REPRINTED FROM
WATERSHED RESEARCH
IN
EASTERN NORTH AMERICA
A Workshop To Compare Results
VOLUME II

February 28 - March 3
1977
Edited
By
David L. Correll

Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Edgewater, Maryland 21037
SIMULATION OF POTENTIAL EFFECTS OF FOREST UTILIZATION ON THE NITROGEN CYCLE IN DIFFERENT SOUTHEASTERN ECOSYSTEMS

Jack B. Waide
Department of Zoology
Clemson University
Clemson, SC 29631

and

Wayne T. Swank
Principal Plant Ecologist
Coweeta Hydrologic Laboratory
Franklin, NC 28754

Abstract—Research at the Coweeta Hydrologic Laboratory is examining effects of management practices on elemental cycles in forested watersheds. Forest harvesting methods may alter both quality of streamwater draining forested lands (the off-site response) and sustainable productivity of forests being managed (the on-site response). Results from Coweeta suggest that long-term changes in water-quality are not likely to result from current management practices, but effects on sustainable yield are unknown. Simulation models of nitrogen cycling were used to assess potential effects of several management alternatives on sustainable productivity and elemental cycling. Responses of nitrogen dynamics in oak-hickory and loblolly pine forests to simulated merchantable-stem and complete-tree harvests with several rotation lengths were examined. Results suggest that some management practices may lead to long-term alterations of nitrogen cycling and productivity, and that conclusions from such simulation studies will depend on how elemental cycling models are conceptualized. Discussions emphasize the importance of evaluating land-management alternatives in the context of current knowledge of forest elemental cycling processes.
INTRODUCTION

As discussed previously in this workshop (Monk et al., this volume), research in progress at the Coweeta Hydrologic Laboratory has two broad objectives. On the one hand, research is designed to elucidate basic aspects of the organization and function of southern Appalachian forest ecosystems. Manipulation of entire forest ecosystems as part of the Forest Service's experimental watershed program at Coweeta allows us to alter ecosystem dynamics, and thereby to understand better how such ecosystems function in the unperturbed state, as well as how these systems respond to and recover from specific disturbances. Net budgets (i.e., input minus output) for selected elements provide holistic measures of ecosystem function and perturbation response (Swank and Douglass, this volume). Research is then focused on elemental cycling processes internal to watersheds as a means of explaining total ecosystem response as revealed by elemental budget data. Such a research design, focusing both on total ecosystem behavior and on elemental cycling processes at lower organizational levels, provides a convenient and efficient approach to the study of forest elemental cycles.

A second complementary objective of our research program involves the application of basic knowledge being acquired about southern Appalachian forests to the evaluation of specific land-management alternatives. Resource management is synonymous with ecosystem management, and requires thorough understanding of functional characteristics of the ecosystem being managed. Elemental cycling is a critical ecosystem process, and provides a major mechanism for integrating specific populations which comprise a given ecosystem together into a holistic system. Thus, management techniques which seriously disrupt elemental cycles may well disrupt the entire ecosystem. Additionally, work at Coweeta and elsewhere has shown that cycles of certain key elements, especially nitrogen, are quite sensitive to forest alterations, and therefore serve as reliable indicators of ecosystem change (Swank and Douglass; Phillips et al., all this volume). However, if resource management is to be effective, we must be able to predict consequences of specific management practices for elemental cycles before any significant degree of ecosystem deterioration has occurred.
Two major questions exist concerning the response of elemental cycles to management practices. The first we might refer to as the off-site response: What effect does a given management practice have on the quality of surface water draining the managed area? Such problems are currently under study by the Forest Service (Douglass and Swift; McSwain, all this volume). The second major area of concern might be referred to as the on-site response: What effect does a given management practice have on sustainable, long-term productivity of the landscape area being managed? Such questions are more difficult to answer, and may be more critical over long time periods. For example, work at Coweeta and elsewhere has shown that, although elevated elemental losses are observed following forest cutting, and may persist for some elements up to about twenty years after treatment (Swank and Douglass, this volume), there are no long term deleterious effects on water quality. Similar statements cannot be made concerning effects on sustainable productivity, nor is it clear what trends might emerge. Yet, obtaining answers to such questions is now mandated by law. The "National Forest Management Act of 1975" requires that, for each management system to be used on Forest Service lands, it must be shown that it "will not produce substantial and permanent impairment of the productivity of the land...."

These questions are especially critical today, in light of projected trends in forest management practices. Projections of future levels of wood fiber utilization suggest large increases in demand for forest products for the remainder of this century. Southeastern forests in particular are projected to supply an increasing share of the nation's need for wood products. Increased rates and amounts of harvest of woody material from forested lands may involve such practices as shortened rotation lengths, complete tree harvests, intensive site preparation techniques, and related methods. Such management practices raise severe questions in relation to sustainable productivity, which should be thoroughly assessed before these methods are used on a widespread basis.

Our approach to addressing such questions has been to construct models of elemental cycles in forest ecosystems, and then to use these models to simulate possible effects of forest cutting alternatives on these systems. Because nitrogen regulates productivity in diverse forest types, and
because the nitrogen cycle is especially susceptible to disturbance, we will emphasize this element. The next section of this paper provides information on models used in this study. Following that, specific simulation results will be discussed and interpreted.

**THE SIMULATION APPROACH**

**Models of the Nitrogen Cycle**

Nitrogen cycling models and simulation techniques used in this study have been described previously (Waide et al., 1974; Mitchell et al., 1975; Waide and Swank, 1975; Webster et al., 1975), and will only be summarized here.

Figure 1 presents a compartmental model of the nitrogen cycle in an undisturbed oak-hickory forest at Coweeta. Data used to construct and quantify this model came from an intensive study of a 12.45 ha north-facing watershed (WS 18) at Coweeta. This watershed has served as a control for much early work on elemental cycling at Coweeta. This diagram depicts amounts of nitrogen contained in various storage compartments in the ecosystem (kg N/ha), transferred among pools (kg N/ha/yr), and retained in plant compartments as annual increments (kg N/ha/yr). Not shown in Fig. 1 are various inputs to and outputs from the system. Inputs include inorganic nitrogen in precipitation (3.4 kg N/ha/yr) and nitrogen fixed by microorganisms (10.9 kg N/ha/yr); outputs include inorganic nitrogen in streamwater and sediments (0.31 kg N/ha/yr) and denitrification (10.7 kg N/ha/yr) (Mitchell et al., 1975; Todd et al., 1975; Waide and Swank, 1975). Gains and losses of nitrogen in organic forms were not included here, as data have only recently become available. Remaining assumptions and data underlying this nitrogen model are discussed by Mitchell et al. (1975).

It can be seen in Fig. 1 that most of the nitrogen in this forest is contained in large storage pools which turn over slowly. Over 80% of total nitrogen is bound within soil organic matter (turnover rate of .007 per year), with about 11% totally in plant pools (turnover rate of .136 per year). However, although the nitrogen cycle in this forest appears to be dominated by large compartments which turn over slowly, a dynamic portion of the cycle exists in the soil. As shown in the right-hand portion of Fig. 1, much greater amounts of nitrogen flow through microbial, NO$_3$-N, and NH$_4$-N.
Figure 1. Compartmental model of the nitrogen cycle in an oak-hickory forest at Coweeta. Values inside large boxes represent standing crops of nitrogen (kg N/ha); values in small rectangles are vegetation increments (kg N/ha/yr); numbers on arrows represent nitrogen transfers among compartments (kg N/ha/yr). The total diagram is broken into two halves for ease of illustration; several compartments appear in both halves.
pools than are contained within them, and turnover rates for these three compartments are quite high. This rapidly recycling part of the nitrogen cycle may be largely responsible for nitrogen conservation in this ecosystem (Mitchell et al., 1975), and may be important in regulating ecosystem response to specific management practices (Waide and Swank, 1975). Hence, analyses which ignore or obscure this part of the nitrogen cycle may not accurately depict the response of the forest to disturbance.

In undertaking this study, we were interested not only in evaluating the response of the nitrogen cycle in the oak-hickory forest on WS 18 to management alternatives, but also in comparing the response of this forest to that of other southeastern forests. However, similar studies available for comparison have not provided such a fine-resolution compartmentalization of nitrogen cycling (e.g., Boyle et al., 1973; White, 1974; Henderson and Harris, 1975; Jorgensen et al., 1975; Patric and Smith, 1975; Wells and Jorgensen 1975; Wells et al., 1975). Thus, to facilitate comparison with other studies, a lumped, seven-compartment version of Fig. 1 was constructed by combining and eliminating various compartments (Fig. 2). Comparison of these two figures reveals which pools were eliminated, or were combined with others into new compartments of the lumped model. Of special importance is the fact that microbial, NO$_3$-N, and NH$_4$-N pools of the expanded or fine resolution model (Fig. 1) are all contained within the single soil pool of the more coarsely resolved model (Fig. 2). Hence, their contribution to nitrogen dynamics has been totally obscured in the smaller model. We should emphasize that these two models are based on the same data, but simply represent different levels of resolution of nitrogen dynamics.

The southeastern forest chosen for comparison with the Coweeta oak-hickory forest was a loblolly pine plantation in the Duke forest. Loblolly pine is the most important commercial tree species in southeastern forests, and many contrasts exist between the two forest types (e.g., natural forest vs managed plantation; uneven aged, many species vs even aged, monoculture; deciduous vs evergreen; etc.). The compartmental model shown in the right-hand portion of Fig. 2 is specifically based on data from a plantation established in 1953, and thinned in 1968 at age 16 (Jorgensen et al., 1975; Wells and Jorgensen, 1975; Wells et al., 1975). Data used here were based upon standing crops and transfers at age 16, and were used as originally
Figure 2. Compartmental model of the nitrogen cycle in southeastern oak-hickory and loblolly pine forest ecosystems. Diagram on the left is a lumped, seven-compartment version of Fig. 1. On the right is a model of the nitrogen cycle in a loblolly plantation in the Duke Forest. Labelling conventions as in Fig. 1.
Following cutting was not considered an alternative to summarization.

A decision-tree model was trained on the forest type, forest features, management alternatives considered in total, and the results were then used to identify potential effects of management alternatives on interaction. The interaction models were then employed to estimate the effects of interaction on the forest.

In order to minimize the effects of interaction on the forest, the models were trained on the forest type, forest features, management alternatives considered in total, and the results were then used to identify potential effects of management alternatives on interaction. The interaction models were then employed to estimate the effects of interaction on the forest.
The exact methods of simulating these management practices are detailed by Waide and Swank (1975). Four successive rotations were simulated for each type and frequency of cut for each model. We will consider simulated effects of management alternatives on the three nitrogen models by examining model outputs for three composite nitrogen pools in each model: amount of nitrogen contained totally in (i) all above-ground portions of plants; (ii) all litter pools, including both woody and leaf litter; and (iii) all non-living soil pools, including NO$_3$-N and NH$_4$-N where appropriate. Using these simulated results, we will make two types of comparisons. First, results of the expanded and lumped oak-hickory models will be compared, to examine how the degree of system conceptualization affects the results of such a simulation study. Second, results of the lumped hardwood model will be compared with those of the pine model. These two models were conceptualized at similar levels of resolution, and such comparisons should be meaningful.

In a related paper, Waide and Swank (1975) used this approach to examine potential changes in forest yield after several rotations for the management practices considered here. Results of this earlier study showed that some management alternatives may definitely lead to long-term decreases in forest productivity. We are concerned here with internal properties or characteristics of nitrogen cycles which might regulate or cause changes in yield.

SIMULATION RESULTS
Nitrogen Removal Due to Harvest

The first question to ask concerning management impacts on nitrogen cycling relates to the amounts of nitrogen removed from each ecosystem for each simulated type and frequency of cut. Table 1 presents simulation results on amounts of nitrogen removed (kg/ha) in forest products or as logging residue, as well as annual nitrogen removal rates (kg/ha/yr), over three simulated rotations. The greatest impact for both forest types, measured either as amount of nitrogen removed or as annual removal rate, was greatest for simulated complete-tree harvests. For the oak-hickory models, the second highest amounts of nitrogen removed occurred in merchantable harvest simulations with 90-year rotations. However, shorter,
Table 1. Impacts of different types and frequencies of cutting on loblolly pine and oak-hickory forest ecosystems. Values indicate the amounts of nitrogen removed from the ecosystems over three rotations, and the rates of removal, for each type and frequency of cut.

<table>
<thead>
<tr>
<th>Ecosystem Model</th>
<th>Type of Cut</th>
<th>Rotation Length (yrs)</th>
<th>Nitrogen Removed (kg/ha)</th>
<th>Nitrogen Removal Rate (kg/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak-hickory (15 compartment)</td>
<td>Merchantable (A)*</td>
<td>90</td>
<td>523.7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Complete-tree (B)</td>
<td>90</td>
<td>1371.8</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Merchantable (C)</td>
<td>50</td>
<td>499.8</td>
<td>0</td>
</tr>
<tr>
<td>Oak-hickory (7 compartment)</td>
<td>Merchantable (A)</td>
<td>90</td>
<td>569.1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Complete-tree (B)</td>
<td>90</td>
<td>1475.8</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Merchantable (C)</td>
<td>50</td>
<td>537.8</td>
<td>0</td>
</tr>
<tr>
<td>Loblolly pine (7 compartment)</td>
<td>Merchantable (A)</td>
<td>30</td>
<td>344.6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Complete-tree (B) (with residue removal)</td>
<td>30</td>
<td>815.1</td>
<td>230.0</td>
</tr>
<tr>
<td></td>
<td>Merchantable (C) (with thinning at age 16)</td>
<td>30</td>
<td>491.8</td>
<td>0</td>
</tr>
</tbody>
</table>

*Captial letters will be used as shorthand codes for the indicated type of cut.
50-year rotations had higher annual rates of nitrogen removed than did 90-year rotations. For the loblolly pine model, the second highest impact was the simulated thinning alternative, while the least impact occurred for the unthinned, merchantable harvest simulation.

In comparing across models, values for the lumped oak-hickory model are seen to be higher than comparable values for the more finely resolved Coweeta model. As discussed below, the more coarsely lumped model predicts less severe effects on the oak-hickory forest than does the fine resolution model, and hence greater yields in terms of amounts of nitrogen removed from the ecosystem as forest products. Comparisons of the lumped oak-hickory model and the loblolly model reveal higher total amounts of nitrogen removed from the hardwood forest, but greater annual rates of nitrogen removal for the pine model due to much shorter rotation lengths for this model.

Impacts due to forest harvesting can be placed in perspective by comparing values in Table 1 with streamwater nitrogen losses following cutting. Swank and Douglass (this volume) reported increased losses of NO$_3$-N of about 2 kg/ha/yr following cutting of Coweeta forests. Hence, rates of nitrogen removal in forest products (Table 1) are greater than are rates of NO$_3$-N loss in streamwater attributable directly to logging. However, these streamwater values do not include organic forms of nitrogen, and the comparison is incomplete. As data from a current logging study at Coweeta become available, the importance of stream losses will be more completely evaluated. Swank and Douglass also reported that such increased rates of streamwater losses typically do not persist for longer than 20 years at Coweeta, giving a maximum total streamwater loss of nitrogen following cutting of about 40 kg N/ha/rotation, again much smaller than simulated rates of nitrogen removal in forest products. Hence, unless post-cutting conditions foster extremely elevated NO$_3$-N and/or organic nitrogen losses (e.g., Likens et al., 1969), nitrogen removal from forest ecosystems in harvestable products is likely to have more severe on-site impacts on forest nitrogen cycles than will elevated stream losses following cutting.

Changes in Nitrogen Pool Sizes

Figure 3 depicts nitrogen dynamics in aboveground plants, litter, and soil for simulations involving the expanded oak-hickory model (Fig. 1).
Figure 3. Simulation results for the expanded oak-hickory model (Fig. 1). Shown are simulated amounts of nitrogen in aboveground plants, litter, and soil over four rotations of each type and frequency of cut. Simulated results of an uncut forest are shown for comparison. Labels on graphs refer to the type of cut (Table 1).
Simulated curves are shown for each management alternative considered, as well as for an uncut forest. Discrete breaks in plant graphs occur at times of simulated cutting. Part of the nitrogen contained in plants is removed from the system at these times, and the rest is transferred to litter pools causing the sudden peaks in litter graphs at these times. The plants then regrow from zero until the forest is again "cut," at 50- or 90-year intervals. Curves for the various harvesting strategies follow curves for the uncut forest exactly up to the time of first cutting (i.e., up to a time of 50 or 90 years). Peaks in litter graphs for complete-tree harvest simulations are much smaller than for merchantable harvest simulations because more material is removed from the system in complete-tree simulations, and hence less is transferred to litter pools at times of cutting.

Several trends are obvious in Fig. 3. First, curves for all three management alternatives lie significantly below the curve for the uncut forest. Peaks in litter graphs for simulated cuts may cross the curve for the "control" forest, but the smoother post-cutting portions of these graphs lie below the control graph. Although significant amounts of material are added to litter pools at times of cutting, this material decays rapidly. Litter pool sizes never recover to uncut levels since litter fall inputs are decreasing as shown by trends in plant graphs. Hence, all three management practices may lead to depletion of nitrogen pool sizes in hardwood forests. Additionally, the magnitudes of differences between simulated cut and uncut forests increase in later rotations, showing that nitrogen depletion may increase with increasing time of management. Finally, the complete-tree harvest seems to have the greatest negative effects on nitrogen pool sizes. This is especially evident in soil nitrogen graphs. Simulated merchantable harvests with 90-year rotation lengths gave the least impact, although nitrogen depletion is still obvious for these simulations. The shorter rotation is intermediate in the degree of change it produces in nitrogen pool sizes.

Figure 4 presents similar simulation graphs for the lumped oak-hickory model. The format of these graphs is the same as for Fig. 3. Although simulation results shown in Fig. 3 and 4 are results of two models of the same system, several striking differences can be observed. First, effects
Figure 4. Simulation results for the lumped oak-hickory model (Fig. 2). Shown are simulated amounts of nitrogen in aboveground plants, litter, and soil over four rotations of each type and frequency of cut. Simulated results of an uncut forest are shown for comparison. Labels on graphs refer to the type of cut (Table 1).
of cutting practices on nitrogen cycles predicted by the two models are quite different. The lumped model predicts that all three cutting alternatives will be less damaging (Fig. 4) than does the expanded model (Fig. 3). This difference is especially obvious in soil graphs for the lumped model, where curves for merchantable harvests closely parallel the curve for the uncut forest. Moreover, trends observed in Fig. 3 for increasing nitrogen depletion through time are not seen in Fig. 4, except for complete-tree harvest simulations. The only similar result is in the relative ranking of the three harvesting methods, with the greatest impact for the complete-tree harvest and the least for the merchantable harvest with a 90-year rotation.

Differences in simulation results for these two models of the Coweeta oak-hickory forest are due to different levels of resolution of the two models. Specifically, the lumped model has obscured the functionally important role of microbial, NO$_3$-N, and NH$_4$-N pools in forest nitrogen cycles. These three compartments have extremely high turnover rates, and significantly regulate forest response to management perturbations. Plants take up nitrogen from pools of free nitrate and ammonium in soil, rather than from some amorphous pool of soil organic nitrogen. Hence, any disturbance which significantly affects these nitrogen pools will have a significant effect on the entire forest ecosystem. Clearly, then, the way in which a given system is conceptualized will strongly influence conclusions on the effects of management practices on ecosystem elemental cycles.

Comparable results for loblolly pine simulations are shown in Figure 5. The only difference in the format of these graphs is the presence of the simulated "pulpwood thinning" (graphs labelled "C"), which produces mid-rotation deviations in several of the graphs. There was little difference between the two simulated merchantable stem harvests, and neither simulated cutting differed substantially from the uncut forest simulation. This result is especially obvious in soil graphs, where simulated merchantable harvest curves lie above the uncut simulation. In contrast, results of the simulated pine complete-tree harvest reveal the greatest nitrogen depletions of any of the simulated cutting alternatives for any model. If sufficient data had been available to construct an expanded model of pine nitrogen
Figure 5. Simulation results for the loblolly pine model (Fig. 2). Shown are simulated amounts of nitrogen in aboveground plants, litter, and soil over four rotations of each type and frequency of cut. Simulated results of an uncut forest are shown for comparison. Labels on graphs refer to the type of cut (Table 1).
A comparison between model outputs and observed target than it should be. In any
terms, the model’s output is more plausible, especially for
the oak-hickory forests at 90 years. Also, in percentage of changes in
A comparison between model outputs and observed target than it should be. In any
terms, the model’s output is more plausible, especially for
the oak-hickory forests at 90 years. Also, in percentage of changes in
Table 2. Simulated changes in nitrogen pools in aboveground plants, litter, and soil in the fourth compared to the first rotation for oak-hickory and loblolly pine forest ecosystems. Values indicate absolute and percentage changes in the indicated components, as well as what percent the indicated change is of the total amount of N removed for the given cutting type over the first three rotations (Table 1).

<table>
<thead>
<tr>
<th>Ecosystem Model</th>
<th>Type of Cut*</th>
<th>Aboveground Plants</th>
<th>Litter</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg/ha % of N removed</td>
<td>kg/ha % of N removed</td>
<td>kg/ha % of N removed</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-95.3 -21.2 -7.0</td>
<td>-32.1 -21.3 -2.3</td>
<td>-831.0 -22.9 -60.6</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>-73.1 -16.9 -14.6</td>
<td>-23.6 -16.7 -4.7</td>
<td>-676.0 -18.6 -135.2</td>
</tr>
<tr>
<td>Oak-hickory (7 compartment)</td>
<td>A</td>
<td>+10.7 +2.4 +1.9</td>
<td>+3.4 +2.4 +0.6</td>
<td>+130.1 +3.2 +8.9</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-40.9 -9.0 -2.8</td>
<td>-12.8 -9.0 -0.9</td>
<td>-330.5 -8.1 -22.4</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>-1.0 -0.2 -0.2</td>
<td>-0.3 -0.2 -0.1</td>
<td>+24.6 +0.6 +4.6</td>
</tr>
<tr>
<td>Loblolly pine (7 compartment)</td>
<td>A</td>
<td>+30.5 +10.3 +8.9</td>
<td>+65.6 +15.3 +19.0</td>
<td>+232.1 +14.7 +67.4</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-113.5 -38.3 -10.9</td>
<td>-175.0 -40.8 -16.7</td>
<td>-567.0 -36.0 -54.2</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>+13.3 +4.6 +2.7</td>
<td>+62.3 +16.9 +12.7</td>
<td>+113.2 +7.2 +23.0</td>
</tr>
</tbody>
</table>

*See Table 1.
case, this net nitrogen accumulation for the pine model (+4.75 kg N/ha/yr) is larger than for the Coweeta models (+3.29 kg N/ha/yr).

CONCLUSIONS

In concluding this paper, we do not wish to belabor points already raised, but rather to emphasize briefly additional aspects of this study.

First, we do not offer results presented here as exact, quantitative predictions of effects of management practices on nitrogen cycles in southeastern oak-hickory and loblolly pine forest ecosystems. In many ways, models of nitrogen cycling used here are incomplete and oversimplified. Basic information is lacking on what ecological processes regulate the extent of forest disruption, as well as the extent and rate of recovery, following forest disturbance. Until our knowledge of regulatory processes affecting elemental dynamics in forest ecosystems improves, all predictions such as those offered here will remain tentative. But that should not prevent us from attempting to apply our presently limited knowledge to the evaluation of forest management techniques. At Coweeta we are currently studying the specific effects of forest cutting on elemental dynamics in another oak-hickory forest (Monk et al.; Douglass and Swift, all this volume). This study and others in progress at Coweeta will help to improve both our knowledge and our models of elemental cycling processes in southern Appalachian forests. Thus, models are being used in our work as evolving hypotheses, continually being refined and improved, but nonetheless useful at each stage of development to evaluate alternative management practices.

In spite of the above qualifications, we do feel confident about qualitative and comparative aspects of our predictions. If anything, we suggest that predictions offered here are conservative estimates of changes expected in southeastern forests subjected to intensive management practices. Any of the regulatory processes currently not accounted for in our models of elemental cycling act in complex fashions, and may involve threshold-types of behavior. Such regulatory processes typically lead to extreme disruptions of elemental cycles once certain limiting values are surpassed (Hutchinson, 1948). For example, models currently predict smaller increases in streamwater NO₃-N losses than we have measured at Coweeta, reinforcing the idea that predictions of management effects on nitrogen cycling are
probably conservative. Perhaps more importantly, effects of forest practices on nitrogen cycles will be site specific, and the two sites considered here are relatively high quality sites. Effects are likely to be much more severe on less fertile soils where nitrogen pools are smaller.

Finally, we should emphasize again the importance of applying basic ecological knowledge to the evaluation of proposed and actual forest management techniques. Management alternatives must be considered in the framework of a sound conceptual approach to ecosystem processes, as well as in relation to their specific impacts on forest elemental cycles. At present, modeling studies are the only means we have available to provide short-term answers to serious problems which may develop over a long period of time. Results presented here in fact strongly suggest that intensive forest management alternatives may have serious consequences for forest nitrogen cycles, and hence for sustainable forest productivity.

ACKNOWLEDGEMENTS

Research supported in part by the U.S. Forest Service, Southeast Forest Experiment Station, and in part by Grant BMS 74-12088 AO1 from the National Science Foundation to the Institute of Ecology, University of Georgia.

REFERENCES


Douglass J. E. and Swift L. W. Jr. (1977) Forest Service studies of soil and nutrient loss from roads, logging, mechanical site preparation, and prescribed burning in the Southeast. This volume.


orgensen J. R., Wells C. G. and Metz L. J. (1975) The nutrient cycle: key to continuous forest production. J. For. 73, 400-403.


Swain M. R. (1977) Baseline levels and seasonal variations of enteric bacteria in oligotrophic streams. This volume.


DISCUSSION

Bliven: Do you have any data to go with that more sophisticated model? Is it really a better predictive model or is that just a hypothesis?

Waide: At this point, it is strictly a hypothesis. I would hope that it is in the sense that it's a more finely resolved look at the system. As you may remember, from some of the previous talks based on Coweeta, they were currently in the process of doing a clear cutting in one of the forests at Coweeta. We hope to look at these kinds of results in the context of that clear cut and hopefully not only evaluate the results but use the information gained there to improve our models. The model in many senses is very simplistic and that's why I'm not really enamored with the exact quantitative predictions. But, at the present time, no, I can't say that one is a better representation although I would hope that the more finely resolved model is.