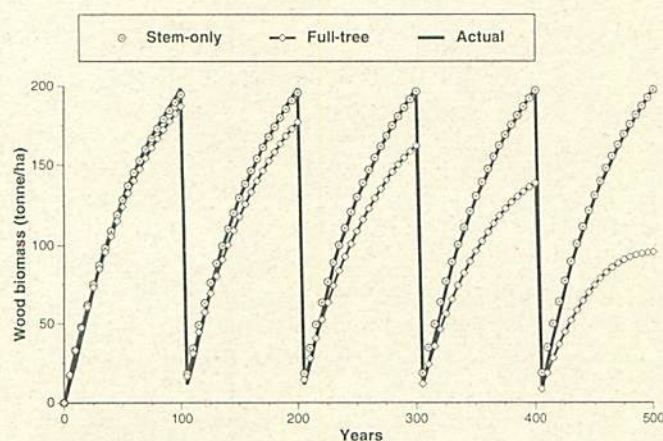


Figure 2. ForSVA simulated wood biomass compared with the biomass yield curve for the Turkey Lake site, starting with the present condition.

management practice for tolerant hardwoods than is stem-only cutting. The model has been tested on only one tolerant hardwood site. There is a need to apply the model to a range of site conditions and biological productivity for tolerant hardwood forests, ultimately within an ecological site classification framework. ForSVA has been developed for analyzing environmental/management stress to forest growth. It can be utilized to i) demonstrate how scientific knowledge on ecosystem functions can be integrated to assess long-term impacts of forest management decisions, ii) determine allowable limits for changes in key site variables that can be used to identify sites at risk of nutrient loss, and iii) assess productivity following harvesting and develop, in the short term, guidelines for environmentally acceptable forestry practices.

ForSVA simulations suggest that full-tree harvesting of hardwoods on the Turkey Lakes site could lead to reduced site productivity as a result of the removal of nutrient cations. Negative impact can be mitigated by the retention of nutrient-rich foliage and branches on the site at the time of harvest. Model predictions, however, need to be validated using the results from controlled long-term field trials (Powers et al. 1989). A trial has been established to investigate the impacts of tolerant hardwood management systems (clear-cutting,

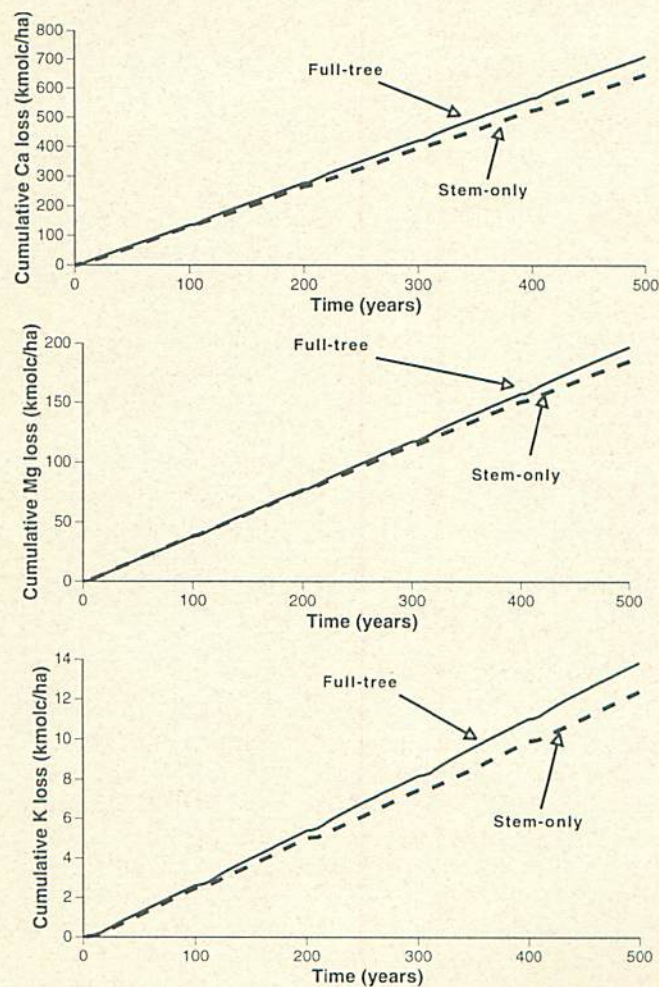


Figure 3. Comparisons of ForSVA simulated leaching losses for  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{K}^+$  under different harvesting scenarios.



selection cutting, and shelterwood cutting) on site vegetation productivity, nutrient capital and nutrient cycling processes, and yield and quality of water derived from the forest at the Turkey Lakes watershed.

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