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PROCEEDINGS OF THE 1986 SYMPOSIUM ON THE PRODUCTIVITY OF NORTHERN FORESTS FOLLOWING BIOMASS HARVESTING

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INTRODUCTION

The Symposium focused on the impacts of biomass harvesting--cutting and skidding of whole trees often followed by chipping of some or all of the material--on forest productivity. Practicing foresters, land managers, and policy makers met to exchange information and ideas with forest scientists and professionals from state regulatory agencies.

Session I was entitled "Regional Overview of Biomass Harvesting: State Policy and Outlook." Representatives of New York, Vermont, New Hampshire, and Maine summarized the following information for each state, respectively: existing and predicted attitudes and legislation concerning biomass harvesting; estimates of the number of facilities using biomass for energy; the total amount of biomass harvested per year; and the number of operators currently conducting harvesting operations. In addition, results were presented from a survey on the influence of wood-fired electrical generating facilities on forest management and cutting practices in the Northeast.

In Session II, "Impact of Biomass Harvesting on Forest Site Quality," scientists evaluated removals of biomass and nutrients, site disturbance associated with cutting and skidding, and changes in nutrient cycles, soil fertility, and rates of decomposition of organic matter resulting from several harvesting procedures.

Session III, "Silvicultural Considerations of Biomass Harvesting," presented the economic, silvicultural, and ecological considerations of biomass harvesting, and subsequent regeneration of coniferous and hardwood species.

At Session IV, Dr. Lloyd Irland of the Maine State Planning Office challenged a panel of the representatives from each of the four states to answer the question "Should the State Regulate Biomass Harvesting?"

Comparisons of forest statistics for New York (NY), Vermont (VT), New Hampshire (NH), and Maine (ME) (Table 1) provide a useful background for the presentations made in this Symposium. ME has the largest total acreage and proportion of the state in forest land. Approximately the same amount of forest land accounts for 90% of the total land area of ME but only 57% of NY. On an areal basis, timberlands in NH or VT are less than one-third of those in NY and ME. The volume of timber on commercial timberlands is predominantly hardwood in NY and VT, about evenly divided between hardwoods and softwoods in NH, and predominantly softwood in ME. Commercial forest land and forest product-related industries are of major interest and concern in all four states.

Recent emphasis on intensive utilization of forest lands in the Northeast has resulted in an increase in the practice of biomass harvesting. Based on the data presented in Session I (Table 2), use of whole-tree chippers and biomass harvesting are most extensive in ME, and least developed in NY. In ME, wood chips are used primarily to generate electricity for regional power grids. Elsewhere, chips are used by a variety of wood-processing and other industries as well as for space heating and generation of electricity.

Both the practice of biomass harvesting and the availability of related data are rapidly changing in all states. By assembling current practical and scientific information, these Proceedings provide a regional prospective on resources, problems, and trends related to biomass harvesting in the Northeast.

Table 1. Summary of forest statistics for four states in the Northeast.[a/] Actual and percent of the total land area of the state in forest land, commercial forest land, and percent hardwood and softwood components of the net volume of all timber on commercial timberlands.

State	Forest Land (x 1000 acres)	(%)	Commercial (x 1000 acres)	Hardwood (%)	Softwood (%)
New York	17,218.4	(57)	14,243.3	74	26
Vermont	4,511.7	(76)	4,429.9	65	35
New Hampshire	5,013.5	(88)	4,692.0	54	46
Maine	17,718.3	(90)	16,864.0	31	69

[a/] From USDA Forest Service. An analysis of the timber situation in the United States 1952-2039. Forest Resource Report No. 23; 1982. 499p.

Table 2. Summary of data on biomass harvesting in New York (D. Smith), Vermont (B. Stone), New Hampshire (T. Natti), and Maine (M. Cyr), presented in Session I of the Symposium.

State	Current No. Operators	No. Whole-tree Chippers	Tons of Whole-tree Chips Harvested	Operations Using Wood Fuel
NY	7	--	300,000[a]	10
VT	29	26	333,000	151
NH	17	29	1,150,000	75
ME	40	50	1,600,000	15

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[a] Approximate Metric/English Equivalents

1 meter (m)	=	3.3 feet or 1.1 yards
1 kilometer (km)	=	5/8 mile
1 hectare (ha)	=	2.5 acres
1 kilogram (kg)	=	2.2 pounds
1 kilogram/hectare	=	1.1 pounds/acre
1 ton/hectare	=	0.446 tons (of 2,000 lb)/acre

NEW YORK STATE BIOMASS HARVESTING POLICY AND OUTLOOK

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The level of use of biomass for fuel in New York is about 5.6 million tons in 1984. 4.6 million tons are consumed as residential fuelwood, with the remaining 1 million tons consumed by 85 industrial and institutional facilities. About 10 of these facilities burn 250,000 tons in the form of whole tree chips. Support for the use of wood for fuel in New York has come from the State Dept. of Environmental Conservation's (D.E.C) technical assistance program, from technical support by the S.U.N.Y. College of Environmental Science and Forestry, and from funding for research, conferences and workshops by the New York Energy, Research and Development Authority. The D.E.C. is also developing an environmental impact statement entitled "Dept. Policy on Whole Tree Harvesting in New York," meant to help guide policy makers' decisions regarding potential impacts of whole tree harvesting. Current State regulations do not address whole tree harvesting, although there are State and local regulations which control some aspects of harvesting. These regulations have not had any specific impact on whole tree harvesting, so further growth in demand for biomass/whole tree harvesting will likely depend on the price of alternate fuels more than anything else.

Biomass harvesting has been practiced in New York on a relatively small scale since the late 1970's. A vast supply of low quality hardwoods and tops are available for consumption. Incentives to use this biomass are not yet strong enough to open a new market for whole tree chips. However, conditions in New York are changing. Use of biomass harvesting has threatened to explode in the past year. Many factors may inhibit this change, but the potential is still there.

Biomass use in New York can be divided by amount of consumption into three categories: residential fuelwood, roundwood used by the timber industry, and other uses. Residential use, by far the largest category, consumed 4.7 million tons in 1983. Roundwood consumed by the timber industry is about 66% of residential fuel by weight. Use of wood for fuel by industries and institutions is about one-fifth by weight of residential fuel use (Table 1).

Biomass harvesting in New York (whole tree harvesting) yields traditional timber products plus whole tree chips used primarily for fuel. There are about 85 wood-burning facilities in New York which could handle whole tree chips, but only a small percentage actually use them. About one million tons of wood, mostly residues from manufacturing processes, are burned by industries and institutions in New York. Of this total, approximately 250,000 tons are whole tree chips, burned by 6 to 10 facilities. These chips are supplied by 6 or 7 whole tree harvesting operations working primarily in New York. In addition, about 20,000 to 30,000 tons of whole tree chips are harvested for use in Canada and Vermont.

Table 1. Annual use of wood for energy in New York, 1983-84.

User	Tons/Year
Residential**	4,672,431
Wood Processing Industries*	641,825
Other Industries*	203,037
Educational Institutions*	56,484
Hospitals*	61,163
Total	5,634,940

* Includes only those combustion units of 1 million BTU's or larger.

**Conversions from cords to tons:
1.51 tons/cord hardwoods @ 15% MC
1.26 tons/cord softwoods @ 15% MC

Users of whole tree chips in New York include the wood processing industry, educational institutions, and a few other industries. Lyons Falls Pulp and Paper (formally Georgia-Pacific) is the largest user of whole tree chips. Clarkson and Colgate Universities have successfully burned wood chips and achieved significant economic savings. Successful use of wood for fuel promotes a positive picture of continued growth in wood-energy facilities in New York.

Currently the State of New York does not have regulations specific to biomass harvesting, nor are any planned. Only a limited number of regulations directly affect harvesting. These can be divided into laws and regulations in affect statewide, and those affecting lands under jurisdiction of the Adirondack Park Agency (APA), a regional land use planning and control authority.

Statewide

* Stream Protection Laws - protect stream banks, stream bottoms, and water quality. Streams with water quality designations may not be crossed without a permit from the Department of Environmental Conservation. Permits usually specify allowable crossing method.

* Top Lopping - as part of the Forest Fire Protection law, harvest of evergreens in towns designated as fire towns must include lopping of branches to a 3" diameter top.

* Wetlands Law - selective harvesting of timber is exempt from regulation. Permits may be required for road construction.

* Town Harvesting Ordinances - any town may pass its own harvesting ordinance. Of 932 Towns in New York about 30 have ordinances; only 11 include major restrictions.

* Wild, Scenic, and Recreational Rivers - a state, not a federal program. Harvesting along rivers so designated must follow certain guidelines for location of roads, erosion control, and cutting.

<u>Adirondack</u> <u>Park</u> - <u>APA</u> <u>Regulations</u>

* Clearcutting - a permit from the APA is required for clearcuts over 25 acres.

* Shoreline - vegetation removal is restricted within 35´ of the shores of all navigable streams, rivers, ponds and lakes.

* Wild, Scenic and Recreational Rivers - similar to statewide regulations, but under APA regulation.

* Wetlands Law - inside the Park and within wetlands, a permit is required for road building and clearcuts larger than 3 acres. Selective harvesting is exempt.

The Department of Environmental Conservation (DEC) is beginning to look closely at biomass harvesting in New York. As a result of concern over proposals for wood-fired electrical generating plants, the DEC is developing a state environmental impact statement entitled "Department Policy on Whole Tree Harvesting in N.Y." This policy applies to the impacts of whole tree harvesting throughout New York, rather than site specific impacts. The intent will be to assemble and evaluate the implications of present knowledge, and to develop DEC policy addressed at real, not perceived, problems with whole tree harvesting. The study will examine the potential impacts of whole tree harvesting, and weigh the risks against policy options.

Why did New York decide to develop an environmental impact statement (EIS)? Environmental impact statements are the most important part of New York´s State Environmental Quality Review program (SEQR). The program has been in effect long enough to establish well-defined rules and regulations. It is also a convenient framework to deal with substantive and procedural requirements and formalize public input into the process. This ensures that assessments are thorough and include input from all interested parties.

In the short term, the drop in the price of oil will hurt development of wood-fired facilities, especially those proposing to generate or co-generate electricity. Utilities have offered developers low purchase rates for electricity, and they have been supported by the Public Service Commission´s pro-consumer stand. As a result, few wood-fired electric generating plants will be built in the next few years. PSC´s stance, probably due to its legal responsibilities, does not consider overall economic benefits of local power resources.

There are incentives to encourage the use of wood for fuel. The D.E.C. has had a very active technical assistance program for encouraging use of wood for fuel. The New York Energy Research and Development Authority has supported use of wood for energy by funding research projects, workshops, and conferences. Governor Cuomo recently proposed expanding the authority of the Power Authority of New York to contract with private companies to generate electric power from hydro, garbage incineration, and wood-fired plants. Air pollution control policies have encouraged use of wood by limiting emissions at coal-burning facilities. Wood chips mixed with coal lower the average emission of sulfates and are an easy solution to emission control. These incentives show wood energy is supported by State policies.

Biomass harvesting will probably increase in New York in the long term. Whole-tree removal is generally accepted by the public and understood to refer to partial cuts as well as clearcuts. Economics are most likely to determine the extent of utilization of wood versus other fuels. The DEC environmental impact statement on whole tree harvesting will focus on what areas of concern there are and where we need more knowledge of the impacts. If present market conditions continue, potential problems can be met before there is a large increase in demand for forest biomass.

REGIONAL OVERVIEW OF BIOMASS HARVESTING: STATE POLICY AND FUTURE TRENDS -- THE VIEW FROM VERMONT

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A "Governor's Task Force on Wood as a Source of Energy" and concurrent Vermont Department of Forests, Parks and Recreation "Study of the Feasibility of Generating Electricity Using Wood as a Source of Energy" concluded that developing the chip harvester technology could contribute to improving the quality of Vermont's forests while suppling economical wood chip fuel. The Forest Resource Advisory Council recommended that chip harvesting operations in the State be monitored, but not regulated, to determine the extent of cutting and quality of forest management associated with supplying an expanding biomass-chip fuel market. In response to the development of Burlington Electric Department's 50 megawatt biomass boiler, Vermont had 26 chip harvesters operating in 1984. Ninety two percent of the operations monitored in 1984 had technical or professional forestry supervision. Biomass harvesting appears to provide Vermont a relatively low risk, high gain opportunity, with a cost-benefit ratio high in benefits.

The 1968 Vermont Forest Survey Report stressed the need for a massive forest improvement effort throughout the state to remove an ever-increasing preponderance (49 percent) of low-quality trees which were clogging forest stands with rough and rotten culls. The report also stressed the need to double an exceedingly low growth rate to better realize the potential productivity of our soils. A continuing lack of adequate markets for low-grade material, and an economical means for harvesting such material were key problems in resolving this silvicultural dilemma.

The tremendous surplus of unmerchantable wood, increasing costs of, and predicted shortages of non-renewable fossil fuel generated electricity, lack of cultural work in the forests due to limited markets, the disappearance of open space and wildlife habitat, and increasing tax rates on marginally productive woodlands, prompted Governor Dean Davis at the Fifth Annual Governor's Conference on Natural Resources in 1972 to propose a rather far out idea to "return Vermont forests to a sustained yield basis by using the current annual timber surplus to fuel steam generating plants for the production of electricity." He admitted the data was fragmentary but stressed that "the concept does not appear totally unrealistic." He cited a 600,000 cord "surplus growth" and "salvageable wood lost in mortality" which contained 10.8×10^{12} BTUs of energy. He calculated that 56% of Vermont's energy needs at the time could be met at a 50% efficiency ratio in converting the surplus wood to electrical energy. At $0.10 per gallon for No. 6 fuel oil (those were the good ole days) he figured wood could compete at $12.00 per cord and finally cited studies indicating that wood-fired steam electric plants should cost no more than fossil fuel plants to build and maintain.

The chain reaction he envisioned from such an event was equally fascinating.

1. There need be no sulfur dioxide emissions,
2. wood ashes could be recycled as fertilizer,
3. Vermont forests could be economically maintained on a sustained yield basis,
4. thinning and full tree utilization could become profitable,
5. surplus hardwood, which has high BTU ratings, would be consumed,
6. there could be complete utilization of clearcuts,
7. yield per acre, and hence tax tolerance per acre of woodlot, would increase,
8. jobs in harvesting and transportation would increase, ...and so on.

After challenging participants in the conference to provide seminal ideas for pursuing such an initiative, he stated, "the opportunities have never been so great."

In Vermont, burning wood for energy played a major role in meeting fuel and heating requirements well into the 20th Century. By 1972, new oil heating technology had pretty well become a way of life which was convenient, economical and "clean" compared to the dirty inconvenience of burning wood or coal. However, as oil prices began to rise, as our dependency upon the Arab-controlled oil cartel began to appear less and less reliable, and as air pollution from high sulfur fuels were starting to cause some concern, Governor Davis' idea began to make more and more sense.

Subsequently, a "Governor's Task Force on Wood as a Source of Energy" and a concurrent "Study of the Feasibility of Generating Electricity Using Wood as a Source of Energy" sponsored by the Vermont Department of Forests and Parks in cooperation with the U.S. Forest Service, concluded that the old notion that wood was a viable and economical source of energy was still true and that an abundance of this native renewable fuel was at hand. In fact, it was estimated that the supply of unmerchantable surplus wood exceeded all previous estimates, when data was converted to units of biomass, and could provide for <u>all</u> of Vermont's heating requirements. It appeared that chip harvester technology could procure, process and deliver wood chip fuel more economically than ever before and that the technology to convert wood to energy did exist, though more research and development was needed. It was believed that proper forestry practices could control environmental damage. In fact, if carried out properly, these practices could benefit the health, vigor and growth of residual stands; although the monitoring of erosion, nutrient balance, wildlife habitat, aesthetics and air pollution should receive attention. Finally, these studies concluded that such a new developing industry could increase employment, produce substantial new revenues, and increase jobs and tax revenues. It appeared that many of Governor Davis' concepts, several years earlier, were indeed not totally unrealistic.

It began to look like we might be able to have our cake and eat it too. A wood energy program initiative could make a significant contribution to the growing problem of energy availability and at the same time provide a substantial market for the large unmerchantable surplus of low-quality trees using biomass harvesting which was impeding silvicultural practices so desperately needed to increase the quality and growth of Vermont forests.

Of course, there remained many unanswered questions: Many "ifs" and "buts," many doubts, skepticism and even alarmism over the prospect that "the chip harvesters are coming!" and our forests would be exploited by widespread clear-cutting. The need for cutting practice regulation was discussed in legislature and debated by the newly created Forest Resource Advisory Council, but a special study committee concluded the problem of overcutting and poor forest practices did not appear to be serious enough to warrant such expensive bureaucratic action at the time; although monitoring of chip harvesters was recommended.

As the use of wood for energy increases, we need to watch the situation and monitor developments and trends to make sure this two-edged sword continues to be used to our advantage. It must not be allowed to get out of control and cause serious damage as has occurred in the Third World. Though renewable, forest resources are not infinite and new mechanized harvesting systems have the capacity to mow down large acreages of trees in a relatively short time. However, there is a temptation to overreact and call for forest practice regulation. Unless things start to get out of hand such drastic and expensive measures should be deferred.

Dire predictions that the "chip harvesters were coming" to clearcut all the timber in ever increasing circles extending outward from the 50 megawatt Burlington electric plant have not materialized. Our chip harvester monitoring program showed an increase in number of machines operating in Vermont from 9 in 1981 to 26 in 1984. These operations included broadly distributed thinning/improvement cuts on 1900 acres (40% of total), agricultural conversion clearcuts on 731 acres and silviculturally acceptable regeneration clearcuts on 2300 acres. Only six of the 74 operations visited did not have technical or professional forestry supervision. Our inspecting foresters also observed that operators were becoming more sensitive to wildlife and aesthetic concerns. Only four of the operations had any notable erosion problems, all of which were subsequently corrected with guidance from the inspecting forester. Conditions did not substantially change in 1985.

Though the monitoring program is only that and not regulatory, it serves as a watchdog process that increases awareness of silvicultural, wildlife, erosion control, water quality and aesthetic considerations by foresters and operators on the job.

Another special survey conducted in response to reports of widespread clearcutting in northeastern Vermont prompted the State Forestry Division to conduct an aerial survey, followed by ground inspections of large regeneration cuts completed in three pilot townships over the past ten years. It was found that 1.2% of the commercial forest land in two towns and 1.6% in the other had been subjected to regeneration cuts per year, not excessive for a 60 to 80 year rotation. For all forest land in the respective towns, regeneration by desired species was more than adequate on all but one of the thirteen selected sites. Problems noted included insufficient waterbarring and so-called shelterwood cuts that were no more than commercial clearcuts with poor quality residuals left for sheltering and seeding.

To calm the fears of some who were concerned about excessive and poorly managed harvesting which would result from a single plant requiring up to half a million tons of wood per year, Burlington Electric developed a procurement policy, which effectively precluded the need for cutting practice regulation in the eyes of the Vermont Public Service Board in granting them a certificate of public good to operate. In consultation with the Department of Forests, Parks & Recreation, cutting practice standards based on accepted U.S. Forest Service and state silvicultural practices and erosion control, guides were adopted, which would be met by their chip suppliers or their contract would be jeopardized. Enforced by BED foresters, violations have been few and minor and the harvesting requirements have posed no problem relative to the procurement of adequate amounts of chips. In fact, the silvicultural impacts of biomass harvesting under these controls are proving to be quite positive. Regionwide, Burlington Electric has calculated that over 75% of the sites from which fuel chips have been harvested in the last year were cut according to good silvicultural practices.

Because of the limitations of harvesting with heavy equipment in steep terrain and the difficulty of maneuvering feller bunchers and grapple skidders in heavily stocked stands, partial cuts are now accomplished using conventional chain saw felling and skidders with stockpiling in concentration yards with a hydraulic knuckleboom for custom chipping. This modified harvest system also precludes much damage to the residual stand, and is advisable for all partial cuts.

Clearcutting, whether used as an acceptable silvicultural method for regeneration in even-aged management or not, is drastic, unsightly and disturbing to many people, especially when it involves large acreages in highly visible locations. The shelterwood system can and should be substituted wherever possible and clearcuts should be limited to 25-50 acres, be contoured, cut in strips, non-contiguous and visually modified.

Common problems associated with logging, including road layout, erosion, muddying streams, slash and trash, create the kind of mess which doesn´t help the image of wood harvesting. Logger education, close supervision, and adherence to erosion control guides are a must.

The highest silvicultural standards should be met. Multiple use objectives to protect or perferably enhance wildlife habitat, watershed, recreational, and aesthetic values should be given special attention.

Aggressive public relation campaigns presenting reliable information to the public, legislators and administrators in <u>understandable</u> form, are especially important in gaining and holding public confidence in forest management and biomass harvesting practices.

In summary, from our perspective, there do <u>not</u> appear to be any significant negatives associated with biomass harvesting which cannot be dealt with.

Questions, risks, problems--yes, but those associated with harvesting and using biomass are not greater than those normally encountered in managing for, or harvesting other wood products. Biomass harvesting provides a relatively low risk, potentially high gain <u>opportunity</u>, with a cost-benefit ratio high in benefits.

In Vermont this harvesting method:

- has provided increased management flexibility by allowing forest managers to carry out needed silvicultural improvements not economically feasible even a decade ago;

- will improve income potential for paying taxes, investing in further cultural work and long-term value added for higher quality products;

- has ancillary benefits such as wildlife habitat improvement and recreational opportunities possible at no extra cost to the landowner;

- can benefit the local and general economy through increased employment, a broadened economic base, stabilized energy costs and increased indirect multiplier benefits; and

- can help instill a forest management ethic among forest landowners; has been a partial answer to a forester´s prayer in Vermont.

We believe that biomass harvesting has had a past and present, and will be a tool of proper forest management for increasing productivity of our forests in the future.

<u>Acknowledgements</u>

This paper was excerpted and adapted from a keynote address by E. Bradford Walker, Director of Forests, Vermont Department of Forests, Parks & Recreation for the New York Society of American Foresters Winter Meeting, January 1986.

NEW HAMPSHIRE OVERVIEW OF BIOMASS HARVESTING: STATE POLICY AND FUTURE TRENDS

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The New Hampshire Division of Forests and Lands has been assertive in encouraging biomass harvesting on small woodlots in the State. A cooperative research project conducted during 1981-82 determined that weedings, thinnings, and selection harvests could be accomplished with results that were pleasing to landowners and acceptable to the public. The 75 facilities that are currently burning wood for space heating, process steam, or electrical production, consume about 1,150,000 tons of forest biomass and sawmill residues annually. An estimated 500,000 tons come from whole-tree chips. Biomass production could readily be sustained at an estimated 2,800,000 tons per year, of which 2,150,000 tons could come from whole-tree chips. The 17 chip operators currently active in the State could expand operations as additional markets develop. Biomass harvesting shows great promise for increasing the quality of the forest, improving the forest economy, and diversifying the energy base of the State.

The improved quality and long term productivity of northeastern forests depends to a considerable degree on the economic use of low grade forest materials. I'm convinced that we should continue to strive for quality in our forests, not just quantity. To achieve that goal will require a substantial increase in utilization of cull trees and other low quality wood. Biomass harvesting represents the most realistic potential in this regard.

At the New Hampshire Division of Forests and Lands, we are enthusiastic about the possibilities. After observing and studying what S.D. Warren Co., Westbrook, Maine, was doing in the late 1970's in the field of biomass harvesting, we adopted an assertive role in encouraging biomass harvesting on small woodlots in New Hampshire.

We sponsored, in cooperation with the Cooperative Extension Service, U.S. Forest Service, and others, a biomass harvesting project during 1981-1982. We wanted to find out if biomass harvesting on small woodlots was economically feasible, following generally accepted operational and silvicultural practices. Also, we wanted to document public reaction to such harvesting procedures. We conducted about 20 integrated operations totalling more than 400 acres, mostly selection cutting. We found out that weedings, thinnings, and tree selection harvest cuts not only could be done satisfactorily, but the results were generally pleasing to the landowner and acceptable to the public.

New Hampshire's forest resources can absorb a significant increase in removals of low grade wood. Here is some 1983 forest survey information to support that conclusion.

1. Total acres of timberland = 4,812,000 acres

2. Total green weight of all standing trees = 502,032,000 tons

   which includes:

   (Growing stock) pole timber and sawtimber trees = 275,199,300 tons

   (Non-growing stock) rough and rotten trees, salvable dead trees, saplings, stumps, tops = 226,833,000 tons

3. Estimated annual increment (whole tree) (a personal analysis)

   4,812,000 acres x 3 tons per acre/year = 14,436,000 tons

   (represents about 3% annual increment)

4. Estimated annual removals (in tons) (developed in conjunction with Governor's Energy Committee)

	Tons
Sawtimber	1,300,000
Shortwood	1,100,000
Biomass (energy wood, other chips)	1,100,000
Residential fuelwood	1,500,000
Total annual removals	5,000,000

5. Total growth/drain ratio

   14.4:5 or about 3:1, leaving about 9,400,000 tons of unused annual growth.

6. Present volume of low grade standing wood available for biomass harvest in addition to annual growth -

	Tons
Rough cull trees	20,300,000
Rotten cull trees	14,800,000
Dead trees	12,900,000
Tops in rough/rotten trees	13,000,000
Total	61,000,000

   or about 12 tons/acre, on the average

7. Reserve factor

As much as 25% - 50% of timberland may not be available for harvesting for various reasons. There is little agreement on this figure, so each observer should apply his own limiting factor on timber availability.

8. Present biomass consumption

Presently in New Hampshire, approximately 75 facilities burn wood either for space heating, process steam, or for electrical production. In total, they consume about 1,150,000 tons of forest biomass and sawmill residues annually. Of this total, an estimated 650,000 tons are sawmill residues and an estimated 500,000 tons come from whole tree chips.

Several new cogeneration facilities are being built, or are planned to be built, including plants in Bethlehem, Springfield, Alexandria, Bridgewater, and Whitefield, each scheduled to use about 200,000 tons of wood annually. Other plants of various sizes are being discussed in West Swanzey, Tamworth, Rochester, Penacook, and Bennington.

The only thing certain is that not all these facilities will be built. However, it is likely that biomass use will double in the next five years. This wood will mostly be derived from whole tree chips.

9. Whole tree chip operators

Currently, an estimated seventeen chip operators are active in the state, using an estimated twenty-nine chippers. Nine of the operators with thirteen machines are located in southern New Hampshire and the remaining eight operators with sixteen machines are found in the North.

Indications are that existing operators would expand their operations as markets demand. Also, potential new operators are sitting in the wings waiting for opportunities.

10. Projected biomass supply

If markets for biomass were to expand as previously described, would the added material be readily available and would the logging industry infrastructure be able to produce and deliver the wood?

On the basis of existing forest conditions, landowner attitudes about biomass harvesting, logging/chipping capacity, and assuming an adequate price structure to provide reasonable financial returns to the various interests from landowner to consumer, it is my estimate that biomass production could be readily increased and sustained at an estimated 2,800,000 tons per year. Sources of this volume are anticipated as follows:

	Tons
1. Sawmill residues	650,000
2. Logging residues from 25,000 acres	1,000,000
3. Whole tree chips from land clearing, forest improvement operations, etc.	1,150,000
Total	2,800,000

General Conclusions

Short term biomass consumption could increase by an estimated 1,650,000 tons without stressing wood supply and production infrastructure. Sawmill residues will remain fairly constant and the bulk of added volume will come from forest operations.

In the long term, considering an increase of biomass usage to 2,800,000 tons, with other utilization holding at current levels, forest removals would total about 7,000,000 tons per year, or about one-half the state's estimated annual growth. However, the available supply is supplemented in the first cutting cycle by the approximately twelve tons per acre average of standing rough and rotten trees.

I think 7,000,000 tons per year total removals is the caution point and the time for detailed assessment of the state's forest resources and implementation of an action program to assure future sustained yields.

There are presently no statutory or other regulatory constraints on biomass harvesting except several existing statutes which apply to all forest operations. New Hampshire does not regulate silvicultural practices.

Public concerns are frequently expressed about nutrient losses due to biomass harvesting. In fact, a bill relating to this topic that was entered in the 1985 legislature is being quietly committed to interim study. If done on a tree selection basis, I have no great concerns about the impact of whole tree harvesting on nutrients, but this conclusion is based on casual study and observation. This conference can be very important in helping bring more understanding to this subject.

It is my continuing opinion that the harvesting and marketing of forest biomass will do wonders for forests and the forest economy. It is an opportunity which has many positive ramifications -

- for landowners in increased income
- for loggers in more business
- for foresters to practice what they preach

- for the public in their improved perception of timber harvests

- for the forests in upgrading quality

- for the state in contributing to a diversified energy base.

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BIOMASS HARVESTING AND ENERGY PRODUCTION: THE MAINE EXPERIENCE

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The Small Power Production Facilities Act of 1979 and the Forest Marketing and Assessment Program of the Maine Department of Conservation are reviewed for their impact on developments in biomass harvesting for generation of electricity. Recent estimates of biomass demand and supply in Maine indicate that 3.1 million green tons of whole-tree chips may be produced each year by 1988. The State of Maine has been active in addressing research needs and policies relating to biomass harvesting, in addition to promoting development of whole-tree chip markets in the State.

Background

The Public Utilities Rate Policies Act (PURPA) which became federal law in 1978 deregulated the nation's electric utilities. This legislation gave independent, privately-financed power producers access to power grids which were previously monopolized by public utilities. In 1979 the State of Maine enacted related legislation, Small Power Production Facilities Act, which set the ground rules for deregulation. This law gave authority to the Public Utilities Commission (PUC) to establish the fair market value of electricity generated from new sources.

The PUC determined that utilities were obligated to pay a price comparable to the costs of financing and constructing new generating capacity from traditional fuel sources. The PUC began establishing prices for new power in 1984 based on the avoided cost of Seabrook II and precipitated a rash of new power proposals for hydro, wood and trash recycling projects. The biomass energy facility at the S.D. Warren mill in Westbrook was one of the earliest projects to take advantage of the opportunities presented by PURPA. By mid-1984 over 20 projects were under development.

Current Status

There are approximately 15 operating installations using wood fuel of some sort to generate electricity for sale to the grid. Seven new plants now under construction are each capable of producing 10 MW or more; 3 of those 7 are rated at 25 MW or more.

The PUC estimates that close to 400 MW of power derived from wood will enter the grid by 1988. This is about 15% of the State's total generating capacity. It essentially replaces the 10% investment (230 MW) that Maine's 3 utilities had in the Seabrook project. The turnaround time for most of these projects is extremely fast compared to large, centrally located nuclear or coal-fired plants. The Signal-Sherman 18 MW power plant in Sherman Station started construction in the spring of 1985. It will produce steam by June of this year and be fully operational this fall. Ultrapower's two 25 MW plants will be constructed in approximately 12 months.

Where is the Wood Coming From?

The 1982 U.S. Forest Service inventory of Maine's timber resources showed a substantial increase in growing stock volume (7%) and sawtimber (20%). Much of the increase in sawtimber occured in the lower construction grades. Now one out of every 5 growing stock trees is considered inadequate for industry specification. There has been close to a 20% increase in the number of cull trees over the last 10 years. Frequently density of growing stock trees per acre exceeds maximum productivity. Furthermore, Maine has the smallest average diameter of all the 14 New England states and the 6" size class makes up 45% of the resource. Hardwood species have increased in the past 10 years as a percentage of the total resources. In short, Maine has a resource which could stand a lot of improvement.

According to the 1982 USFS inventory, there are 1.5 billion green tons of wood and bark above ground or about 88 tons per acre on the average. About half that volume occurs as tops, branches, culls, saleable dead trees, saplings, and stumps above ground level. According to Maine Forest Service analysis, about 400,000,000 tons of this total biomass could be considered available for energy. This figure includes accessibility, landowner attitudes, higher value uses, and prudent utilization standards with respect to measures of stand improvement. Over 20 million tons of the resource are added to this standing inventory each year.

In 1985 about 1.6 million tons of whole tree chips were produced in Maine. Capacity of the proposed new plants will increase by another 1.5 million tons.

Sawmill residues will play a part in this new market for wood. Most sawmill residues are marginally profitable because of such factors as transportation distances and contract terms. Consequently, sawmill residue could be reallocated to the new power plants as they come on line. In addition, about 500,000 tons of sawmill residues from Quebec and New Brunswick may enter the Maine market.

Total resource availability is substantial, and the new plants are spaced well enough apart to prevent unnecessary competition.

In 1985 there were 38 whole tree chipping firms operating 47 chippers. By January of 1986, the number had increased to 40 firms with 50 machines.

Statewide 1,647,000 tons of chips were produced from 41,309 acres. A registered professional forester was involved in harvests covering 87% of this area or 36,174 acres. Management practices included selection, shelterwood and diameter limit methods, 19,665 acres (48%); thinning and weeding in plantations and natural stands, 3,914 acres (9%); clear-cutting with site preparation for planting, 7,355 acres (18%); clear-cutting followed by natural regeneration, 6,995 acres (17%); and conversion from forest to non-forest uses such as pasture and house lots, 3,380 acres (8%). Considerable variation was noted in types of practices between regions. For instance, land use change was the reason for 19% of the cut in Southern Maine but only 2% of the cut in Eastern Maine. Clear-cutting followed by site preparation for planting was the cutting method used on 64% of the area in Western Maine but only on 4% of the area in Southern Maine.

Firms involved with whole tree chipping operations have about $40,000,000 in capital investment, account for about 620 jobs in Maine and provide $13,000,000 worth of annual payroll.

Forty percent of the operations are fully mechanized with the possible exception of use of an individual with a chain saw on the landing. Twenty percent do not use feller-bunchers to cut trees, but rely instead on hand crews. The remaining 40% use a combination of hand crews and feller-bunchers.

The chippers were operating at about 54% of their designed production capacity. Limited chip markets was the number one problem faced by contractors, along with the associated problems of fluctuating delivery schedules and low chip prices. Over one half of the operators sold their chips to only one market. Firms delivering to more than one market still sold most of their production to a single market. Additional markets opening within the next two years are expected to consume another 1,500,000 tons of chips.

Chips accounted for 44 percent of total wood production with round pulpwood, fuelwood logs and boltwood representing the other 56 percent. Optimum product utilization is enhanced by availability of markets for chips and other products, a product price structure that rewards good utilization, and an efficient wood handling system in the woods and on the landing.

The State's Initiative: Policy, Education & Research

Ever since the late 70's Maine's PUC has made a definite commitment to encourage small, independent sources of power and avoid the large generating plants that most utilities were accustomed to building and operating. The PUC has endorsed an overall policy based upon "conservation, cogeneration, and a greater reliance on the state's wood resource". Apparently the policy has been successful: There was so much new capacity from wood sources under contract in 1985, the PUC felt justified in asking Maine's three major utilities to sell their shares in the Seabrook Project.

In 1983 Commissioner Anderson set up a Forest Marketing and Assessment Program within the Department of Conservation. The program was designed to develop new markets for Maine's inventory of low grade and unmerchantable fiber. Through this positive commitment to market development, the DOC was able to play a key role in making the PUC energy policy a distinct reality. Over a two year period DOC helped over 15 major developers determine if, how, and where they could locate and license a wood-fired power plant in Maine.

On another front, the DOC had to respond to the many issues that were raised as a result of all these new and expanding demands on the resource. The Commissioner felt obligated to respond to two important questions in particular:

1) What actions are necessary to make sure that fuel chips are harvested properly?

2) What are the research priorities with respect to whole-tree harvesting?

In January, 1985 the Commissioner appointed two separate committees of leaders from industry, state government, the College of Forest Resources, and appropriate environmental organizations to analyze these issues and make recommendations to him.

The Biomass Strategy Task Force addressed the first question. In its final report it urged the DOC to pursue an active educational program. They discouraged the State from taking any regulatory approaches to whole-tree harvesting, and felt that whole-tree harvesting did not belong in a class by itself since it was merely one of many valid harvesting systems. In response to these recommendations DOC began to experiment with biomass harvesting demonstrations as a possible tool for educating the public, and well as professional foresters who were eager to learn more about the subject.

A new Biomass Coordinator position was created within the Maine Forest Service and staffed by an experienced service forester. The forester acts as a source of information and gives advice and assistance to the general public regarding biomass issues. This position effectively provides the continuous committment to education that the Biomass Strategy Task Force requested.

The Biomass Research Committee took charge of the second question--what are the research priorities?

The committee recommended a comprehensive literature review of whole-tree harvesting from all regional, national, and international sources to determine if more research was warranted. The committee insisted that researh needs had to be defined in the context of the biological, economic, and technological aspects of whole-tree harvesting.

Finally, working from the assumption that some additional research needs would ultimately be identified in the review, the committee went on to recommend how those new goals should be achieved. A formal program or research institute needed to be established to address all the biological, economic, and technological issues in an integrated and comprehensive fashion. The committee envisioned this institute as a preferred alternative to a piece-meal or random approach lacking direction and coordination. Ideally the institute would function not only as a center for research but as a valuable library of data for extension services.

The committees response to this question reflected the members' convictions that whole-tree harvesting was certain to play a greater role in all areas of forest management in the future. Well-defined and balanced research goals were essential to make certain that comprehensive information on the proper application of whole-tree harvesting systems was available on a timely basis.

IMPACT OF LARGE BIOMASS DEMAND CENTERS ON THE FOREST RESOURCE BASE

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A survey was conducted to characterize the impacts of four northeastern wood-fired electric generation plants on forest management practices. The survey focused on the fuel procurement systems for each plant, predominant harvesting methods being used to supply fuelwood chips and the site and residual stand quality resulting from the operations, and the opinions of foresters, loggers, landowners, and chipbrokers about the impact of fuelwood-chip harvesting on forest management. These plants receive large amounts of fuel from land clearing operations for agricultural or development purposes. The predominant harvesting system supplying these plants is a mechanized, single-entry, integrated-product removal system involving hot-yarding procedures. The increase in fuelwood chip markets does not appear to have had an impact on the quality of forest management being practiced. The public-sector foresters must continue to monitor trends in fuelwood chip harvesting so that they can anticipate forest management issues and improve forest management practices.

Many forest products companies have been using bark, sawdust, slabs from sawn timber, and other by-products to generate energy at their sawmills and pulp and paper factories on a small scale for years. The first large energy-specific demand for chips developed in the late 1970s at S.D. Warren in Maine (1979 and 1980) and the Burlington Electric Department (BED) in Vermont. These plants were constructed with the idea of selling power to the public sector, although S.D. Warren actually uses up to half of its power for cogeneration, in this case for pulp and papermaking.

This report discusses the procurement systems that supply fuelwood chips to private corporations and public utilities for production of electricity and/or power for manufacturing. These consumers have the potential to rapidly affect both forest resources and markets in their supply areas or "wood-sheds."

The study focused on four demand centers: Procter and Gamble, Co. (P&G) facilities on Staten Island, New York; P&G in Baltimore, Maryland; Scott Paper Company's S.D. Warren plant in Westbrook, Maine; and BED's McNeil power station in Burlington, Vermont. Together, these plants have a potential capacity to consume more than 1.5 million tons of chips annually, and they represent the forerunners of wood-fired electrical-generating facilities in the northeastern United States. The BED plant is apparently the largest wood-fired power plant in the world built explicitly to generate electricity for sale to the public. Similar types of plants, proposed for New York and Maine, could dramatically increase the consumption of wood in this sector. In Maine alone, new or planned wood-fired electrical-generating facilities would require a new supply of approximately 1.5 million green tons of chips in the next 3 to 5 years.

This study focused on the impacts of the wood procurement systems of four wood-fired power plants on future forest management practices. On the one hand, these plants (and others like them) have been advocated as a means of drastically improving both the quality and intensity of forest management in the Northeast. On the other hand, they have been criticized for their potential to reduce the quality of forest management by encouraging more clear-cutting and the inappropriate conversion of high-quality sawlogs into wood chips, or ultimately, causing rampant, uncontrolled harvesting.

Study data gathered were principally from people who are directly involved in wood chipping for energy and, to a limited degree, examined actual forest management activities in the field. Data collection included: 1) descriptive case studies of four wood-fired power plants--BED's McNeil plant in Burlington, Vermont, the S.D. Warren plant in Westbrook, Maine, and two P&G plants in Baltimore, Maryland, and Staten Island, New York; 2) formal structured surveys with 45 foresters, 20 loggers and 12 private, nonindustrial forest landowners; 3) unstructured interviews with 21 wood-chip brokers, transporters and suppliers; and 4) post-harvest stand examinations of 37 logging sites in northern New York and New England.

Wood Supply

Both P&G plants receive their wood supply through a procurement system that keeps very little, if any, information on where the wood actually comes from. Neither P&G plant has staff foresters to manage their procurement programs. Instead, P&G forestry staff from other facilities helped set up the procurement system, but now have little input in daily program activities.

BED is probably the best-known and most visible example of a stand-alone, wood-fired, electrical power plant in the United States, if not the world. It is primarily a public facility, and has been subjected to more study, regulation and public review than any of the other plants. A staff of foresters guide its wood-procurement activities, led by a forester with experience in private-sector forest industry. Though not part of the traditional forest products industry, it is quite different from other non-forest products energy facilities because of the degree to which it emphasizes forest management in its supply system.

S.D. Warren has one of the longest records of wood procurement prior to 1978. Now, as part of Scott Paper Company, it is procuring wood for use in manufacturing. The company owns little forestland, but for years, it has had a staff of foresters to manage the wood procurement program. Its procurement system has served as an example to BED and other plants. S.D. Warren is the best-known case where a private-sector power plant with forestry expertise is not regulated to the extent that BED is.

The supply networks for these power plants usually include loggers, foresters, landowners, companies involved in the transportation or chipping business, and chip brokers. BED depends on 10 logging companies and S.D. Warren on 14, and these figures have not changed since the start-up of the plants. This study found that most of the loggers involved in chip harvesting for the power plants are very experienced--70 percent had over 10 years of experience and 65 percent have been working with the plants for over 2 years. These loggers learned their trade on the job, rather than in the classroom or other training programs. They also appear to rely heavily on the power plants' demand for chips. For example, 11 out of the 20 loggers interviewed indicated that over 50 percent of their work is devoted to supplying the power plants. S.D. Warren officials state that a typical logger signs a contract that is written for 5 years and may call for delivery of 20,000 tons per year (or 386 tons a week for 52 weeks), or about $7,000 per week in gross income for the operator.

In S.D. Warren's case, about 20 percent of the wood supply comes through brokers, and most of it is in the form of forest-products residues (e.g., bark and sawdust). BED maintains supply agreements with two brokers and gets most of its sawmill residues (15 percent of the plant's total supply) through brokers. According to P&G officials, neither of their plants currently purchase through brokers, although Staten Island previously used up to two brokers.

The P&G/Staten Island plant is in the unique position of serving as an alternative to landfills for the dumping of wood waste. Between 150 and 200 different trucking and demolition firms (of all sizes) have delivered wood waste to P&G rather than pay fees at local landfills. In most cases, P&G pays little, if anything, for this ample supply. In contrast, P&G/Baltimore relies on the land-clearing business for most of its wood supply.

Data from Vermont's Department of Forest, Parks and Recreation (DFPR) chip-harvest monitoring program and a survey of loggers in Maine indicates that most chip harvests in those two states involve foresters. In Vermont, foresters work on all of BED's chip harvests and 87 percent of <u>all</u> chip harvests in the state, according to the DFPR data. From a recent survey of chip producers in Maine, roughly 87.6 percent of all chip harvests there appear to involve foresters. In terms of sheer numbers, more foresters work with the different power plants than loggers. However, foresters are generally less dependent on the power plants than loggers.

Neither P&G plant has information about the types of landowners that provide their wood supply. However, a large percentage of their supply comes from land clearings for development, on land that probably is privately owned.

Both the S.D. Warren and BED design studies used 40 tons per acre as a working figure to calculate the expected volume of wood on a per acre basis. S.D. Warren estimates that woodlot thinning operations yield approximately 40 to 50 tons an acre, whereas land conversions and/or clear-cuts produce between 60 and 80 tons per acre. BED would not commit to any specific per acre estimate. Very general figures from the recent chip supplier survey in Maine show that approximately 1,647,000 green tons of chips were harvested from 41,309 acres, or just under 40 tons per acre (Maine Forest Service, 1985). Loggers indicate that if chips are the primary product, between 20 and 30 tons an acre are required to make their operation profitable.

Conventional cost limitations on transportation, which were expected to define the supply radius for each plant, meant little or nothing overall. The logger survey found that distance from the demand center was much less important in making a harvest profitable than other variables, such as skidding distance, distance from access roads, site topography and stand conditions. All of the power plants received some of their supply from over 150 miles away. It is estimated that in some cases, as little as 50 percent of their supply may come from within the commonly expected 50- or 75-mile radius. Thus, a 50- or 75-mile radius is useful for examining the availability of wood supplies at a general level, but a significant amount of the supply comes from outside those limits. Future wood supply studies for regional planning or analysis should carefully consider larger supply areas.

In BED's case, a more substantial proportion of the supply probably comes from outside the state of Vermont than originally anticipated. Also, as is discussed in greater detail below, a great percentage of the current wood supply comes from clear-cuts of one sort or another. This has important implications for the public's perception of harvesting, value of regulations and reputation of those involved in chipping operations (particularly foresters and loggers).

<u>Predominant Harvesting Methods</u>

Fully mechanized, single-entry, integrated harvesting is the predominant harvesting method for fuelwood chip suppliers at this time. The harvesting site is entered one time, and all merchantable material is removed and skidded to a landing for sorting and processing. Whether for energy or pulp and papermaking, this type of chip harvesting usually involves "hot-yarding," a process where, in most cases, whole trees are skidded to a central landing place, run through a chipper and immediately blown into waiting chip vans for transport to the demand center. The key to this rapid and large-scale production of chips is maintaining a continuous supply of stems from the forest moving at a high rate so that expensive chipping and transportation equipment is not sitting idle. However, unless a site is being clear-cut or heavily thinned, the logger is under a lot of pressure to keep up with the chipping and transportation equipment. This pressure may translate into a hurried logger, greater likelihood of damage to the site or remaining trees, and more safety problems particularly where chain saws are being used.

While hot-yarding is still common and probably remains the predominant harvesting method, more "cold-decking" appears to be taking place. Cold-decking involves the stacking of trees on a landing, with chipping at a later time. The advantage of cold-decking is that it reduces the pressure on the logger for rapid production and facilitates easier sorting of logs into piles for different product markets (e.g., chip logs for pulp and paper or energy, pallets, sawtimber, and veneer logs). Also, conventional operations, using a chain saw and skidder rather than a feller-buncher, operate at less of a disadvantage. Interviews with BED foresters indicate that 5 years ago about 10 percent of harvests came from conventional operations involving stockpiled logs. Today, BED estimates that as much as 50 percent comes from such operations.

In addition to the switch from hot-yarding to cold-decking, loggers have moved away from owning chipping equipment to subcontracting the chipping and transportation to other operators. The decision by some loggers to avoid owning, leasing or maintaining chippers appears to have been made for three main reasons. First, loggers want to reduce high initial capital and recurrent costs--chippers and feller-bunchers are expensive pieces of equipment that require constant and costly maintenance. Second, many loggers do not want to spend time away from the woods and on the telephone making contacts and scheduling to keep the chipper busy. Third, the volatile nature of chip demand often translates into production lulls that are costly because either chipping equipment is sitting idle or operating at little, if any, profit. However, the results of the logger survey indicate that this is far from a universal trend (15 to 20 loggers interviewed had their own chippers).

Logger and forester interviews, as well as the post-harvest stand exam, suggest that integrated harvests are the rule. Integrated harvests involve product separation and the sorting of higher-value products (sawlogs, veneer logs, pallet wood and tie logs) in association with fuelwood chip harvesting. Seventy-eight percent of the foresters and 68 percent of the loggers interviewed indicated that integrated harvests are the rule in fuelwood chip harvesting. Similarly, 84 percent of the foresters and 61 percent of the loggers said that they separate high-quality and low-quality logs during fuelwood chip harvests. This was further supported in forester interviews conducted for the post-harvest stand exam. Other survey research conducted in Maine (1985 WHOLE TREE CHIPPING OPERATIONS SURVEY AND REPORT, Department of Conservation) indicates that higher-grade material may be the only profitable forest product for some logging operators. The Maine study and the Coalition of Northeastern Governors (CONEG) post-harvest stand exam also confirm that, if chipping of higher-value products occurs, it is most likely to be marginal sawlogs, and pallet wood or tie logs (for railroads). Chipping of higher-value products increases when chips are the main product being sought in a harvesting operation or when regional markets for sawtimber, veneer logs or pallets are weak.

Impacts of Biomass Energy Facilities on Forest Management

In practice, neither P&G plant knows (beyond some general percentages) what type of forest management or practices are involved in procurement of its wood supply. This is not the case with BED or S.D. Warren. Both of these plants have staff foresters, and in the case of BED, the documentation on its harvesting operations in the state of Vermont is exceptional.

Using data developed in the CONEG case studies, Table 1 shows a static illustration of a highly dynamic wood supply system.

Table 2 is a specific, and probably more accurate, representation of the implications of fuelwood chip harvesting for forest management. It presents information on all chip harvesting in

Table 1 -- Supply Characteristics of Four Wood-Fired Power Plants

Source	BED	S.D. Warren	P&G/Baltimore	P&G/Staten I.
	(% of total supply to plant)			
agricultural/development clearing	17	35	67	76
forest product residues	15	13	33	0
industrial waste	0	2	0	24
silvicultural harvests	68	50	0	0

Table 2 -- Vermont Chip-Harvesting Program Monitoring Data for 1981-1985

	1981	1982	1983	1984	1985
# of chipping machines	9	10	17	29	30
total acreage cut	2,073	4,163.5	6,469	5,056	7,004
# of chip harvests	26	54	72	74	117
average # acres/chip harvest	79.7	78.5	89.8	68.3	59.86
% with forester involved	57%	74%	86%	92%	87%
% harvested for thinning	23%	17%	39.3%	45.4%	53.4%
% regeneration cuts	71%	67%	49.4%	38.2%	32.1%
% non-forestry clear-cuts	5%	16%	11.3%	16.4%	14.4%

Vermont, gathered through fieldwork and interviews with loggers by the state's DFPR chip-harvesting monitoring program, which has been in place since 1981.

From a forest management perspective, it is important to note that clear-cuts for forestry, agriculture and development are the source of a large percentage of the wood supply for these power plants. This observation is reinforced by data from Maine, where a 1985 chip supplier survey found that approximately 43 percent of the chip harvesting followed a clear-cut of one type or another. Many foresters and loggers have pointed to the benefits of clear-cutting for the purposes of regenerating a new, improved forest, and the poor quality of much of the existing northeastern forest makes it ideal for regenerative clear-cut harvesting.

Two important issues concerning clear-cutting should be addressed: 1) regardless of the purpose of clear-cutting, the public does not have a generally favorable impression of it--this practice is accepted when it is used to open up farmland or areas for development, but this has little if any direct relationship with forest management; and 2) there are long-term silvicultural concerns with clear-cutting. Clear-cutting usually, but not always, results in the same species of trees growing at the site. In some cases, however, there is concern that the species which will predominate after a clear-cut are not commercially favorable (e.g., red maple versus such higher-value hardwood species as sugar maple or black cherry, or pine-cherry versus spruce or fir). Also, unless subsequent thinning and selection treatments are done, there is no guarantee that the regenerated forest will be any better than the present one.

To date, it appears that no dramatic change in either silvicultural concepts or the intensity of forest management have resulted from fuelwood chip harvesting. The post-harvest stand exam did not find stands of small-diameter, pioneer species that need silvicultural treatment. Extensive thinning or TSI of high-value stands is not happening on a large scale. The logger, forester and landowner surveys and post-harvest stand exam did not uncover examples of poor, uncontrolled chip harvesting. Interviews with foresters suggested that fuelwood chip harvesting is generally an aid to better forest management, although there are some concerns relating to wildlife habitat impacts.

Forester supervision has often been suggested as a guarantee of good forest management, under the assumption that forester involvement will probably result in better forests and harvesting practices. If, in fact, forester supervision is an indicator of better forest management, then fuelwood (in fact, all) chip harvesting should result in better forest management. Loggers indicate that less than 10 percent of their harvests are "logger's choice," and data from research in Maine and Vermont show that foresters are involved in 80 to 90 percent of all chip harvests.

Forest Management Impacts of Biomass Energy Projects Versus Traditional Harvesting Practices

This study focused on comparison of fuelwood chipping with traditional round-wood harvests, not related to chipping. In practice, fuelwood chip harvesting methods do not appear to be generally different from chip harvesting for pulp and papermaking or composite board production. However, fuelwood chip harvesting is different from other chip harvesting in at least two major ways. First, chip buyers pay a lower price for fuelwood chips than pulp chips. Those who purchase fuelwood chips are also less discriminating about what they buy because any tree can be chipped for energy use and will have roughly the same energy value per ton. Chip harvesting for fuel significantly broadens the market for wood fiber and ultimately increases the total volume of wood harvested in the region. Second, according to the BED case study, more fuelwood than pulp and paper chips come from agricultural and development clearing.

Foresters and loggers were asked to compare fuelwood chip harvesting with traditional round-wood harvesting. In terms of soil erosion, only 15 percent of the loggers and foresters interviewed believe that fuelwood chip harvesting has resulted in increased erosion problems. There was a slight increase in concern about residual stand damage, as 42 percent of foresters and 30 percent of loggers indicated that there was a noticeable increase in residual stand damage with fuelwood chip harvesting. Most of the problems observed during the post-harvest stand exam (e.g., random, erratic silvicultural systems, poor tree selection with logger's choice, low-grade coppice regeneration and high residual damage from mechanical harvesting operations) are not specific to fuelwood chip harvesting, but rather, are characteristic of most conventional operations as well.

Foresters were also asked if fuelwood chipping increased either the number or average size of clear-cuts in the region. Two-thirds of those interviewed indicated that fuelwood chipping has had no effect on the size of clear-cuts. From Vermont's chip-harvest monitoring data, the average size of BED's harvests was 31.1 acres, compared to 59.9 acres for other chip harvesting. However, 40 percent of the foresters surveyed think that the number of clear-cuts has indeed increased with fuelwood chip harvesting.

Another potentially important difference between fuelwood chip and traditional harvesting is the relative input of foresters into the procurement process. Some energy facilities (e.g., P&G/Baltimore and Staten Island) do not have foresters managing their procurement operations. As noted, forester involvement is often suggested as a way to ensure good forest management. For BED and S.D. Warren, staff and public foresters have beeen active in gathering information on chip harvesting. When no one with forestry expertise is involved in chip procurement operations, there will likely be little information about the type of harvesting being practiced in supply areas. Unless the public sector takes an active role, the impacts and implications of forest management may not be known, acknowledged and/or dealt with until some public disturbance or reaction requires such action. This may be entirely appropriate, but it may also leave the door open for more inaccurate and potentially damaging claims about negative impacts of fuelwood chip harvesting.

Overall, fuelwood chipping still represents a small portion of all the forest harvesting taking place in the region. However, what appear to be insignificant trends could become important concerns, if the rate of increase in fuelwood chipping continues. Monitoring important variables, such as percentages of agricultural clearings and TSI cuts, will allow public-sector forestry specialists to anticipate forest management issues and work with the private sector to improve forest management.

Summary

First, a large portion of the wood supply for each of the four power plants comes from private, nonindustrial forestland outside the previously accepted norm of a 50- or 75-mile supply radius. Second, all four plants receive large amounts of wood from agricultural and development clearings-- 17 percent at BED, 35 percent at S.D. warren, 67 percent at P&G/Baltimore and 76 percent at P&G/Staten Island. Third, highly mechanized, single-entry harvesting (with hot-yarding) remains the predominant harvesting method; however, more cold-decking is now taking place. Fourth, two important wood procurement trends are discernible: 1) chip suppliers are subjected to constant fluxes in the demand for chips by both the energy and pulp and paper sectors; and 2) a large percentage of the fuelwood chip supply comes from clearing land of one type or another. (The authors of this study were unable to determine whether the high proportion of clearing will be a short- or long-term trend.) Fifth, no dramatic change in the intensity of quality of forest management has occurred due to fuelwood chip harvesting. Sixth, fuelwood chip harvesting does not appear to be different from chip harvesting for pulp and paper or composite board production. Finally, there is no clear or conclusive information to indicate either positive or negative impacts on forest management from regulations specific to chip harvesting.

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NUTRIENT CYCLES AND FOREST PRODUCTIVITY

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Biomass harvesting, which may involve increased product removal, shortened rotations, and greater soil disturbance, raises legitimate concerns about effects on nutrient cycling and future stand productivity. Selected processes from the nitrogen cycle are used to illustrate how forest managers can apply knowledge about nutrient cycling to maintain forest productivity. The first 10 years after harvest are an especially critical period. Two important goals are to protect the forest floor from severe disturbance, and to provide for rapid reestablishment of vegetation.

Most foresters have been exposed to some aspect of nutrient cycling during their college training. This exposure may vary from a passing mention of the 16 essential plant elements to a complete course focused on biogeochemical cycling. Unfortunately, no matter the extent of exposure, nutrient cycling considerations seldom find their way directly into forest management.

Since knowledge about nutrient cycling has broadened in the past 10 to 20 years, it seems a good time to ask if nutrient cycling might now be more directly involved in management decisions. Some urgency is added to this question by the rapidly expanding use of biomass harvesting. Increased product removal, shorter rotations, and potential for greater site disturbance raise legitimate concerns about nutrient cycling effects and future stand productivity.

Why Nutrient Cycling?

Nutrient cycling is the movement of nutrient elements into, within, and out of a forest. Nutrients accumulate slowly in forests, often with large expenditures of energy. For forest managers, the challenge is to keep as much of the nutrient capital as possible within the forest and available for plant growth. Fortunately, the job is made easier by the fact that forests tend to have "tight" nutrient cycles. For example, compared to agricultural ecosystems, forests accumulate large stores of nutrients in organic matter, and lose few nutrients to erosion or as dissolved solids in streamflow. However, when a forest is harvested, not only is some of the capital removed, but the nutrient cycle can become "leaky," especially for the first few years after harvest. The concern then becomes whether there will be an adequate supply of nutrients for optimum productivity in the regenerating forest. By understanding nutrient cycling, steps can be taken to ensure that productivity is maintained, and possibly even enhanced.

Nitrogen as an Example

Nitrogen is a logical element for illustrating how nutrient cycling considerations might be used in forest management. Harvests both remove a substantial amount of nitrogen in forest products and trigger processes that increase losses of gaseous or dissolved nitrogen from the forest ecosystem. These losses may be critical, especially since fertilizer trials have shown that nitrogen is often limiting to tree growth in the Northeast. Consequently, research has focused more on nitrogen and nitrogen cycling than on other plant nutrients.

Data on nitrogen capitals are available from four sites in the Northeast where the USDA Forest Service and others are studying the impacts of biomass harvests (Table 1). These data suggest that forest managers have about 5,000 to 7,000 kg

Table 1. Nitrogen data for mature forests in New England. The data were derived from Bormann *et al.* (1977), Hornbeck and Kropelin (1982), Tritton *et al.* (1982), and Smith *et al.* (1986).

Forest type and location	Total site capital	Nitrogen in: Mineral horizons	Forest floor	Above-ground whole trees	Merchantable boles	Input in precipitation	Output in streamflow	Net gain
	$kg\ ha^{-1}$					$kg\ ha^{-1}\ yr^{-1}$		
Northern hardwoods, Hubbard Brook Experimental Forest, NH	5,051	3,600	1,100	351	97	7	4	+3
Northern hardwoods, Success, NH	6,735	4,802	1,738	255	142	6	3	+3
Central hardwoods, Cockaponsett State Forest, CT	4,868	3,570	995	303	166	8	0	+8
Spruce-fir, Weymouth Point, ME	7,162	5,833	919	410	97	4	1	+3

ha^{-1} of total nitrogen to work with. Between 70 and 80 percent of this total comprises one pool located in the mineral soil horizons, and 13 to 26 percent forms another pool in litter and humus or forest floor.

The above-ground, whole trees contain 4 to 7 percent of the total nitrogen capital, or 255 to 410 kg ha^{-1}. The merchantable boles of trees at the study sites contain 97 to 166 kg ha^{-1}. Thus, a biomass harvest that removes most of the above-ground vegetation may more than double the nitrogen removed in traditional bole-only harvests.

Because bedrock and glacial till do not supply nitrogen (though they do supply other elements), precipitation is a major source for replacing harvest losses, with inputs ranging from 4 to 8 kg ha^{-1} yr^{-1} (Table 1). In turn, up to 4 kg ha^{-1} yr^{-1} are lost as dissolved nitrogen in streamflow. The net gain to the forest of 3 to 8 kg ha^{-1} yr^{-1} is small in relation to harvest losses, so much of the nitrogen in the regrowing forest must be made available from the existing site capital.

A variety of pools and pathways are involved in supplying available nitrogen for tree growth. These have been defined by Bormann et al. (1977) at the Hubbard Brook Experimental Forest as part of detailed research on nutrient cycles of mature, northern hardwood forests. Their research shows that the nitrogen cycle is extremely complex, with 9 major pools and 13 interrelated pathways for transfer of nitrogen from one pool to another.

Each of these pools and pathways is affected by forest harvest. Other symposium papers elaborate on these changes, and provide data. These data, together with the general understanding of nitrogen cycling that has been provided by research, form the core information available for managing the nitrogen cycle. Figure 1 is an attempt to condense this information into a form useful to forest managers. The figure shows hypothetical rates for important nitrogen cycling processes before, during, and immediately after harvest, and through 10 years of regeneration. These processes are discussed in the context of providing forest managers with a basis for considering how to manage forest nutrients to maintain optimum productivity. The discussion emphasizes the first few years following harvest, an especially critical period for protecting forest nutrient cycles.

Vegetative Uptake

In mature forests, annual uptake by vegetation is the largest of the various paths which nitrogen follows, usually ranging from 80 to 100 kg ha^{-1} yr^{-1}. With harvest, uptake plummets to near zero (Fig. 1), and begins to rise only upon regrowth of vegetation. During this period of reduced uptake, leaching losses to streams and groundwater usually increase, depleting the supply of available nitrogen.

Thus, to conserve nitrogen, it is important to encourage rapid regeneration and renewed uptake. In the Northeast, this is usually taken

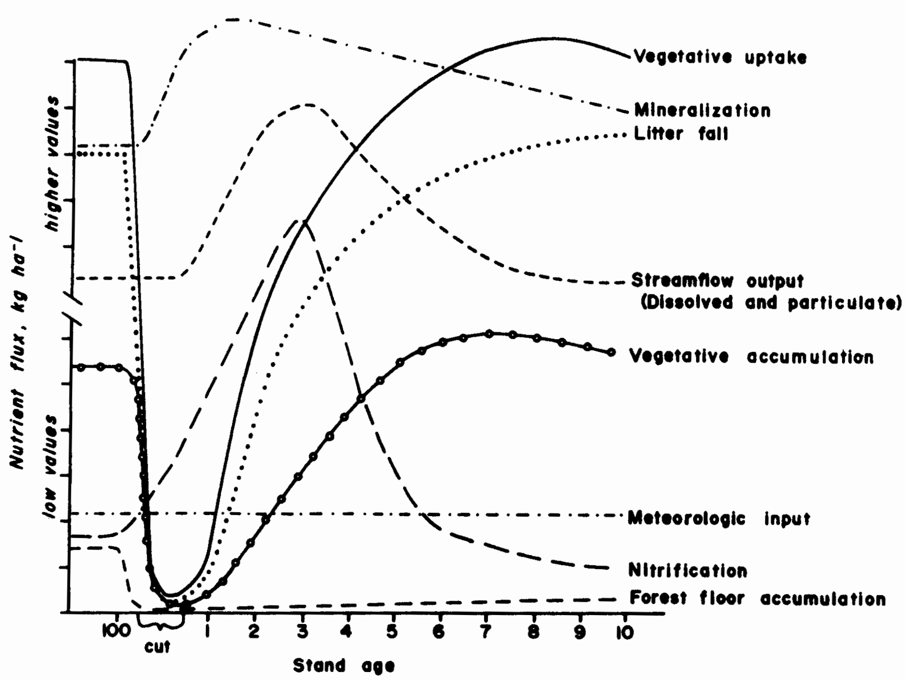

Figure 1.--Hypothetical curves of changes in fluxes of nitrogen.

care of naturally by a variety of pioneer species that rapidly occupy harvested sites until woody species become established and form a closed canopy. A main role of the manager is to ensure that harvest practices do not disturb the site to the extent that nutrient supply to regeneration is hindered. Another symposium paper discusses the potential for soil disturbance during biomass harvesting, and offers guidelines for protection. Managers also must be aware that more intensive site preparation, such as scarification or use of fire or herbicides, may prolong the period of decreased uptake and increased leaching.

Vegetative Accumulation

Only about 10 to 20 percent of annual uptake accumulates in above- and below-ground vegetation. The remainder is returned to the site capital, mostly in the form of litterfall and root litter (Fig. 1). To achieve maximum accumulation of nitrogen in regenerating forests, and thus minimize opportunities for leaching losses, perennial or woody vegetation must be reestablished quickly. The forest manager can promote a rapid transition from invading annuals to more desirable woody species by planning harvests to coincide with good seed years, leaving seed trees, or using other schemes to take advantage of reproductive and growth strategies of the various species that will inhabit the site. Papers in Session III discuss these strategies in detail.

Litterfall and Forest Floor Accumulation

Most nitrogen taken up but not permanently stored in living biomass is returned to the forest floor (the combined litter, fermentation, and humus layers) via litterfall. In mature forests, the forest floor annually accumulates a small amount of the nitrogen added in litterfall. For example, under northern hardwoods at Hubbard Brook, the rate of accumulation of nitrogen in the forest floor is estimated at about 8 kg ha^{-1} yr^{-1} (Bormann *et al*. 1977).

After a biomass harvest, litterfall stops temporarily. At the same time, the forest floor undergoes a rapid decline in weight, depth, and nutrient content as a result of logging disturbances, increased moisture content, and exposure to light and heat. Covington (1981) showed that the forest floor in northern hardwood stands declines by about 50 percent in weight, and by more than 800 kg ha^{-1} of nitrogen in the first 15 years after clearcutting. In bole-only harvests, a considerable amount of slash is left on site and serves as a source for replenishing some of the depleted nitrogen. However, in biomass harvests, this material, which can contain 100 to 300 kg ha^{-1} of nitrogen, is removed.

To minimize nitrogen losses from the forest floor, the manager's job is again to protect the forest floor during logging and promote rapid regeneration. Protection of the forest floor requires some judgment. Disturbance is not necessarily a harmful impact since some mixing of the forest floor and mineral soil helps create a favorable seedbed for future regeneration. The trick is to prevent severe disturbance that results in excessive compaction, exposure of large amounts of mineral soil, rutting, and eventual erosion. Harvesting during winter snowcover and avoiding the spring mud season are ways to minimize severe disturbance to the forest floor. As a further precaution, the manager must consider the importance of nutrients contained in tops, branches, and leaves, and evaluate the advantages and disadvantages of removing them. The paper that follows provides some insights for making such evaluations.

Mineralization

Mineralization is the process by which organic matter in the forest floor and mineral horizons decomposes and provides available nitrogen for plants. In mature forests, the final product, ammonium (NH_4), is available for direct uptake by plants and also is held tightly by soil and organic matter.

Upon harvest, soil temperature and moisture rises, creating a favorable environment for a rapid increase in mineralization. Since uptake is simultaneously reduced, some surplus ammonium is produced and either becomes mobile in soil solution or is further oxidized to nitrate (NO_3). This explains in part the loss of nitrogen from the forest floor that was discussed earlier.

Mineralization is obviously a beneficial process, but only to the extent that it meets plant needs. The forest manager can attempt to control increases in mineralization after harvest by arranging the cutting configuration to provide some shade (using shelterwood cutting, for example), by promoting rapid reestablishment of vegetation as discussed earlier, and by following known guidelines for protecting the forest floor.

Nitrification

Ammonium serves as a substrate for the process of nitrification, the oxidation of ammonium by microorganisms to nitrate (NO_3). Unlike ammonium, nitrate is not held tightly by soils. If not taken up quickly by plants, nitrate is readily leached to streams and groundwater and lost from the site.

The nitrification rate usually is extremely low in mature forests. However, harvesting of vegetation rapidly accelerates nitrification (Fig. 1). Within a few weeks of growing season harvests, nitrate concentrations begin to rise in soil solution and streams. As an added concern, the process of nitrification also produces two hydrogen ions for each nitrate ion. The hydrogen ions replace or mobilize other nutrient ions held by the soil, such as calcium, potassium, and magnesium, freeing them to be leached from the system. Thus, nitrification is a major factor in determining losses of nutrients to leaching after harvest.

The response of nitrification to harvest is highly variable, depending on soil characteristics and cover type. It is well documented that podzolic soils under northern hardwood forests have a strong tendency to nitrify after harvest. By contrast, podzolic soils under conifers seem to have less tendency to nitrify. Recent research has suggested that nitrification also may be controlled by soil drainage, responding much more slowly to harvests on poorly drained soils.

Forest managers can apply the kinds of information described when making decisions about harvest intensity. For example, sites with shallow and relatively infertile soils and a high potential for nitrification are not good candidates for biomass harvests.

Streamflow Output

Nutrient outputs in streamflow occur as two forms: dissolved inorganic ions such as ammonium and nitrate, and as particulates and bedload such as soil and organic matter. In older, undisturbed forests, the dissolved forms of nitrogen exceed particulate and bedload forms by a ratio of 4:1 or greater. After harvest, this ratio usually narrows, and in cases of substantial increases in soil erosion, can even fall well below 1:1. There is little excuse for this happening as there are known precautions for protecting against erosion during and immediately after logging, no matter what the intensity of harvest (Hornbeck et al. 1986). If managers ensure that these precautions are followed, then the main concern is to minimize outputs of dissolved ammonium and nitrate.

As shown in Table 1, outputs of dissolved nitrogen in streams from mature, undisturbed forests ranges from 0 to 4 kg ha yr^{-1}. These outputs increase substantially after harvest, often quadrupling by the second year. The increases are a concern from the standpoint of being direct losses from the plant-available pool, and also as a potential source of stream eutrophication (Martin et al. 1985).

The forest manager's role is to first understand the mineralization and nitrification processes. These are discussed in greater detail in other papers at this symposium. Application of this knowledge involves many of the guidelines already mentioned. The major objective is to suppress nitrification and leaching losses as quickly as possible after harvest, which is best done by reestablishing uptake and a closed canopy.

Meteorologic Input

One of the few ways in which nitrogen can be added from outside the ecosystem is by meteorologic inputs, either as dissolved ions in precipitation, as aerosols, or as a gas. Gaseous and aerosol additions are extremely difficult to measure and not much is known about them, though the Hubbard Brook studies suggest that as much as 14 kg ha^{-1} yr^{-1} of nitrogen could be added through fixation from the atmosphere (Bormann et al. 1977). Additions of dissolved nitrogen in precipitation range from 4 to 8 kg ha^{-1} yr^{-1} in New England (Table 1). Industrial and automotive emissions are a significant source for much of the dissolved nitrogen in precipitation.

The forest manager has relatively little control over meteorologic inputs. Removal of the canopy affects interception of airborne aerosols and probably changes the rate of nitrogen fixation. But too little is known about these processes to make management recommendations.

Conclusion

The nutrient cycles of mature forests, with the nitrogen cycle being a good example, are relatively conservative. That is, nutrients are pretty much maintained on site with only minor losses to erosion and leaching. Biomass harvesting is a severe disruption to nutrient cycles. The first 10 years after harvest are especially critical in terms of nutrient transformation, movement, and loss from the ecosystem. During this period the forest manager can play a decisive role in protecting the nutrient cycle, and, in turn, assuring future productivity.

As mentioned a number of times, there are at least two primary goals: rapid reestablishment of vegetation, preferably with a maximum of perennial species, and protecting the forest floor and its associated nutrient capital from severe disturbance. Neither of these goals is new to foresters, but new information relating to nutrient cycling is available and should be merged with the usual economic and practical considerations to enhance forest productivity.

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AN EVALUATION OF THE NUTRIENT REMOVALS ASSOCIATED WITH WHOLE-TREE HARVESTING[1/]

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The significance of the nutrients removed with whole-tree harvesting to site fertility and future forest productivity has been estimated using a variety of approaches. These approaches have included static comparisons of harvest removals with soil reserves of nutrients, estimates of nutrient budgets following harvest to determine which nutrients might be replaced by natural processes, computer simulation of forest productivity following various combinations of rotation length and biomass utilization, and empirical evaluation of stand growth following various utilization levels. All these approaches indicate the importance of conserving site fertility by minimizing nutrient removals, where possible; however, it is difficult to predict the level of biomass removals that various sites can sustain without reducing future forest productivity.

Introduction

Whether increased levels of biomass utilization may reduce forest productivity has been a subject of debate since the early 1800's (Alway and Zon 1930). One of the earliest reports of experiments on forest litter removals was published in 1876 by Ebermayer. These studies, and others initiated in the United States in 1925 and 1930 (Cope 1925; Jemison 1943), were initiated because foresters were concerned that annual forest litter removals for animal bedding and agricultural mulch would probably cause a decline in forest productivity due to removals of organic matter and associated elements necessary for tree growth. There has been little reduction in the intensity of the debate in the 110 years since the publication of Ebermayer's book, and in fact forest biomass utilization and its effect on forest productivity continues to be the subject of numerous studies, computer simulation models, and lengthy review papers. At one time or another, the same concerns about forest productivity have been raised with respect to annual litter removals, prescribed burning, a variety of site preparation treatments, clearcutting, whole-tree harvesting when used in both intermediate cuttings and final rotation harvests, and complete tree harvesting (Young 1968), where stump and root systems are utilized in addition to the above-stump portions of trees.

[1/]Scientific Contribution No. 1428 from the New Hampshire Agricultural Experiment Station.

In the Northeast, increased utilization of forest biomass has occurred recently because of interest in 1) offsetting foreign oil requirements of industry and electric utilities, 2) improving stand quality and increasing rotation yields through increased utilization of rough, rotten and cull trees, and 3) reducing the impact of a predicted timber shortage, caused by age class imbalances, through the increased utilization of existing biomass. This has renewed the productivity debate and indicates that we do not understand as much about forest ecosystems as is necessary to objectively evaluate the impact that biomass removals have on the factors that contribute to forest productivity.

Three factors contribute to the lack of finality in the debate. First, is the seemingly endless combination of levels of ecosystem variables such as species composition, soils, and climate. Second, in many forest ecosystems there have been no adequate studies, relating biomass utilization to forest productivity. Third, in one way or another, increased utilization usually involves maximization of profits in a commercial venture with forest products. One of the most difficult costs to quantify in comparing forest management alternatives is the cost associated with potential reductions in future yields as a result of current increased utilization. The inability of forest scientists to place a number on this cost seems to place the debate in the philosophical arena, and makes it impossible to resolve with complete objectivity. Forest managers, and others involved with forest resource management issues, are not able to incorporate realistic yield information into their management decisions given the current level of uncertainty associated with these issues.

The objectives of this paper are to 1) review the major questions to be answered in evaluating the impact of biomass utilization on forest productivity, 2) discuss the approaches that have been taken to answer these questions, and 3) summarize our current understanding of the relationship between forest productivity and biomass utilization in northern forest types.

Quantifying the Impact

The impact of harvesting on site productivity can be analyzed under the categories of 1) removals and redistributions of biomass and elements necessary for plant growth, 2) disruptions to forest ecosystem processes caused by the removal of all or part of the forest, 3) machine impacts and mechanical disturbance of the site, and 4) changes in forest stand structure. This paper will focus primarily on analyses relating to the first and second categories. Studies evaluating harvest removals of organic matter and nutrients may address one or more of the following questions.

1. What quantities of biomass and nutrients are removed with different utilization practices?

2. What proportion of site reserves of organic matter and nutrients is removed by the harvest?

3. What other nutrient losses occur as a result of harvesting (i.e., leaching, volatilization)?

4. How do harvest removals affect the capacity of the site to supply current and future developing stands with adequate amounts of nutrients?

   a. Where do plant nutrients come from?

   b. What are the key processes involved in making nutrients available for plant uptake?

   c. How will changes in nutrient availability affect forest growth rates?

   d. How do nutrient uptake requirements vary between trees and within a stand over the length of the rotation?

5. What is the relative importance of nutrients to stand growth when compared with soil physical factors and stand structure?

6. Do intermediate cuttings significantly increase biomass and nutrient removals over those associated with end-of-rotation harvests?

7. What management decisions will be made regarding future number of intermediate cuts and rotation lengths?

Questions 1 to 3 can be answered using relatively straightforward, though costly, methods. Answers to questions 4 to 6 can only be obtained with more complex and expensive studies extending over a long period of time and requiring extensive replication. Several studies exist that can answer questions 1 to 3 for northern forest types. Answers to questions 4 to 6 are not generally available for the Northeast, but various studies provide first approximations that require further validation.

General approaches to evaluating the effect of biomass harvesting on site productivity include a) a static balance sheet approach, where nutrient removals from bole-only (conventional) and whole-tree harvesting are compared with site nutrient reserves (Weetman and Webber 1972; Hornbeck and Kropelin 1982; Weetman and Algar 1983; Boyle and Ek 1972; Smith et al. 1986; White 1974; Freedman et al. 1981; Johnson et al. 1982); b) a dynamic balance sheet approach, where nutrient input-output budgets are used to estimate which nutrient removals might be replaced by atmospheric inputs during successive rotations, usually in addition to estimates made in the static approach (Norton and Young 1976; Johnson et al. 1982; Smith et al. 1986; Freedman et al. 1981); c) a computer simulation approach, which generally combines models of nutrient cycling and tree nutrient uptake to predict forest productivity (Weetman et al. 1979; Kimmins and Scoullar 1983; Swank and Waide 1979; Aber et al. 1982); and d) empirical studies, comparing growth rates between stands (or plots) that have been harvested using varying levels of utilization, usually on a replicated-plot basis (Andersson 1984a, 1984b; Andersson 1985; Bjorkroth 1984).

The static balance sheet approach can be used to answer questions 1 and 2. The dynamic balance sheet approach can be used to answer questions 1, 2, and 3. The computer simulation approach is capable of addressing questions 1 through 7, depending on model complexity, and data quality. Empirical studies in the most important forest types are necessary to provide validation feedback for simulation models.

Static Balance Sheet

The static balance sheet approach is a first step that must be taken in a variety of forest ecosystems. Such studies form the basis for relating utilization levels to biomass and nutrient removals, and establishing base-line information on soil nutrients. They may be used to evaluate economic gains due to increased biomass relative to the removal of increased nutrients (Table 1), in stands of different ages, species composition and biomass.

Table 1 summarizes biomass and nitrogen-removals study data for conventional and whole-tree harvesting in the red spruce-balsam fir-hardwood, mixed northern hardwood, and mixed upland oak forest types. This summary indicates that for the spruce-fir-hardwood type, a change from conventional to whole-tree utilization increases biomass removals between 29 and 61% (avg. 45%) while increasing nitrogen removals between 122 and 390% (avg. 201%).

Changing from conventional to whole-tree harvesting causes similar increases in biomass and nitrogen removals in the mixed northern hardwood type. Biomass removals increase between 34 and 64% (avg. 47%), while nitrogen removals increase between 72 and 374% (avg. 159%).

For mixed upland oaks the magnitude of the percentage biomass increase is much larger (avg. 155%) than for the other types, while increases in nitrogen removals are about the same (range 83 to 184%, avg. 133%).

Table 1 also reveals that the percentage increase in biomass removed is smaller in mature stands than in pole-sized stands. This can be seen in the inverse relationship between total stand biomass and the percentage increase in biomass removed due to the switch in utilization. This relationship was significant (α = 0.01) for both spruce-fir-hardwood (r = -0.78) and mixed northern hardwoods (r = -0.93).

Table 1. Biomass (oven-dry t/ha) and nitrogen (kg/ha) removals, and weighted mean nitrogen concentration (kg N/t) in the harvested biomass, for conventional and whole-tree harvesting in spruce-fir-hardwood, mixed northern hardwoods, and mixed upland oaks forest types.

	Conventional harvest			Whole-tree harvest			% Increased Removal	
Reference[a]	Biomass (t/ha)	N (kg/ha)	kg N/t	Biomass (t/ha)	N (kg/ha)	kg N/t	Biomass	N
Spruce-fir-hardwood								
1	68	79	1.16	101	218	2.16	49	176
1	80	89	1.11	119	263	2.21	49	196
2	82	80	0.98	117	260	2.22	43	225
3	82	79	0.96	132	387	2.93	61	390
1	93	111	1.19	144	339	2.35	55	205
4	105	98	0.93	152	239	1.57	45	144
1	107	120	1.12	155	335	2.16	45	179
5	130	97	0.75	180	322	1.79	38	232
1	167	192	1.15	224	469	2.09	34	144
1	189	214	1.13	243	475	1.95	29	122
Mixed northern hardwoods								
1	56	92	1.64	92	274	2.98	64	198
6	69	142	2.06	111	255	2.30	61	80
1	87	123	1.41	138	365	2.64	59	197
7,8	92	74	0.80	134	351	2.62	46	374
1	113	159	1.41	157	355	2.26	38	123
9	120	120	1.00	167	207	1.24	39	72
1	121	182	1.50	165	407	2.47	36	124
1	158	235	1.49	205	480	2.34	30	104
Mixed upland oak								
10, 11	60	166	2.77	151	303	2.01	152	82
10	64	110	1.72	165	312	1.89	158	184

[a]1. Freedman et al. 1982.
2. Norton and Young 1976.
3. Weetman and Webber 1972.
4. Freedman et al. 1981.
5. Smith et al. 1986.
6. Hornbeck and Kropelin 1982.
7. Whittaker et al. 1974.
8. Bormann et al. 1977.
9. Boyle and Ek 1972.
10. West and Mann 1983.
11. Hornbeck (this publication, previous paper).

For all forest types there is a greater percentage increase in nitrogen removals than biomass removals, with any shift from conventional to whole-tree harvesting (Table 1). This is because crowns contain a greater proportion of stand nitrogen than do boles, even though boles contain a greater proportion of stand biomass for all stands (Figures 1 to 4). The weighted mean concentration of nitrogen (kgN/t) in the harvested material is always greater for whole-tree than for conventional harvests (Table 1). The average increase in the weighted mean concentration associated with increased utilization is 107% for spruce-fir-hardwoods, and 77% for mixed northern hardwoods.

In general, young stands with low total biomass contain a higher proportion of biomass in their crowns than do older stands with greater total biomass (Figures 1 and 2). This implies that whole-tree harvests in young stands will remove more nitrogen per ton of harvested biomass than in older stands, as a result of "bolewood dilution". This was demonstrated by Switzer et al. (1978) for loblolly pine (*Pinus taeda* L.). However, for the studies investigated here, there is no statistically significant trend in weighted mean nitrogen concentrations (Table 1), or in the distribution of stand nitrogen between crowns and boles (Figures 3 and 4). The lack of a statistically significant relationship between stand biomass and the distribution of stand nitrogen is probably due to variation among study areas in stand age, species composition, stand density, and site quality. For example, the composition of the mixed northern hardwood stands

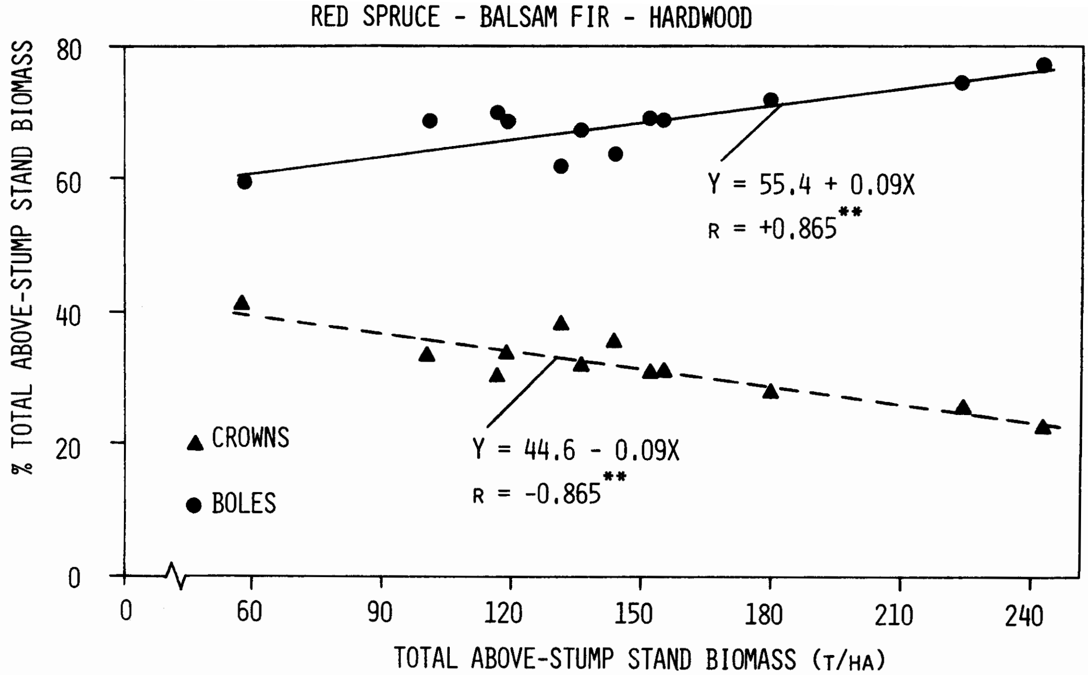

Figure 1. Relationship between total above-stump stand biomass and the proportion of that biomass contained in crowns and boles for red spruce-balsam fir-hardwood stands (data from Table 1). The correlation coefficients are highly (**) significant (α = 0.01).

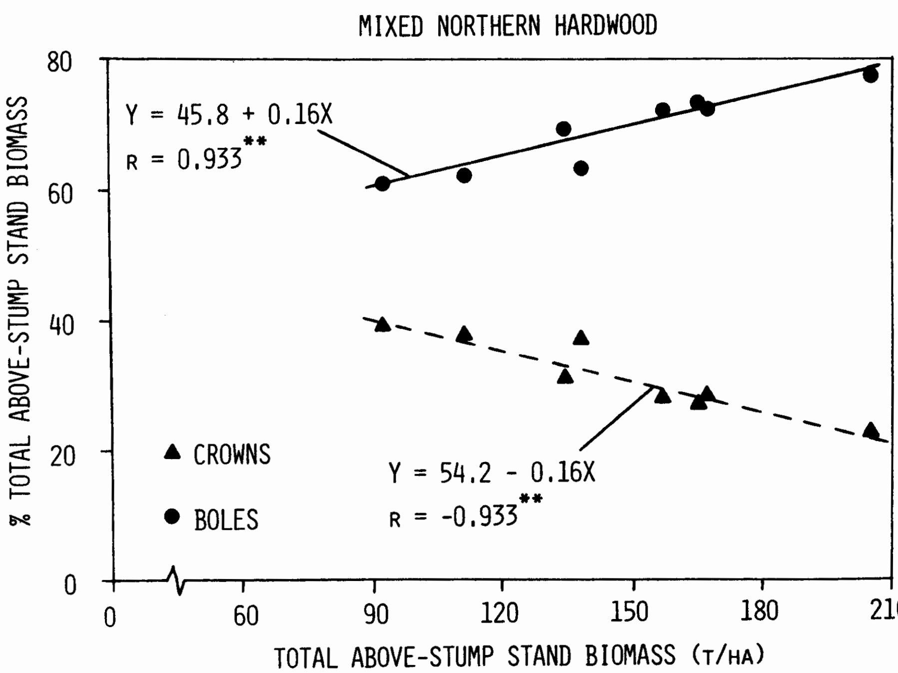

Figure 2. Relationship between total above-stump stand biomass and the proportion of that biomass contained in crowns and boles for mixed northern hardwood stands (data from Table 1). The correlation coefficients are highly (**) significant (α = 0.01).

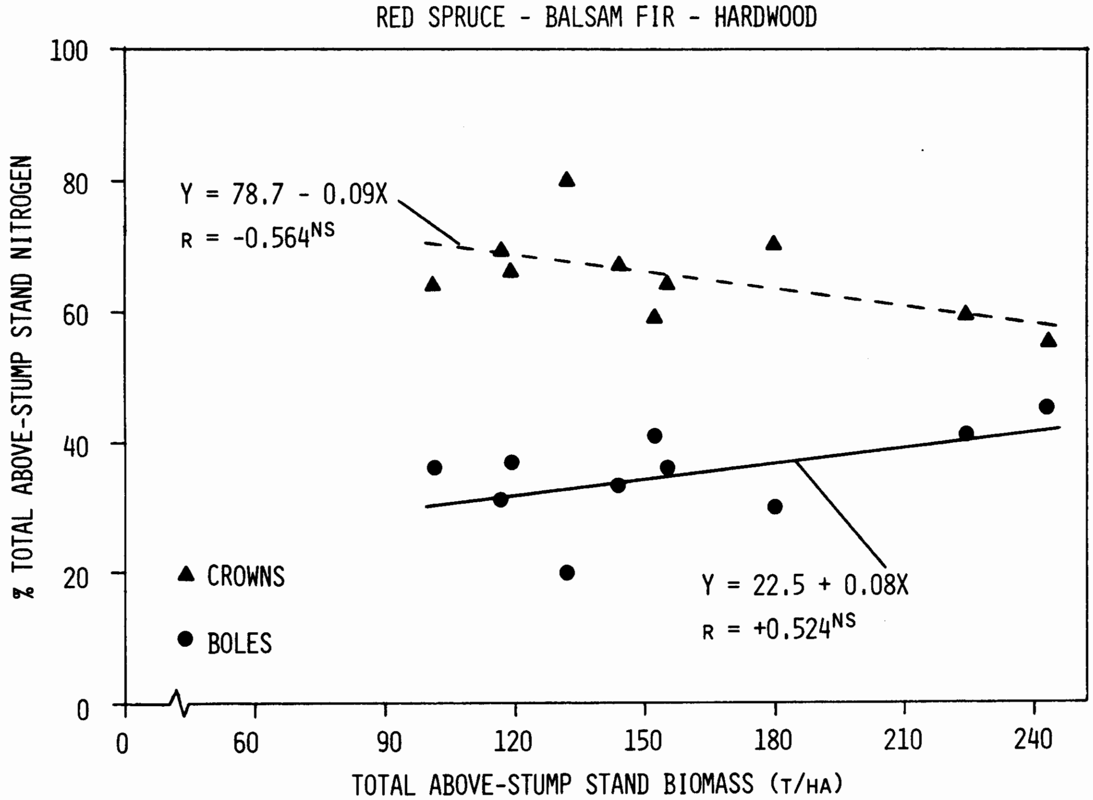

Figure 3. Relationship between total above-stump stand biomass and the proportion of total stand nitrogen contained in crowns and boles for red spruce-balsam fir-hardwood stands (data from Table 1). The correlation coefficients are not significant (NS) at α = 0.05.

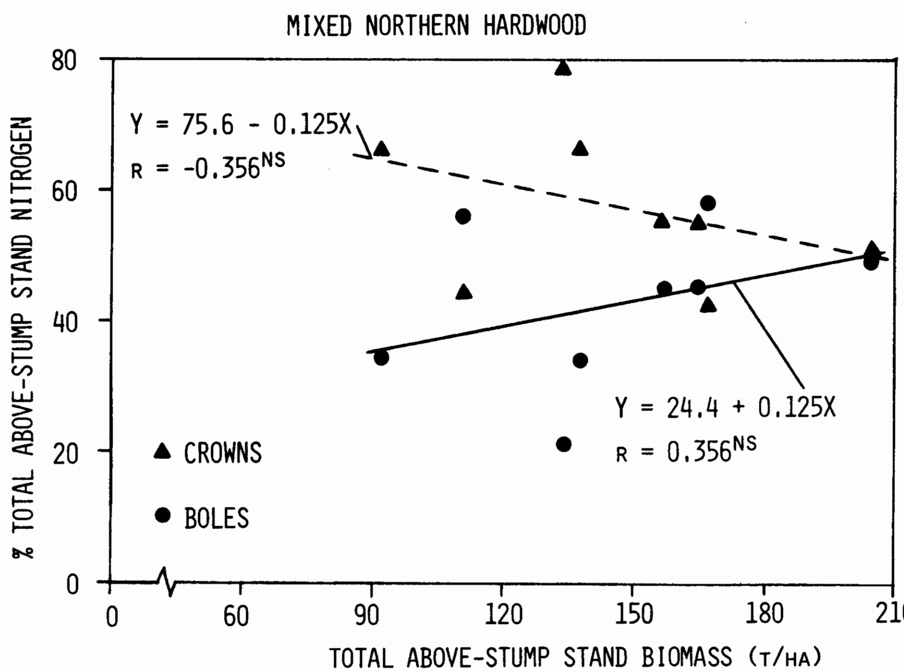

Figure 4. Relationship between total above-stump stand biomass and the proportion of total stand nitrogen contained in crowns and boles for mixed northern hardwood stands (data from Table 1). The correlation coefficients are not significant (NS) at α = 0.05.

had variable proportions of beech (Fagus grandifolia Ehrh.), sugar maple (Acer saccharum Marsh.), red maple (Acer rubrum L.), yellow birch (Betula alleghaniensis Britton), and white birch (Betula papyrifera Marsh.) (Freedman et al. 1982); and the composition of the spruce-fir-hardwood stands had variable proportions of red spruce (Picea rubens Sarg.), white spruce (Picea glauca [Moench] Voss), balsam fir (Abies balsamea [L.] Mill.) and northern hardwoods. Experimental control over these variables may clarify the inverse relationship between stand age and nutrient concentrations in harvested biomass.

The amounts of nutrients removed with these end-of-rotation harvests have generally been found to be small compared with total site nutrient reserves, but quite large when compared with "exchangeable" soil reserves, as determined by various accepted extraction methods (Table 2). This static balance sheet approach is useful both for highlighting those nutrients which are in short total supply, as indicated by the ratio of total reserves to harvest removals, and for identifying the nutrients for which various cycling processes may be critical to site productivity, as indicated by the ratio of exchangeable reserves to removals.

The major limitation of these comparisons as a potential index of future productivity reductions is the lack of calibration studies relating the various ratio values to forest productivity. Another limitation is inherent in the static nature of the harvest removal and soil reserve values. Harvest removal values indicate the amount of nutrients the stand contained at a certain harvest age, but do not directly indicate the amount of a certain nutrient the stand needs at any specific younger age to achieve adequate

Table 2. Comparison of ratios of soil nutrient reserves to whole-tree harvest removals for selected studies (from Smith et al. 1986).

Source	Forest type	Soil depth (cm)	Ratio of soil reserves to harvest removals: N	P	K	Ca	Mg
			Total nutrient reserves				
Smith et al. (1986)	mature red spruce-balsam fir	54	21	60	53	25	823
Freedman et al. (1981)	mature red spruce-balsam fir	40	20	36	101	17	48
Weetman and Webber (1972)	mature balsam fir-red spruce	26	5	4	66	2.5	35
Weetman and Algar (1983)	200-yr old black spruce	55	10	9	40	0.4	16
Hornbeck and Kropelin (1982)	40-yr old northern hardwoods[a/]	86	28	102	71	42	-
Hornbeck and Kropelin (1982)	40-yr old northern hardwoods[b/]	86	35	132	83	47	-
Boyle et al. (1973)	45-yr old mixed northern hardwoods[b/]	20	8.7	-	-	-	-
Johnson et al. (1982)	50-120 yr old upland mixed oak[b/]	45	9.5	62	202	5.6	-
			Exchangeable nutrient reserves				
Smith et al. (1986)		54	-	5	0.8	0.9	5
Freedman et al. (1981)		40	0.2	3	0.6	0.3	1
Weetman and Webber (1972)		26	0.04	0.1	0.4	0.3	0.8
Weetman and Algar (1983)		55	0.2	0.8	1.1	0.2	1.4
Hornbeck and Kropelin (1982)[a/]		86	-	-	1.1	3.1	-
Hornbeck and Kropelin (1982)[b/]		86	-	-	1.2	3.5	-
Boyle et al. (1973)[b/]		20	-	8.4	1.7	1.7	4.8
Johnson et al. (1982)[b/]		45	0.05	1.8	2.3	0.5	-

[a/] trees with leaves

[b/] trees without leaves

growth rates. Soil reserve values can not be used directly to determine the rate at which nutrients were available for tree uptake over the length of the rotation.

Dynamic Balance Sheet

The dynamic balance sheet approach goes one step beyond the static approach by estimating input-output budgets of nutrients on a watershed basis. Input-output budgets are useful because they suggest which nutrients tend to accumulate in a watershed over time, and which nutrients tend to be depleted. If a nutrient accumulates naturally over time, then harvest removals may be gradually replaced during successive rotations. Input-output budgets for northeastern watersheds typically show that nitrogen and phosphorus accumulate in the uncut forest, while calcium, potassium, and magnesium are naturally depleted because leaching losses exceed atmospheric inputs (Freedman 1981; Johnson et al. 1982; Hornbeck [unpublished data]).

Input-output budgets are also useful because comparisons can be made between uncut and harvested watersheds to determine if harvesting causes increased leaching losses of nutrients. Studies conducted in the spruce-fir-hardwood, northern hardwood, and mixed upland oak types generally indicate that harvesting results in increased leaching losses of nutrients for several years after harvest. These studies have found that harvest removals of nitrogen and phosphorus may be replaced over time, and have indicated the importance of quantifying the rates at which nutrients like calcium, magnesium and potassium are made available to plants from soil minerals, recycled organic matter, and precipitation, because harvest removals of these nutrients will not be replaced over time.

The results of several studies may be applicable to extensive areas of New England. For example, the Becket-Lyman soils studied by Hornbeck and Kropelin (1982) at Mt. Success, New Hampshire, and also found at the Hubbard Brook Experimental Forest, New Hampshire (Bormann et al. 1977), are typical of the foothills of the White Mountains and the hills and low mountains in northern, central, and southwestern regions of New Hampshire, comprising some 1.2 million acres (20%) in that state alone. These studies may also apply to extensive areas of New York, Vermont and Maine with deep, well drained soils formed in compact sandy glacial till derived from granite, gneiss, and schist parent materials.

The Chesuncook catena soils studied by Smith et al. (1986) in north-central Maine are typical of some 3.5 million acres of the rolling, hilly parts of Maine between Mt. Katahdin and the New Hampshire and Quebec borders, and the results could probably be applied to other areas with deep, poorly to moderately well drained soils formed in glacial till derived from dark gray fine grained quartzite, slate, shale, and some calcareous sandstone parent materials.

The Chatfield-Canton-Hollis soils found on the Cockaponsett, Connecticut study area (West and Mann 1983) are found in approximately 9% of New Hampshire, and are also found in extensive areas of Connecticut, Massachusetts, Rhode Island, and New York that have mixed upland oak forests.

Computer Simulation and Empirical Studies

The perennial nature of trees and relatively long rotation length of forests require complex and lengthy studies to piece together the relationship between harvesting, site fertility, and forest productivity. This is where computer simulation models, in conjunction with empirical validation studies, become useful. Model development requires us to conceptualize and quantify how various processes function, and how these processes and forest productivity are affected by management practices. This development process should help to clarify the factors that are most limiting to tree growth, and to point out those areas where more research is needed. Until empirical results become generally available for major forest regions, forest managers only have output from simulation models to evaluate the interactions between biomass harvesting and forest productivity. The few existing attempts at simulating forest growth and yield following biomass harvesting have generally indicated reductions in yield due to soil nitrogen depletions following either shortened rotation length or increased utilization levels (Swank and Waide 1979; Aber et al. 1982). However, the results of these simulation studies are difficult to interpret on the basis of our limited knowledge of many ecosystem processes related to the nitrogen cycle. This is especially true in the absence of empirical validation studies in the forest types being simulated. In addition, these simulation models would not be useful in ecosystems where the supply of nitrogen is adequate for plant growth, or where some other factor may be limiting productivity.

An examination of the literature from Australia (Keeves 1966) and New Zealand (Whyte 1973) indicates that second rotation reductions in yield have occurred with *Pinus radiata*. In some cases, these reductions have occurred on phosphorus - deficient sites; however, the yield declines can not always be fully explained by harvest-related declines in site fertility, since soil compaction and diseases can also be important causes of post-harvesting declines in yield.

The studies compiled for Table 3 from the United States and Scandinavia indicate that removals of litter, thinning slash, and whole-tree harvesting have caused reductions in second rotation yields ranging from 5 to 25 percent. In many cases, these declines in yield have been attributed to reductions in site fertility; however, there is no firm support for these conclusions.

Northeastern forests typically are second or third generation forests growing on lands that have been subject to farming, pasturage, coppice

Table 3. Experimental results of studies comparing productivity following various levels of biomass utilization.

Source	Date study established	Location	Species	Removal	Change in Productivity
Ebermayer (1876)	1860	Germany	Pine, beech, spruce	Litter	Decrease
Cope (1925)	>1925	Maryland, USA	*Pinus taeda*	Litter	-25%
Jemison (1943)	1930	North Carolina, USA	*Pinus echinata*	Litter	Decrease
Andersson (1984)[a]	1928	Norway	*Pinus sylvestris*	Thinning slash (0/2x)[b]	-10 to -20%
	1964	Sweden	*Pinus sylvestris*	Thinning slash (0/1x)	-10 to -12%
	1972	Norway	*Pinus sylvestris*	Thinning slash (0/1x)	-5%
	1977	Norway	*Picea abies*	Thinning slash (0/1x)	-11%
Bjorkroth (1984)	1960's	Sweden	*Picea abies*	Thinning slash	-21%
	1960's	Sweden	*Picea abies*	Whole-tree harvest	-20%

[a] See also Folke Andersson (1985)

[b] 0/1x indicates treatments of slash removal versus slash left in place.

0/2x indicates treatments of slash removal versus double slash applications.

production for charcoal, or wildfire. These now-forested ecosystems are considered to have recovered their fertility and to show no growth losses due to these disturbances. Current forest management alternatives, including shorter rotation lengths and increased biomass utilization, are viewed as mild compared with past ravages. However, the point should be made that no studies using replicated plots currently exist in the Northeast that were designed to evaluate the effect of increased utilization or past land management practices on forest productivity. The establishment of such studies should be a high priority of forestry research since the results from simulation studies and empirical results from Australia, New Zealand, and Scandinavia have indicated fertility declines following biomass harvesting may be responsible for second rotation yield reductions. Future studies must obviously combine soil fertility research with empirical yield results following various biomass utilization levels.

Summary and Conclusions

A review of studies conducted in the spruce-fir-hardwood and mixed northern hardwood forest types indicate that whole-tree harvesting with shorter rotations will substantially increase the rate of nutrient removal from the site and the rate of nutrient depletion from the soil. Nutrient removals are small when compared with total soil reserves, but much more significant in relation to plant-available supplies of nutrients.

Simulation studies indicate that increased utilization and shorter rotations will cause depletion of soil nitrogen levels, and that this will cause yield reductions. However, the results of these simulation studies should be interpreted with caution. For simulation models to be useful across a variety of ecosystems and harvesting systems, they must be able to accurately simulate the relationships between forest productivity and a wide array of site-related factors. These factors include soil compaction, moisture levels, macro- and micro-nutrients, insects and diseases, since these have all been shown to affect post-harvesting productivity.

Empirical validation studies combining nutrient cycling and growth and yield studies will probably be needed in the Northeast before forest managers can objectively balance increased utilization and shorter rotations against increased nutrient removals and potential reductions in productivity. Various studies in Europe, Scandinavia, Australia, and New Zealand have found second rotation reductions in yield; however, the reasons for these declines in yield are not well established.

All the studies conducted in our northern forest types have dealt with end-of-rotation harvests. Future studies also must evaluate whole-tree harvesting during intermediate cutting, a practice which will increase both biomass yield and nutrient removal per rotation, and which has been associated with yield reductions in Scandinavia.

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BIOMASS HARVESTING, SOIL DISTURBANCE, AND REGENERATION

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Soil disturbance caused by mechanized whole-tree harvesting was estimated at a central hardwood site in Connecticut, a northern hardwood site in New Hampshire, and a spruce-fir site in Maine. Undisturbed soil covered 29% of the central hardwood site and about 8% of the other sites. Mineral soil was exposed on 8 to 18% of the sites after cutting, and wheel ruts greater than 30 cm deep occupied less than 3%. Results indicate that mechanized whole-tree harvesting caused a greater proportion of soil disturbance than other harvesting systems, and may impact regeneration to a greater degree.

Introduction

In forest soils, the organic matter at the top of the mineral soil, known as the forest floor, is a continuing source of available plant nutrients. It contributes to the water-holding and infiltration capacity of the soil, prevents erosion, and contains a bank of buried seeds vital for regeneration (Bormann and Likens 1979). Harvesting of forest products can disturb the structure and subsequently the function of forest soils. Disturbances range from light scarification, often beneficial and even essential to some types of reproduction (Marquis 1965), to severe compaction and deep rutting that may adversely affect tree growth (Moehring and Rawls 1970) and cause permanent loss of forest soils through erosion (Patric 1976). Compaction of the soil by logging equipment may reduce soil pore space, which in turn may affect root penetration of seedlings and subsequent seedling growth (Hatchell et al. 1970). Compaction also affects infiltration, leaching, and storage of soil water (Lull 1959). Compaction is most severe in truck roads, landings, and major skidroads, and may take large areas out of production for many years (Kochenderfer 1977; Case and Donnelly 1979).

The objective of this study was to determine the extent and severity of soil disturbance following whole-tree harvesting of central hardwood, northern hardwood, and spruce-fir stands, to assess the potential impacts on regeneration, and to develop recommendations for forest managers. The study by Holman et al. (1978) in the spruce-fir forest of Maine seems to provide the only other data on soil disturbance following mechanized harvesting with whole-tree removal in the Northeast.

Harvested Sites

At the central hardwood site in Connecticut, stems less than 30 cm at the stump were felled by hydraulic shears mounted on a modified front-end loader. Sawtimber and trees on slopes greater than 30% were felled by chain saws. Whole trees were hauled to a landing by rubber-tired skidders. Skidding was in the winter, mainly on frozen ground with little or no snow cover. The soils were moderately deep, somewhat excessively drained Chatfield and well-drained Canton, very stony fine sandy loams on 3 to 25% slopes; shallow, somewhat excessively drained Hollis-Chatfield-rock outcrop complex on 8 to 50% slopes; and poorly drained Leicester, a very stony fine sandy loam on 0 to 3% slopes.

At the northern hardwood site in New Hampshire, a hydraulic shear mounted on a tracked vehicle (Drott feller-buncher) was used to fell and bunch the trees. Hauling was by skidder. Half of the harvest was done in winter on snow and the other half in midsummer. The soils were an assemblage of excessively drained Lyman, a very rocky fine sandy loam on 3 to 15% slope; Becket, a well-drained, very stony fine sandy loam on 3 to 15% slopes; and moderately well-drained Skerry, a very stony fine sandy loam on 3 to 8% slopes.

At the spruce-fir site in Maine, trees on 63% of the area were cut and forwarded by a rubber-tired Koehring feller-forwarder. A Drott feller-buncher was used to harvest trees on 29% of the area with forwarding provided by skidders. Chain saws and skidders were used to harvest sawtimber trees as well. The remaining 8% of the area was occupied by a major truck road. Harvesting was in June and July. The soils were moderately well-drained to well-drained, coarse-loamy, mixed Chesuncook; somewhat poorly drained, coarse-loamy, mixed Telos; and poorly drained, coarse-loamy, mixed Monarda.

Measuring Disturbance

To assess types and degrees of soil disturbance at these sites, a modified line transect technique was adopted. At the central and northern hardwood sites, 50 starting points were selected at random with replacement at each site. At the spruce-fir site, 100 starting points were chosen at random with replacement. Random azimuths were selected with replacement for each point to avoid bias in transect alignment with skid trails. Line transects 2,500 cm long were established from the starting points along the azimuths. Soil disturbance was categorized by subjective visual placement into 1 of 10 disturbance classes. The length of each disturbance and elevation change of the soil relative to the estimated soil surface before harvest were measured along each transect line in 10-cm units. The disturbance classes were only visual identifications, but the depths were measured. The class definitions used at all three sites were:

Undisturbed--no visual disturbance of any type.

Depressed--forest floor not disturbed laterally, but depressed by equipment or by a falling tree.

Organic scarification--forest floor disturbed laterally, but no evidence of compression by wheels, tracks, or falling trees.

Mineral scarification--complete removal of the organic horizons but no disruption of the mineral soil.

Organic mounds--mounds of soil, still covered by organic material, created during harvesting usually as a berm parallel to wheel ruts or near tree roots disturbed during shearing.

Mineral mounds--mounds of mineral soil or organic soil covered by mineral soil deposits created during harvesting.

Organic ruts--shallow wheel or track ruts within the organic horizons with lateral movement or deep compression ruts still lined with organic soil.

Mineral ruts--wheel or track ruts in mineral soil.

Slash--stumps, logs in contact with the soil, or slash too dense to allow evaluation of soil disturbance.

Rocks--bare rocks that occupied 10 cm or more of the transect line.

Results and Discussion

Undisturbed

Twenty-nine percent of the central hardwood site remained undisturbed. Only 7% of the northern hardwood site and 8% of the spruce-fir site were undisturbed (Fig. 1).

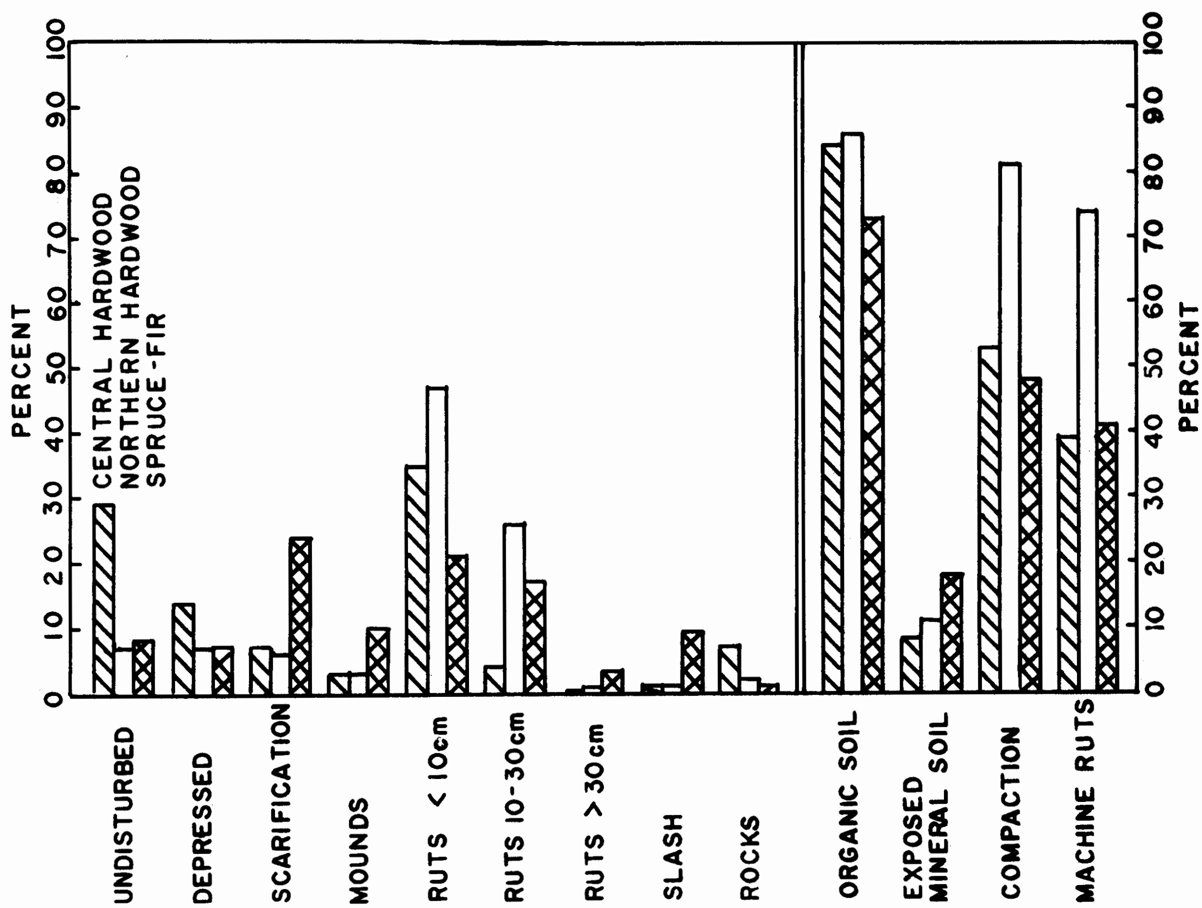

Figure 1. Soil disturbance created by whole-tree harvesting of a central hardwood, a northern hardwood, and a spruce-fir forest by percentage of the areas disturbed and by disturbance types. Left of the double line, the percentages add to 100% for each forest type. For each bar left of the double line, standard errors were less than 3%. Disturbance types have been combined to produce the bars right of the double line.

Depressed

This disturbance occurred on 14% of the central hardwood site and on 7% of the other sites. In terms of impact on regeneration, this could be classified as undisturbed.

Scarification

Scarification occurred when tree branches brushed over the forest floor during whole-tree skidding. Also, if the hydraulic shears failed to make a clean cut the first try, the stumps and root systems were often lifted slightly and shaken which would disrupt the organic horizons for several meters from the stump. Six to 24% of the study sites were scarified. Higher incidence of scarification at the spruce-fir site occurred because the Koehring feller-forwarder seemed to shake stumps more than the other harvesters, and the spruce-fir may have shallower root systems on this site than the deciduous trees at the other sites. The spruce-fir tops skidded during the Drott phase of the operation may also have scuffed the soil more than did the deciduous tops. This mixing of the litter, humus, and mineral soil without compaction has been shown to be very advantageous to birch regeneration (Marquis 1965). Scarification would be a distinct advantage at the northern hardwood site where birch is the preferred species. However, it may be a disadvantage at the spruce-fir and central hardwood sites where birch species are low-value competitors to the preferred species.

Mounds

Mounds were usually associated with wheel ruts. They were more prevalent at the spruce-fir site because of the higher percentage of poorly drained soils. Three to 10% of the sites were in mounds created during harvesting. Some species, especially yellow birch, seem to be more productive on the mounds (Tubbs 1963). They may have advantages in the spruce-fir region by providing better drained planting sites in wet areas, which in turn may increase productivity.

Ruts

The northern hardwood site had the highest incidence of organic ruts less than 10 cm deep, and a low incidence of deep ruts indicating that much of the skidding was dispersed over the entire watershed with little attempt to use predetermined skid trails. Most of the trails were made by only one or two passes.

The spruce-fir site had the lowest percentage of organic ruts less than 10 cm deep, the least area still covered by organic soil, the least area of compaction, a lower incidence of rutting, but the highest incidence of deep ruts. The Koehring feller-forwarder fells and transports trees so it enters an area only once and makes only one set of tracks, but they are deep tracks often into mineral soil. The wheels also tend to pull or squeeze mineral soil from lower layers to be deposited on top of organic soil adjacent to the ruts.

Ruts greater than 30 cm deep, which occupied 3% of the spruce-fir site, are almost certainly detrimental to regeneration and may represent an erosion threat. Deep ruts may divert subsurface water flow, channelize it, and lead to severe erosion. Ruts may also form pools of stagnant water, that disappear only through evaporation. This water-logging, though often only temporary, may be deleterious to regeneration (Patric 1978).

Slash

The spruce-fir site had the largest amount of logging slash left on site since all dead conifers and all deciduous trees were felled and left in place.

Rocks

The central hardwood site had the highest percentage of bare rocks. This contributed to the lowest incidence of deep ruts, the lowest incidence of exposed mineral soil, and the highest incidence of undisturbed soil.

Organic Soil

Undisturbed and depressed sites and sites with organic scarification, organic mounds, and shallow ruts were covered with organic soil. The northern hardwood site had more area covered with organic soil than any other site even though it also had the highest incidence of compaction and machine-made ruts (Fig. 1). The spruce-fir site had the least area of organic soil remaining after harvesting. Seventy-three to 86% of the sites still had organic soil remaining after the severe disturbance of whole-tree harvesting. In the glaciated soils of the Northeast, the organic layers contain much of the fertility, buried seeds, and water-holding capacity essential for successful regeneration. Therefore, so long as the forest floor remains on the site, disturbance is not as critical as if mineral soil is exposed.

Exposed Mineral Soil

Exposed mineral soil is generally considered detrimental to regeneration. Glacially derived mineral soils at these sites are low in fertility and are not conducive to vigorous regeneration (Hoyle 1965). Exposed mineral soil can become crusted and compacted, solely by rainfall impact, to the point where seedling roots may have trouble penetrating the soil (Lull 1959). Mineral scarification with no compaction, mounds of mineral soil, and wheel ruts in mineral soil occupied 8 to 18% of the three study sites.

Compaction

At the three study sites, 48 to 81% of the soil received some compaction. Compaction was minimal in areas with organic ruts less than 10 cm deep because only the forest floor was compressed, thereby cushioning and not compacting the soil beneath. If we subtract the organic ruts less than 10 cm deep, potentially serious compaction occurred on 23% of the central hardwood site, 35% of the northern hardwood site, and 31% on the spruce-fir site. Even one pass of a tractor reduces macropore space in the mineral soil which in turn reduces infiltration capacity (Lull 1959). Soil loss from erosion and sedimentation of streams and lakes also may result (Lull 1959).

Holman et al. (1978), working in 100-foot-wide strips cut with a Drott and hauled with skidders near the spruce-fir site in Maine, concluded that the top three inches of the mineral soil was compacted to a greater degree than the 3 to 6 inch depth. They also concluded that compacted soils can be restored to their original bulk density by freezing and thawing, wetting and drying, root penetration, and animal activity. They found that in non-skid-trail areas of the cut, bulk density returned to pre-cut levels within one year. Bulk density of skid trails in winter cuts returned to normal after two winters, but skid trails in summer cuts had not returned to normal after three winters.

Management Recommendations

As mechanized harvesting becomes more prevalent, it seems prudent for landowners, managers, foresters, and loggers to consider the following suggestions while planning harvesting operations.

* Deep ruts may take a small percentage of an area out of production for an extended period. If deep rutting occurs on wet soils, equipment use on such soils should be discontinued until drier conditions prevail. Winter logging may be an option; or conversion from wheeled to tracked vehicles; skid trails should follow the contours.

* Mechanized harvesting can cause compaction on more than 90% of a site. Compaction reduces seedling germination and growth to some degree. Foresters should predetermine travel routes to reduce the area of compaction and to keep equipment on well-drained sites.

* Mineral soil in the glaciated Northeast has relatively low fertility with the upper organic layers generally containing the major concentrations of available nutrients. Practices that remove the organic soil should be avoided or minimized. Reduction of deep ruts, reduction of the area in the main skid roads and landings by careful planning, and use of forwarders that transport rather than drag the whole tree would reduce the exposure of mineral soil.

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TIMBER HARVESTING, SOIL ORGANIC MATTER, AND SITE PRODUCTIVITY

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Soil organic matter is important for the maintenance of forest site productivity. Recent studies of eastern forests have shown organic matter reductions in both the forest floor and mineral soil following cutting and site preparation. Although reduced soil organic content may affect soil chemical, physical and biological properties, most concerns have been on possible nutrient losses or changes in nutrient availability. Little is known about the effects of decreased organic content on other soil properties such as water retention, structure, and cation exchange capacity.

The trend toward total-tree harvesting in eastern forests will increase biomass removal and dramatically reduce the amounts of wood residue left on a site after cutting. Logging residues improve soil nutrient storage, water retention, and seedling establishment but may increase disease incidence. In some western conifer forests, certain amounts of logging slash are left after harvesting for environmental concerns, especially on droughty sites. The effects of reducing wood residue following harvesting in the generally moist, mixed conifer-hardwood forests of the East are largely unknown.

Soil organic matter is important for the maintenance of site productivity because of its role in soil water retention, cation exchange capacity, and nutrient supply. Organic matter is also essential for the soil microflora and microfauna that are active in nutrient cycling, production of humic compounds essential for soil aggregation, and disease incidence (Harvey et al. 1976). By removing woody materials from a site, timber harvesting alters the cycling of organic matter from forest vegetation to the soil. In the past, wood removal was not considered detrimental to site productivity because of long stand rotation ages and the large amounts of residue usually left after harvest. Organic matter losses from fire, either as wildfire or prescribed burns, were considered a much more serious threat to future stand growth (Patric and Smith 1975; Wells et al. 1979). However, recent trends toward shorter stand rotations, coupled with total tree harvesting or increased residue utilization, have raised concerns on the possible impacts these management systems have on soil organic matter and consequently, on site productivity (Harvey et al. 1980b).

Many studies have been conducted on the environmental consequences of timber harvesting. Much of this research has centered on the relationship of harvesting to: (1) soil compaction as a result of equipment traffic, (2) stream damage from erosion, and (3) depletion of site nutrients (Frederiksen et al. 1975; Bengtson 1978; Froehlich and McNabb 1984; McColl and Powers 1984). The loss of soil nutrients can result from biomass removal, increased soil erosion from skid trails and landing areas, and accelerated decomposition of the forest floor or organic matter in the mineral soil following harvest (Bormann and Likens 1979; Vitousek 1983).

While the contribution of organic matter to soil nutrient levels will be of major concern in any evaluation of harvesting effects on site productivity, the question also arises as to the importance of this soil organic component as a physical entity apart from its nutrient content. As noted earlier, organic matter influences soil properties such as water-holding capacity, aeration, drainage, and cation exchange. Changes in these soil physical and chemical properties following harvesting may be more subtle than losses in soil nutrients, but may be just as significant for subsequent stand growth. Heiberg (1939) emphasized the biological and physical effects that the forest floor and logging slash can have on site productivity by reducing soil moisture losses through a mulching effect, improving soil drainage and aeration by decreasing bulk density, and reducing frost heaving.

Soil Organic Matter Content

The effect of logging operations on soil organic matter levels will depend on the intensity of the harvest and associated site preparation. Since timber harvesting would have greatest impact on the surface soil layers, sites having a higher proportion of organic material in the forest floor probably are affected more than sites having greater amounts in the mineral soil. The majority of organic matter in the soil of eastern forests is found in the mineral horizons, but as shown in Table 1, the amounts differ widely among stands depending on tree species, age, and soil type. The occurrence of earthworms in a soil and their incorporation of forest floor material into a mineral A horizon is a major factor in the organic matter distribution pattern. However, the presence or absence of earthworms in the soil was not indicated in most of the studies cited. One problem comparing these results was the variability in depth used for sampling the mineral soil. The shallower the mineral soil was sampled,

Table 1. Organic matter content in selected forest soils of eastern North America.

Stand	Location	Organic Content: Forest Floor (Mg/ha)	Organic Content: Mineral Soil (Mg/ha)	Mineral Soil Depth (cm)	Ref.
N. Hardwoods	N. Hampshire	92	256	66	3
N. Hardwoods	N. Hampshire	47	173	45	2
Oak	N. Hampshire	36	287	75	3
Oak	Connecticut	11	274	81	3
Oak	New Jersey	11	238	60	5
Aspen/Maple	Wisconsin	4	84	30	8
Aspen	Minnesota	27	50	36	1
Jack pine	Minnesota	33	67	36	1
Jack pine	Ontario	26	92	42	7
Balsam fir	N. Hampshire	92	214	90	4
Spruce/fir	Maine	139	218	44	3
Spruce/fir	Maine	58	344	54	9
W. Spruce	Minnesota	33	71	36	1
Red pine	Minnesota	30	78	36	1
Red pine	New York	19	263	48	6

(1) Alban _et al_. 1978; (2) Bormann and Likens 1979; (3) Federer 1983; (4) Lang _et al_. 1981; (5) Lang and Forman 1978; (6) Madgwick 1962; (7) Morrison and Foster 1979; (8) Pastor and Bockheim 1984; (9) Smith _et al_. 1986, C.T. Smith, personal communication.

the greater the concentration of organic matter in the forest floor. Another difficulty is the subjectivity in separating the humus layer of the forest floor from the mineral A horizon (Federer 1982).

Losses of Soil Organic Matter

The losses of soil organic matter as a result of timber harvest operations have been determined by several methods. The most direct and statistically appealing is measuring organic matter content in the forest floor and mineral soil before and at different times after harvest. A less satisfactory but faster method is organic matter measurements on adjacent cut and uncut stands. Results from these types of studies have indicated appreciable losses in forest floor biomass after cutting (Table 2). The losses of soil organic matter from these cut sites were even greater than shown, since appreciable amounts of logging slash were added to the forest floor (e.g. Johnson _et al_. 1985). However, it is not known how much of the forest floor and harvest residue were incorporated into the mineral soil and not lost from the site. Such organic matter changes in the mineral soil are not well documented.

These types of studies have indicated short term losses of soil organic matter following timber harvest. Longer term organic matter changes that occur with subsequent stand development have been evaluated by comparing soil organic content in stands having different ages since cutting. Because the preharvest soil conditions in these stands are not known, sites of similar stand history, species composition, topography, etc. are selected to reduce the inherent variability in organic matter levels among soils.

Both Covington (1981) and Federer (1984) used this approach with northern hardwood stands in New Hampshire to show that the forest floor organic content decreased for at least 20-25 years after logging before recovering to preharvest levels in 50 to 60 years. A smaller, less defined pattern of forest floor losses and recovery following clearcutting was reported by Wallace and Freedman (1986) for hardwood stands in Nova Scotia. These studies did not examine concurrent organic matter changes in the mineral soil. A decrease in the organic content of mineral soil was found by Durgin (1980) for 35 to 45 years after the logging of redwoods in California. However, possible problems with chronosequence studies were shown by the results of Silkworth and Grigal (1982) in northern Minnesota who reported a forest floor biomass of 13.4 Mg/ha in an uncut aspen stand and 88.8 Mg/ha in another stand five years after a total-tree harvest. This difference was attributed primarily to the presence or absence of earthworms at these sites.

Decreases in the forest floor as a result of timber harvesting have generally been attributed to increased microbial decomposition of organic matter due to changes in soil environmental conditions. Tree removal usually increases soil

Table 2. Soil organic matter before and after timber harvest.

N. Hardwoods - Michigan[1]		Before Harvest	After Harvest
		(Mg/ha)	
High Site Quality		60.9	17.7
Medium Site Quality		38.3	16.9
Low Site Quality		24.8	14.5
N. Hardwoods - New Hampshire[2]		**Uncut**	**Cut, Herbicided Wood Not Removed**
		(Mg/ha)	
0-15 cm		74.8	60.7
15-30 cm		81.7	76.9
Mixed Oaks - Virginia[3]		**Before Harvest**	**After Harvest**
		(Mg/ha)	
		15.4	10.5
Longleaf - Florida[4]	**Uncut**	**Cut, Burned and Chopped**	**Cut, Bladed, Disked and Bedded**
		(Mg/ha)	
	87.9	69.1	53.1

[1] Forest floor sampled 30 months after harvest (Mroz et al. 1985).
[2] Forest floor included in 0-15 cm depth. Sampled 42 months after harvest (Dominski 1971).
[3] Forest floor sampled 28 months after harvest (Johnson et al. 1985).
[4] 0-20 cm soil sampled 24 months after harvest (Burger and Pritchett 1984).

moisture levels and temperature in the surface soil horizons (Dominski 1971; Hungerford 1980; Johnson et al. 1985). Changes in soil acidity also occur, especially if fire is used for slash disposal (Jurgensen et al. 1981). However, Gadgil and Gadgil (1978) attributed increased organic matter decomposition following harvest to the removal of an inhibitory effect of tree mycorrhizae on the forest floor microflora.

Populations of bacteria increase in the soil after clearcutting, but fungal biomass has been reported to decline (Hendrickson and Robinson 1982). The levels of soil carbon dioxide on cut sites increase as a result of greater microbial activity (Piene 1974; Edwards and Ross-Todd 1983) and could contribute to the accelerated nutrient leaching losses occurring after harvest (Johnson and Cole 1980). Soil microorganisms active in the nitrogen cycle are also influenced by clearcutting (Jurgensen et al. 1980). Most notable is the rise in nitrification rates in both the forest floor and surface mineral horizons of many soils and the resulting increase in leaching losses of nitrogen (Vitousek et al. 1982).

The disruption and mixing of the forest floor into the mineral soil by the logging operation is another factor which can reduce soil organic matter levels. This effect would be more pronounced on whole-tree harvested sites where logs and tops are dragged off the cutting area. Mroz et al. (1985) attributed the greater reduction of forest floor on a high quality northern hardwood site to the impact of skidding larger trees with bigger tops, as compared to the forest floor losses resulting from skidding smaller trees with less crown from lower quality sites. Such forest floor disturbances are common on whole-tree harvested sites in New England and the Lake States (Crow 1985; Martin 1986).

Incorporating forest floor into the surface mineral horizons does not constitute a loss of this organic material from the site. In fact, mixing of the forest floor may be a benefit to the underlying mineral soil. Forest floor that is incorporated with mineral soil is decomposed more rapidly by soil microorganisms than when the forest floor is left undisturbed (Salonius 1983). Forest floor disturbance and resultant increased organic mineralization rates have been advocated to improve soil productivity on sites where appreciable nutrient capital is "tied-up" in slowly decomposing humus layers (Siren 1955; Weetman and Nykvist 1963). The mixing of forest floor and mineral soil has been shown to improve the growth of both hardwood and conifer seedlings (Tubbs and Oberg 1966; McMinn 1974).

While the benefits of enhanced nutrient availability in soil after harvesting, as compared to the negative effect of greater nutrient leaching, have not been fully resolved, such nutrient losses are normally low when the site is rapidly revegetated (Bormann and Likens 1979; Vitousek 1983). What still is not clear are the changes in mineral soil organic contents which result from harvesting. Lower inputs of organic matter from litter fall would occur for at least ten years on the harvested sites (Covington and Aber 1980), but this would be offset by increased root mortality from the cut trees.

Most environmental impact studies on soil organic matter have concentrated on changes in the forest floor rather than the mineral soil. Bormann and Likens (1979) feel this is justified based on the annual organic matter inputs and turnover rates in these soil layers, and the relative unresponsiveness of the mineral soil to environmental change. However, Federer (1983) recommended that the mineral soil not be ignored in favor of research on the forest floor after finding nitrification occurred only in the mineral soil beneath four mature forest stands in New England. Debyle (1980) found organic matter changes ranging from +65% to -21% in the 0-5 cm mineral soil layer five years after various site preparation treatments were applied on a cut lodgepole pine site in Wyoming. Burger and Pritchett (1984) reported large losses of organic matter from the 0-20 cm soil depth after harvesting southern pine plantations followed by slash burning and mechanical site preparation (Table 2).

Woody Residues

Timber harvesting, especially whole-tree logging, removes a large percentage of the woody material which would be added to the forest floor of an uncut stand. Woody residue is important in nutrient cycling, the maintenance of soil biological functions, and the incidence of tree disease. In his discussion of forest floor dynamics, Covington (1981) emphasized the role logging slash, particularly woody materials, could have on soil nitrogen availability. The nutrient relationships of woody residue removal on site productivity have been discussed by other authors in this symposium.

Dead wood is a major component of eastern forests and may equal or surpass other organic biomass in the forest floor (Table 3). Large woody residue is an active site in energy flow and nutrient cycling in both soil and stream ecosystems. Downed logs are also important for seedling establishment of certain tree species and are sites of enhanced mycorrhizae development and nonsymbiotic nitrogen fixation (Larsen et al 1978; Harvey et al. 1980a; Maser and Trappe 1984; Harmon et al. 1986).

Wood Decay

The rate and type of organic matter decomposition is closely tied to the decay organisms involved. Woody residue decay is

Table 3. Biomass of the Forest Floor and Dead Wood on the Soil Surface in Northeastern Forests.

Stand	Age (yr)	Forest Floor	Deadwood
		Mg/ha	
N. Hardwoods	20	52[1]	31.6[2]
	30	61	12.8
	40	67	7.6
	57	73	4.7
	200	90	38.4
Balsam Fir[3]	78	98	14.0
Spruce-Fir[4]	65	58	17.0
Oak[5]	>250	11	23.5
Aspen/Maple[6]	65	4	4.4

[1] Uncorrected values of Covington (1981) as presented by Federer (1984)
[2] Wood >3 cm in diameter (Tritton 1980).
[3] Wood >5 cm in diameter (Lang et al. 1981).
[4] Includes all litter on top of forest floor (Smith et al. 1986; C.T. Smith, personal communication).
[5] Wood >2.5 cm in diameter (Lang and Forman 1978).
[6] Not including twigs (Pastor and Bockheim 1984).

primarily a function of invertebrate activity and the colonization of wood by white-rot and brown-rot fungi (Larsen et al. 1980; Harmon et al. 1986). In North America there are approximately 1,700 known wood-rotting fungi of which 1580 cause white rots and only 120 cause brown rots (Gilbertson and Ryvarden 1986). Typically, white-rot fungi remove cellulose and lignin at a similar rate, while brown-rot fungi remove cellulose and leave the lignin essentially unchanged (Highley and Kirk 1979).

The extractive content of heartwood and sapwood exerts a limiting or selective influence on the activities of both brown-rot and white-rot fungi. Sapwood and heartwood of hardwood residue is overwhelmingly decayed by white-rot fungi. In conifer wood, initial sapwood decay appears to be of the white-rot type, which eventually shifts to brown-rot. Heartwood is usually decayed by the brown-rot fungi (Larsen et al. 1980). Thus, in hardwood or mixed forest types wood decay by white-rot fungi would predominate (Table 4).

Table 4. Rot type of fungi important in the decomposition of logging slash in the Northeastern United States[1].

Decay	Number of Fungal Species
White Rot	54
Brown Rot	16
Unknown	12

[1] Adapted from Spaulding and Hansbrough (1944).

Hardwood residues decayed by white-rot fungi decompose at a much faster rate than conifer wood decayed by brown-rot fungi (Spaulding and Hansbrough 1944; Harmon et al. 1986). At the advanced decay stage white-rotted residues are less acid, have higher rates of nonsymbiotic nitrogen fixation, and have a more rapid nutrient flux than brown-rotted wood (Larsen et al. 1980; Jurgensen et al. 1984). However, once white-rotted wood is incorporated into the forest floor, it quickly loses its structural integrity. In contrast, brown-rotted residues may persist in the forest floor for hundreds of years (McFee and Stone 1966; Harvey et al. 1981) and have a longer effect on soil properties than white-rotted wood.

Soil Wood

When woody residues become incorporated into the forest floor, they can rightfully be termed soil wood. At this stage the wood is often covered by litter and not noticed as a part of the soil. However, brown-rotted soil wood has been found to comprise up to 15 percent of the surface 30 cm of soil in northern Rocky Mountain forests (Harvey et al. 1980a). Brown-rotted wood volumes ranging from 14 to 30 percent of the forest floor were found in a mixed hardwood-conifer stand in northern New York (McFee and Stone 1966). In subalpine balsam fir forests of New Hampshire, soil wood amounted to 3.9 Mg/ha, as compared to a forest floor biomass of 92.2 Mg/ha and 13.5 Mg/ha of woody residues on the soil surface (Lang et al 1981). The relationship of soil wood to nutrient cycling in these balsam fir stands was discussed by Lambert et al. (1980).

The impacts of brown-rotted soil wood on the forest soil ecosystem are considerable. Soil wood is usually wetter and cooler than the surrounding forest floor (Hungerford 1980). Consequently, root activity is favored in soil wood, particularly on dry sites (Harvey et al. 1980a). Because of its high moisture-holding capacity, brown-rotted soil wood is also an excellent seedbed for conifer regeneration and for nonsymbiotic nitrogen fixation (Lees, 1972; Larsen et al. 1982; Harvey et al. 1983).

Disease Incidence

As noted earlier there are nearly 1,700 species of fungi in North America that decay wood (Gilbertson and Ryvarden 1986). However, the numbers of fungi that decompose woody residues and cause significant losses in live standing timber are relatively few. Spaulding and Hansbrough (1944) listed 16 fungi capable of causing slash decay and heart rot in trees of New England. Harvey et al. (1976) reviewed the implications of timber harvesting and residue management on forest diseases and concluded that a reduction in woody slash left on a site after cutting would generally reduce disease incidence in the following rotation. However, such a disease - residue relationship may be limited for the heart-rot fungi. Removal of woody slash by intensive harvesting techniques would likely have a minor effect on the incidence of heart rot in the subsequent stand, because adjacent forest areas have many fungal fruiting bodies with spore-producing potential. Unfortunately, specific studies relating heart-rot incidence to the kinds, quantities, and distribution of logging residues have not been done.

In contrast, residue removal may be more effective in reducing the incidence of root rot caused by *Armillaria mellea*. This white-rot fungus is widely distributed in eastern forests due to its ability to rapidly colonize stump-root systems and other woody residues in contact with the soil. The rhizomorphs of *A. mellea* attack both hardwood and conifer seedlings, the susceptibility of which is dependent on predisposition of the seedling (Wargo and Shaw 1985). Since *A. mellea* can use logging slash as a food base from which to infect regeneration, a reduction in woody residue by intensive harvesting practices should be of some benefit. Other important root-rot fungi in eastern forests, such as *Phaeolus schweinitzii*, *Heterobasidion annosum* and *Inonotus tomentosus*, would be less affected by improved residue utilization, since they primarily colonize stump-root systems.

Stump pulling has been advocated to reduce the incidence of root-rot diseases after harvesting, particularly for A. mellea (Roth and Ralph 1978). In the Pacific Northwest, stump removal has received limited use for control of laminated root-rot caused by Phellinus weirii (Theis and Russell 1984). Approximately 4,000 acres have been treated in the state of Washington and 500-1,000 acres in Oregon. Stump harvesting is widespread in the Southeast for the production of naval stores, with disease considerations being secondary (W.G. Theis, personal communication). At present, stump removal as a disease control protocol is time consuming, labor intensive, and not cost-effective.

Implications for Management

Recent studies on radiata pine plantations in Australia have indicated that losses in soil organic matter following harvesting and subsequent site preparation resulted in site deterioration by lowering soil cation exchange capacity, reducing moisture retention, and increasing soil compaction. This reduction in soil productivity was particularly evident on coarse-textured, droughty soils (Flinn et al. 1980; Sands 1983; Squire 1983). The importance of soil organic matter to the productivity of pine plantations on droughty soils in the southeastern United States was also stressed by Burns and Hebb (1972).

The relationship of the forest floor to soil hydrological properties and site productivity was emphasized by Sands (1983). Litter removal has been shown to increase moisture stress in longleaf pine plantations and reduce growth in jack pine stands (Ginter et al. 1979; Weber et al. 1985). Tree roots are concentrated in the forest floor and surface mineral soil, and would react to disturbance or environmental changes in these soil layers (Safford, 1974). Annual litter removal from a radiata pine stand in New Zealand caused the zone of major root activity to move from the forest floor and surface five cm of mineral soil to the 5 - 10 cm soil depth. Such root displacement would reduce nutrient uptake from the forest floor and surface mineral layer, and may be partially responsible for a 12 percent reduction in stand volume increment (Ballard and Will, 1981).

Timber harvesting methods have a considerable impact on the integrity of the forest floor and on the amounts and type of woody residue remaining on a site after cutting. The trend toward whole-tree harvesting in northern hardwood forests will reduce the amount of organic materials returned to the soil. Whole-tree logging, as its name implies, would remove more tree biomass than so-called "conventional" harvests. When stands are whole-tree logged, additional biomass yields generally range from 15 to 100 percent higher than in conventional cuts (Freedman et al. 1981; Hornbeck and Kropelin 1982; Phillips and Van Lear 1984).

With greater wood removals resulting from harvest operations, the amount of woody material left on the site can be quite small. Residues remaining after whole-tree logging a northern hardwood stand in New Hampshire averaged only 4 Mg/ha out of a total above-ground tree biomass of 115 Mg/ha (Hornbeck and Kropelin 1982). Harvesting red spruce-balsam fir in Maine with total aboveground biomass of 232 Mg/ha added 39 Mg/ha of woody residue to the forest floor (Smith et al. 1986). In a total-tree harvest of central hardwoods in Connecticut, less than 13 percent of the above ground biomass was left as residue (L.M. Tritton, personal communication). Whole-tree harvesting a mixed hardwood-aspen stand in northern Michigan left 19.5 Mg/ha of wood residue on the site. In comparison, 3.8 Mg/ha of organic matter remained in the forest floor of the same site after cutting (G.D. Mroz and M.F. Jurgensen, unpublished data).

Most environmental concerns on wood removal and forest floor disturbance have been on possible soil nutrient losses or changes in nutrient availability (White and Harvey 1979; Smith 1985). However, as discussed earlier, the decomposition and subsequent incorporation of litter and/or logging slash into the forest floor have important implications for soil biological and physical properties, especially of droughty sites (Harvey et al. 1980b; Jurgensen et al. 1982; Sands 1983). Even on moist sites, increased organic matter decomposition following harvesting has caused appreciable reductions in soil cation exchange capacity (Dominski 1971). Stone (1979) emphasized the need of determining the effects of such harvest-related changes in cation exchange capacity and its impact on soil nutrient retention.

In final analysis, many studies have shown that organic matter levels in the forest floor and mineral soil decrease for an appreciable time following timber harvest. Subsequent site preparation and slash disposal will further lower soil organic matter levels. The implications of such reductions in the soil organic resource on site productivity are largely unknown, but would seem to be detrimental, particularly in dry or shallow soils. The significance of increased removal of woody residues on site productivity in eastern forests is unclear. Woody residues and soil wood have been shown to be an important factor in soil water and nutrient availability in many western coniferous forests (Harvey et al. 1980b; Harmon et al. 1986). In the Intermountain West, changes in harvesting and site preparation practices are being implemented to ensure adequate amounts of organic matter remain on the site following cutting (Harvey et al. 1986). Whether a similar practice will be beneficial in the generally moist, mixed conifer-hardwood forests of the East remains to be seen.

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SOIL LEACHING IN NORTHERN FOREST ECOSYSTEMS

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Natural leaching is being increased by both acid deposition and harvesting in northern forest ecosystems. Acid deposition is increasing the rates of calcium (Ca), potassium (K), and magnesium (Mg) leaching, but deficiencies of these elements are, as yet, rare. If deficiencies of a particular nutrient arise, both chemical and biological processes will act to conserve that nutrient.

Harvesting usually causes a temporary increase in nutrient mineralization from litter and soil organic matter. This flush of nutrients is beneficial to nutrient-demanding regenerating vegetation, but if mineralization exceeds uptake, leaching losses will temporarily increase. This is especially common with respect to nitrate (NO_3^-) and, consequently, Ca, K. and Mg leaching, especially in nitrogen-rich northeastern forests. In most cases, however, this post-harvest increase causes less nutrient export than that removed in biomass. Nevertheless, excessive NO_3^- leaching should be avoided to protect water quality. Nitrate leaching can be influenced by forest management practices, such as the type of cut, amount of woody residue left, and rate of regeneration. Accelerated leaching by acid deposition cannot be controlled by forest management, but fertilization can be employed to offset cation nutrient losses if they become critical.

Introduction

In this paper we will briefly review soil leaching processes as they are naturally and as affected by acid deposition and harvesting, with emphasis upon northern forest ecosystems. Soil leaching is the major mechanism of nutrient export from most undisturbed forest ecosystems. Leaching by naturally produced acids (primarily carbonic acid and organic acids) is a major cause (along with tree nutrient uptake and soil humus buildup) of soil acidification. In northern forest ecosystems, where Spodosols dominate, organic acids are the major natural soil leaching agent (Johnson _et al_. 1977). In the northeastern United States (and northern Europe) this natural leaching rate has been accelerated by acid deposition (Cronan _et al_. 1978; Mollitor and Raynal 1982). Since acid deposition is a relatively new phenomenon, its contribution to total soil acidity is minimal as yet, but the historical rates of soil acidification have probably been increased. It has also been known for some time that leaching can be temporarily increased following harvesting, as a result of a combination of reduced plant uptake increased mineralization, greater water flow and, in some cases, increased nitrification leading to an elevation in nitrate (NO_3^-) concentrations in soil solution (Likens _et al_. 1969). However, the magnitude and duration of these increases vary widely from site to site, and in some cases the enhancement of leaching by harvesting is very minor (e.g., Richardson and Lunt 1975).

Natural Soil Leaching in Northern Forest Ecosystems

Many strong and weak acids are produced naturally in forest soils, but three major naturally produced acids (one of the three is actually a group of acids) have been identified as major causes of leaching in undisturbed forest ecosystems: carbonic acid (H_2CO_3), organic acids (so-called fulvic acids as well as smaller molecules) and, most recently, nitric acid (HNO_3) (McColl and Cole 1968; Johnson _et al_. 1977; Van Miegroet and Cole 1984). The former two are referred to as "weak acids", since they do not release H^+ (i.e., do not contribute to acidity) at low pH, but they can nevertheless create very acid soil conditions during soil development. Carbonic acid is produced when CO_2, which accumulates in the soil atmosphere due to root and microbial respiration, combines with water:

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

When soil solutions reach pH 5 or lower, H_2CO_3 no longer significantly dissociates and thus no H^+ (acid) is produced. Organic acids of numerous kinds are released into crown wash and soil solution from tree canopies and decomposing litter. Their chemistry is much more complex than that of carbonic acid, because they range from short-chain acids like citric and malic to very complex molecules with phenolic cores (so-called fulvic acids; Schnitzer 1980). A very general representation of their acidifying effects in solution is:

$$\phi\text{-}OH \rightarrow \phi O^- + H^+ \qquad \text{Phenolic hydroxyl group}$$

$$R\text{-}COOH \rightarrow R\text{-}COO^- + H^+ \qquad \text{Carboxyl group}$$

where R = an organic group and ϕ = phenolic group. Some of these organic acids can release significant amounts of H^+ below pH 5, and are therefore not as weak as carbonic acid.

Nitric acid has been found to be produced in nitrogen-rich ecosystems regardless of whether the nitrogen (N) has been added naturally (e.g., by N fixation) or artificially (fertilization or atmospheric pollution). Nitric acid can also be produced in disturbed ecosystems, as will be discussed further in the next section. The general reaction for nitric acid production is:

ammonification

$$R\text{-}NH_2 \xrightarrow[H^+]{H_2O} R\text{-}OH + NH_4^+ \xrightarrow[3/2\ O_2]{\text{nitrification}} 2H^+ + NO_3^-$$

Van Miegroet and Cole (1984) found very high rates of nitric acid leaching in a stand of red alder (<u>Alnus rubra</u>), an N-fixing species, in western Washington. There have not been any other studies in N-fixing forests as yet, but some northern hardwood forests also appear to have a moderately elevated rate of nitric acid production, as evidenced by soil solution NO_3^- concentrations (Foster 1985; Cronan 1985).

In unpolluted, cold coniferous forests in the high-elevation Cascade mountains of Washington and in coastal southeastern Alaska, we found a pattern of organic acid production and leaching from tree crowns through upper soil horizons (Fig. 1a; Johnson 1975; Johnson <u>et al</u>. 1977). Organic acids precipitate in the Bh or Bsh horizons during the podzolization process, allowing the pH to rise and carbonic acid to become the dominant natural leaching agent. This pattern might be expected in unpolluted coniferous forests of the northeastern United States, also; however, as will be shown in the following section, atmospheric inputs often dominate leaching in these ecosystems.

<u>Effects of Atmospheric Deposition on Soil Leaching</u>

Numerous reviews and several books have been written on the controversial subject of atmospheric deposition effects on leaching, and thus only the briefest summary can be presented here. Two elements of atmospheric deposition - sulfur (S) and nitrogen (N) - have the major effects on soil leaching, and thus the following discussion is limited to them.

Deposition of S as either H_2SO_4 or gaseous SO_2 (which oxidizes and hydrolyzes to H_2SO_4 on plant and soil surfaces) will cause increased leaching unless SO_4^{2-} is immobilized by uptake or adsorption in soils. Since total cations must balance total anions in solution, the removal of an anion (in this case, SO_4^{2-}) results in reduced cation concentrations and leaching (Johnson and Cole 1980). This phenomenon is illustrated schematically for an SO_4^{2-}-adsorbing soil in Fig. 2.

Nitrogen deposition in excess of plant and soil heterotrophic (decomposer) organism uptake usually results in nitrification, internal HNO_3 production, and NO_3^- leaching. Fortunately, there are few known cases where atmospheric N inputs exceed forest N demand, and therefore atmospheric N inputs are beneficial in most cases. There are exceptions, however, where N inputs are very high and/or tree demand is very low (e.g., Van Breemen <u>et al</u>. 1982), and it appears as if at least some northern hardwood forests have a rather low atmospheric N retention rate (Martin 1979; Foster 1985; Cronan 1985). Whether these forests are naturally N rich or have been enriched by atmospheric N inputs is currently unknown. However, judging by current rates of N input, it seems most likely that these systems are simply naturally N rich.

The interactions of atmospheric H_2SO_4 and HNO_3 with natural leaching by organic and carbonic acids are depicted in Fig. 1<u>b</u>. The introductions of H_2SO_4 and HNO_3 greatly depress precipitation pH; however, they only slightly depress throughfall and soil solution pH, because of

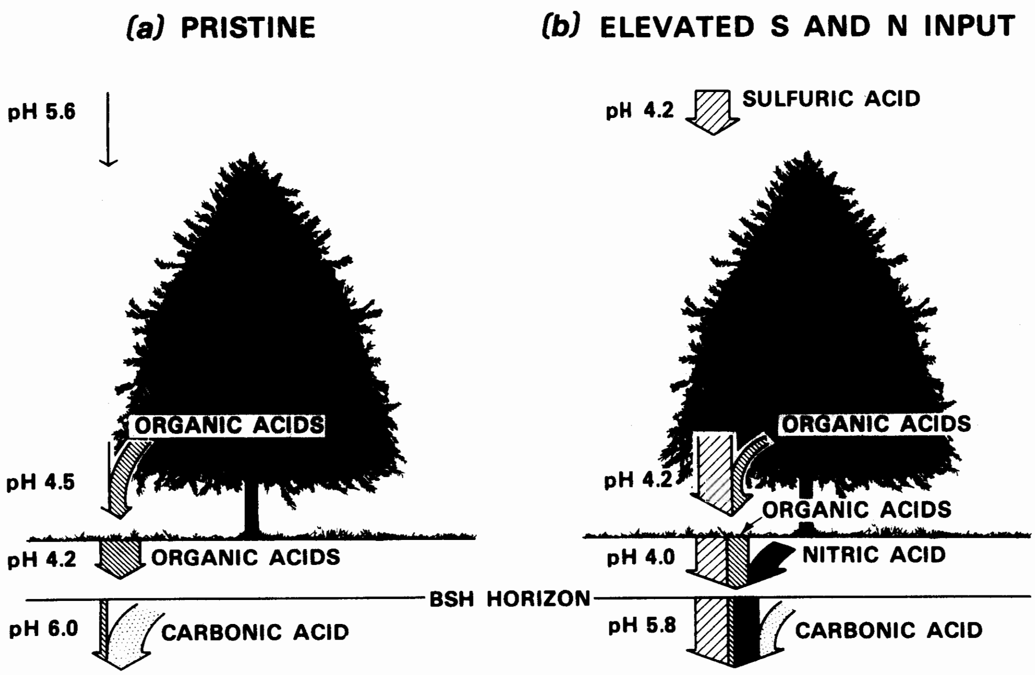

Figure 1. Schematic representation of leaching by organic and carbonic acids in (a) unpolluted and (b) polluted northern/subalpine forests.

EFFECTS OF SOIL SULFATE ADSORPTION ON ANION AND CATION LEACHING

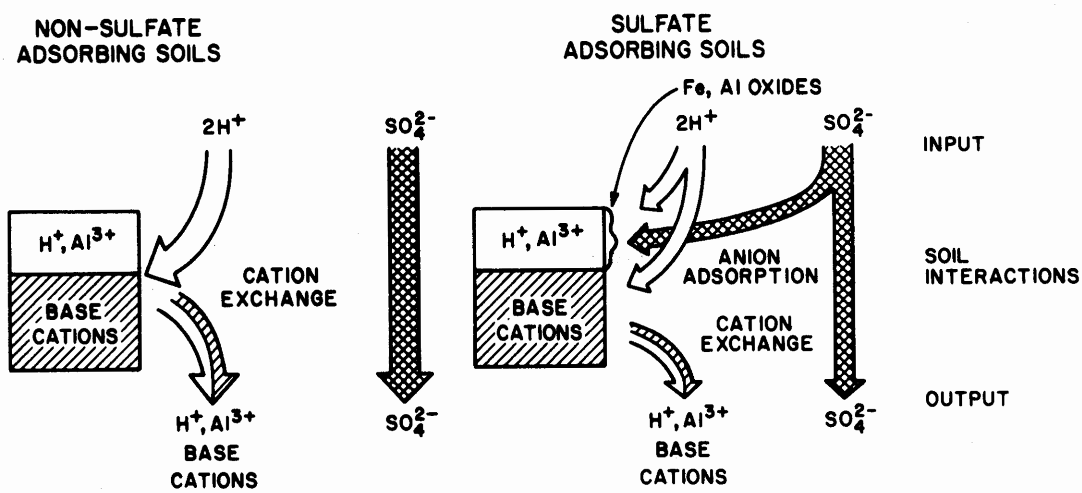

Figure 2. Schematic representation of effects of SO_4^{2-} adsorption on soil leaching by H_2SO_4. Soil at left does not absorb SO_4^{2-} and therefore cation leaching equals H^+ input. Soil at right absorbs SO_4^{2-}, and charge balance requires an equivalent reduction in potential cation leaching.

buffering by cation exchange and organic acids in tree crowns and soil. This slight pH depression reduces the contributions of organic and carbonic acid anions to leaching (via protonation of the weak acids; Krug and Frink 1983), but overall leaching rates increase nevertheless (e.g., Cronan et al. 1978).

Effects of Harvesting on Leaching

The combined effects of increased nutrient mineralization from litter and soil organic matter, increased water flux, reduced plant uptake, and in some cases, increased nitrification rate following harvesting usually result in short-term (2- to 10-year) increases in leaching. Several studies have documented substantial increases in NO_3^- (and associated Ca^{2+}, K^+, and Mg^{2+}) leaching following harvesting in forests of the northeastern United States (Likens et al. 1978; Pierce et al. 1972; Martin and Pierce 1980; Hornbeck and Kropelin 1982; Smith 1984). On the other hand, studies in the northwestern (Cole and Gessel 1965; Brown et al. 1973; Fredriksen et al. 1975), southwestern (McColl 1978), north central (Richardson and Lunt 1975), mid-south (Aubertin and Patric 1974) and southeastern United States (Swank and Caskey 1982; Johnson and Todd, in press) have shown much smaller increases in NO_3^- leaching than in the northeastern United States. Reasons for this apparent regional phenomenon are not clear, but probably relate to the generally better N status of northeastern sites discussed earlier. Vitousek et al. (1979) concluded from an intensive interregional study on N cycling processes in disturbed forest ecosystems that four major processes exerted the most control over NO_3^- leaching: (1) N uptake by vegetation, (2) N immobilization by soil heterotrophic organisms, (3) lags in nitrifier response, and (4) lack of water for NO_3^- transport. They further conclude that more fertile sites have a high potential for NO_3^- leaching following disturbance. Thus, the greater NO_3^- leaching following harvesting in northeastern sites may reflect a generally better N status of those forests, in particular a large reservoir of forest floor N which, upon harvesting, is subject to accelerated decomposition and N mineralization. This explanation certainly does not explain post-harvest leaching patterns in all cases, however. Biggar and Cole (1983) noted drastically lower NO_3^- leaching following harvesting in red alder stands in Washington state, even though these alder sites had very large N reserves and high pre-harvest NO_3^- leaching rates.

Summary and Conclusions: Implications for Forest Management

Leaching plays a major role in the export of Ca, K, and Mg over a full harvest-regrowth-harvest rotation, often exceeding the effects of even whole-tree harvesting on the export of these nutrients (Johnson et al. 1985). In the eastern United States, leaching has been substantially increased as a result of acid deposition. While the leaching losses of base cations by acid deposition and natural causes cannot be effectively controlled by forest management, fertilization with K, Ca, or Mg is a long-lasting and effective means of overcoming any potential deficiencies caused or exacerbated by leaching. Fortunately, Ca, K, and Mg are seldom limiting to forest growth (with exception in some sandy northeastern soils noted; Heiberg and White 1953; Stone 1953), and nutrient budget studies suggest that while leaching has been increased by acid deposition, soil reserves are often large enough to preclude any rapid decline in Ca^{2+}, K^+, or Mg^{2+} fertility (Krug and Frink 1983; Johnson et al. 1985). Furthermore, if the soil reserves of a particular nutrient (such as K^+ for example) are low, both chemical and biological mechanisms will act to conserve this nutrient (e.g., Stone and Kszystyniak 1977), while allowing more abundant (and therefore more readily leachable) nutrients to leach from the soil with SO_4^{2-}, NO_3^-, organic, or carbonic acids (Johnson and Richter 1984).

Harvesting usually causes a temporary increase in nutrient mineralization from litter and soil organic matter. This flush of nutrients usually benefits nutrient-demanding regenerating vegetation, but N mineralization in excess of plant uptake can result in N loss via NO_3^- leaching. While NO_3^- leaching can be increased substantially for a time following harvesting, the total nutrient exports during this period usually account for less than export in biomass itself (e.g., Hornbeck and Kropelin 1982). There remains, however, an additional reason to avoid NO_3^- leaching: the EPA drinking water standard is 10 mg of NO_3^--N per liter. Thus, it is important from a water quality perspective to minimize post-harvest NO_3^- leaching even if total nutrient exports during this period are not excessively large.

Post-harvest NO_3^- leaching can be strongly influenced by forest management in a number of ways. Encouragement of rapid regeneration will help minimize NO_3^- leaching by maximizing water and N uptake. Strip cutting (i.e., leaving strips of uncut forest between clear cuts on a watershed) or leaving buffer strips by streams has been shown to reduce potential NO_3^- losses via streamflow, presumably because of N uptake by uncut forests (Martin and Pierce 1980; Hornbeck et al. 1975). Woody residues immobilize N as they decompose, and they may play a major role in conserving N following harvesting (e.g., Vitousek and Matson 1984). Much more research is needed on the optimal amount of residue to be left, however, since too much N immobilization could cause a temporary N deficiency (Johnson 1983).

Finally, it should be emphasized that nutrient losses due to either leaching or biomass removal can be compensated for by judicious fertilization, if necessary. In the cases of P, K, Ca, and Mg, fertilization usually has a long-lasting effect and has little effect on water quality. In the case of N, however, more research is needed to optimize tree recovery and minimize ground and surface water NO_3^- pollution.

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SOIL NUTRIENTS, WHOLE-TREE HARVEST AND PRODUCTIVITY IN NORTHEASTERN FORESTS

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Impacts of whole-tree harvest on site productivity are complex and poorly understood. The results of forest fertilization trials in the Northeast can be used to make inferences of the impact of intensive biomass harvests on the soil chemical resource. These results indicate that whole-tree harvesting would aggravate existing potassium and magnesium deficiencies on coarse-textured outwash sands, and phosphorus deficiencies on sites where this element is limiting tree growth. Sites that are shallow to bedrock on hardpan, or that have high seasonal water tables, or high percentages of coarse fragments, are also sites that are prone to having productivity declines following whole-tree harvest nutrient removals. The impact of whole-tree harvesting on calcium, magnesium, potassium and nitrogen supplies should be small on relatively fertile sites with medium to high productivity.

The impact of whole-tree biomass harvesting on soil productivity is currently an emotional subject. In meetings concerning biomass harvesting it becomes readily apparent that technological advances in removal of woody biomass from the forest have far outstripped research and knowledge on the environmental impact of such intensive harvests. Although consideration has been given to the long-term effects of such harvesting upon future forest soil productivity, the immediate, short-term economic advantages of biomass harvests have taken precedence over environmental concerns. Scientists, researchers and environmentalists have questioned the impact of such harvesting practices on future soil productivity.

I do not support extractive industries, and do not defend them; however, the hard data that many researchers and environmentalists use to defend their case is inadequate and open to interpretation. For example, suppose a soil analysis in a timber stand has determined there are 200 lbs/a of extractable or available phosphorus, and the standing biomass contains about 40 lbs of P per acre at time of harvest. It is not permissible to divide the 40 pounds into the 200 pounds and claim the site will be exhausted of phosphorus in five rotations of trees. The relationship between nutrients and forest productivity is more complex than such a simple calculation assumes. Yet individuals have done such simple calculations and are making claims opposing total tree harvesting. The answer is not a blanket "NO" to tree cutting. We need to understand the ecological processes and encourage practices that will have a minimal detrimental impact on future soil productivity and design ameliorative practices to maintain productivity for future generations.

However, the use of nutrient budgets and simulation models do indicate that intensified biomass harvests dramatically increase nutrient removals from forest sites (Marion 1979; Morrison and Foster 1979). Ballard (1979), in a major review indicated that there is currently no definitive field evidence to relate the increased nutrient drain by whole-tree harvests to any reduction in site productivity. He concluded that the lack of a growth decline is not an indication that nutrient depletion associated with biomass harvest is not of significance to forest site productivity but rather that it reflects lack of experimentation on the subject and the technical difficulty of quantifying any productivity decline that may occur some 50 to 100 years in the future.

In spite of the lack of knowledge, inferences of the impact of intensive biomass harvests on the soil chemical resource can be made from the data base that exists with forest fertilization trials in the Northeast. At the very least, caution can be exercised in harvesting stands from sites and soils that have been shown to be nutrient deficient and strongly responsive to increasing productivity by the addition of various fertilizers.

Generally, the fertilizer responses in established stands in the Northeast have been with conifers, i.e., red pine, white pine, and spruces on the widely distributed potassium (K) and magnesium (Mg) deficient glacial outwash sands (Leaf 1970) as represented by the long-term 50-year data base developed at the Pack Experimental Forest, Warrensburg, New York. This research has clearly demonstrated that a single application of K fertilizer to pine or spruce corrected a limiting nutrient deficiency and sustained a long-term 50 year increase in productivity. This K deficiency has been shown to be a wide-ranging problem on coarse textured outwash soils in the Northeast and eastern Canada (Stone and Leaf 1967). Clearly, one would not advocate whole-tree biomass harvest on such soils, i.e., coarse-textured, low organic matter content, low cation exchange capacity, low buffering capacity and low inherent fertility. This practice would aggravate an already serious nutrient deficiency. Previous research has demonstrated a critical Mg deficiency on many of these same coarse-textured outwash sands (Stone 1953) that could be aggravated by whole-tree biomass harvests.

Numerous fertilization experiments and reports indicate that nitrogen and phosphorus are often the limiting factors in tree growth in eastern hardwood forests (Auchmoody and Filip 1973; Auchmoody 1986; Stanturf and Stone 1985). Auchmoody (1982, 1986) has indicated that such responses in black cherry stands may be large and last five years or more. These responses are affected by species, age, stand structure and stocking and other site limiting factors (Auchmoody 1986).

At first impression it would appear that such nitrogen responsive stands should not be whole-tree harvested since large amounts of nitrogen would be removed in the biomass. However, the amounts of nitrogen removed by whole-tree harvest are a small proportion of the total nitrogen capital on most forest sites in the Northeast. The nitrogen economy of sites is not dependent upon soil parent material. Annual wet and dry atmospheric inputs of nitrogen are relatively large, on the order of eight to ten pounds per acre per year. The amounts of nitrogen inputs from non-symbiotic, and symbiotic N-fixing organisms, while poorly understood, are generally thought to be large, i.e. 30 to 200 pounds per acre per year (Davey and Wollum 1979). The impact of whole-tree harvest would be related to the balance between mineralization of nitrogen from organic matter on the site and nitrogen immobilization. In general, higher temperatures and moisture conditions on harvested sites, versus those on uncut sites, results in relative large increases in mineralization of nitrogen following whole-tree harvest. Assuming rapid, adequate regeneration, much of this mineralized nitrogen may be taken up by regrowth and be retained on site (Outcalt and White 1981).

Whole-tree harvest impacts on phosphorus should not be ignored especially on sites of demonstrated phosphorus deficiencies within the Northeast. The supply of phosphorus to trees depends largely upon weathering inputs from parent material and primary soil minerals and there is no similar process in the phosphorus cycle analogous to N-fixation to aid in return of phosphorus to forest ecosystems. In addition, atmospheric inputs are generally low and phosphorus is easily fixed into unavailable forms in the soil. The phosphorus removal from sites by whole-tree harvest certainly is an area of concern that must be explored.

Potassium, calcium, and magnesium reserves, with the exception of the outwash sands, on most sites in the Northeast, tend to be relatively large and, although the supply of these elements is dependent on soil weathering inputs, atmospheric inputs are much greater than those of phosphorus. Thus on relatively fertile sites with medium to high productivity, impacts of whole-tree harvest on supplies of K, Ca and Mg should be small. The impact of Ca removal in biomass, if important, most likely will be on the role Ca plays in modifying the soil environment, i.e. pH, for the various processes associated with microflora and microfauna populations and not as a nutrient element. Little information is available concerning this hypothesis except to note that trees have not generally been shown to respond to Ca as a nutrient element, per se, in the vast numbers of forest fertilization reports in the literature.

Actual reductions in productivity caused by whole-tree harvests in the Northeast have not been demonstrated. General conclusions concerning the effects of whole-tree harvesting on soil nutrients and productivity must be drawn with care. Sites that would tend to be sensitive to nutrient mediated reductions in productivity caused by whole-tree biomass harvest are those of known nutrient deficiencies of elements whose supply depends mainly on soil reserves, i.e., phosphorus, potassium and magnesium. Examples are the K- and Mg- deficient outwash sands illustrated by the work from Pack Forest in New York and the phosphorus responsive eastern hardwood stands in northwestern Pennsylvania. Sites that have major root restricting problems would be more prone to negative impacts of whole-tree harvest due to nutrient mediated productivity declines, than would soils that are relatively deep with rooting volumes that are not restricted. Root growth is typically restricted on sites that are shallow to bedrock or have fragipan soils that limit rooting volume, soils with high root-restricting water tables and soils with high percentages of coarse fragments. Sites that have major portions of the soil nutrient capital in unavailable forms will be more negatively impacted by whole-tree harvest than sites with major portions of the soil nutrient capital "flowing" readily into available nutrient pools.

Conclusions

- Specific forest stands in the Northeast are currently deficient in nitrogen, phosphorus or potassium.
- Impacts of whole-tree harvest on site productivity are complex and poorly understood.
- Whole-tree harvest could negatively impact nutrient supply on specific sites.
- Nitrogen, although limiting tree growth on many sites, probably will not be a major problem because a series of processes exist to return N to the forest ecosystems after harvest and through the following rotation.
- Phosphorus may be seriously impacted on low-P soils and sites currently P deficient and fertilization may be necessary to maintain productivity.
- Potassium and magnesium would be seriously impacted on low-K and -Mg soils and sites currently deficient in K and Mg and fertilization would be necessary to maintain productivity, especially on inherently deficient parent material.
- Serious nutrient impacts of whole-tree harvest could occur on sites with restricted rooting volumes.

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STAND DYNAMICS AND PRODUCTIVITY OF NORTHEASTERN FORESTS -- BIOMASS HARVESTING CONSIDERATIONS

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Stand dynamics is an emerging science in forestry concerned with how associations of trees become established, compete, and develop through time. Understanding the dynamics of any forest type is central to formulating productive silvicultural systems. Here, I review some important aspects of stand dynamics common to most commercially important species in the Northeast, and focus on specific aspects of biomass harvesting which force a renewed attention to these principles.

Characteristics of Northeastern Forests

Northeastern forests have in common the following attributes which strongly influence their management:

Forest Structure

Most important northeastern forest types have unbalanced age structures, and during the past two decades they have become dominated by sawtimber stands. These maturing age classes originated mostly after major disturbances or land-use changes during a 40-year period centered around 1900 (Seymour et al. 1986). The age-class imbalance, and its effects on wood supplies and possible relationship to pollution-related growth reductions, has received considerable attention for Maine's spruce-fir forest (Seymour 1985; Hornbeck 1985), but other types also exhibit this trend. For example, during the past decade in northern New England, the area in seedling-sapling stands of eastern white pine dropped 72 percent; only six percent is now in this size class.

As this maturation continues, landowners will face increasing economic pressure to "cash in" the high values tied up in growing stock. Most harvests will regenerate new stands, so the composition of the next forest will become an important forest practices issue. Fortunately, the longevity of many northeastern species permits regeneration to be delayed when trees are financially immature, but the process cannot be postponed indefinitely. As biomass harvesting expands, foresters should think beyond improving the growing stock to when stands will be replaced.

Abundant Natural Regeneration

The abundant, evenly distributed precipitation during the Northeast's growing season favors prolific natural regeneration. This would seem like a blessing, because it allows foresters to avoid the high costs of artificial regeneration. However, conditions which favor commercial species also foster development of competing vegetation which can prevent establishment or inhibit development of desirable species. In fact, regeneration is considered easiest where extreme site conditions exclude all but the chosen species. Notable examples include eastern white pine on coarse glacial outwash soils, and spruce-fir on poorly drained tills. More commonly, a variety of species regenerate after harvest; advance seedlings can even develop after subtle natural disturbances. Therefore, achieving adequate stocking is rarely a problem. The challenge is to direct species composition in an economically valuable direction.

Great Species Diversity

The variety of species and forest types give northeastern foresters many options. Most commercially valuable species in this region, including white pine, red spruce, sugar maple, yellow birch and red oak, tend to be "late bloomers." They usually do not regenerate prolifically, but eventually dominate sites because they can persist in a sub-dominant position and outlive early competitors. These species dominated pre-settlement forests where large-scale, lethal disturbances were infrequent and longevity was the major factor determining species abundance.

During the past century, selective harvesting (high-grading) at frequent intervals, without compensatory treatments to reduce less valuable species, has diminished the importance of longevity as a determinant of stand composition. As disturbance intervals become more frequent, regeneration strategies, not longevity, determine which species dominate. Species which grow on a variety of sites and reproduce by several different mechanisms will eventually replace those with more restrictive requirements. The most familiar example is the ubiquitous red maple, which recent forest surveys suggest is gradually over-running the Northeast. This species invades old fields, reproduces from advance regeneration, and sprouts profusely on a wide variety of sites. After harvest, it often replaces more valuable species such as red oak or white pine.

Without markets for low-value species, foresters have few options to reverse this undesirable compositional change. Hence the wide appeal of biomass harvesting: it offers a commercially viable treatment to break out of the high-grading syndrome that has seriously reduced economic productivity. However, switching from high-grading to "low-grading" (harvesting mainly low-value trees) gives valuable species only a temporary advantage. Unless direct measures are taken to prevent their reproduction, biomass harvesting will, in the long-run, still favor low-value, easily regenerated species, and could even encourage their dominance of future forests.

Stand Structure

Northeastern species commonly regenerate after "releasing disturbances" (Oliver 1981; Smith 1986) which kill much of the overstory but leave the understory to respond. After release, each species develops into a different vertical stratum based on its height growth and competitive ability; initial height differences when released also can govern a tree's future status. Over time, these differences exaggerate and stand structure becomes highly differentiated as dominants emerge, tolerants lapse into the understory, and others fill in between. These stands often seem to contain several age classes, but careful examination often reveals that they are effectively even-aged.

The concept of the stratified mixture (Smith 1986) provides a useful means of analyzing the development and management of such stands which defy characterization by simple crown classes. Stratified, even-aged mixtures are much more common in the Northeast than pure stands, but the development of only a few has been examined scientifically: mixtures of red oak, red maple and black birch (Oliver 1978) and hardwood-hemlock stands (Kelty in press) in northeastern Connecticut; sugar maple-beech-yellow birch stands in the White Mountains (Hill 1977); Allegheny hardwoods (Marquis 1981, 1983); and red spruce-balsam fir stands (Seymour 1980). These studies facilitate design of silvicultural systems which take advantage of species inherent growth patterns. Elucidating the relationship between early and late stand composition provides useful guidelines on regeneration composition, and permits intermediate treatments to be timed when they do the most good.

Quality Controls Productivity

Silvicultural systems that take maximum advantage of the site's biological potential will not necessarily produce "productive" stands. Productivity is strongly determined by stand composition and tree qualtiy, probably more so than in other regions where species choices are foregone conclusions and treatments emphasize maximum fiber production. To maximize productivity, silviculture usually focuses on manipulating stands so that value, not volume, is produced faster than in nature. Except spruce-fir pulpwood in Maine, only high-quality sawlogs warrant silvicultural investment in the Northeast. For example, consider two options: the 2.2 million acres of white pine (72 percent of which is grade 3 or 4) and 3.4 million acres of red maple, aspen and gray birch that presently exists in northern New England, or the same total area, all in well-stocked grade 1 pine. Biomass productivity would be similar, but the pure-pine forest would be orders of magnitude more rewarding financially.

No one in the Northeast is seriously considering silvicultural systems to maximize biomass production, even though markets now exist. Because its value is so low, harvesting biomass makes sense to most landowners only if it helps achieve another more rewarding goal. In theory, biomass harvesting overcomes what many consider has been the most serious impediment to intensive silviculture--the lack of markets for poor-quality, small-diameter trees. The option to harvest biomass reduces the economic pressure to high-grade stands during conventional operations, and offers a commercial (though not lucrative) means of making improvement cuts in immature stands.

Unfortunately, there are drawbacks, mostly associated with the harvesting operation itself. Residual trees and advance regeneration--two important keys to productive stands--can be damaged or destroyed. Any treatment that seriously degrades crop trees or promotes regeneration of low-value species, will reduce long-run productivity and must be examined critically.

Stand Development

The concepts reviewed above provide the necessary background for examining northeastern forest types in a dynamic sense. This discussion is divided into three successive stages corresponding to the periods of stand development at which specific silvicultural treatments are directed. Viewing stand development as a succession of stages is not restricted to even-age management. These processes occur in stands with any age structure; with uneven-age management, the spatial scale simply is compressed with several even-aged "mini-stands" included in a single uneven-aged stand.

Stage One: Regeneration and Establishment

Events during this stage largely determine species composition for the entire rotation, and must be managed carefully. The importance of the regeneration process is emphasized by Smith (1986): "Physicians bury their worst mistakes but those of foresters can occupy the landscape in public view for decades." Once the species mix is established, only marginal changes are possible without large investments in site preparation and artificial regeneration.

Most commercially important species in the Northeast germinate and become established best in partial shade, and a few even benefit from an extended period in the understory before being freed completely from overhead competition. This dependence on advance regeneration, coupled with the even-aged or two-aged structure of most stands, makes the shelterwood method a logical choice. With few exceptions, most successful regeneration treatments in the Northeast are some variety of shelterwood. This includes the crude but common variant, the "one-cut" shelterwood method (Smith 1986), where the overstory is removed or "clearcut" in a single operation, releasing advance growth that established naturally.

True clearcutting--where new seedlings become established in the open after the final harvest--

is an unreliable method for regenerating most northeastern species. Clearcutting can produce spectacular successes, for example paper birch on strip clearcuts or white pine on old fields, but is risky. If a "catch" is not obtained immediately, clearcuts usually are overwhelmed with pioneer weeds. When browsing pressure is high, clearcuts may not even regenerate to trees, but revert to orchard-like stands dominated by ferns and grasses (Horsley 1985).

The status and fate of advance growth usually explains contradictory results from seemingly similar harvesting operations. When the overstory is removed prematurely (before advance seedlings are established) or carelessly (destroying advance growth), the result inadvertently becomes a true clearcut that favors weed species. If advance seedlings are present, survive the harvesting operation, and become established, regeneration is invariably successful. Each step is critical; whether it requires a separate silvicultural treatment, or simply occurs as a result of normal harvesting activities, is unimportant. Survival and establishment may require no more than careful overstory removal once seedlings have adequate root development in mineral soil to withstand abrupt exposure. Ideal timing varies by species; guidelines on the required numbers and sizes of advance seedlings are available for several forest types (e.g.: Frank and Bjorkbom 1973; Marquis 1982). If brush species that germinate after overstory removal threaten to overtop and suppress desirable species, early release treatments may be needed. The one-cut shelterwood method followed by prompt herbicide release is presently the most common method used to successfully regenerate spruce-fir.

If the stand is ready to be regenerated and advance seedlings are not present, a light cutting can be successful if followed by a timely seed crop. Sometimes, a complex of tolerant undesirable vegetation, such as red, striped, or mountain maple, witch hobble, or beech suckers, dominates the understory. In this common situation, herbicide treatment to eliminate or set back the understory just prior to the seed cutting can improve success greatly (Kelty and Nyland 1981; Horsley 1982).

Stage Two: Immature Development

Once species composition is established, stands develop rapidly. Competition soon causes vertical strata and crown classes to form and potential crop-tree qualities become apparent. During this stage, the key decision is if or when silvicultural intervention is needed. Historically this has been a moot question, since early thinnings were strictly expensive precommercial ventures. However, biomass harvesting offers a commercially viable means of thinning a broad category of previously untreatable stands, and this issue is now very real.

If the goal is to grow high-quality sawtimber, thinnings are best delayed until the merchantable bole is fully formed and, for hardwoods, naturally pruned. Depending on stand density, this occurs between age 15 and 25 when dominant stems are 20-30 feet tall. Because dense young stands of northeastern species generally do not stagnate, thinnings before this stage are usually unnecessary, and can be counterproductive if stem quality is lowered. Early intervention with biomass harvesting is warranted only where a major improvement in species composition is expected. Examples include: when weed species overtop more valuable intolerants, or where ineffective regeneration cuttings left overtopping culls from the previous stand.

Early thinning also can be justified to fill a strategic gap in future wood supply. Recent spacing programs for spruce-fir stands in Maine are motivated by the projected shortfall early in the 21st century (Seymour 1985). The high cost of motormanual (brush-saw) operations has prompted studies of systems that utilize small material (5-10-foot tall stands) in an attempt to offset the cost. Prototype systems show poor production, and yields are low compared to mature stands. At this developmental stage, a high percentage of the biomass is concentrated in the nutrient-rich crowns; in dense stands, early spacing could permanently remove as much as 90 percent of this material from the site. For these reasons, attempts to utilize biomass from spruce-fir precommercial thinnings offer little promise.

As spruce-fir fiber becomes scarce within 20 years, many opportunities for early thinning will exist in immature, 25-40-year-old stands. Then, higher values for softwood fiber may make early thinning by whole-tree harvesting an important silvicultural treatment, especially for nonindustrial landowners whose objective is mainly sawlogs. An important stimulus would be an improved capability to debark, screen and sort whole-tree softwood chips, as is now done in several hardwood plants.

In general, thinning should be delayed until stands are well developed. Biomass yields are higher, and release is less likely to degrade crop-tree quality. Once the merchantable bole is formed, future high-value crop trees can be reliably selected. Then, biomass harvesting may permit heavy crown thinning that induces rapid diameter growth and high rates of return.

Stage Three: Maturation-Final Harvest

During this stage, there are two main concerns: optimum financial manipulation of the growing stock, and preparation for regeneration. Trees removed in any harvest are generally merchantable for pulpwood or sawlogs. Whether biomass harvesting is appropriate involves mainly economic questions: Does the added yield from the tops outweigh the extra effort in sorting products at the landing? Is potential growth response worth the added risk of damage to residual trees and to regeneration from skidding whole trees?

If the operation is essentially a low thinning in which mostly small trees are removed, damage can be controlled and regeneration is not an issue. However, if larger trees are removed in an attempt to leave poles and saplings, changing from conventional tree-length to whole-tree utilization can be disastrous. There are so many combinations of equipment, stand structures, and silvicultural treatments, and so few studies of damage under varying conditions, that foresters currently must rely heavily on their judgement and experience.

Many mature stands in northern New England are so poor that regeneration is the only option. This can be done in two ways: naturally by shelterwood cutting coupled with understory control, or artificially by clearing the site and planting. The main obstacle to both is removing large amounts of biomass in large-diameter culls of low-value species such as beech and red maple. Because residual stand damage is not an issue, biomass harvesting greatly facilitates these treatments. In Maine this technology has provided a free site preparation tool and has made possible several industrial landowners' efforts to convert degraded hardwood stands to highly productive conifer plantations.

The Technological-Silvicultural Interface

If used appropriately, markets for biomass can be a positive force for improving the productivity of northeastern forests. However, foresters should not assume that logging engineers will automatically develop the specific technology to harvest excess biomass without compromising the silvicultural objectives. In North America, production, not silvicultural efficacy, has been the goal in equipment design. Whole-tree harvesting is no exception.

Conflicts between logging and silviculture did not appear with biomass harvesting, but several aspects of this technology bring these problems into focus:

- --smaller wood (means higher cost per unit, regardless of the product);
- --the need to process whole trees rather than pieces; and
- --the very low product value, leaving little margin for innovation.

These factors put logging contractors in a bind. To survive, they must handle larger pieces (or larger bunches of small pieces), faster and more cheaply than with conventional products. This means large, expensive machinery and larger-scale operations (more skidders per job) especially where woods labor is expensive. These constraints are hardly compatible with the silvicultural goal of avoiding damage to residual vegetation. If biomass is going to improve forest productivity by providing an effective means to achieving the goal of growing high-value products, then logging systems must mesh well with the dynamics of the favored species.

Are current systems adequate? Consider the following silvicultural treatments for which biomass harvesting conceivably could be used:

Regeneration:

1) Site preparation for artificial regeneration (usually species conversion from low-quality hardwoods to conifers).

2) Overstory removal, releasing small advance growth less than one foot tall (as in a classical shelterwood).

3) Overstory removal, releasing larger advance growth 3-15 feet tall (as in an irregular shelterwood or group selection).

Intermediate Treatments

4) Commercial thinning from below, removing trees 3-6 inches dbh.

5) Commercial thinning, removing 7-10 inch trees.

6) Improvement cutting in irregular stands, removing a variety of sizes from large culls to overtopped, undersized stems.

In all treatments except 4, biomass would be produced as part of an integrated multi-product operation from the tops of merchantable trees and undersized stems. Table 1 shows my assessment of the ability of several different logging systems to carry out these treatments. All but one, the clam-bunk skidder with long-reach boom, are in operation in the Northeast. Also included for comparison is the conventional tree-length chainsaw and cable skidder system.

All systems with mechanized felling work well for site preparation, where the purpose is to destroy as much vegetation as possible. Chainsaw-and-skidder is not effective here because small stems (under 5 inches dbh) are expensive to handle individually and many are not cut.

In overstory removal operations, the goal is to preserve the advance regeneration. This is best achieved by leaving harvest residues well distributed over the site and concentrating skidder traffic on systematically spaced, re-used trails. The conventional tree-length chainsaw-and-skidder system therefore rates highest for this treatment. No whole-tree system ranks above fair for removing the overstory from small advance growth. Harvesting all logging residues can cause small seedlings to succumb from abrupt exposure that would otherwise survive if protected initially by "dead shade" from limbs and tops. Drive-to-tree feller-bunchers must operate over a high percentage of the site and can produce disastrous results; they are virtually unsuitable for this treatment. Although large feller-forwarders are not ideal, they are less damaging to small advance growth than feller-buncher grapple-skidder systems, especially where skidder traffic is uncontrolled.

Table 1. Ability of various whole-tree harvesting systems to carry out typical silvicultural treatments in the Northeast.

Logging System	Silvicultural Treatment: Site Preparation	Overstory[a] Removal: < 1[b]	Overstory[a] Removal: 3-20[b]	Commercial Thinning: 3-6[c]	Commercial Thinning: 7-10[c]	Improvement Cut
(1) Chainsaw & Cable Skidder (tree length)	POOR	GOOD	FAIR	FAIR	FAIR-GOOD	FAIR-GOOD
(2) Chainsaw & Cable Skidder (whole tree)	POOR-FAIR	POOR	VERY POOR	POOR-FAIR	FAIR	POOR-FAIR
(3) Drive-to-Tree Feller Buncher & Grapple Skidder	GOOD	VERY POOR	VERY POOR	FAIR-GOOD	FAIR-GOOD	POOR-FAIR
(4) Swing-to-Bunch Feller Buncher & Grapple Skidder	GOOD	POOR-FAIR	FAIR	POOR-FAIR	FAIR	FAIR
(5) Feller-Forwarder	GOOD	FAIR	POOR	UNSUITABLE	UNSUITABLE	UNSUITABLE
(6) Clam-Bunk Skidder, Long Reach Boom	GOOD	FAIR	POOR-FAIR	FAIR	GOOD	FAIR-GOOD

a/ Assumes no snow cover. Results would improve with snow depth for all systems.

b/ Height of advance seedlings/saplings in feet.

c/ Dbh of trees removed in inches.

GOOD | FAIR-GOOD | FAIR | POOR-FAIR | POOR | VERY POOR | UNSUITABLE

Removing overstories from larger advance seedlings and saplings is probably the most difficult operation in silviculture, and whole-tree utilization does not make it any easier. Swing-to-bunch feller-bunchers, which have the capability to "pluck" trees and lift them to piles in the skid trail, are better than any system that requires the tree to be felled and dragged directly from the stump. With careful layout and operation, this system is probably better than others for this purpose, although as much as one-third of the site still can be heavily disturbed by skid trails. Feller-forwarders cannot manuever around saplings, and tend to damage or flatten most that are taller than their undercarriage.

In small-diameter commercial thinnings, damage to regeneration is not a concern, and small, highly maneuverable drive-to-tree feller-bunchers can do an excellent job when skidder traffic is controlled. However, on sites where trees are shallow-rooted, damage can be high, even with prior trail layout (Ostrofsky et al. in press). Larger machines such as the swing-to-bunch feller-buncher and clam-bunk skidder can do an adequate job, but require more maneuvering room which can lead to unacceptably large "holes" in the residual stand. In addition, their high operating cost makes harvesting very small wood prohibitively expensive. They are better suited for thinning larger-diameter stands where residual-tree spacing is wider. The clam-bunk skidder has an advantage over all but the cable skidder, because its long-reach boom allows fewer skid trails. However, these machines are largely untested under North American conditions, and their potential to damage residual trees is unknown.

Surprisingly the chainsaw-and-skidder whole-tree system does not rate highly for any treatment, though it is probably the most widely used method in the Northeast. Its main virtue is its flexibility to operate under most conditions.

In summary, current systems seem inadequate for carrying out many important silvicultural treatments. There is a critical need for new equipment that is better suited to the dynamics of northeastern forests. Unfortunately, such machines would be more costly, and are unlikely to be produced unless the value of biomass increases. This presents an interesting paradox: if the price of biomass rises to a level that permits more silvicultural flexibility, will power generated from it be too expensive to society?

Conclusions

Foresters must recognize that the wood-energy industry has developed to seize an economic opportunity--replacing imported oil by exploiting an underutilized component of the resource that has grown "for free." Whether this ultimately leads to better silviculture is up to us. Given the wide variety of possible biomass harvesting applications, foresters' greatest challenge will be to use this technology wisely. In the absence of definitive long-term research, a good appreciation for stand dynamics should help foresters decide where biomass harvesting "fits" and where it doesn't.

Acknowledgements

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SILVICULTURAL STRATEGIES AND SPECIES COMPOSITION FOLLOWING BIOMASS HARVESTING IN MIXED HARDWOODS

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Chip harvesting for biomass has been conducted in Vermont for about 12 years. Biomass harvesting systems have been evaluated for both unevenage and evenage regeneration cuts in national, state, industrial, and small private forests. Preliminary results indicate that unevenage systems may result in high residual stand damage and marginal economics depending on product removals. Species composition and stocking of natural regeneration following unevenage and evenage strategies in hardwood stands is excellent; but is strongly dependent on amount of advanced regeneration, occurrence of seed years, time of year of harvest, and site quality. Regeneration of softwood stands is a major concern for the future. Regeneration surveys should be conducted three to five years after harvest.

Forests of the state of Vermont offer a prime opportunity for biomass harvesting. The state is more than 75% forested. The forest consists of about 75% mixed hardwoods predominated by maple. Pole size or small sawlog size trees account for 90% of the stocking. Most of the state is adequately stocked with almost 60% fully or overstocked. Everywhere there are vast quantities of nonacceptable and cull trees. These statistics indicate a need for action. These statistics offer an opportunity for new markets for undifferentiated wood fiber products. These statistics indicate a need for regeneration cuts to achieve species diversity, age class diversity, and enhancement of the residual stand quality. The chip harvester and biomass harvesting in Vermont may offer one solution to our problem.

It has been about 12 years since chip harvesting for biomass first began in Vermont when new processes in paper making allowed the use of a lower quality chip as a raw material. Have we learned anything? Have we achieved the goals? Have we capitalized upon the opportunity?

The Vermont experience is an example. An experiment in the Victory State Forest, another on private land in South Duxbury, a series of surveys on the Green Mountain National Forest, and a broad range of monitoring and survey efforts on state, industrial and small private ownerships in the Northeast Kingdom have helped to answer these questions. Many strategies have been tried and the preliminary results are in. They are preliminary because the rotation age has not been achieved and the final judgement must be reserved until then.

Silvicultural Strategy

For nearly half a century, starting with the earliest professional foresters in the United States, the correct silvicultural strategy was an unevenaged, single tree selection system, a vestige of forestry brought from Europe. It was an appropriate hedge against the exploitation of the resource which had occurred since the initial colonization. More recently this strategy, perhaps more appropriately called "cut the best and leave the rest" as it was applied in the U.S., was found to be wanting for the management of forests for species diversity, quality, or age class diversity. In fact, foresters didn't really control much of what went on in the forest. Clearing for agriculture, cutting to support the wars, salvage from hurricanes, development, charcoal, trains and residential firewood all brought about a dichotomy of practice. Silvicultural strategies of the past were the function of the economics of the moment and not specifically aimed at long term environmental concerns or silviculture.

Throughout these times foresters spent much time lamenting the fact that they needed markets for low grade material that would allow them to apply silvicultural strategies with acceptable forestry goals. Has the chip harvester or biomass harvesting helped achieve that? I believe that it has. We still must practice economic silviculture. But now we have a tool that makes those strategies realistic and the initial results indicate that it is working.

First, let's look at the options. We have at our disposal unevenaged and evenaged techniques for regeneration of forest stands. In the unevenaged category, our goal is to achieve a distribution of age classes in a single stand. Our knowledge of forest ecology tells us that this technique will favor the shade tolerant species, maples in particular. Does it work? It certainly does. It works in Vermont even if we don't want it to. There does not appear to be a disparity between the theory and the practice here.

How does biomass harvesting fit into the technique? In practice there are some problems. Residual stand damage was very high in Duxbury, and species diversity wasn't helped. Worse yet, in many cases the economics of the technique are very marginal.

The second strategy is evenaged silviculture. Ranging from shelterwood to clearcutting. The main characteristic here is that when rotation age is achieved most of the trees will all be the same age. Again, our experience shows that theory and practice can meet on the ground with satisfactory silvicultural results. But public opinion doesn't always see it that way.

What is the solution? Let's use big business as the example. In the past, most big industry specialized -- good at one product but not interested in other types of products. Today the watchword in big business is diversify -- get into all kinds of products and meet public demand. I believe that this is forestry's alternative. Diversify our silviculture; use the strategy that will work; use the tools that make the strategy work. We must think about the land, the people, and the trees. We must mold our strategies to fit.

The Experience

Vermont's first experiment with biomass harvesting was in the Victory State Forest. Chosen for its location and forest type (mixed northern hardwoods), Victory seemed a logical place to start.

The major benefits of the operation which were foreseen in the design of the experiment were:

1. doubling of the yield of wood fiber per acre,
2. fourfold increase in financial return,
3. weeds and culls would be utilized,
4. creation of an environment favorable for the regeneration of valuable high quality hardwoods.

Several strategies were chosen to model what would happen under various conditions:

1. a 120 acre clearcut modified for aesthetics by a scattering of 1/4 acre islands,
2. a shelterwood,
3. a selection cut.

All of these silvicultural strategies were applied to learn as much as we could about what would happen.

The regeneration of northern hardwoods on all the sites was achieved. On the clearcut, which was inventoried three years later, we discovered 38,000 stems per acre with about 95% sugar maple. A close look indicated that most was advanced regeneration which was released by removal of the overstory. Another apparent problem was what to do with an overstocked seedling and sapling stand in the shelterwood areas. There was a larger component of yellow birch, probably due to wetter site conditions in that area. The regeneration cut results were exciting and encouraging, and led us to Duxbury.

In 1976, a cooperative experiment was tried in Duxbury, Vermont. This operation was an attempt to simulate small woodlot operations, and to develop a wood supply to be used for energy. We had the market; we wanted to experiment with silvicultural strategies. In Duxbury four strategies were tried:

1. clearcut - 21.4 acres,
2. shelterwood - 25.85 acres,
3. heavy selection - 6.53 acres,
4. light selection - 14.74 acres,
5. control - 4.97 acres.

The light selection removed 35% of the basal area; the heavy selection removed 50% of the basal area; the shelterwood removed 60-70% of the basal area.

There are no statistical data on the various cuts but observations indicate that the clearcut regenerated to aspen, pin cherry, and a significant amount of other northern hardwoods. The stand is now 15-25 feet tall, dog hair thick, and presenting a problem of what to do next. In all the other strategies I could see very little change in the condition, composition or structure of the understory. It is probably time to do a detailed regeneration study of the whole area.

I strongly believe from the Victory operation, the Duxbury operation and many, many others that regeneration of stands through clearcutting assures adequate stocking of appropriate species.

Since 1981, the Vermont Department of Forests, Parks and Recreation has been monitoring chip harvester operations. This monitoring, authorized by statute, has allowed our foresters access to biomass harvesting sites to determine if regulation might be needed. This program has been successful in two ways. First, we find that most operations are well done, and secondly, we get the opportunity to do a lot of educational work along the way.

In 1985, a total of 6,959 acres were harvested for biomass. This was less than two-tenths of one percent of all the timberland acres in the State. That year 34% were regeneration cuts, 55% were improvement cuts, and 11% were agricultural clearing and development.

In 1984, we looked at the regeneration on the monitored sites. The conclusion was: "The quantity and species composition of natural regeneration is excellent no matter what type of cutting practice is used. However, pioneer hardwoods are so aggressive that replacing a softwood cover type is very difficult." The regeneration of softwood is a major concern for the future.

In addition to the chip harvester monitoring program, we undertook a regeneration survey in six towns in two different years. Essentially it was to determine the extent of regeneration cutting in the Northeast Kingdom of Vermont. The highlights of this survey were:

1. quantity and species composition of natural regeneration in hardwood stands was excellent; large clearcuts in softwood stands usually do not regenerate to softwood;

2. no significant interference to natural regeneration from noncommercial species was found; in general, the sites with predominately noncommercial species were poor quality sites (wet or ledgey areas);

3. non commercial species (pincherry) often tended to dominate the site visually; however, sampling usually showed more than adequate stocking of commercial species;

4. it was necessary to wait at least four years after an area had been cut to obtain accurate survey results; it takes four years for regeneration to become well established.

Tom Striker, Ranger, Rochester District, Green Mountain National Forest, reported that a three year interval is required to make adequate surveys. Their surveys after three years showed: "That there is some difference in stocking between summer and winter logged stands one year after harvest; but after three years, not only does the difference narrow but the stocking approaches a reasonable, if not acceptable, level." Further, "In the stands studied, summer logging and, as expected, clearcutting favored yellow birch and spruce, while winter logging, and especially shelterwood, favored sugar maple."

Conclusions

Biomass harvesting combined with appropriate silvicultural strategies can produce desirable results.

When we consider future operations that involve the regeneration of northern hardwoods, we must have a full understanding of the silvicultural tools available, apply them correctly, diversify our strategy, and check to see if it worked three to five years later. I think it will, at least in northern New England.

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BIOMASS HARVESTING AS A SILVICULTURAL TOOL IN MANAGING EASTERN WHITE PINE

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Biomass or whole-tree harvesting is not always suitable for thinning or stand improvement of white pine stands 25-40 years old. Plantations can be treated with excellent success with biomass systems. On well-drained soils, in pole and sawtimber stands, herbicide treatment is necessary to get white pine reproduction established, and to bring it through where it can compete on its own. Competition is less of a problem on a glacial outwash, so herbicides may not be needed.

Biomass harvesting as site preparation for conversion, is also a good tool on many sites.

White pine is intermediate in shade tolerance and, as such, can be reproduced by using almost any silvicultural system, from modified single tree selection on glacial outwash and droughty tills, to shelterwood on heavier soils, such as fine, well-drained till and other more productive soils. Once established, white pine seedlings and saplings can survive in an understory, <u>remain very tenacious</u> for thirty years or more, and respond when released with excellent results.

Biomass harvesting has been used for TSI operations in natural stands, to thin plantations, and for site preparation for stand conversion. Biomass harvesting is fast, although controversial, and may cause as many problems as it solves. It is important for anyone who is managing land for white pine sawtimber production to understand where and when biomass harvesting can be applied.

I will discuss four situations where biomass harvesting can be used in white pine management. These are:

1. Natural white pine stands 25-40 years old and less than pole size,

2. Natural white pine stands, pole size and larger,

3. Plantations, and

4. Site preparation for conversion.

In many natural stands 25-40 years old, establishing reproduction is not priority. However, if biomass operations take place, due to the size of the harvesting equipment, these stands are usually thinned too heavily for maximum future growth. If scattered hardwoods such as poplar and red maple are removed, sprouting is usually prolific and undesirable. The poplar may die if the stand is allowed to close and stay closed before another operation occurs; otherwise, the sprouts have to be dealt with continually in all future operations. If the site is to remain in white pine, it is then questionable whether biomass operations should be done in stands where red maple, particularly, is present, and the stand is less than pole size. In these situations, the best route to improve stand composition may be a conventional TSI operation using either chemicals or chainsaws; the main reason being, better control of hardwood sprouts.

The key to control of sprouts is, in large part, the amount of sunlight reaching the forest floor. Since the use of most whole-tree harvesting equipment necessitates driving to each tree to remove it, younger stands are necessarily thinned far too heavily, and as a consequence can lead to less desirable, less valuable future stands, or create a very expensive hardwood control problem. One solution, of course, would be to design harvesting equipment that will do a good silvicultural job, rather than having to rely on equipment designed to harvest only for high volume production. So in young stands 25-40 years old, and less than pole size, conventional TSI is probably the best route, particularly when improving stand composition, but also in thinning pure stands given the requirements of whole-tree harvesting equipment.

When removal of poplar and tolerant hardwoods has occurred in pole size and older stands, sprouting is not only inevitable, but is extremely prolific, creating a problem for white pine reproduction. Sprouting seems to be much more prolific than after conventional harvesting methods, evidently because so many smaller stems are taken by the machinery. To secure pine reproduction, hardwood control is generally needed, although hardwood sprouts are less prolific on glacial outwash and droughty till soils. On deep, well-drained tills and clays, herbicides must be used to get a stand established after biomass harvesting, even if the harvesting is done in a white pine seed year. So, it would appear that whole-tree cutting operations in pole size and larger stands on droughty sites will need to be followed up with hardwood control to assist white pine regneration that has become established. On the heavier, well-drained tills and clays, herbicides, or some means of hardwood control, will be necessary to get pine regeneration established as a site preparation method. On these sites, follow-up with herbicides will be necessary to insure survival of white pine reproduction.

In white pine plantations that are grown under high density management, biomass thinnings should be delayed until the stand is at least 25 years old, and as much as 40, depending on the incidence of successful weevil attack.

Stand composition, up until this time, should be done by cutting with brush saws or chain saws, or by chemical means, either by treating individual trees, or by foliar application.

The first biomass thinning should remove every fourth row, leaving a middle third row to be removed at the next thinning.

Plantations lend themselves to biomass thinning better than any other situation, because light can be controlled so well. Also, stand closure is faster and reduces the chances of hardwood establishment either from sprouts or seeds.

Biomass harvesting for conversion, can best be done on glacial outwash and droughty till soils. If the area is planted in the fall of the year that the trees were cut, herbicide treatment may not be necessary. On more productive soils, it will take one or more herbicide treatments to bring through a good stand. If genetically superior planting stock is available, the chances of reducing the number of herbicide treatments by one are that much better.

In any case, biomass harvesting enhances the conversion to white pine.

Conclusion

From what I have observed, until such time that we have harvesting equipment designed to do a silviculturally acceptable job in natural stands of white pine 25-40 years of age, we should probably stick to conventional TSI methods, using herbicides or chainsaws, primarily to achieve hardwood control via controlling the amount of light reaching the forest floor.

In pole sized and larger stands, whole-tree harvesting on drier sites should be followed up by chemical treatment to control hardwoods after white pine seedlings are established. On deep, well-drained tills and clays, it will be necessary to apply herbicides as a site preparation technique to get pine reproduction established. Undoubtedly, it will be necessary to follow-up with a second herbicide application to bring through an acceptable stand of pine.

Plantations lend themselves very well to whole-tree cutting as a silvicultural tool, as the trees are in rows, and stand opening is easily controlled.

Whole-tree harvesting operations are excellent for site preparation when converting stands to white pine. Follow-up with a herbicide treatment may be necessary on glacial outwash and droughty tills, and are a must on well-drained sites.

BIOMASS HARVESTING: ECOLOGICAL AND ECONOMIC CONSEQUENCES

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The Tug Hill Stand Management Model was used to study the economic and ecological interrelationships associated with biomass harvesting in northern hardwoods. The model indicates that economically optimal rotation lengths for whole tree chipping may be long enough to allow sites to recover ecologically. This conclusion is heavily influenced by such variables as stand structure, harvesting system, product prices, and site quality; but indicates that economic and ecologic values may be compatible.

Introduction

The linkages between economics and ecology are critical in evaluating the benefits and risks of biomass or whole tree chipping harvests. This paper incorporates some of these linkages, and concludes that some of the possible benefits are not likely to be realized and that some of the conventional concerns seem unwarranted.

These conclusions derive from the results of a simulation study focused on the use of whole tree chipping on a site in upstate New York. The site presently has a stand that is approximately 30 years old, but has some remnant trees which were not cut in the last logging operation. We suspect that the previous harvest removed only sawlogs and that the remainder of the stand was left uncut at the time. We determined the economically optimal harvest age for the present stand, and the optimal rotation length for a series of biomass cuts to follow in the future. It is unlikely that the optimal rotation age for the first stand will equal that for subsequent ones because the extant stand arose from a sawlog harvest which left larger standing trees than will a biomass harvest. After determining the economically optimal harvest age (calculated separately for cuts that include all trees and cuts that only remove trees with positive delivered value), we explored the ecological effects of these alternative biomass harvests. Three ecological effects are presented here: species composition, standing biomass, and estimated amount of available nitrogen in the forest floor. After a brief description of the simulation model and study site, we detail these results.

The Tug Hill Stand Management Model

In order to investigate the combined ecological and economic effects of forest management alternatives for the region of northern New York known as Tug Hill, we assembled a computer simulation model which we have called the Tug Hill Stand Management Model (THSMM). The model consists of four parts which are shown in Figure 1; inventory, stand development (forest growth), conversion, and economic evaluation. The model works from a detailed economic and ecological description of a forest stand: a tree list of current inventory, a description of the current forest floor, detailed description of the climate and soil, a description of the logging equipment and crews, current and future product prices and delivery point. To simulate a particular management regime, the initial stand is grown, harvested, and regenerated, and the economic and ecological effects are computed.

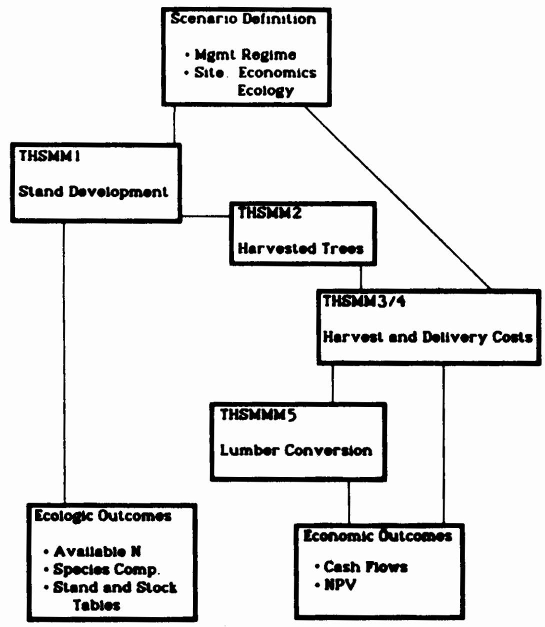

Figure 1. General structure of the tug Hill model (THSMM). The important components are numbered 1-5 and were once stand alone computer models.

The stand development module is a refinement of the individual tree growth model known as JABOWA (Botkin, et al. 1972) and later amended and called FORTNITE (Aber and Meilillo 1982). Growth in these models is based on the diameter increment of individual trees. Other important dimensions of individual trees are based on regression equations which use diameter as an independent variable. Growth increments are based on the physiological status of the trees (amount of light, nutrients and moisture, and the temperature regime). Species-specific parameters are used to estimate the response of each tree to a certain set of environmental conditions. Included in the stand development module is a forest floor component which assigns different decomposition rates and nitrogen content to each species and category of material. Therefore, all inputs to the forest floor (including logging slash) are decomposed and a portion of the nitrogen made available to the growing trees.

The strengths of this type of model are twofold. First, it is designed to handle mixed species, northern hardwood stands, including nitrogen status of the forest floor. Second, it is based on physiological parameters, models and assumptions, so it is well suited for exploring situations which may not have yet occurred in nature.

The growth module has the capability of simulating the growth of any size square plot. The physiological assumptions of THSMM mandate that plots remain (i) small enough so that each tree may potentially compete with any other trees on the plot, but (ii) large enough so that each tree competes with enough other trees to prevent all trees from growing as if they were dominant or open-grown. At the time of harvest a tree list is transferred to the harvest module and an expansion factor is used to express the results on a per acre basis.

Because regeneration and natural mortality are modeled as stochastic processes, several simulations of each plot are made. For the purposes of most studies, each replication of each plot can be treated as a separate sample and the results combined into a single tree list with the expansion factor reduced appropriately to reflect the outcome of one single large plot.

Total costs associated with bringing standing wood to the point of valuation (for chips the point of valuation is the millyard) are determined in three steps. First, the production rate, measured in physical units (e.g. tons) per unit time is computed for each production activity (felling, yarding, in the woods chipping, trucking). Second, the cost per unit time of the activity is estimated. Third, the total production cost for an individual activity equals the cost per unit time divided by the production rate. The total production cost for each product equals the sum of the production costs for all the activities necessary to bring each tree to the point of valuation.

In each case, production rates are modeled as a function of piece characteristics, specifically diameter, length, and volume. The production models were, to the extent possible within the scope of the project, calibrated to the conditions prevailing in the Tug Hill region. For example, the number of working days per year for logging was estiamted from a small survey of loggers from the Tug Hill area.

Production costs were developed from a cost accounting model. Estimates were made of the individual costs associated with a particular piece of machinery (e.g. purchase price, maintenance expense, fuel consumption, labor costs). These costs are reduced to an hourly operating cost for a piece of equipment. The cost per unit of production, then, equals the hourly cost divided by the hourly production rate.

The return to the landowner is then calculated as a conversion surplus based on residual value after all costs are subtracted from the value at the point of valuation. In this case the chips are sold at the millyard and all harvesting and transportation costs are subtracted in order to estimate the value to the landowner.

A management regime may have several harvests occurring at different points in time. The regime might also require case expenditures such as plantation establishment or timber stand improvement. To compare regimes with different temporal patterns of expenditures and revenues, some method of aggregation is needed. Of the possible choices -- internal rate of return, payback period, and net present value -- we chose the latter because it best measures the wealth of the landowner and because it does not suffer the theoretical shortcomings of the other methods. We do not subtract costs such as property taxes which are the same for any management regime. Thus, the estimates of net present value (NPV) reported below actually represent the contribution of a management regime to the profits of land ownership.

Background Information for Simulation Runs

A large number of descriptive parameters for the site are needed to run the simulation model. These parameters are summarized in Table 1. The site chosen is in the Tug Hill area of upstate New York and is within easy reach of both sawmills and a pulp mill that uses biomass chips for an energy source. The simulation runs use two 100 square meter field inventory plots that were replicated 5 times each. The results are aggregated to simulate the growth and harvest of 10 one hundred square meter plots (0.1 ha).

Results

Two harvesting intensities were simulated on this site, a 7 in. lower diameter limit cut and a 0 in. diameter limit cut (which removes all standing trees). The growth of the stand which regenerates after the first harvest depends on the timing and the intensity of the first harvest as well as the stand structure of the harvested stand. First we compute the economically optimal timing (highest NPV per acre) for each harvest intensity. Then we trace out the economic and ecological implications of each harvest intensity given that its timing has been optimized from an economic perspective.

Minimum Merchantable Diameter

Figure 2 shows the relationship between DBH and conversion surplus per tree when chipped and delivered to the millyard. For this site, trees less than 7 inches in diameter cost, on average, more to harvest than they return at the sale

Table 1. Descriptive information for the stand, site, harvest system, and product-price variables used to run the Tug Hill Stand Management Model.

Stand Description	
Age structure	Basically 30 years old
Large tree	9.8 inches dbh
Species composition (in order of percent of total basal area)	Sugar maple Beech Red Maple Ash Yellow birch Black cherry Others
Soil	Loamy sand
Slope	Flat
Logging crew	1 cable and choker rubber-tired skidder 1 chipper 1 tractor and van 3 people (+1 truck driver)
Harvest method	chain saw felling whole tree cable skidding chipping at landing truck to mill
Average skidding distance	1200 feet
Distance to mill	45 miles
Price at mill	$12/ton

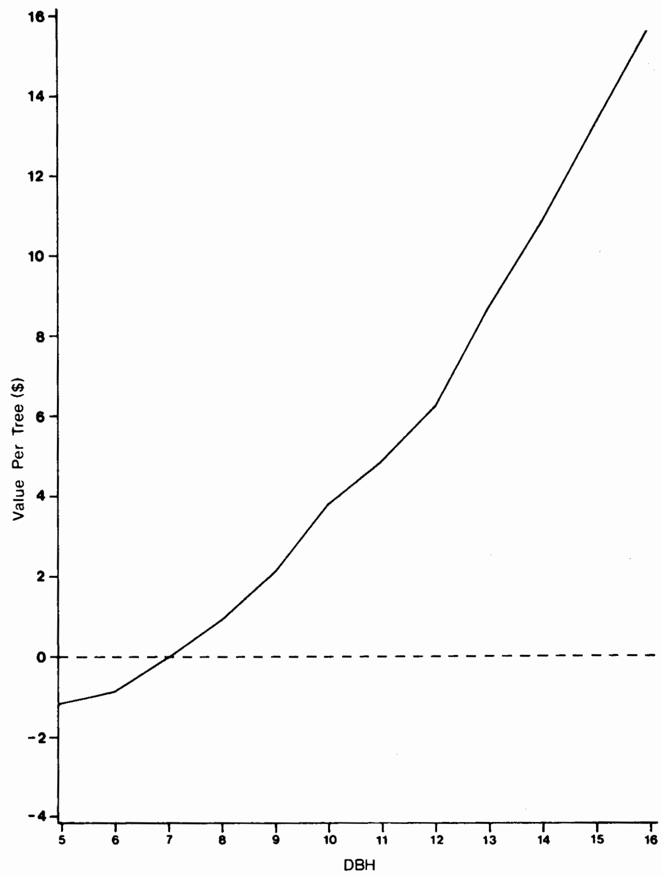

Figure 2. Graph of value per tree as diameter increases. This graph shows that trees below 7 inches DBH had negative value in our scenario; in other words they did not "pay their way out of the woods".

point. A logger and a landowner trying to maximize return from the sale would leave uncut all trees less than 7 inches DBH.

Figure 2 reflects data from the second biomass harvest. Harvest costs are moderately affected by stand basal area, so the relationship between value and DBH is influenced by the timing and diameter limit of the antecedant harvest. The size of the marginal tree (i.e. the tree with zero value) shifts by less than 2 inches among any of the harvest age and intensity combinations studied, and is much more influenced by site parameters not associated with the stand structure (such as distance to the mill).

Optimal Economic Rotation

Table 2 shows the undiscounted harvest values per acre for several rotation lengths in the case where only those trees with positive value are harvested. Notice that the length of the first rotation has a marked effect on the level and time path of the second rotation. Trees in the present stand which are just below harvestable size greatly affect the next rotation. Forgoing harvest value at the first harvest leaves many more harvestable trees at a future rotation if they are allowed to grow until reaching sufficient size.

Table 3 shows the harvest values discounted at a real rate of 4%. Row et al. (1981) argue that this real rate of return appropriately reflects the investment possibilities in the U.S. economy. Maximizing NPV at this rate requires continuing the present rotation for 15 more years (to age 45 since the stand is currently 30 years old) and harvesting future stands on 45 year rotations.

Figure 3 (a, b) shows the effect of the discount rate on the optimal first and second rotations. Higher discount rates usually just shorten rotations, but at 6% in this complex situation the first rotation remains at 45 years and future rotations are reduced to 35 years.

Table 2. Undiscounted harvest values per acre for a range of rotations for both the first and second cuts. Only trees with positive value were harvested. To find the appropriate number find the rotation length for the first rotation along the top column and the length of the second rotation along the left most column.

Time to First Cut (Years)							
FIRST CUT	Rotation Length (Years)						
	5	10	15	20	25	30	35
	300	565	920	1071	1372	1556	1518
SECOND CUT							
35	506	422	443	565	670	769	717
40	837	623	607	730	860	983	885
45	1021	799	802	907	981	1167	1033
50	1167	1043	907	1053	1135	1192	1127
55	1316	1253	1067	1283	1177	1222	1044
60	1601	1502	1235	1340	1319	1401	1136
65	1916	1545	1298	1494	1265	1576	1086

Table 3. Discounted harvest values per acre for a range of rotations for both the first and second cuts. Only trees with positive value were harvested. To find the appropriate number find the rotation length for the first rotation along the top column and the length of the second rotation along the left most column.

Time to First Cut (Years)							
FIRST CUT	Rotation Length (Years)						
	5	10	15	20	25	30	35
	245	379	505	481	505	469	374
SECOND CUT							
35	141	96	83	83	84	79	60
40	180	110	88	86	83	78	57
45	173	111	91	84	75	73	53
50	157	115	82	77	68	59	46
55	141	110	77	75	57	48	34
60	138	106	71	63	51	44	29
65	133	88	60	57	39	40	23

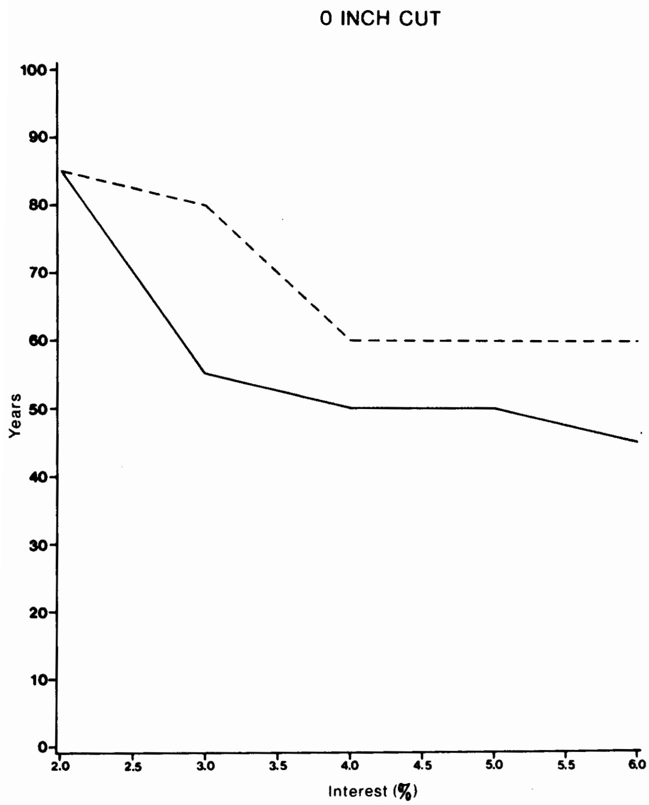

Figure 3a. Graph of optimal rotation length as interest rate varies assuming that all trees were cut in each harvest. The solid line is the length of the first rotation and the dashed line is the length of the second rotation. Notice the difference in length of the two rotations at any given interest rate.

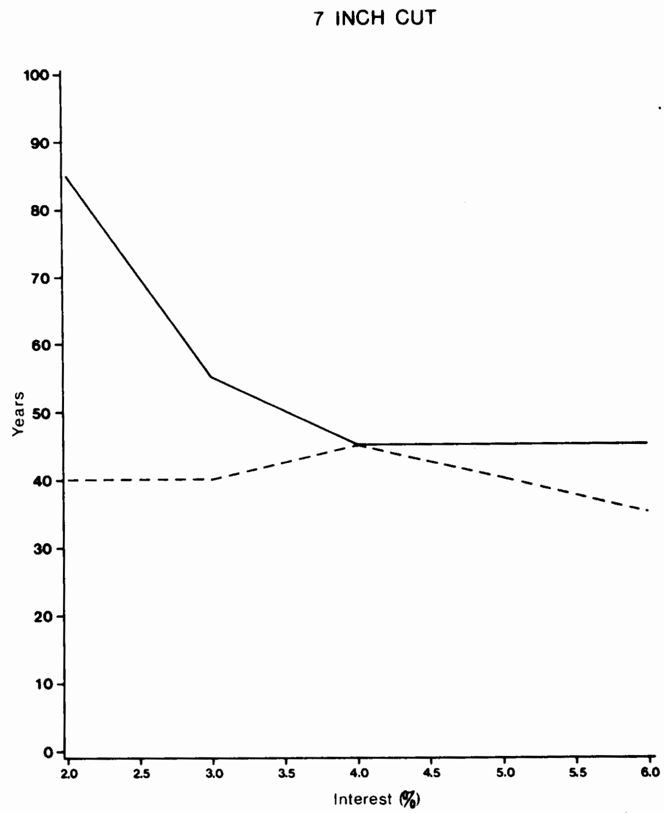

Figure 3b. Graph of optimal rotation length as interest rate varies assuming that only trees above 7 inches were cut in each harvest. The solid line is the length of the first rotation and the dashed line is the length of the second rotation. Notice that at 4% the optimal rotation lengths are the same: 45 years.

Note that the response of optimal rotation to the discount rate is strongly influenced by the harvest intensity. In both the 7" and 0" diameter limit harvests, the optimal first rotation declines as the discount rate increases. In the 7" diameter limit case, however, the optimal second rotation actually increases as the discount rate increases. This occurs because the growth of the second stand depends on the timing on the first harvest, which in turn depends on the discount rate.

Ecological Consequences

What are the ecological consequences of the economically optimal harvest schedules? In the first place, the sum of the rotation lengths (first and second rotation) at each interest rate is about 20 years longer for the 0 inch diameter limit than for the 7 inch diameter limit. If the more intensive (lower diameter limit) harvest strategy is chosen, maximizing economic returns dictates a longer ecological recovery period. The optimal economic solution for the less severe disturbance results in a shorter recovery period. It is possible that the ecological consequences of the two regimes are not very different.

Available nitrogen in the forest floor as predicted by the model is graphed for the two harvest intensities under the rotation combinations which are optimal at a 4% interest rate (Fig. 4). Standing biomass for the two regimes are shown in Figure 5. Finally, percent of standing biomass which is beech is shown in Figure 6.

Discussion

It is important to study economic and ecological constraints simultaneously for many reasons; not the least of which is the fact that either one solved independently is probably incorrect. We have demonstrated an example of this relationship by showing that optimal economic rotation length is intimately connected to the stand structure which is in turn determined by the length of the cutting cycle and type of harvest. Traditionally, optimal rotation length has been determined as a single figure rather than a series of values determined by changing stand structure. The structure of a stand is highly influenced by the structure and disturbance history of the previous stand. Since almost no stand in the

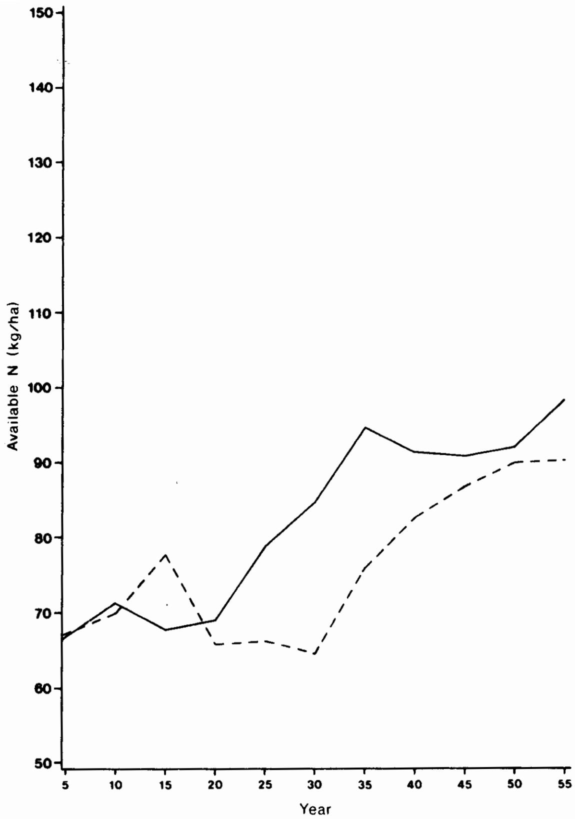

Figure 4. Graph of available nitrogen per hectare by year. The solid line is the 7 inch minimum diameter harvest and the dashed line is the harvest which includes all trees. The rotation lengths are those optimal for a 4% interest rate given the type of harvest described.

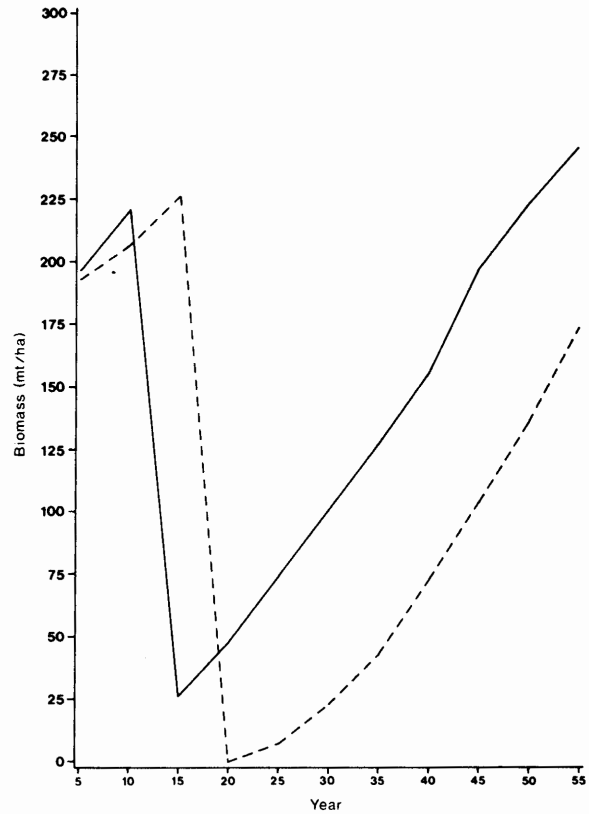

Figure 5. Graph of biomass (metric tons) per hectare by year. The solid line is the 7 inch minimum diameter harvest and the dashed line is the harvest which includes all trees. The rotation lengths are those optimal for a 4% interest rate given the type of harvest described.

Northeast will be harvested (especially if whole tree chipping is used) in the same manner as the stand was harvested the previous time, the rotation lengths of the present and future stands must be determined separately.

It is often poorly understood that small trees cost more to harvest and process than large trees, even with whole tree chipping. For the scenario described in this paper, the "breakeven" DBH is about 7 inches. At a 4% interest rate the highest NPV is $596/acre for cutting all trees over 7 inches, but is only $560/acre for a regime which cuts all trees.

The relationship between optimal rotation length and the interest rate is determined by the diameter and volume distribution of the present stand. In the initial stand, there are a significant number of trees just below the 7 inch harvest limit which will move into the larger size classes in a few decades. If these trees are left for a future rotation then the next stand reaches a relatively large standing biomass in a short period of time. On the other hand, if all the trees are cut, the next stand will take longer to develop.

The actual relationship between the structure of the stand in the two rotations depends very strongly on the characteristics of the stand and site. One should not infer that the particular rotation lengths presented here are necessarily the optimal lengths for all stands in the Northeast. However, the strong interaction between rotations is probably the typical situation for this region.

There is considerable concern that biomass harvesting will degrade the productivity of the site. This result may occur, but our model demonstrates that more intensive treatments lead to longer economically optimal rotation lengths and therefore longer recovery periods. Both harvesting intensities studied lead to optimal economic rotations which allow the standing biomass and available nitrogen in the forest floor to recover to preharvest levels. The possibility of intense removals and short recovery periods is unlikely given the present range of harvesting

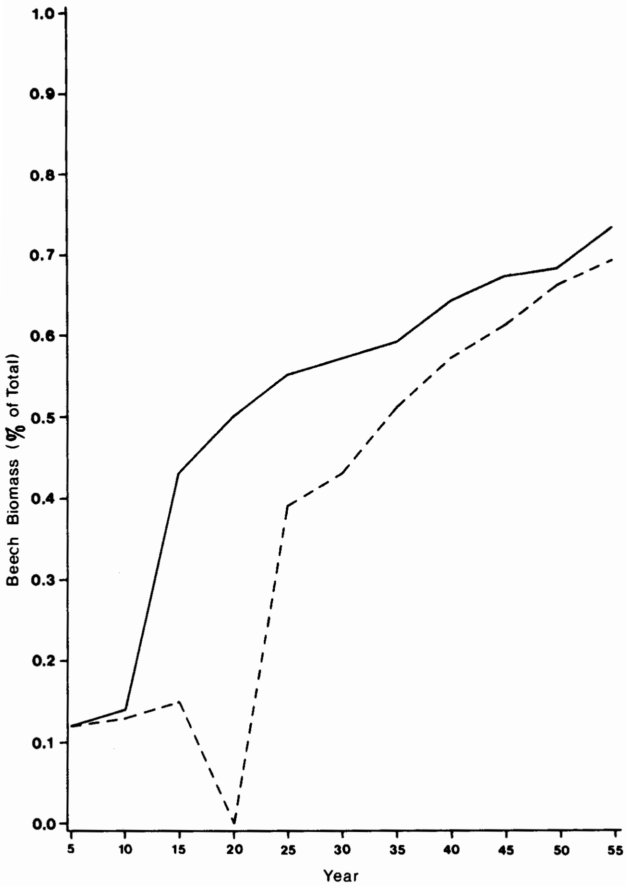

Figure 6. Graph of percent biomass which is beech by year. The solid line is from the 7 inch minimum diameter harvest and the dashed line is from the harvest which includes all trees. The rotation lengths are those optimal for a 4% interest rate given the type of harvest described.

costs and prices. In other words, present economic and technological conditions tend to stabilize the ecological status of the forest.

This result may be less true if harvesting cost differences across diameter ranges were reduced through changing technology. Examination of such effects is possible within THSMM, but is beyond the scope of the present analysis.

In both harvest scenarios beech comprises a much larger component of the future stands than of the present one. This speculative result may be an artefact of the regeneration routine in the model. Furthermore, THSMM does not incorporate any factors such as beech bark disease which may be important in controlling the abundance of beech. Nevertheless, many clearcuts in upstate New York experience an increase in beech. For biomass harvesting, undesireable shifts in the species composition may be a greater concern than nutrient depletion.

Conclusions

We have used a simulation model to demonstrate some of the interrelationship between economic and ecological factors associated with biomass harvesting. There are six important conclusions that can be drawn from this analysis:

1. The optimal economic rotation length is highly influenced by stand structure which is, in turn, influenced by the timing and diameter limit of the previous harvest.

2. Because stand structure changes in response to stand age and type of harvest, rotation lengths for a sequence of stands need to be solved for each stand separately rather than averaged over several rotations.

3. Because of their high handling costs per unit volume, small trees are uneconomic to harvest even with whole tree chipping.

4. Economic optimization of rotation lengths creates a positive relationship between intensity of harvest and rotation length: as harvest intensity increases, so does the period of ecosystem recovery.

5. Economically optimal rotation lengths for whole tree chipping apparently result in sufficient time for the site to recover in an ecological sense.

6. Changes in species composition may be an important concern in biomass harvesting.

The details of these conclusions depend heavily on the choice of a specific site. However, choosing rotations on the basis of discounted economic values does not necessarily lead to decisions that are short-sighted from an ecological point of view.

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SUITABILITY OF CONTEMPORARY STOCKING GUIDES IN PLANNING BIOMASS HARVESTS

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Development of contemporary stocking guides for northeastern tree species is reviewed. The guides are useful for establishing stocking levels following intermediate cuts by conventional or whole tree methods. Additional data is needed to determine stocking levels for optimum growth in stands that have multiple thinnings. Silvicultural objectives must be clearly defined in using stocking guides. Economic constraints may limit use of biomass harvesting equipment to thin only to minimum recommended stocking levels. If optimum potential in growth and value is to be achieved from a stand, the damage to residual trees and the site must be kept minimal irrespective of harvesting methods and equipment used.

Removal of the entire above-ground portions of trees for multiple products or as chipped biomass for home energy, electrical generation, or heat is a new technology to consider in managing our forests. Whole-tree harvesting adds a new dimension of ecologic and economic issues to contemporary forest management. These issues challenge the manager at the implementation level when decisions must be made on the appropriate tree stocking levels for a particular stand condition and management objective. The manager's decisions will often be a compromise that should be guided by their assessment of economic constraints, understanding of ecological requirements of the species, and a studied interpretation of appropriate silvicultural and stocking guides.

Stocking guides are a fairly new addition to silvicultural practice to guide us in recommending cultural prescriptions. The first stocking guides of the form we use today were constructed about 25 years ago for upland central hardwoods dominated by oaks. Gingrich (1964) presented the bases for development of these guides combining the principles of crown competition factor (CCF), tree area ratio (TAR), stand basal area, and number of trees per acre.

Ascertaining appropriate levels of stocking at different stages of stand development has been a long-standing problem in American forestry practice. The stocking guides in use today for northern hardwoods, oaks, spruce-fir and white pine are the result of a long development period and, in my view, are one of the major breakthroughs in silviculture in the last three decades. Prior to the present stocking guides, Reineke (1933) developed stand density index (SDI) as a measure of stocking. Reineke found a maximum of about 1,000 trees per acre of red fir (Abies magnifica), a tolerant western tree, in stands with a mean stand diameter (MSD) of 10 inches, and thus an SDI of 1000 at MSD of 10 inches was used as the comparative base for stand density throughout the U.S. Most eastern species have maximum SDI levels much lower than do western species.

Wilson's spacing factor, a guide to establish spacing between trees based on percent of height was used in pine stands (Wilson 1946). Neither of these stocking guides were refined for establishing optimum stocking levels to achieve best and most efficient growth.

When Bitterlich (1947) developed the variable radius plot method for forest sampling using an angle gauge or wedge prism, it was a major breakthrough in permitting us to readily determine basal area and number of trees per acre. We then began using basal area more effectively as a measure of stocking and relating growth to different levels of basal area. The method was convenient but we still required a means of defining where a stand was fully stocked versus understocked and where growth may be optimum.

The convenient use of basal area as a measure of stocking and ideas from two major papers led to the breakthrough in developing the guides and charts we have today. In 1961, Krajicek and others introduced the concept of crown competition factor (CCF), a concept based on the biological limitation of how large a tree crown may become when free to grow (Krajicek et al. 1961). They found that for any species, or closely related species groups, a tree of any given dbh would establish a maximum crown diameter. If a stand were constructed of trees with maximum size crowns, such that all crowns touched and their projection fully covered the ground, then all trees would be competing with each other and the stand would be at the CCF 100 level of density. Chisman and Schumacher (1940) studied stands of trees where there was a high degree of competition such that all trees had small crowns and mortality was occurring. Individual trees according to species and size projected a minimum crown area required for survival that they defined as the tree area ratio (TAR), expressed in milacres of crown projection.

Gingrich (1964) envisioned stands with a closed canopy and all trees with minimum crown areas (TAR) as representing the maximum level of stocking. At the other end of the spectrum, closed canopy stands where trees had maximum crown areas (CCF) he envisioned as at the minimum level of stocking. He linked these two principles graphically by plotting them as number of trees per acre for an even-aged stand and aggregate basal area of those trees. The result was the stocking charts for upland central hardwoods, dominated by oaks (Central States, 1962). In these charts, position of the A line is derived from tree area ratio while the B line position is derived from crown competition factor. Data from long-term thinning studies was used to confirm the charts and also served as the basis for establishing the C line, stocking that would reach the B level in 10 years. The central hardwoods charts were constructed for use in even-aged stands where all trees 2-inches dbh and larger were measured; the charts apply to stands beginning at a mean stand diameter of 3 inches.

The central hardwoods stocking chart readily became popular and easy to use and in due time similar charts were developed for other species, including northern hardwoods (Leak et al. 1969), (Tubbs 1977), Allegheny hardwoods (Roach 1977), northern red oak (Sampson et al. 1983), spruce-fir (Frank and Bjorkbom 1972), and white pine (Philbrook et al. 1973) (Figs. 1 and 2). Most of these charts specify counting trees only in or touching the main canopy, but the Allegheny hardwoods chart requires a count of all trees greater than 1-inch dbh. It is important to tally trees as prescribed, otherwise serious errors can be made in the estimate of stocking. This is particularly critical when using a BAF10 prism, for example, since one 2-inch tree represents 458 trees per acre.

Obtaining data for CCF and TAR to construct stocking charts can be time consuming and eventually shortcut procedures were developed. The Tree Area Ratio defines maximum stocking and thus theoretically an even-aged "normal" fully-stocked stand. The A line on the stocking chart can thus be derived by determining basal area and number of trees for normal fully-stocked stands representing a range of mean stand diameters. Different methods have been used to establish the B line. In some instances a new crown competition factor is determined by measuring crown spread of dominant trees in forest stands representing a range of mean stand diameters. This point is important; the B line determined from forest grown dominants is likely to be higher than one based on crown measurements of open grown trees and will thus indicate a higher basal area at B-level stocking.

Application of Stocking Guides

The primary purpose of stocking guides is to establish acceptable levels of stocking following intermediate cuttings, primarily thinnings and improvement cuts, in stands of sapling size and larger. The objective is to implement a degree of thinning that will achieve a good growth response in volume increment among remaining trees, and increased quality and value of that increment. A further goal is to maintain a stocking level that utilizes the full productive capacity of the site. If stand conditions require a sanitation or salvage cut, other factors likely override the need to adhere to minimum stocking levels. When stocking of healthy trees will be exceedingly low following sanitation or salvage cuts, the forester must decide whether to retain the few good trees at low stocking or regenerate a new stand by artificial or natural means. If the decision is to regenerate an even-aged stand by the shelterwood or seed tree method, the stocking guides are then replaced by silvicultural prescriptions that will create the best conditions for regeneration. If regeneration is by the clearcut method, other considerations prevail, including planting.

When the various stocking guides were constructed, they were not necessarily extensively tested to confirm whether the site would be fully utilized if stocking was reduced to the B line following a thinning. Gingrich (1964) hypothesized that between the B and A line the site would be fully utilized and thus growth for the stand should be at or near maximum. As stocking progressed from the B to the A line, associated with changing number of trees or basal area, growth adjustments would occur among individual trees to yield about the same total increment per acre. At stocking levels below the B line, growth per individual tree would remain the same as at B-level stocking, but growth per acre would decrease.

Studies of growth in relation to different levels of stocking as defined by the appropriate chart indicated this hypothesis may not hold. Leak (1981) examined some of these anomalies and found for northern hardwoods that total and net annual basal area accretion, as observed by Solomon (1977), peaked at a basal area of 60 ft^2 for a stand of 9-inch MSD that includes trees 4.5-inch dbh and larger. Leak points out B-level stocking for this stand would be 70-75 ft^2 of basal area for main canopy trees and if small trees are added, the total stocking would be about 80 ft^2. Solomon's study indicates best growth occurs below B-line stocking. The northern hardwoods guide indicates that basal area increment in an uneven-aged stand would be maximum at about 90 ft^2 of basal area at the mid-point of the cutting cycle. In even-aged stands this stocking would be at B level for a 14-inch MSD stand, but nearing A level for a 5-inch stand. If most trees greater than 4.5-inches dbh are touching the main canopy as defined for the stocking charts, then 5 ft^2 need not be added and the two estimates of residual stocking differ by about 13 ft^2. If stocking is increased to 80 ft^2, then, using Solomon's data, annual basal area growth decreases by about 0.1 ft^2 (ca. 6 ft^3/ac/yr). If we assume even-aged stands have basal area increment similar to uneven-aged stands, and use Solomon's data to adjust for mortality, then according to the guide, northern hardwoods with 80 ft^2 of basal area would accrue about 2.35 ft^2 versus 1.82 ft^2 as indicated by Solomon, potentially a volume growth difference of perhaps 25 to 30 ft^3/ac/yr. Yield comparisons have evidently not been confirmed for different levels of stocking as determined by the northern hardwood guide. Empirical data may demonstrate close agreement, or the need to adjust the B line and revise our concept of full and optimum stocking.

It appears B-line stocking for northern hardwoods is based on measures of free-to-grow forest trees and not open-grown trees as Krajicek et al. measured them. These measures would place the B line at a higher level than a line based on

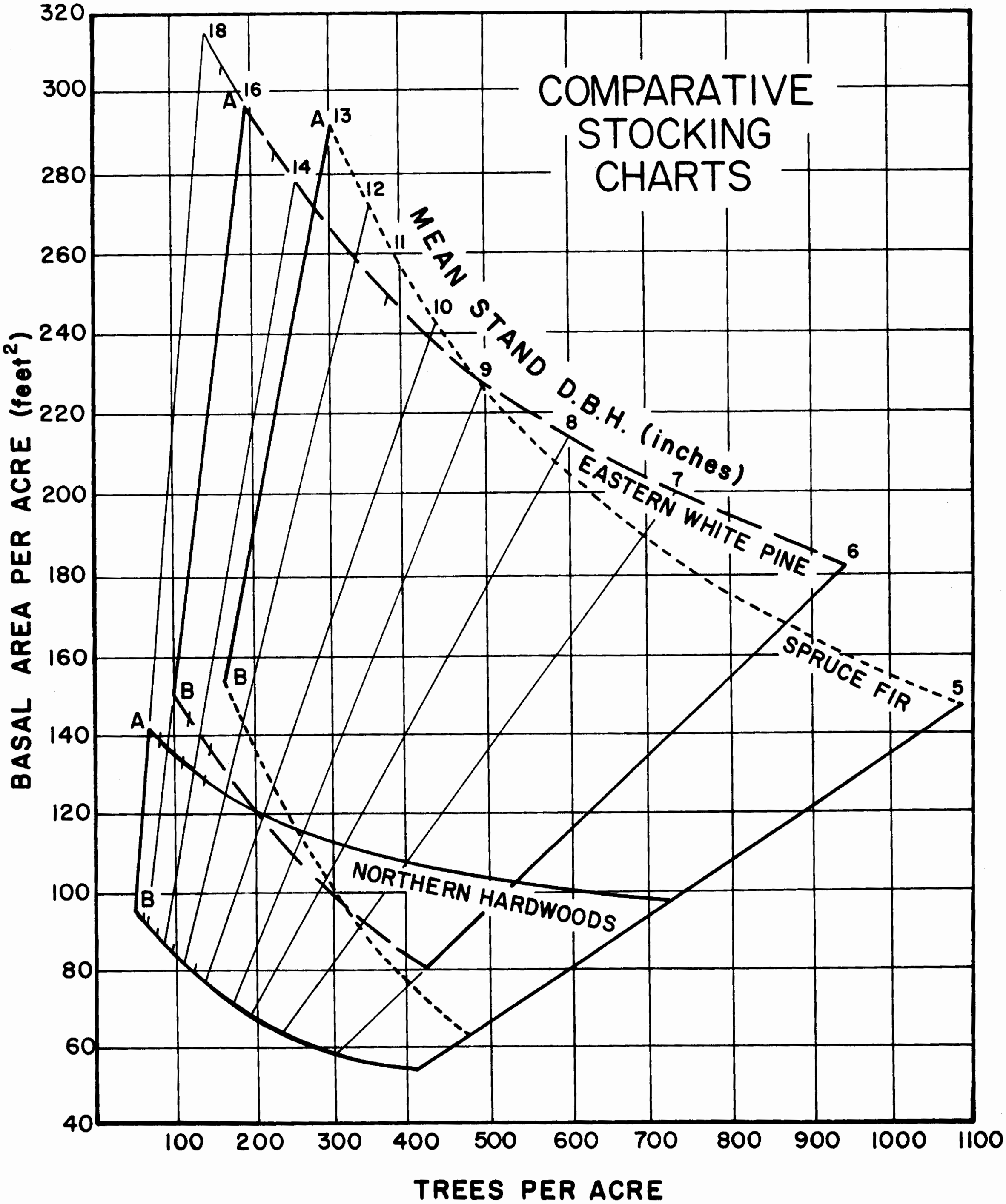

Figure 1. Comparison of stocking charts for spruce-fir, white pine, and northern hardwoods adapted from the cited references. These charts enable comparison of stocking levels, space requirements for trees based on crown spread characteristics of trees, and tolerance to shade. Conifers have narrower crowns and therefore more basal area per acre.

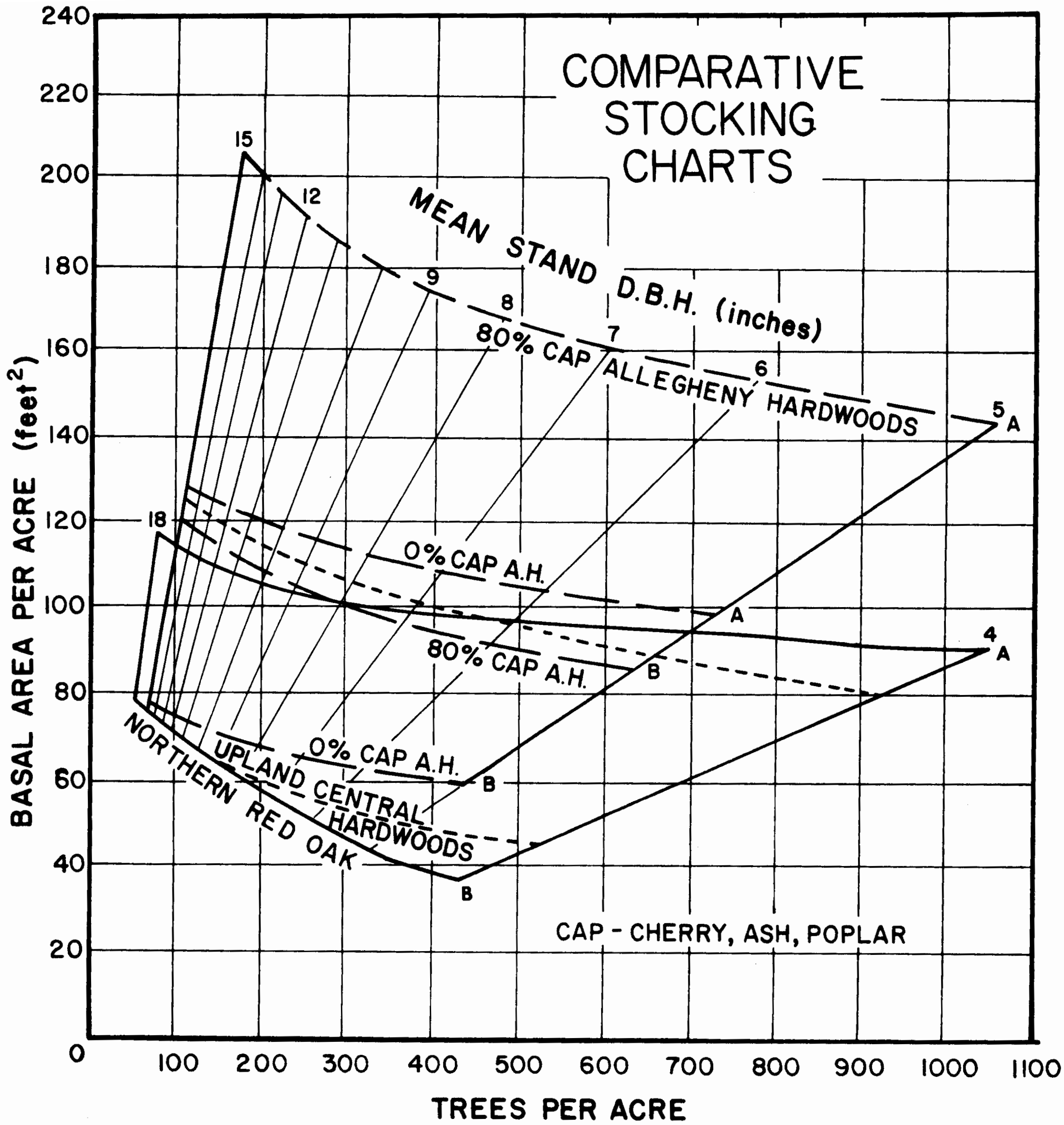

Figure 2. Comparison of stocking charts for Allegheny hardwoods, Central hardwoods (primarily oaks) and northern red oak. As the ratio of black cherry, white ash, and tulip poplar, trees with the narrowest crowns, increases in Allegheny hardwoods, the basal area at A and B level stocking increases. Oaks in the Central hardwoods, and northern red oak develop broad crowns and thus A and B level stocking is considerably lower when oaks dominate the stand composition.

open-grown trees. It is possible that Solomon's data defines a more appropriate level for the B line and possibly closer to a level determined by the CCF method. It seems clear that more data is needed to verify the appropriate stocking level for optimum growth. We should also consider quality of growth in terms of stem taper and branching characteristics as Leak (1981) and Dale (1972) have pointed out.

Among oaks, growth studies by Dale (1972) indicate that maximum 10 year cubic foot volume increment occurred at stocking levels 10 to 20 ft^2 below the B line for central hardwoods. In Leaks' study of these data, the differences between B level and optimum growth level are greatest for 80-year-old stands on good sites, yielding a difference of greater than 42 ft^3 in 10 years. These differences occurred for oak stands thinned to 50 and 70 ft^2 and left to grow for 10 years. Assuming there were no changes in tree form and thus errors in the volume estimates, it appears trees in stands near 50 ft^2 of basal area on good sites are able to respond rapidly, utilize all site space very efficiently, and grow more volume per acre than trees at higher stocking level combinations. There is less discrepancy in these estimates than in the northern hardwood estimates, about 5 ft^3/ac/yr versus about 25 ft^3/ac/yr, lending validity to the CCF method of estimating B-level stocking. Though growth of oaks may be better at stocking levels below the B line, additional precise data and further experience is needed before we argue strongly for thinning much below the B line.

In Leak's evaluation of white pine growth in relation to stocking, he points out that maximum 9 year cubic foot volume growth, as measured by Barrett and Goldsmith (1973), occurs at maximum basal areas of about 270 ft^2/ac for ages between 20 and 90 years. Net cubic foot increment at age 50 occurs at 210 ft^2/ac for stem densities ranging from 100 to 800 trees per acre. Barrett and Goldsmith's tables show no bounds denoting sampling limits of the field data; some combinations in the tables are unlikely to occur. These data suggest that stands at B-level stocking with considerably less basal area than recommended for optimum growth should have markedly less growth, but comparisons are not made with growth in thinned stands. Assuming net growth is 141 ft^3/yr for 300 trees at 210 ft^2 of basal area, I estimate annual diameter growth of the average tree (11.3-inch dbh) is about 0.17 inches per year. If the stand were thinned to the B line, about 130 ft^2 of basal area with 185 trees per acre, then depending on form and volume, trees must grow about 0.4 inches in diameter annually to achieve the same annual volume increment of 141 ft^3. If stocking is changed abruptly from 210 to 130 ft^2/ac in one cut, trees are not likely to utilize the available growing space immediately, but in time an annual diameter increment of greater than 0.4 inches per year is not unreasonable. If comparisons are made on the basis of board foot (bf) increment, the relationships may be different. Recent growth measurements in heavily thinned white pine plantations in Vermont to about 130 ft^2/ac or less indicate volume increments of about 1000 bf/ac/yr and diameter growth of 5 rings/radial inch or 0.4-inches diameter growth per year on the larger trees. There are some who will argue that, based on field measurements of growth response following thinning, the B line in white pine stocking charts should be lower. The B line in the white pine stocking guide, as computed by Philbrook (1971), is based on crown diameters of dominant forest-grown trees and not free-to-grow trees. The B line is therefore shifted above a level based on CCF calculations and a lowering of that line may be appropriate.

Studies of growth in relation to stocking density as measured in pines, and possibly other conifers, indicates they are very efficient at accruing biomass. Pine stands often show annual increments three or more times that of hardwood stands but often on twice the basal area per acre because their crowns are narrower and thus more trees occur per acre. Pines usually also have greater merchantable height to accrue volume increment on.

We have little data on white pine growth under sustained thinning schedules. While the analysis by Leak suggests maximum cubic foot volume growth occurs at maximum stocking, it seems conceivable that after adjustment to available growing space, fewer but larger trees could produce near the same annual increment as an unthinned fully stocked stand. Maximum board-foot increment may occur on fewer trees at a lower level of stocking. It is becoming evident that heavily thinned pine on good sites can grow high annual board-foot increments. Given the data available thus far we have some basis for thinning below the present B line for white pine. With experience we may see fit to adjust that B line up or down to optimize board-foot or cubic-foot increment.

Among northern hardwoods and oaks, some data suggests the B level could be set lower. Most growth comparisons are based on basal area change. If the trees are reacting to the available space by increasing taper, the actual volume increment could be the same or even less than at higher stocking levels. More study of growth responses seems essential before a decision is made to adjust B-level stocking.

In evaluating growth following stocking reductions to near the B level, we must recognize the potential for delayed response associated with drastic stocking changes. When a heavy thinning is made in a stand of any species, reducing stocking from near the A line to the B line, some reduction in growth should be expected until crowns expand and roots grow into vacated soil space. The remaining trees represent B-line basal area, but on the average they have narrower and shorter crowns than open-grown trees, or forest-grown dominants of comparable dbh. Theoretically, each year after the thinning, the annual volume increment should increase as crowns expand, until the site is fully utilized. The forester must then decide when to thin again, and how much to thin to maintain the stand on the optimum growth path for board-foot, cubic-foot, or biomass increment. For a conifer species like pine, these growth adjustments give the appearance that B-level stocking may be too low. Frequent less drastic thinnings begun when stands are young may result in minimal delay in response and more efficient site utilization regardless of species.

We should remember that stocking guides we use today are guides; the forester should make adjustments for local conditions and consider individual tree growth rates and final product value in the adjustments. Agreement between B-level stocking and maximum growth may be closest for average site conditions. On low quality sites where soil depth and available water may be factors limiting tree response, maximum growth may be at stocking levels below the B line. On good quality sites, levels of stocking higher than the B line may give maximum growth.

Leak (1981) has pointed out some anomalies between hypothesized and observed growth that we must recognize can occur. With experience in use of the guides we can make adjustments to achieve better agreement. This is not necessarily a major task for researchers, every forester should be aware of, and possibly test adjustments for their particular locations that may be unique or differ greatly from the norm because of genetic, climatic, and soil conditions.

We have been in the business of managing forests in the United States for about 100 years but there are few areas in the U.S. where we have good data on expected yields from managed stands. We have about 20 years of experience with our stocking guides but still little data is available to validate the guides and make adjustments. This situation is perhaps more a criticism of level of management rather than of the stocking guides that we think may not accurately reflect growth. We still practice much of our silviculture by eye and gut feeling; if a stand looks good after a thinning and that appearance is supported by close agreement to the guides, then we probably are okay. We seldom need the guides for ascertaining the upper level of stocking unless we need to verify a stand is overstocked; virtually any naturally stocked stand needs thinning. We do need the guides to make judgements on the critical lower limit of stocking.

In view of the experience and data we have on use of stocking guides, it appears they are adequate for the purpose intended--adjusting stocking during intermediate cuts. They should thus be useful for guiding intensity of biomass harvesting in intermediate cuts. The silvicultural objective of the cut must be clearly kept in mind and distinguished from the economic objective of the biomass harvest. The guide should be used to set stocking levels for best future development of the stand in terms of future growth rate, tree and wood quality, and value. There are data to indicate that low stocking can promote branch retention (Godman and Books 1971) and thus knot defects that reduce grade recovery. Oaks in particular have a high potential for forming epicormic branches following release. Trees with good crown ratios are likely to sprout less than those with small crowns, and sprouting potential can vary among trees within a species.

To some extent it matters little whether trees are removed by biomass harvesting or by conventional methods to meet stocking and stand quality objectives. If economic conditions necessitate a volume removal that reduces stocking below levels that will give appropriate responses in growth and quality, then silvicultural objectives of intermediate cuttings are secondary, and the use of stocking guides is a moot point. Silvicultural and economic objectives must be clearly defined before one can assess the appropriateness of an intermediate cut and the stocking level achieved. Hopefully, the two objectives will be in reasonable agreement and the stand will be set on course to a higher potential than before it was treated.

Other Site and Growing Stock Considerations

A close adherence to current stocking guides does not necessarily mean there will be no undesirable stand or site impacts by either conventional or biomass (whole-tree) harvesting. There is ample data on possible effects of removing the entire above-ground stem from the forest and the potential impact on site fertility. Even conventional wood removal from the forest draws down site fertility because of the bark and wood removed from the site. We are uncertain how much the logging of the last 300 years, the major harvests of white pine, spruce-fir, hemlock and hardwoods, and in some cases succeeding fires, diminished nutrient supply and thus productive capacity of forest sites. An increment of site deterioration due to soil losses must also be considered. One may wonder whether geologic weathering since first harvests replenished all of the soil nutrient supplies. Our base of reference for judging the impacts of biomass or conventional harvests, in their various intensities of application, is the site status at this point in time. Good quality sites probably have greater resilience or buffering capacity against changes in productivity than poor quality sites. All sites, however, deserve the best silvicultural treatment that foresters can prescribe given the economic constraints at hand. If the proposed treatment for compromise is too risky ecologically, then it should be modified or not implemented.

Damage to the residual stand during conventional or whole-tree harvesting is an important factor to consider in the silvicultural outcome of intermediate cuts. If a suitable stocking goal is achieved, but many of the residual trees have stem damage that become serious defects or degrade factors in the future, much of the benefit of thinning may be lost. If the management goal is purely biomass, then concern for stem damage may not be as great. If, however, the goal is to maximize returns from management, this can be best achieved by maximizing the number of high quality logs in future harvests. Owners of small forest land holdings are concerned about damage to remaining trees, how the stand looks following harvest, and its impact on other uses. These landowners control a large proportion of the forest land in the eastern U.S. Many would rather not have wood cut than see their stands degraded when a good multiple-use silvicultural prescription is scuttled by poor harvesting practice. Firms with large land holdings should have the same concerns for their own land, both from the standpoint of investment return and the image it portrays to the public of silvicultural practices in use. If the private woodland owners have an unfavorable impression of forest practices on large holdings, they will be guarded about having wood harvested from their small private holding.

With modest additional effort we can harvest in stands of natural stocking density, reduce the stocking to near the recommended minimum level (B line) and keep stand damage minimal. Any damage to stems and roots provides entry points for decay that degrade the future product and possibly lead to high mortality. Careful felling and use of appropriate logging equipment is essential to minimizing damage. To help further minimize damage, all skid trails and roads should be well planned in their spacing and alignment and located in advance of cutting. If roads are designed and constructed for reuse, the next thinnings should be done at less expense. Directionally fell trees to minimize major turning of the stem, a major cause of residual stem damage. Segment long trees and remove large limbs as necessary to minimize skidding damage. This added effort to leave a good quality stand following an intermediate cut will cost more; that cost may be shared through a combination of lower stumpage prices to the landowner, higher mill prices, and possibly slightly lower profits to the logger. Considerable gain on this investment may be made by all participants when the next thinning or final harvest is made 10 to 20 years in the future. These same attitudes on harvesting should hold if a shelterwood, seed tree or selection cut is made. In this case the stocking guides are replaced by canopy density guides to achieve regeneration. Usually some of the best trees are left as a source of seed, shade, and high value increment, thus stem damage to these trees should be kept minimal.

Summary

Our contemporary stocking guides are appropriate for planning minimum stocking levels for thinnings and improvement cuts. To improve our management we must become more knowledgeable of how stands respond at different levels of stocking for various management objectives, and adjust our guides accordingly. Market opportunities for low quality wood, and increased mechanization in whole-tree and conventional harvesting afford us an excellent opportunity to make harvests that improve the present quality and future potential of our forest stands. The stocking guides developed over the last 25 years, though they may not be perfect, should be effective in helping us accomplish these objectives.

Stocking has for decades been a difficult attribute to quantify and measure for forest stands. The development of stocking guides we use today is one of the major breakthroughs in silviculture of the last three decades. These guides are fairly easy to use and have a sound ecological foundation.

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PUBLIC ROLE IN BIOMASS HARVESTING: FOUR CHALLENGES

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The recent increase in whole-tree chip markets has presented foresters with silvicultural opportunities that were not available ten years ago. This opportunity, and the associated harvesting and chipping machinery, has been met with a mixture of optimism and pessimism in the forestry community and general public. Foresters and the public must face the four challenges of 1) finding a sound balance of regulations and private responsibility; 2) expanding and improving research and monitoring; 3) maintaining and communicating to the public a balanced perspective on biomass utilization; and 4) promoting not only particular forest practices but a land ethic. Answering these challenges will help us in our pursuit of the task of passing on a higher quality forest to future generations.

I recall sitting around at forestry summer camp in Upper Michigan, too many years ago. Someone mentioned wistfully, "boy, the things we could do if somebody would invent a way to chip a lot of this stuff in the woods..." Little could we know then what challenges would emerge for public policy from just such an invention.

Today large electric generating plants burn whole-tree chips; a few paper mills use them for pulp after screening. In our timber surplus region, this is a welcome market. As Maine's Conservation Commissioner Richard B. Anderson likes to quip, it enables you "to weed the garden--and sell the weeds". Loggers, electricity users, and landowners have found biomass utilization appealing enough to generate a considerable business. Silviculturists now see opportunity where ten years ago they saw only puckerbrush. Enthusiasm among foresters is widespread, but far from unanimous, as is often true of newly developed technologies. We may recall the adoption of the chainsaw and the skidder as innovations with comparable effects on forestry.

Has this tremendous new opportunity been received with the public approval that ought to attend major leaps forward in forest practice? Not exactly; concern is widespread over possible destructive effects of whole-tree utilization. The press reflects this concern.

Wholetree biomass utilization involves a limited acreage and timber volume. Biomass accounts for less than 10% of the fuelwood use in New York; less than 10% of total wood use in New Hampshire. Only in Maine is biomass use large--some 1.6 million green tons per year, which could double if all likely plants are built. But regulations have been imposed on chipping in the woods and biomass utilization that would never be considered for chainsaws, skidders, and sawmills. Why?

Mechanized harvesting and chipping are psychologically threatening to some poeple. Their visibility makes them the focus of wider concerns about the future of a forest which displays evidence of more cutting than has been seen in generations. Optimistic projections of ever-rising biomass consumption seem scary to some.

Across the Northeast, legislatures and public regulatory authorities have been urged to take action regarding biomass utilization. In many instances, the agencies are not especially conversant with forestry issues. This conference, then, is a useful time to take stock of where we have been and what the basic public issues are. My task is to identify issues and stimulate discussion, not provide the answers.

I will not review existing regulations, but will summarize the four basic challenges that foresters face. These are:

1. Finding a sound balance of regulation and private responsibility;

2. Expanding and improving research and monitoring;

3. Maintaining and communicating to the public a balanced perspective on biomass utilization;

4. Promoting not only particular forest practices but a land ethic.

Regulation and Private Responsibility

A first challenge is to find a sound balance between effective, minimal public constraints and the stronger exercise of private responsibility.

A standard way our society responds to a group that feels threatened by new technology is to regulate the technology's uses. In many areas, this approach is needed and should have been started sooner than it was. What is troubling about many regulatory schemes regarding forest biomass use is, however, their ad hoc development. Biomass regulations often arise in a regulatory process designed to set power rates or to regulate air emissions, as a side issue to the agency facing the problem. They emerge from compromises designed to mollify opponents of a project, not necessarily from sound and informed analysis of the need for regulations and the effectiveness of different approaches.

Regulations of which I am aware all address loggers--not a very popular interest group in legislatures. But what about the landowners who might permit their land to be abused? When the state regulates the logger rather than the landowner, it takes the politically easy way out. This perpetuates the fallacy of failing to hold landowners responsible for their actions -- or inactions. No doubt, since there are fewer loggers, regulating them has some appeal. Also, extension and educational work with loggers is a recognized practice that often gains in market penetration when punishments for infractions are threatened.

Government regulation of forest practice, in my view, reinforces the landowners' inclination to perceive conservation as the government's job, rather than the landowner's job. Forestry will be better off in the long run, the longer we resist the temptation to relieve landowners of this responsibility.

So it is time for all of us concerned about better wood markets and about the future condition of the forest to obtain careful reviews of the cost-effectiveness of existing regulations. Key questions will be:

Do they have clear objectives?

Are they funded adequately to obtain them?

Are there avoidable side effects?

Should they be looser? Tougher?

The forestry community should develop a shared sense of what responsibilities should be met by large users of biomass products. What obligations should they assume to assure that their biomass comes from sound silvicultural treatment, is carried in legally loaded trucks, and that landowners are paid for it at a fair rate?

These obligations should be voluntarily undertaken by biomass users. Some have done so already. Some are public or quasi-public entities, like hospitals or military bases, whose policies are more readily influenced in this way. Biomass processors and users have a strong common interest in being able to demonstrate that destructive harvesting is not being practiced by their suppliers.

Obviously, states should be looking over the shoulders of loggers and users in biomass utilization, but I would hope that the right combination of private responsibility and cautious public observation could achieve sound results with minimal regulatory machinery.

Research and Monitoring

A second public challenge is to foster sufficient research and monitoring that basic questions, over time, will find answers. As is true in any new product market, too many facts are lacking. Markets run on information. Providing it is a basic government task. There are four key areas:

Biomass Silviculture

There is an urgent need for research and monitoring on the use and abuse of biomass harvesting in silviculture. Too much of the "research" on this topic consists of literature reviews or individual plot studies of extremely narrow topics.

State agencies and the research community must get silviculturists into the actual logging jobs to fully evaluate stand prescriptions, past treatments, and alternative extraction systems for their longterm effects on nutrient status and flows, advanced and postcut regeneration, residual trees, and mitigating measures if problems are found.

Evidence has been cited in previous papers showing that there is a basis for concern about the effects of biomass utilization on future soil productivity. But research must clarify, over a range of site conditions, rotation lengths, and management treatments, and over a sufficient span of time, under what conditions biomass utilization presents a serious hazard to productivity.

We need to look diligently for additional surprises that may be there, as yet unnoticed. A better base of research will enable us to narrow the differences among ourselves as to the benefits and risks of biomass utilization for future site potential.

Biomass Logging & Logistics

There is little research and evaluation on logging costs and systems in the Northeast compared to the need. This is especially true for biomass. Prospective equipment buyers and designers of silvicultural systems find themselves in a world of myth and fantasy, stories, and jokes, rather than clear, documented performance and cost data.

It could be that refined application of the marginal log principle to biomass utilization would by itself constrain excessive utilization and automatically tend toward mitigating any concerns about nutrient depletion.

Increased public concern with infrastructure and fair public facilities funding suggests that the incremental highway loads occasioned by increased biomass use could be the last straw. This could have severe repercussions in an industry in which hauling charges are currently set not by the average costs of legally loaded trucks, but by the incremental costs of overloaded ones.

Foresters need to design and publicize logging systems that exploit the fact that mechanized harvesting and skidding, chipping in the woods, and related technology are not synonymous with clearcutting. They are consistent with many different silvicultural treatments during the life of stands.

Monitoring the Regulatory Process

Careful, ongoing scrutiny of state regulatory processes is needed to assure that requirements are actually applied and enforced, that loggers, landowners, and foresters are well informed about them, and that emerging policy issues can be caught before they explode. In our political system, regulations usually emerge from a lot of posturing and exaggerating. Even when an agency reluctantly accepts the regulatory task, it soon declares that the rules are working-- the only problem being inadequate staff and funding. Those opposed to the technology will support the agency's view. The technology's users will howl about unreasonable costly constraints--which costs they can't document. Objective, outside monitoring of the regulatory process should help to keep everyone honest.

Monitoring the Marketplace

For biomass, the number of market participants is limited; they are usually easy to find. This should simplify the basic public task of maintaining accurate and timely data describing the ebb and flow of the marketplace--quantities, prices, contract terms, structural trends, imports and exports.

One aspect of this work is accurately assessing the physical and economic supply. Despite reams of studies documenting the enormous size of northern New England's surplus biomass stock, conveying this message to legislators and the public is proving to be difficult.

A Balanced Perspective

It is critical for public forestry agencies to maintain and convey to the public a balanced perspective on the risks and opportunities of biomass utilization. This is the third challenge.

Biomass use is a double-edged sword. It holds high potential for supporting upgraded silviculture--just at a time when the region needs it. But it holds potential not only for landowners to abuse individual woodlots, but for the already nervous public to be dealt a dose of severe skepticism and even hostility to all forest practice. This is perhaps the real risk. The credibility of public forestry agencies and large biomass users hangs in the balance.

For some reason, the high-grading of hundreds of thousands of acres by hundreds of men with chainsaws seems invisible--perhaps it's so familiar as to be part of the landscape already. But the possible abuse of future biomass chipping is highly threatening. The threat arouses citizens to letterwriting and attending hearings; it raises concerns among foresters as well.

Public officials must maintain a sound balance between responsible promotion of biomass for the benefits it can bring, at the same time being alert to and concerned about possible abuses that threaten future productivity. They cannot be seen as either mindless promoters or mindless opponents of this new technology. We must welcome public concern, treating it as an opportunity to educate. When we see other public agencies acting in a biased manner--either promotionally or negatively--public and private foresters should be ready with facts and reasoned argument. In short, we must offer the public a balanced perspective. Stating what that perspective is is not my purpose today.

One way for state and federal agencies to develop and advocate this balanced perspective is to use publicly owned lands to showcase best-practice silviculture using biomass markets to enhance management opportunities. Public agencies should also devleop tentative guidelines to define conditions under which biomass use would run unacceptably high risks of degrading site quality.

Much more is at stake in this than a few chipping contractors or a few hundred thousand cords of wood a year. At stake is our credibility as foresters and as public servants. This credibility is a scarce resource and should be treated as such.

A Land Ethic

Concerns about the abuse of biomass technology exemplify our tendency to blame a problem on machines rather than on people. To the extent that state regulations focus on loggers rather than landowners, they reinforce this misconception. If biomass technology and markets threaten the forest, it is primarily because landowners are not prepared and not willing to harvest their woods wisely. Can we change this by regulating the chippers? Clearly not.

As in so many other forestry questions, this resolves itself into a question of the ethical commitment of the individual landowner. The nature of the commitment can vary--fear of neighbors' disapproval; concern for the wildlife and the soil; concern for the yields available to descendants.

The biomass issue is a tremendous educational opportunity. The high level of public concern and the novelty of the technology guarantee public and press interest. The interest is far more likely to focus on abuses rather than constructive uses of the technology. So we should be alert for these and not hide from them.

The Land Ethic has several advantages:

-- It focuses on the landowner, where responsibility for forest practice belongs;

-- It transcends wood, wildlife, or any individual resource value;

--It is readily communicated, not least through the considerable body of fine literary work surrounding it;

-- It points to values higher than self when many landowners are facing modest trade-offs in cash terms anyway.

To the extent that spreading the Land Ethic concept is successful, it will treat the disease--sloppy land management--rather than the symptom--misused chippers and mechanical harvesters.

Summary

So, here are four public challenges. I hope they provide a useful focus for debate and a sensible direction for consideration by wood users, foresters, landowners, public officials, and legislators.

-- Develop a sound balance between public regulations and private responsibilities borne by biomass users. Assure that regulations are minimal and that they in fact work.

-- Implement necessary research and monitoring of biomass silviculture, biomass logging and logistics, observing the regulatory process, and monitoring trends in the marketplace. Emphasize identifying site and stand conditions and treatments that present risks of harm to future productivity.

-- Maintain and communicate to the public a balanced perspective on the risks and benefits of biomass utilization. Far more than the biomass market is at stake here--it is our professional credibility itself.

-- Use the public interest in biomass as one way to reach people with strong advocacy of a land ethic. Use the land ethic in turn to treat the root cause of abusive harvesting--landowner indifference.

Little of this is really distinctive for the biomass issue. These four challenges are only common sense, as foresters and landowners pursue the larger task of caring for and transmitting a higher quality forest for future generations.

SUMMARY AND MANAGEMENT RECOMMENDATIONS

The condition of present-day forests in the Northeast reflects the general history of the region. The majority of timberland in the Northeast was partially or completely cut or cleared for farming by the early 1800's, then abandoned in the late 1800's. Most forests are second- or third-growth, depending on subsequent events like insect and disease outbreaks and logging operations. They are characterized by unbalanced age structures, and dominated by sawtimber stands with little in the seedling-sapling category (Seymour, Session III). The most valuable species, commercially, are sugar maple, red oak, yellow birch, white pine, and red spruce. Because merchantable trees of these species have been selectively removed from the forests, a large percentage of the remaining forest consists of cull or damaged trees with an increasing amount of red maple, beech and other less desirable species. In order to improve the species composition and quality of forests in the Northeast, this low-grade forest material must be removed.

Biomass harvesting involves the felling and removal of the above-stump portion of a tree followed by chipping of some or all of the bole, branches, and twigs. Although wood chips of certain species may be preferred for pulp, paper, and composite board, almost any trees, even standing dead ones, may be chipped for fuel. Thus, biomass harvesting offers a means for substantial increase in utilization and improvement of northeastern forests.

Biomass harvesting was introduced into the Northeast in the 1970's. The market for wood chips arose in response to increased demand for local fuel supplies in place of imported oil. At the same time large, mechanized equipment - feller bunchers, feller-forwarders, whole-tree chippers - became available. Currently more than 3,000,000 green tons of whole-tree chips are harvested annually from NY, VT, NH and ME with over 3/4 of this utilization occurring in ME and NH (Cyr, Session I; Natti, Session I; D. Smith, Session I; Stone, Session I). Large increases in utilization are projected over at least the next five years. However, no major changes have occurred, to date, in the quality of forest management due to the advent of biomass harvesting (Donovan and Huyler, Session I).

The silvicultural, ecological, and economic implications of biomass harvesting and associated trends in policy have been the focus of these Proceedings. The following is a summary of concerns and recommendations relative to biomass harvesting based on the preceding papers.

Silvicultural

Biomass harvesting should be regarded as one of the many tools of the forest manager, with advantages and drawbacks common to all silvicultural treatments. One goal of silviculture is to maximize commercial productivity of forest stands in the Northeast by promoting growth of high quality sawtimber and pulpwood. Towards that end, mechanized whole-tree harvesting systems are well-suited to certain types of thinnings and site preparation. However, economic use of specific machinery must be matched with silvicultural treatments on a job-by-job basis (Seymour, Session III).

The following points should be considered (Foster, Session III; Hannah, Session III; Seymour, Session III).

* Thinning by means of biomass harvesting should be delayed as long as possible in order to obtain a high biomass yield while minimizing degradation of the residual stand.

* Whole-tree harvesting technology may not always be appropriate for conducting intermediate cuts, depending on residual stocking levels and residual tree quality considerations.

* Stand conversion, thinning, or regeneration harvests may favor hardwood species. Depending on site and other stand-related factors, competition control with herbicides is required to promote conifers.

* Short-rotation biomass harvests favor regeneration of low-value, hardwood species.

* Residual stand damage - breakage of tops, basal wounds, breakage of advance regeneration - can be minimized by avoiding the use of large, heavy equipment in heavily stocked stands or on steep terrain. Plantations, in which spacing permits maneuvering of equipment and access to designated trees, are more suited to biomass harvesting.

* Winter harvests can mitigate damage to advance regeneration.

Ecological

Productivity of forest ecosystems is maintained by complex interactions between biological, geological, meteorological, and anthropogenic factors. Because biomass harvesting is a recent innovation, and research on affected forests tends to be long-term, only a few studies of northeastern forest types have been initiated and none have been followed over a complete rotation. So far, at least two areas of major concern have been identified: soil disturbance and nutrient conservation.

The following are soil types on which biomass harvesting should be avoided (Hornbeck, Session II; Martin, Session II; White, Session II).

* Soils that are shallow-to-bedrock or -hardpan.

* Soils with restricted rooting volumes or high percentages of coarse fragments.

* Coarse-textured outwash sands.

* Soils deficient in phosphorus.

* Poorly-drained soils, especially around streams and stream channels.

The following are recommendations for minimizing soil disturbance on areas undergoing biomass harvesting (Hornbeck, Session II; Johnson, Session II; Martin, Session II).

* Harvest when soils are dry or under snow cover.

* Plan skid roads along site contours; plan minimum of stream crossings located in least sensitive areas; and concentrate impacts of heavy equipment rather than allowing widespread, diffuse damage.

* Minimize or avoid practices that remove organic layers of soil.

* Use tracked rather than wheeled vehicles, wherever possible.

Several authors made recommendations for maximizing nutrient conservation (Hornbeck, Session II; Johnson, Session II; Jurgensen, Session II; T. Smith, Session II).

* Cut in winter or allow trees felled in summer to drop nutrient-rich leaves on site.

* Promote rapid regeneration of the site by avoiding biomass harvesting on certain soil types and minimizing disturbance on others.

* Allow for natural regeneration or accomplish site conversion and planting as rapidly as possible.

* Leave some logs on site to improve organic matter in soils and allow for establishment of seedlings.

* Lengthen rotation to allow for natural replenishment of nutrients removed in products or leached from the site, and consider fertilization to offset cation losses.

* Retain buffer strips of trees along streams or use strip cutting to reduce leaching losses to streamflow.

Economic

From a forest management standpoint, biomass harvesting can be cost-efficient in the short term through increased utilization of low-grade forest materials, and in the long term through improved quality of sawtimber stands. The actual practice of biomass harvesting, however, also depends on factors like current markets for wood chips relative to other forest products, the quality of the stand, and the costs of a specific harvesting operation.

The following observations pertain to the economics of biomass harvesting (Donovan and Huyler, Session I; Foster, Session III; Larson and others, Session III; Seymour, Session III; Stone, Session III).

* Added yield from chips must be compared with the cost of added effort required to sort products at the landing.

* Economical use of mechanical equipment favors "cold-decking" over "hot-yarding" to ensure a constant supply of trees to the chipper.

* A large percentage of fuelwood chips is supplied by land-clearing operations rather than silvicultural treatments.

* Supplies of fuelwood chips have fluctuated widely depending on demands by pulp and paper industries.

* Handling costs-per-unit-volume increase with decreasing diameter of trees, thus harvests of small trees tend to be economically marginal.

* Economic evaluation of intermediate cuts must reflect depreciation of the residual stand resulting from damage by mechanical equipment.

* Economically optimal rotation lengths tend to coincide with the rate of ecological recovery of the site.

Policy

Currently, NY, VT and ME specifically monitor and/or regulate biomass harvesting to some degree, whereas NH does not. Most regulations focus on licensing of logging equipment as well as size of clearcuts. In an effort to minimize both regulations and poor logging practices, the following concerns have been raised (Cyr, Session I; Irland, Session IV; Natti, Session I; D. Smith, Session I; Stone, Session I).

* Landowners must be educated to assume private responsibility for appropriate ecological as well as economic use of timberland.

* Foresters, scientists, and policy makers must make every effort to communicate a balanced perspective on biomass utilization to the public.

* Biomass harvests should include planning of factors like time of year, location of skid trails, and suitable types of equipment. The logging operation should be supervised by foresters to facilitate adherence to the plan.

* Forest management plans should incorporate a variety of silvicultural tools.

* Research and monitoring of biomass harvests should be expanded. Results of scientific studies should be made accessible through conferences as well as publications.

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