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ASPEN

SYMPOSIUM PROCEEDINGS

College of Forestry, University of Minnesota
Minnesota Forest Industries Information Committee
North Central Forest Experiment Station
Forest Service, U. S. Department of Agriculture

FOREWORD

The aspens — chiefly *Populus tremuloides* and *grandidentata* — are probably the most widespread hardwood timber species in Canada and the United States. Once looked upon as weed species in both countries, aspens are now recognized as valuable not only for timber products but also for wildlife food and cover and as essential to the esthetics of the North Country.

Aspen management and utilization are changing rapidly. Technology and experience have shown aspen to be extremely versatile: it can be managed intensively, it can be used for a variety of products, and it is adaptable to modern methods of harvest.

The Symposium speakers were purposely selected from a broad geographical base in Canada and the United States. The information they offer represents many years of research and experience by government agencies, universities, and private industry. We hope these papers will serve as a base upon which further progress will be built.

JOHN H. OHMAN, *Director*
North Central Forest Experiment Station
FRANK H. KAUFERT, *Dean*
College of Forestry, University of Minnesota
M. RUSSELL ALLEN, *Executive Secretary*
Minnesota Forest Industries

North Central Forest Experiment Station
John H. Ohman, *Director*
Forest Service, U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55101
(Maintained in cooperation with the University of Minnesota)

ASPEN: SYMPOSIUM PROCEEDINGS

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SOME PROBLEMS AND ISSUES IN MANAGING THE ASPEN RESOURCE

John R. McGuire, *Chief*
USDA Forest Service
Washington, D.C.

I am happy to be here with you in Duluth, in the heart of our beautiful North Country. I am particularly pleased to have our Canadian associates join us to discuss ways to increase the production and improve the use of aspen, one of our most versatile hardwood trees. And, of course, it is fitting that we should meet here in the Lake States where aspen plays a key role in providing raw material for industry and jobs for local residents. This region is also noted for its wildlife and recreation resources, and aspen contributes significantly to the support of these resources. In this short meeting, we will be unable to discuss the management and use of aspen over its entire range, but much of what we learn here will also apply to aspen where it occurs elsewhere in Canada and the United States.

This symposium is one of several held in recent years to bring together the expertise on how to best manage and utilize some of our important tree species. By reporting here what has been learned about aspen through research and practical experience, we hope we can help each other to accelerate progress in solving many of the remaining problems of managing this valuable species.

We share a common objective: to improve and stabilize the economic status of those people who depend on the northern forests for all or part of their living. At the same time we must satisfy the needs of the general public for other forest values.

I am pleased with the broad scope of the program for this meeting. We will find out how much aspen is available and where it is located. We will learn the results of many years of research and experience in growing and utilizing aspen — from the establishment of new stands through the harvesting of mature stands and the conversion of aspen wood to usable products. We will be brought up to date on the latest logging techniques and new opportunities in utilization. And we will find out how to best manage aspen for wildlife habitat.

But, as managers and users of the aspen forest resource, we must recognize the increased public concern about how both private and public forest land is managed. We must be able to evaluate the impact of our management and timber harvesting practices on the total environment and find how to minimize these impacts. How and where we harvest forest products will always be strongly influenced by economics, but scenic and recreation values must receive proper weight in decision-making. Although it will be impossible to satisfy everyone's desires, I believe we can steer a course that will in the long run benefit most of our clients. This symposium should give us some direction for doing this.

National timber needs are steadily increasing. We already have exceeded the consumption rates predicted in 1962. The use of aspen by forest industries has increased steadily over the past three decades. Aspen now provides half the roundwood used by the pulp and paper industry in the Lake States. This use will increase. Recently-adopted grading rules are expected to result in expanded use of aspen by the housing industry. The aspen resource will play a major role in the future development of the forest industries in the Lake States.

The area of aspen type is declining, primarily because of ecological succession. However, the volume per acre and the resulting total supply of aspen growing stock is increasing in the Lake States. Overall, the aspen resource is adequate to satisfy the needs of an expanding industry for at least the next two decades. Local shortages could force industry to change procurement patterns and harvesting techniques in order to maintain an adequate wood supply. The total aspen resource picture is favorable, but how much of this resource will be available to industry is unknown.

The aspen resource is generally producing far below its potential. If we can do a better and more intensive job of management, aspen will provide an even greater share of the national timber needs in the decades to come.

Regardless of our needs for wood, however, we must not overlook the tremendous demands that are being made on forest land for other purposes. This region is blessed with cool summers, abundant lakes and streams, and extensive forests. Skiing, hunting, and fishing attract many visitors. Many come here just to relax in the forests. Forest landowners — and especially public landowners — are under constant and increasing pressure to provide more and better recreation opportunities.

How can we provide adequate timber products while maintaining an acceptable forest environment for the many people who come here to see and enjoy the forests and lakes? How can we increase or even maintain a variety of game for the hunter to harvest and for others to admire? How can we do all these things and also improve the economic status of the rural communities?

We are gathered here to consider these and related problems. Fortunately, some guidelines are already well established. First, we must intensify efforts to develop and improve the productive capacity of the aspen resource.

Second, we must do a better job of aspen management. We must manage each aspen stand and site combination to get maximum benefits from this resource. At the same time, we must minimize adverse impacts on esthetic and other values. Aspen management will require more skill and finesse than we have used in the past.

Third, we must be prepared to modify our timber management practices where necessary to create the conditions needed for wildlife habitat and other special values. For example, where deer and grouse populations need to be increased, we

need to plan and coordinate aspen harvests so the necessary food and habitat conditions are provided over large areas.

Fourth, we must do a better job of educating the public about the need for our aspen harvesting practices. These will be more acceptable to the viewing public once people understand that clearcutting is an essential part of aspen management. We can minimize disturbances and reduce their esthetic impact by more judicious arrangement and location of our harvest tracts. I am confident that both public and private land managers can do a better job in this respect.

And finally, we must improve utilization standards. Too much usable material is still left in the woods. Pulp yields and quality can be increased through improved technology. Profit margins might be increased by sorting aspen raw material for its highest use— veneer, lumber, or pulpwood.

Within these guidelines, we must provide managers with workable alternatives so they can cope with the changing pressures on the forest resource. The task will not be easy, but it can and will be done.

During this symposium we will be reminded that aspen has many desirable characteristics from the forest manager's viewpoint. Its vigorous suckers make aspen easy to regenerate. It is so intolerant that rapid natural thinning and pruning occur. Volume growth is rapid over a short rotation. Industry can use the wood for pulp and paper products as well as for veneer and lumber. At all stages in their development, aspen stands furnish food and cover for wildlife. And the golden aspen leaves provide color and variety in our fall landscapes.

Geneticists have developed aspen trees that promise to be even faster growing and possibly more disease and insect resistant than the trees in most natural stands. When adequate supplies of these superior aspens are available, we will want to upgrade our present stands.

Recently our Forest Engineering Laboratory at Houghton, Michigan, has found better ways to separate the bark from aspen chips. Once a commercially feasible system is developed, we will be able to chip whole trees in the woods and significantly improve utilization of the aspen resource and the esthetics of harvested areas.

These pluses make our job a little easier, but in themselves they will not solve our problems. This symposium will bring us up to date on what we know about managing and using the aspen resource. I hope it will also pinpoint those areas needing further study so that researchers can get busy on these problems as soon as possible.

One last word. We all grant that aspen is an important component of our northern forest resources, but we must not lose sight of the fact that conifers and many other hardwoods are equally important. Together, they comprise one of the most valuable and heavily used resources in the world. As we focus our attention on aspen here, we must be mindful that aspen is only part of an ecological complex that will challenge our scientific and managerial talents.

THE RESOURCE AND ITS POTENTIAL IN NORTH AMERICA

J. L. Keays, *Research Scientist*
Western Forest Products Laboratory, Canadian Forestry Service
Vancouver, British Columbia, Canada

ABSTRACT. — The United States and Canada have different problems with respect to the utilization of their aspen resources. In the United States, aspen is more highly concentrated and its use, particularly in pulping, is well established and increasing. The present cut of aspen is roughly 50 percent of allowable cut, and within 30 years the allowable cut will probably double: growth and use will be in close balance by the end of the century. This pattern of aspen use arises from the fact that in the regions where it is most abundant (Lake States) there is a diminishing supply of softwoods, and also a well-established and diverse pulp and paper industry. Compared with the United States, Canada has five times as much aspen and harvests less than half as much. Aspen resources are more widely spread; the cut is small and is not increasing appreciably. No change in this trend is anticipated in the near future. Even by the turn of the century, it is likely that less than half of Canada's annual allowable cut of aspen will be utilized. Present evidence points to the conclusion that most of the aspen in North America will be used for fiber products — pulp, paper, paperboard, fiberboard, and composition board. A mill complex utilizing aspen and softwoods is outlined.

The *Populus* genus in general and the *tremuloides* species in particular occupy a unique position among commercial woods. They are among the most widely distributed, they grow on a wide range of sites, and under favorable conditions, they can be extremely fast growing (Bella and Jarvis 1967). They are particularly susceptible to a host of diseases and predators (Graham *et al.* 1963), and compared with many species, they are rather short-lived. In many areas, they have been considered to be an undesirable weed species; in other areas, they are considered among the more desirable of plantation species. Although they represent only a small fraction of total forest stock [7 percent in North America (table 1), 2 percent in the Soviet Union (Tseplyaev 1965)], their anomalous position generally, and the extent to which they represent problems and opportunities in growth and utilization, is indicated by the fact that there is more technical literature relating to *Populus* species than to any other wood. A number of comprehensive bibliographies (Brown *et al.* 1957, Roth and Weiner 1964, Farmer and McKnight 1967, Shoup *et al.* 1968, Pronin and Vaughan 1967) and reviews (Lamb 1967, Maini and Cayford 1968) on aspen[1] have been published.

Table 1. — *Forest resources of the United States and Canada*
(In million cubic meters)

Country	Total	Softwoods	Hardwoods	Aspen
United States 1/	19,800	13,100	6,700	(2/) 460
Canada 3/	21,200	17,200	4,000	(4/) 2,300

1/ Net volume of timber on commercial forest lands. Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 150, 159, 160. 1965.
2/ Aspen plus cottonwood. The most recent value obtained from the U.S. Dep. Agr. is 500 million cubic meters.
3/ Merchantable volume. Taken from: Can. Dominion Bur. Statist. Canadian forestry statistics, 1963 and 1964, Cat. 25-202, Ottawa, Ont. p. 7. 1967.
4/ Populus spp., mainly P. tremuloides.

[1] *Unless otherwise specified, in the balance of this paper the single name "aspen" refers to "aspen plus cottonwood" for United States data and to* "Populus *spp., mainly* P. tremuloides *Michx." for Canadian data.*

The purpose of the present report is to broadly review *Populus* in North America in terms of resources and utilization, and to indicate probable trends in growth and utilization over the next three decades.

TOTAL GROWING STOCK — PRESENT

General

The relative position of aspen to other wood resources is shown in table 1, which gives the total wood resources of the United States and Canada.

It will be noted that hardwood growing stock is much greater in the United States than in Canada, whereas the growing stock of aspen is much greater in Canada.

Distribution in the United States and Canada

In the United States, 63 percent of the total aspen reserves are in the East (table 2); the bulk of aspen is concentrated in the Lake States and Colorado (table 3). In 1964, the aspen cut in the Lake States for pulp was 3.56 million cubic meters and the total aspen cut was 5.0 million cubic meters (Lamb 1967).

In Canada, the largest volumes of aspen are found in Ontario, British Columbia and Alberta (table 4).

TOTAL GROWING STOCK — FUTURE

United States

Projections for hardwood timber growth in the United States are given in table 5. No detailed analysis was found for inventory changes in the total aspen resources in the United States. However, individual studies (Stone 1961, Chase 1968) indicate that the area of aspen forest, and the aspen growing stock, have increased substantially over the past 40 years, and would be expected to continue increasing (Quinney 1961, Groff 1966). It is assumed, optimistically, that the growing stock of aspen will show no less than the 3 percent uncompounded increase indicated for hardwoods generally in table 5. In the United States, the basic problem of aspen utilization is one of economics rather than developing new ways to utilize the species. There is sufficient aspen at present to warrant, say, twice the present cut, but the present cut is limited by the fact that there is not a sufficient

Table 2. — *Net volume of timber in the United States*[1]

Species	Million cubic meters
Eastern softwoods	2,800
Eastern hardwoods	6,100
Eastern aspen[2]	290
Western softwoods	10,300
Western hardwoods	600
Western aspen[2]	170

1/ Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 149, 150, 159, 160. 1965.

2/ Aspen plus cottonwood.

Table 3. — *Net volume of aspen*[1] *in the United States*[2]
(In million cubic meters)

Region	Total hardwoods	Aspen	Percent of total aspen
New England States	500	25	5.4
Mid-Atlantic States	1,290	27	5.8
Lake States	780	208	45.0
Central States	880	22	4.7
Colorado	102	69	15.0
Total	6,700	460	100.0

1/ Aspen plus cottonwood.

2/ Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 149, 150, 159, 160. 1965.

Table 4. — *Net merchantable volume of aspen*[1] *in Canada*[2]
(In million cubic meters)

Region	Total hardwoods	Aspen	Percent of total aspen
Ontario	1,920	496	27
Alberta	470	470	25
British Columbia	550	397	21
Saskatchewan	286	246	13
Total	3,400	1,860	100

1/ Populus spp., mainly P. tremuloides.

2/ Taken from: Maini, J. S., and J. H. Cayford (editors). Growth and utilization of poplars in Canada. Can. Dep. For. Rural Dev. Publ. 1205: p. 219. 1968.

Table 5. — *Estimate of future growing stock, growth and cut of hardwoods in the United States*[1] *(In million cubic meters)*

Year	Growing stock	Growth 2/	Cut
1952	4,700	187	94
1962	5,500	207	82
1970	6,200	207	99
1980	7,100	198	122
1990	7,700	181	156
2000	7,600	181	204

1/ Taken from: USDA Forest Service. Timber trends in the United States. Resour Rep. 17: p. 132. 1965.
2/ Net annual growth plus ingrowth.

supply of quality logs at competitive prices to warrant exploitation.

The above assumption that the growing stock of aspen will double within the next 30 years assumes some application of new logging, silvicultural, and utilization practices. It is reasonable that application of new harvesting techniques (Paper Trade Journal 1971), the harvesting of smaller diameter trees (Keays 1970a, p. 25), shorter rotations (Keays 1970a, p. 24) and the utilization of puckerbrush[2] would increase the volume of aspen available for use. The problem is one common to most projection analyses — to distinguish between what might be done and what actually will be done (see pages 10-15).

Canada

The same general principles discussed above are applicable to aspen growing stock and use in Canada. The area of aspen forest will probably increase somewhat, particularly as the result of a retreat from uneconomical farm lands; the use of smaller diameter trees and shorter rotations (Bella and Jarvis 1967) would give appreciably more aspen than the 2,300 million cubic meters considered as growing stock at the present time. As discussed below, the serious problems in Canada are to find ways to utilize a larger part of the aspen already growing, and more particularly, to develop new concepts of aspen utilization.

[2] *Young, H. E. Personal communication.*

PRESENT UTILIZATION

As evidenced by the world literature, aspen can be used for a large number of end products. Table 6 gives the broad categories of aspen use in Canada.

Table 6. — *Use of aspen in Canada*[1], *yearly average, 1961-1965*

Distribution	Million cubic meters
Allowable annual cut	41.00
Actual annual cut	2.14
Pulpwood	1.24
Plywood	.28
Composition board	.25
Sawmills	.14
Exports	.23

1/ Taken from : Maini, J. S., and J. H. Cayford (editors). 1968. Growth and utilization of poplars in Canada. Can. Dep. For. Rural Dev., Publ. 1205: p. 233.

The general pattern of aspen use is much the same in the United States as in Canada, but the magnitude and trends of use have been different. In Canada, pulpwood accounts for 60 percent of aspen use. In the Lake States, pulpwood use is a higher percentage of total aspen use (Lamb 1967). However, where there has been a slight decrease in the use of aspen for pulpwood in recent years in Canada (Clayton 1968), there has been a fairly steady increase in the use of aspen in the Lake States pulp mills (table 7).

FUTURE UTILIZATION

United States

It is expected that aspen use in the United States will follow much the same patterns as in the past. The use of aspen for many solid products (Vaughan 1965) will show a moderate increase. Growth in the use of aspen for solid products will be limited by competitive products, markets, and particularly by a limited supply of high-quality peeler and saw logs.

Much of the increased aspen cut will be used for fiber products— fiberboard, composition board and pulp. Table 8 gives an estimate of future pulpwood production in the United States.

Table 7. — *Aspen pulpwood production in the Lake States*

Year	Million cubic meters	Percent of total pulpwood cut
1930 1/	0.14	4
1940 1/	.37	9
1950 2/	1.5	37
1960 3/	3.4	48
1969 4/	4.1	50

1/ Taken from: Pulpwood stands, procurement and utilization. 1947. Tappi Monogr. 4, New York. p. 50.

2/ Taken from: Horn, A. G. 1952. Ten years' pulpwood production in the Lake States (1942-1951). USDA Forest Serv. Tech. Note 38-, 2 p. Lake States Forest Exp. Sta., St. Paul, Minn.

3/ Taken from: Horn, A. G. 1961. Lake States pulpwood production up 11 percent in 1960. USDA Forest Serv. Tech. Note 606, 2 p. Lake States Forest Exp. Sta., St. Paul, Minn.

4/ Taken from: Blyth, James E. 1970. Lake States pulpwood production rises 11 percent in 1969. USDA Forest Serv. Res. Note NC-100, 3 p. N. Cent. Forest Exp. Sta., St. Paul, Minn.

Table 8. — *Production of roundwood pulpwood in the United States (In million cubic meters)*

Year	Softwoods	Hardwoods
1960 1/	55.5	17.5
1970 1/	76.1	34.4
1980 1/	121.0	59.2
1985 1/	146.0	73.9
1990 1/	3/ (167.0)	(90.0)
2000 1/	(210.0)	(120.0)

1/ Taken from: Hair, D. Use of regression equations for projecting trends in demand for paper and paperboard. USDA For. Serv. Resour. Rep. 18: p. 53. 1967.

2/ Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 70. 1965.

3/ The numbers in parentheses represent projections of Dwight Hair's 1965 estimates.

Increased use of aspen in pulping would be expected to parallel increased use of hardwoods generally, and the next 30 years should see a fourfold increase in the use of aspen for fiber products.

Canada

In Canada, no more than a modest increase in the use of aspen for solid products or for pulpwood is expected in the near future (Canada Department of Forestry and Rural Development 1968). In spite of vast aspen reserves, there is a limited supply of quality logs that can be extracted and processed economically. At the present rate of expanded aspen use, the total use in Canada might reach 10 to 15 percent of the annual allowable cut within 15 years. Realization of any large part of the aspen potential will have to involve new patterns of use. One example would be large-scale use of aspen for light framing lumber. Another example, inclusion of steamed aspen in standard diets for ruminants (Bender *et al.* 1970), is undergoing extensive trials (Heaney and Bender 1970).[3] Initial results indicate a potentially new use for aspen, but the quantity of aspen that might be thus consumed is difficult to predict. A third possibility is increased use of aspen for furniture stock, which is under active study by the Eastern Forest Products Laboratory, the Manitoba Department of Industry and Commerce, and the Canadian Department of Industry, Trade and Commerce.

With present knowledge, it is difficult to guess when these new Canadian use patterns might evolve. Most of the recent expansion in pulp production has involved use of preferred softwood species, particularly in British Columbia (British Columbia Hydro and Power Authority 1966). There are still reserves of preferred softwoods in British Columbia, the prairie provinces, and in eastern Canada, and it is reasonable that these resources will be used prior to any massive expansion in aspen use. This trend may be modified by government policy necessitating increased aspen cut. Large-scale use of softwoods in the prairie provinces may be delayed because of distance from markets and other adverse economic factors.

At some time between now and the year 2000, probably between 1980 and 1990, the world demand for fiber products (Keays 1970b, Solomko 1970) combined with unavailability of softwoods will lead to the exploitation of Canadian aspen resources. It is likely that there will be an interim period when existing pulp mills will use more aspen, and there will be increased pressure for the use of aspen by mills not presently doing so.

[3] *Bender, F. Personal communication.*

A number of developments can be expected in this quantum-jump increase in the use of Canada's aspen resources: (1) The development of large, integrated complexes combining plywood, lumber, veneer, dimension stock, and fiber products; (2) the use of large amounts of aspen in kraft pulping for fine papers; (3) the development of a pulp suitable for high-quality newsprint, probably with no more than a small addition of softwood pulps, by chemical treatment of aspen, followed by refining and by brightening or a mild bleaching step; and (4) the manufacture of fine papers from pulp mixtures of mature softwoods and hardwoods.

A suggestion for a future mill complex, or an extension of the complex suggested by Vaughan (1965) utilizing aspen and softwoods, is shown schematically in figure 1. Stream A involves manufacture of softwood bleached kraft pulp, which can be sold as such or partly converted into newsprint. Stream B involves manufacture of aspen bleached kraft pulp and aspen chemigroundwood pulp (Richardson and LeMahieu 1965). The latter in admixture with softwood bleached kraft pulp could make up a newsprint furnish (Perry and Canty 1971). The remaining aspen bleached kraft pulp could either be sold as such or used with softwood bleached kraft pulp to manufacture a variety of fine papers.

SUMMARY

The aspen resource and its uses in the United States and Canada are summarized in table 9. It is apparent that the two countries have different aspen utilization problems. In the United States, aspen is more highly concentrated and the use of aspen, particularly in pulping, is well established and increasing. The present cut of aspen is roughly 50 percent

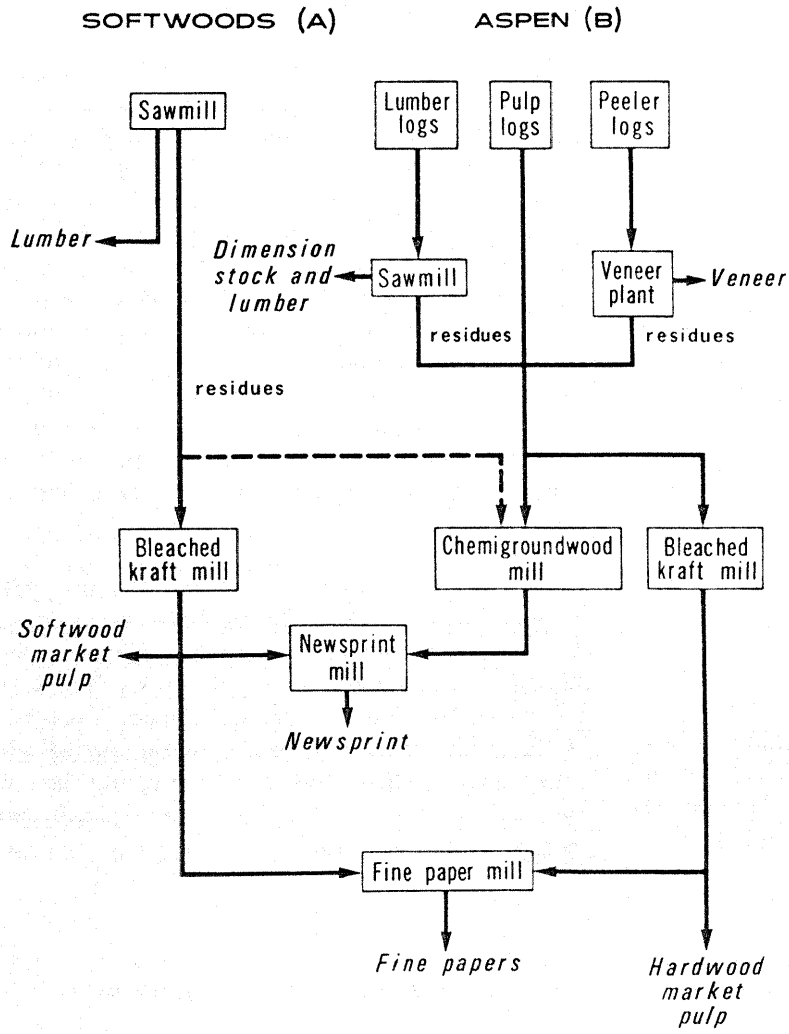

Figure 1. — *Schematic diagram of proposed softwood-aspen pulp mill complex.*

of allowable cut, and within 30 years, the allowable cut will probably double; growth and use will be in close balance by the end of the century. This paper of aspen use arises from the fact that in regions where aspen is most abundant (Lake States), there is a diminishing supply of softwoods and a well-established and diverse pulp and paper industry.

Table 9. — *Estimate of future aspen resources and use (In million cubic meters)*

Period	Timber volume	Allowable annual cut	Actual annual cut
United States			
Present	460	9	4
In 15 years	>700	14	10
In 30 years	>900	18	18
Canada			
Present	2,300	46	2
In 15 years	>3,000	60	6
In 30 years	>3,500	70	25

Compared with the United States, Canada has five times as much aspen and exploits less than half as much. Aspen resources are more widely spread; the aspen cut is small and is not increasing appreciably. No change in this trend is anticipated in the near future. Even by the turn of the century, it is likely that less than half of Canada's annual allowable cut of aspen will be utilized. All evidence points to the conclusion that most of the aspen in North America will be used for fiber products — pulp, paper, paperboard, fiberboard, and composition board.

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PROJECTIONS OF INVENTORIES IN THE LAKE STATES[1]

William A. Leuschner, *Assistant Professor*[2]
Division of Forestry and Wildlife Sciences
Virginia Polytechnic Institute and State University

ABSTRACT. — Today's apparent aspen surplus cannot continue indefinitely in all regions if the historical trends of cut, growth, and utilization continue. The greatest potential difficulties lie in northeastern Wisconsin and Michigan — the brightest outlook is in Minnesota.

In 1970 nearly two million cords of aspen pulpwood were cut in Michigan, Minnesota, and Wisconsin. This cut was about 50 percent of the roundwood pulpwood harvested in the region. The results of a recent study indicate that in parts of Wisconsin and Michigan recent cutting trends cannot be sustained in the future.

The study had two objectives. The first was to provide a common source of inventory data for aspen by describing the current status of the growing stock in a base year for all survey units in the study.[3] The second objective was to project to the year 2000 future levels of cut and growing stock under several sets of likely conditions. The present paper will discuss only the second objective.

The full results of the original study and the details of the projection procedure will be published soon by the North Central Forest Experiment Station as a research paper. Individuals making serious use of the results are urged to obtain this paper because a summary as presented here cannot give sufficient background and details.

FUTURE RESOURCE CONDITIONS

Projections were limited to three sets of conditions that were judged generally indicative of what could happen to the resource. The sets of conditions, or assumptions, were called *recent trends, breakup,* and *positive practices* and were used to project cut and growing stock in each survey unit.

The *recent trends* projections show what the cut and growing stock would be if trends which prevailed in the last decade or so continued into the future. They are derived from changes between the last two forest surveys or from recent historical trends. These projections can act as a standard of comparison and may indicate whether or not we should change our current practices.

Aspen trees begin to deteriorate rapidly after they reach maturity, a process commonly called "breakup." Although most foresters agree breakup occurs, there is a difference of opinion about the amount now and in the future. Unfortunately, field data to answer these questions are not readily available. The *breakup* condition simulates widespread breakup occurring immediately thereby projecting a minimum or "worst-likely" condition.

Land managers' actions could diminish breakup or

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[1] *This paper summarizes the results reported in Leuschner, William A., Present and future aspen inventories in the Lake States. (Manuscript in preparation.)*

[2] *The author was Economist, North Central Forest Experiment Station, USDA Forest Service, St. Paul, Minnesota, at the time this paper was written.*

[3] *Survey units in the study were Michigan's Eastern and Western Upper Peninsula and Northern Lower Peninsula; Minnesota's Lake Superior, Central Pine, and Rainy River; and Wisconsin's Northeast, Northwest, and Central units.*

change recent trends. Some actions will usually have an additive or positive effect on the level of aspen growing stock. The *positive practices* assumptions indicate what these actions could accomplish if they were instituted today — they are NOT a prescription of what should be done to increase the volume of aspen resource in the Lake States.

REGIONAL PROJECTIONS

Goods and services, including harvested aspen, flow within and sometimes between economic regions. Three regions were identified for use in this study: (1) the three northernmost survey units in Minnesota, (2) the northern three survey units in Wisconsin and the two units in Michigan's Upper Peninsula (U.P.), and (3) the Northern Lower Peninsula survey unit in Michigan. These three regions were projected separately which meant the units within any one region could interact with each other but not with the units in other regions.

Before discussing the results it should be mentioned that these are projections, not predictions. Although they give an exact amount of inventory or cut at a precise point in time, they really indicate the general level and approximate timing within the bounds of the assumptions.

The reader should be careful to understand the assumptions before making major decisions based upon the projections. He should not interpret the projections too literally, and he should remember that land managers can change conditions and hence results. Although the projections are qualified and should be made anew every few years, they are, nonetheless, useful tools.

Minnesota

The Minnesota region has the weakest data base, due in part to the data's age and in part to the inaccesibility of cooperator data. The results for this region must therefore be considered the least reliable for the three regions.

Regardless of the set of assumptions used the inventory is sufficient to sustain the projected cut in each of the units over the entire period of the projections. If *recent trends* continue there is a sizeable increase in growing stock in every survey unit, and even under the *breakup* assumptions most units maintain their inventory levels. The *positive practices* projections generally show a redistribution of inventory to more realistic levels and the advantage, if any, is in improved volume distribution by diameter (fig. 1).

Wisconsin and Michigan's Upper Peninsula

Five survey units in Wisconsin and Michigan's U.P. were allowed to interact for this set of projections. The *recent trends* and *breakup* projections show that in 15 to 25 years northeast Wisconsin and the U.P. will not be able to support their projected cut.

Further, all the timber cut from these areas after the cut is diminished is projected in the 6- and 8-inch d.b.h. classes. However, if industry will take this small diameter stock the region as a whole can support the projected cut until about 1995 (fig. 2).

There is a rapid and steady decrease in growing stock inventories in the early years for those units with a diminished cut. The other units show varying degrees of increased growing stock, at least in the early years of the projections.

Under the *positive practices* assumptions each unit is able to support its projected cut. Essentially, the cut is shifted from those units which did not sustain it and is added to the other. Positive practices also project an increased proportion of volume in the larger diameter classes. The growing stock projections, while improved, still show a downward trend in most survey units.

Michigan's Northern Lower Peninsula

In this region of only one survey unit, cut is maintained under both the *recent trends* and *positive practices* assumptions until the final years of the projections, while the *breakup* assumptions cause a diminished cut about five years earlier. Almost all the cut is in the 6- and 8-inch d.b.h. classes by the time it is diminished (a trend common by now) except under *positive practices* where only 70 percent is in these classes. In all projections the growing stock shows a sharp downward trend although the reallocation of cut under *positive practices* does not have its usual significance because there is only one unit in this region (fig. 3).

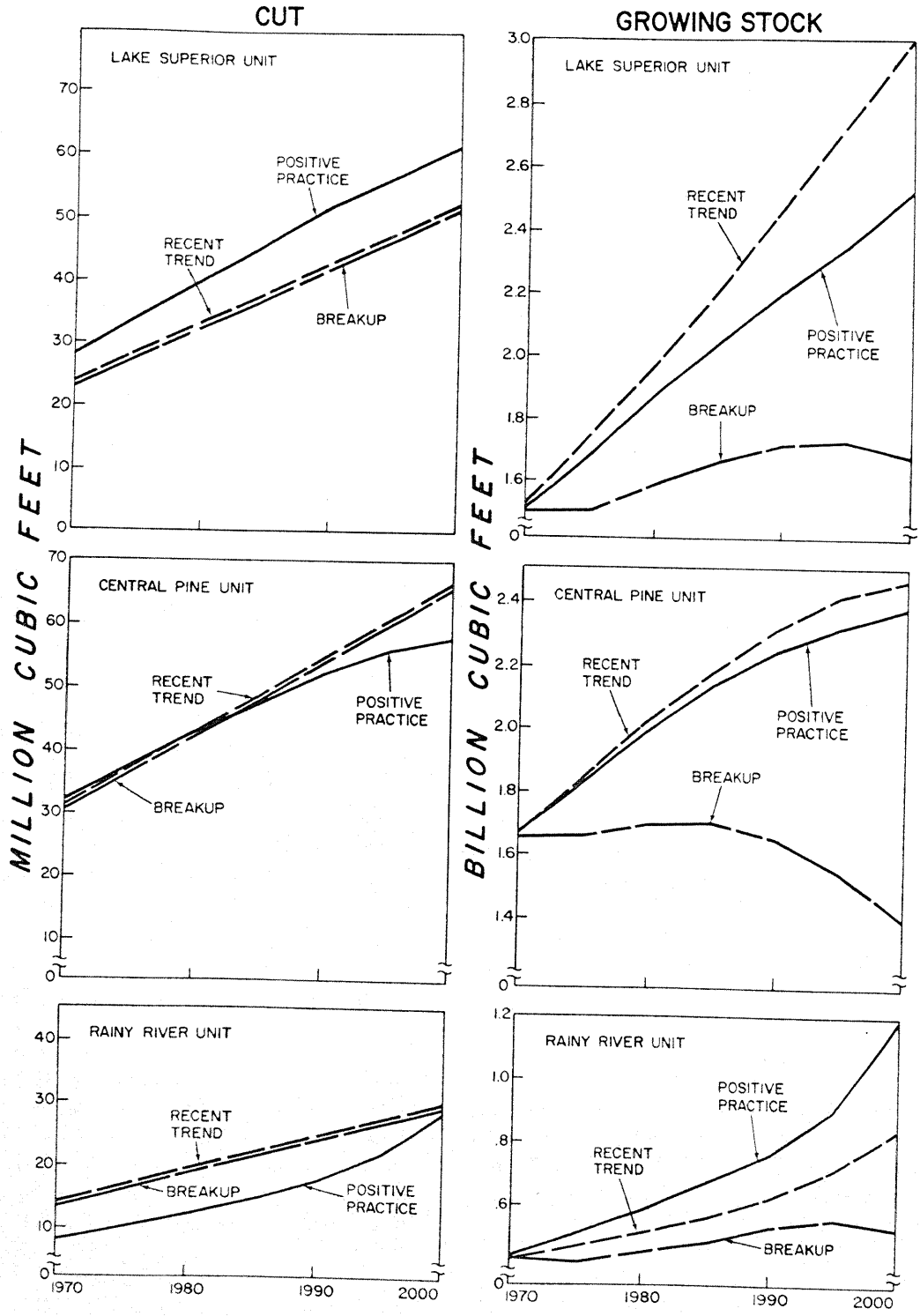

Figure 1. — *Projections of cut and growing stock for Minnesota region, by assumption. 5-year average every 5 years.*

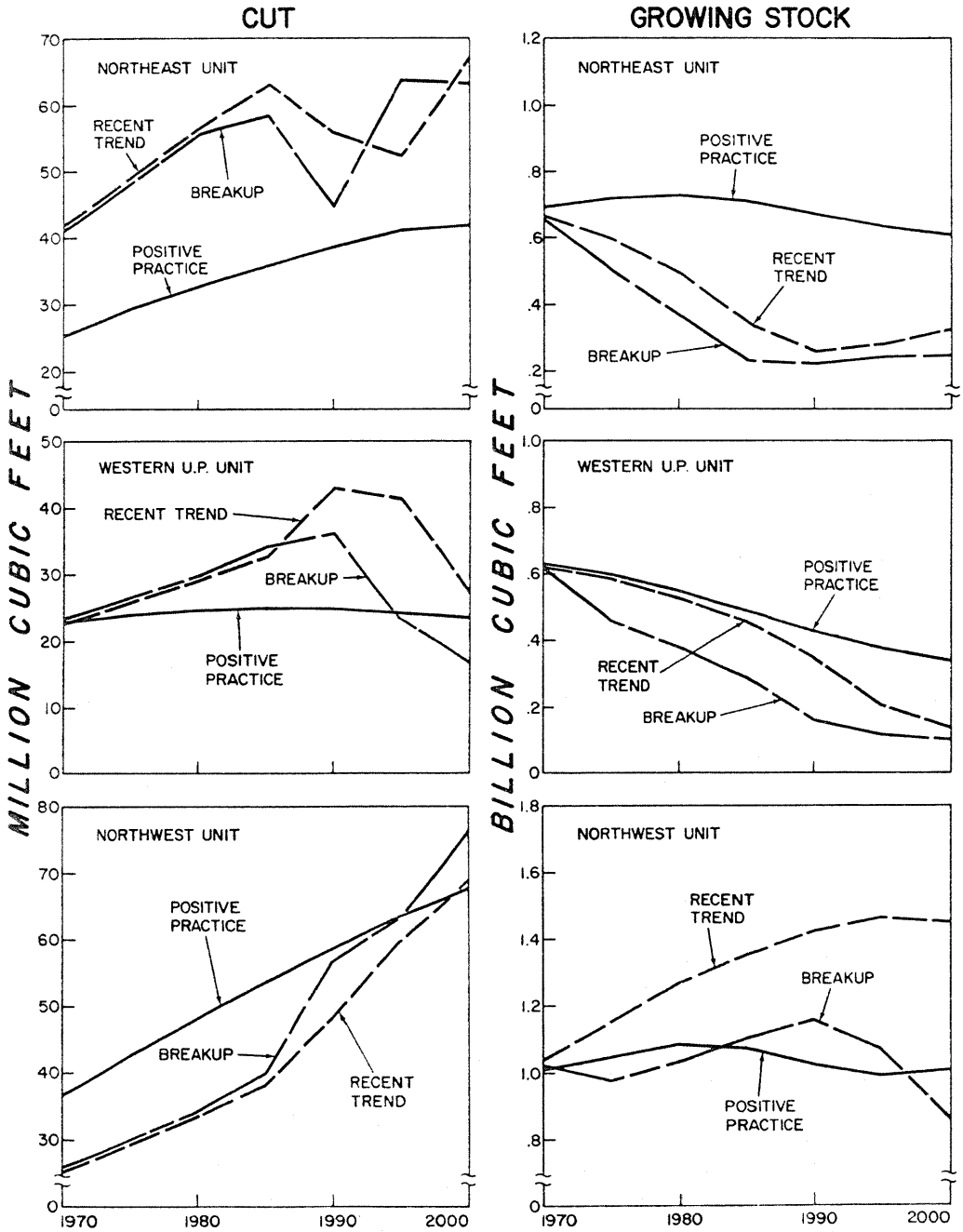

Figure 2.—*Projections of cut and growing stock for Wisconsin and Michigan Upper Peninsula region, by assumption, 5-year average every 5 years.*

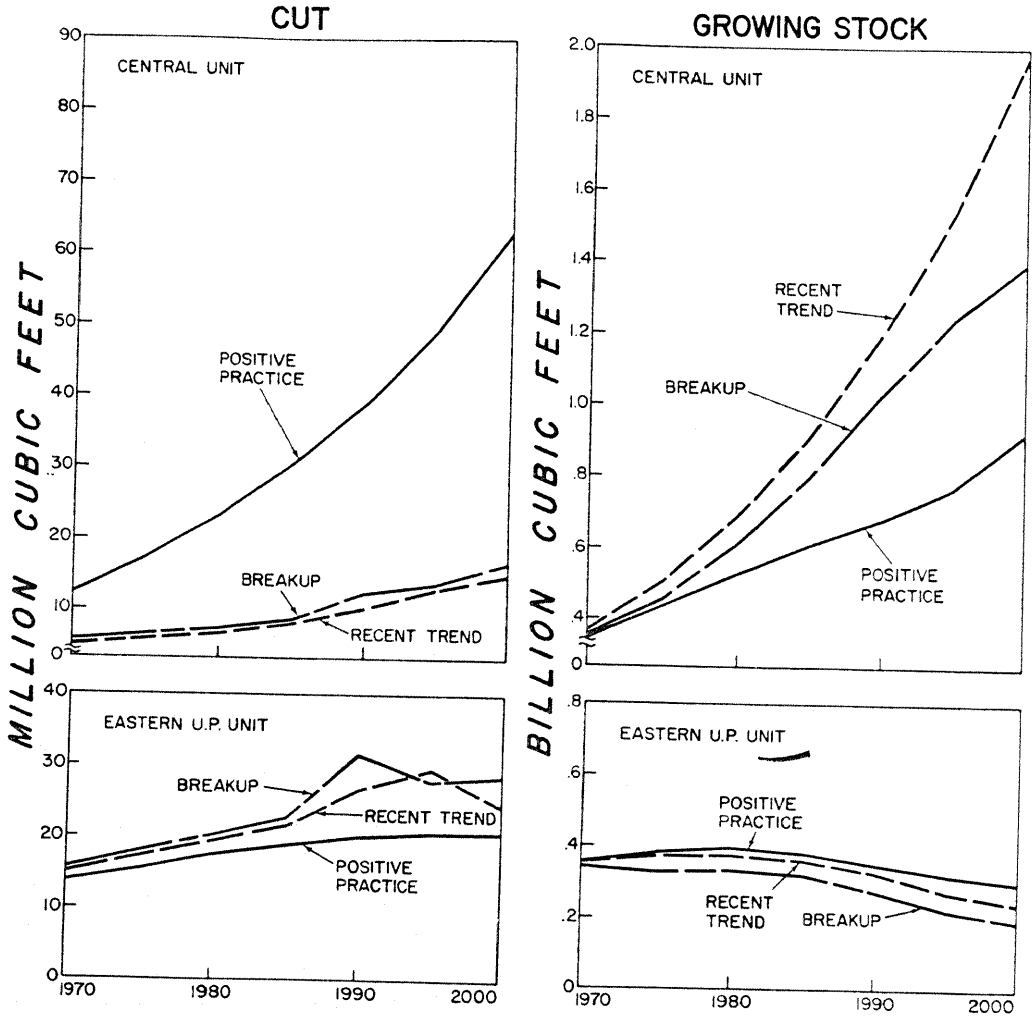

Figure 2. — *(Continued)*

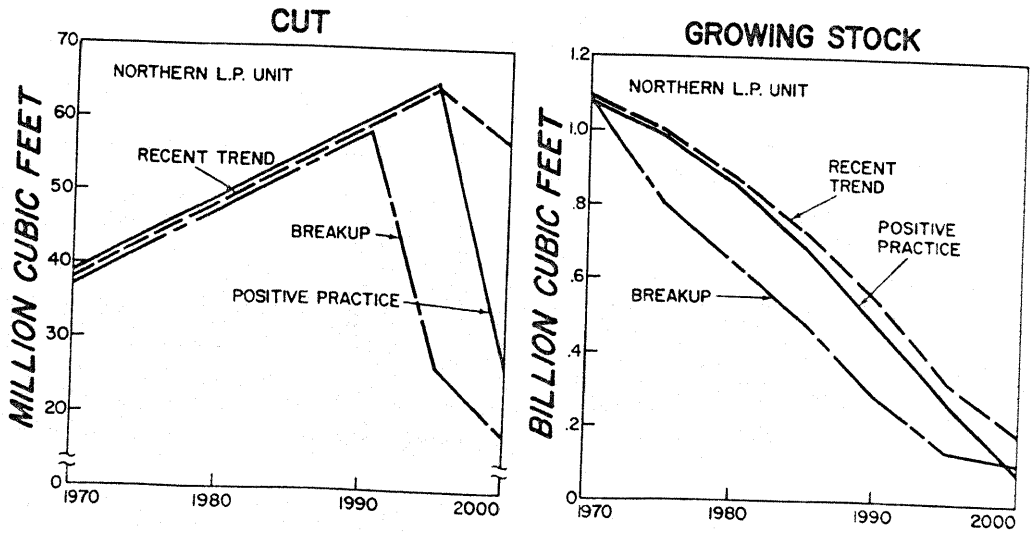

Figure 3. — *Projections of cut and growing stock for Michigan Northern Lower Peninsula region, by assumption, 5-year average every 5 years.*

SUMMARY AND CONCLUSIONS

We cannot expect today's apparent surplus of aspen to continue indefinitely in all regions of the Lake States if the historical trends of cut, growth, and utilization continue into the future. The degree to which historical trends cannot be followed varies by geographical location.

The northernmost survey units in Wisconsin and all of Michigan's Upper Peninsula, show a generally unfavorable picture. The historical trend of cut is likely to be diminished in Wisconsin's Northeast unit in 15 to 20 years and in the U.P. in 20 to 25 years. In addition, almost all the cut in these units from the time it is diminished is projected in the 6- and 8-inch d.b.h. classes. With a few exceptions the growing stock projections show a generally deteriorating picture. However, the *positive practices* projections indicate each survey unit can support its reallocated cut and that the overall condition of the resource can be improved from what it would have been if historical trends had continued. These projections also show more cut and growing stock volume in the larger diameter classes.

The Northern Lower Peninsula survey unit supports its historical trend of cut during most of the projection period but at the expense of a constantly deteriorating resource.

The northernmost survey units in Minnesota have the brightest outlook. The projected cut is supported and the ending inventory is higher than present in all cases except the *breakup* projections in the Central Pine unit. The consistently higher inventory may indicate the region can support more than the projected cut.

Several conclusions can be drawn from these projections. First, forest industries drawing their aspen from Michigan and Wisconsin must plan to procure their wood elsewhere within these States, substitute other species of wood for aspen, or cut less than the projected amount during the next 15 to 25 years. Further, firms planning replacement of their capital equipment would be wise where possible to install equipment and processes that can substitute other wood species for aspen at minimum cost.

Second, the diminished cuts of aspen are almost always accompanied by increased cutting in smaller diameter trees. If these diameters are unacceptable users will have to reduce their cut even further. In addition, the smaller diameters may mean increased material handling costs from harvesting through chipping or sawing, and increased difficulty and expense for industries requiring large diameter aspen as a raw material.

On the other hand, the *positive practices* projections indicate, particularly in the Wisconsin-U.P. region, that actions taken by land managers can maintain an even and increasing flow of aspen from most survey units while improving the relative condition of growing stock inventories. We are not helpless in the face of the existing and possible future condition of the aspen resource.

However, the actions necessary to effect a change mean that costs must be incurred. As in most forestry investments, the costs are incurred today whereas the benefits are received in the future and it is not always certain that the parties bearing the costs will receive the benefits. Whether these costs would, or more importantly, should be incurred was not answered by this study. We believe we have demonstrated that it is reasonably possible to maintain both an increasing aspen cut and the resource in the Lake States if we choose to do so.

ECONOMIC OPERABILITY — FACTORS AFFECTING HARVEST AND TRANSPORT COSTS

Dennis P. Bradley, *Associate Economist*
North Central Forest Experiment Station
Duluth, Minnesota
and
Frank E. Biltonen, *Research Industrial Engineer*
Forest Engineering Laboratory, North Central Forest Experiment Station
Houghton, Michigan[1]

ABSTRACT. — Present forest inventories do not allow forest managers to estimate strategic transport and harvest costs for the forest resource. To improve this situation we have tested a method, originally developed in Sweden, for describing the distribution of forest inventory volumes by transport costs. We have also developed a prediction equation relating stand factors to harvest productivity for aspen pulpwood using chain saw felling and wheeled skidders. Harvest and transport cost estimates applied to the forest inventory data can yield delivered cost estimates. This kind of information can help answer important economic questions facing resource analysts.

We all agree that a forest inventory performs an essential service by giving us a broad overview of our forest resource. But it should be clear that existing procedures do not provide enough economic data to estimate harvest and transport costs.

For example, recent inventories from many areas in the Lake States suggest the need to increase the cut of aspen to balance growth and drain. These suggestions have prompted the widespread feeling that an economic surplus of aspen exists. While we may have a surplus from a silvicultural or timber management point of view, the big economic questions remain unanswered: How much timber can be cut, from which areas, and delivered to market at what cost?

Various features of this "surplus" may discourage harvest. First, the timber may exist in sparse stands, where harvesting by present logging systems is not profitable. Second, the timber may be located too far from the road system or processor to permit economic transport. And third, certain landowners will not allow timber sales — they would rather hold the forest land for other uses.

As managers of the forest resource, acquiring the information necessary to assess the potential of the forest for economic timber harvest will help us achieve maximum benefit from all forest uses.

WHAT IS ECONOMIC OPERABILITY?

The term "economic operability" denotes an attempt to determine the potential of the forest resource for timber harvest. It recognizes that factors, such as tree size and terrain, interact with location to determine "delivered costs." Moreover, it attempts to assemble the delivered costs for the entire inventory into a "supply" schedule. Included in this schedule would be high-volume stands situated on the mill's "doorstep" with a low delivered cost, as well as sparsely stocked stands on a mountaintop with an expected high delivered cost. In other words, all stands are operable by definition. If one is given this "supply schedule" containing all stands, one can use actual market prices to determine the volumes that might be *feasibly* harvested under the specific price conditions.

Note that our term "delivered cost" is not the same as "delivered price" used by wood buyers. When a

[1] *The Station's Duluth office is maintained in cooperation with the University of Minnesota - Duluth. The Laboratory at Houghton is maintained in cooperation with Michigan Technological University.*

wood buyer speaks of a "delivered price" the harvest component is fixed, although he often recognizes differences in the cost of transporting the wood. Thus, in the buyer's eyes, a cord of rough aspen has the same value at roadside whether it came from an easily reached, dense stand of aspen or from a rocky crag with three trees per acre. In contrast, the concept of operability recognizes that both harvest and transport costs are dependent on a variety of factors. This is certainly a more realistic approach to assessing economic potential.

In one sense, what we are describing is nothing new; every logger estimates harvest and transport costs each time he bids on a job. The difference is, we are looking at methods that will extend conventional forest inventory systems and give useful answers on operability for an entire inventory unit.

HOW CAN WE USE ECONOMIC OPERABILITY DATA?

If we know the delivered cost of wood from various stands in an inventory unit, we can more accurately answer questions that have plagued resource analysts for a long time. For example, owners of existing mills often ask these questions: If we expand our mill, will we have to pay more for additional wood supplies? Would any cost increases be due primarily to harvest or transport?

In areas devoid of forest industry, prospective investors ask: If we build a mill on a particular site, how much wood can we buy, in what sizes of which species, and at what cost?

Analysts ask these questions about alternate resource uses: If forest land is withdrawn from commercial use, what will the impact be on local wood industries in terms of delivered cost? Can existing mill requirements be met without delivered cost increases?

In addition, because location is such an important determinant of value, these data would allow a more objective ranking of alternative forest investments in timber management, road construction, and even land purchase.

The fact that owner intentions are ignored has variable consequences. In areas where large public or industrial forest ownerships exist, the delivered-cost distribution of growing stock or desirable cut may be a fairly accurate picture of what is operable *and* available. But the uncertainties concerning availability will probably increase as the proportion of private ownership increases.

OUR APPROACH

Manthy and James (1964) have described the relative importance of the three components of delivered cost for various species in the Lake States. For rough aspen trucked directly to the mill, stumpage costs averaged 12 percent, harvest costs 48 percent, and transport costs 40 percent.

Although actual "delivered prices" for a species do not reflect differences in harvest costs, we know that costs for any logging system are affected by stand and operating conditions, terrain, and climate. In a 15-month study, we found that productivity in felling and skidding tree-length aspen pulpwood varied from less than a cord to over 7 cords per man-hour. This much variation in productivity obviously affects harvest costs. By including these known variables in a suitable prediction equation, we could estimate harvest costs for a given stand of timber.

Similarly, hauling distance, truck size, and road quality all interact to determine transport costs. Manthy and James showed that transport costs ranged from $3.00 to $8.00 per cord when hauls ranged up to 140 miles. While actual costs have increased since 1964, similar variation probably exists today. If we can sample the geographic distribution of timber volume in relation to a road system and delivery points, we can then estimate transport costs.

Finally, samples of timber volume with their harvest and transport-cost estimates can be summarized to more accurately estimate the delivered-cost distribution of the forest resource in any inventory unit.

While many studies of harvest productivity have been carried out over the past 50 years, none is directly applicable to current methods or to the aspen cover type. Similarly, there has been a lack of research in North America to evaluate the effectiveness of forest transport systems. Mathews (1942) and Lussier (1961) suggested some optimal systems of road construction and transport for specific logging

chances, but the analysis of transport systems in forestry has been ignored.

The work of several Scandinavian forest researchers (Larson 1959, Nilsson and Segebaden 1962, and Segebaden 1964a, 1969) is directly applicable to questions of harvest and transport cost. They have developed several methods to (1) measure the economic impact of a road system on forest use, (2) integrate general transport-cost data with harvest-cost distributions of growing stock, and (3) apply these results to real problems.

From this work, we developed a three-phase study of economic operability. First, we conducted a study of aspen pulpwood harvesting that related productivity to the stand factors gathered by forest survey. Second, we modified and tested the Swedish methods for describing forest access and its impact on transport costs. Third, we are developing computer programs to combine harvest and transport-cost information with regular forest inventory data. Although this entire effort is aimed primarily at aspen, it also has application to other species and cover types.

PRODUCTIVITY OF PULPWOOD HARVESTING

The aspen type was chosen because of its large and growing economic importance in the Lake States. Although several logging systems are used for harvesting aspen pulpwood in north-central Minnesota, we studied the most widely used system — tree-length logging with chain saw felling and wheeled skidders.

Because it was impractical to do our own logging and control all variables that influence productivity, we conducted an observational study of aspen pulpwood logging. We used a gross-data approach, which measures gross inputs of man and machine time and the output of wood. Because stand and terrain factors may change as harvest proceeds through a stand, work areas averaging 15 acres were measured each week. For the next 7 days, the logger himself recorded daily man-hours, machine-hours, approximate skidding distances, weather conditions, and wood output. This process started in July 1969 and was repeated weekly for each of five cooperators until September 1970; 238 workdays on 42 work areas were examined.

The principal stand factors of the work areas examined were: Harvestable volume per acre averaged 17.6 cords but ranged from 2.5 to 38.0 cords. The number of harvestable trees per acre averaged 151 and ranged from 35 to 383. The number of harvestable trees per cord averaged 8.6 and ranged from 2.6 to 16.1. Total daily production averaged 24.8 cords and ranged from less than a cord to 96 cords. Total daily production of trees averaged 203 and ranged from 3 to 898.

Productivity for felling and skidding functions averaged 1.26 and ranged from 0.03 to 7.49 cords per man-hour. In trees per man-hour, productivity averaged 10.3 and ranged from less than 1.0 to 38.7.

We found that the *number of trees harvested per man-hour* (felling through skidding) is a function of (1) the ratio of harvestable trees per acre to total trees per acre, (2) harvestable volume per acre, and (3) spacing of the nonharvestable stand. Trees per man-hour can be converted to cords per man-hour given mean volumes per tree for the stand. This step avoids the errors of estimating individual tree volumes as the logging takes place. It is also more realistic because logging is primarily piece-oriented and not volume-oriented; that is, it takes almost the same time to fell and skid a small tree as it does a large tree.

Our best equation took the following form: trees per man-hour (felling through skidding) = 8.343 + 19.455 x ratio (harvested trees/acre ÷ total trees/acre) — 0.347 x harvested volume /acre (cords) — 0.138 x equilateral spacing[2] of nonharvested trees (feet).

How reliable and applicable is this equation? It did explain one-half of the variation in the data, $R^2 = 0.49$. Although this equals the amount of variation explained by other more detailed production studies, it still means that individual estimates of productivity using our model will have a large possibility for error. While it may not be accurate enough for a logger to use in his day-to-day harvest-cost estimates, we feel that it is accurate enough to estimate harvest costs over a forest inventory unit.

On the other hand, it deals only with one harvest system — chain saw felling and wheeled skidders.

[2] *Equilateral spacing in feet* = $\sqrt{43{,}560 \div 0.866 \times \text{tree/acre}}$.

Other systems are in use and more mechanized systems are growing in popularity. In this sense, its application is limited. It does serve as an example of what can be done and it could be used to summarize operability for aspen pulpwood in selected study areas.

Although the productivity estimates have not been converted to harvest costs per unit volume, this can be done for specific labor and machine rates and overhead charges.

FOREST ACCESS AND TRANSPORT COSTS

The method used in our study of forest access was developed primarily by Segebaden (1964b). It relates transport distances and costs to (1) road network length per unit area, (2) road network distribution (geometry), (3) terrain, and (4) a specific delivery point. In his system the theoretical parameters describing an ideal road network are modified by two correction factors to permit the consideration of real road networks. This procedure answers two questions: (1) How far is the nearest road from any given stand of timber? (2) How far must a given volume of timber be transported to market?

In practice, inventory plots were located on aerial photos or maps. Straight-line distances were measured from each plot to the nearest road and then to the delivery point. While only one destination may be considered during each measurement of a forest inventory unit, additional points can be considered in successive measurements.

Because a distribution of timber volumes by transport distance and cost would be useful by itself, we developed a computer program to deal solely with timber transport. This FORTRAN IV program entitled ACCESS summarizes forest inventory data by transport distance and cost for each cover type and species.

Two kinds of transport-cost histograms can be constructed from these summaries. One kind (fig. 1) shows the volumes transportable at each of several cost levels. For example, the first point shows that 2,200 cords can be transported to market for $4.70 per cord. The second point shows that the next 215,000 cords can be transported for $5.00 per cord.

Of more value, however, is a cumulative distribution of volume by transport cost (fig. 2). This histogram shows cumulative volumes transportable to the delivery point at a cost equal to or less than any specified cost maximum. For example, the first point shows, as it does in figure 1, that 2,200 cords can be transported to market for $4.70 per cord *or less*. But the second point shows that 217,200 cords (215,000 plus 2,200) can be transpored to market for $5.00 per cord *or less*. Note the change of scale on the vertical axis between figures 1 and 2.

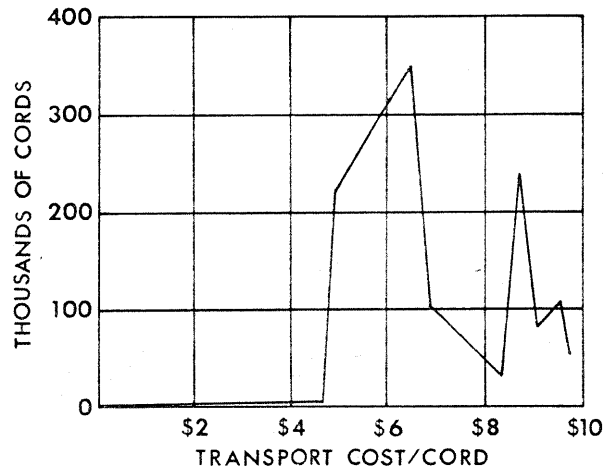

Figure 1. — *Distribution of aspen growing stock on Koochiching County lands by transport costs to International Falls.*

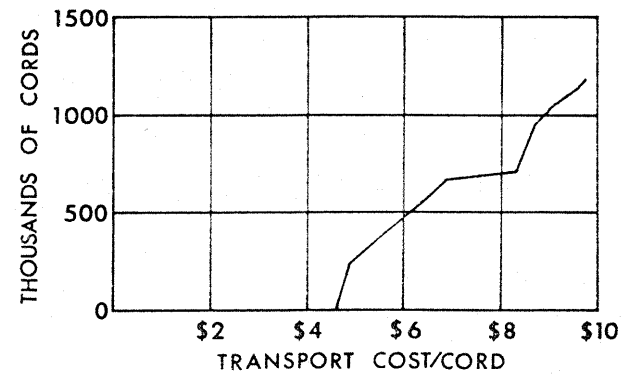

Figure 2. — *Cumulative distribution of aspen growing stock on Koochiching County lands by transport costs to International Falls.*

These data are of immediate value to the wood procurement manager. Putting this information in perspective with his wood requirements, it could indicate an upper limit to the wood he can expect to receive with the specific transport costs he can afford. Looking further, he can consider changes in the road system and construct new transport-cost histograms. He can then compare the effect of existing and planned road nets on the transport-cost distribution: will the investment pay off in reduced transport costs?

While the development and testing of a new process is always a challenge, the real task is applying it to actual problems. This method was applied to the forest inventory data of Koochiching County, Minnesota, to demonstrate the ease and low cost of gathering transport-cost information. From this work we developed transport-cost distributions for all cover types and species. The inventory data were 10 years old and the results did not warrant publication, but a summary of the methods employed will be published soon. We are now applying the method to current inventory data in Michigan's Upper Peninsula. This will provide a realistic test of our procedures.

PUTTING IT ALL TOGETHER

Economic operability is an important concept. By relating harvest and transport costs to forest survey data, we hope to give land managers a better idea of the forest's economic potential for timber production. Our most significant development has been achieved with forest access and its effects on transport costs. These methods, originating in Sweden, are simple, inexpensive, and can shed light on many important questions.

Results of our efforts to relate stand factors to harvest productivity and cost are less clear. While we were able to derive a good prediction equation for the broad strategic purposes intended, the work points out one major problem: logging systems are dynamic. Yet our study, which examined only one cover type and harvest system, took 2 years to complete. This suggests that estimating harvest costs for all commercially important cover types rapidly enough to avoid obsolescence would be a large task indeed.

A more rapid and flexible way must be found to examine how man and machine systems interact with stand factors. Computer simulation seems to offer substantial advantages. Instead of dealing with whole systems, the effect of environmental factors on individual components could be studied in closely controlled experiments. Given system characteristics, computers could rapidly evaluate many alternative combinations. Only highly promising systems would be actually field tested.

We hope the need for economic inventory data has been highlighted. Certainly something must replace the existing groping for answers about economic feasibility. To achieve this goal, however, more than a token research effort must be made to find the most effective means for gathering the needed information.

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THE ECONOMIC IMPACT OF HYPOXYLON CANKER ON THE LAKE STATES RESOURCE[1]

Robert Marty, *Professor of Forestry and Resource Development*
Michigan State University

ABSTRACT. — A 1971 field survey comprised of 196 sample locations randomly distributed over the aspen type in Michigan, Wisconsin, and Minnesota, showed the following effects of hypoxylon canker: The average proportion of live aspen trees currently infected in the Lake States aspen type is 12.1 percent. Observed infection rates ranged from zero to 40 percent. The average proportion of the aspen-type area that will be denuded by the observed rate of infection is 5.6 percent. This reduction in stocked area means an eventual reduction in the aspen harvest each year of 21 cubic feet per acre or 300 million cubic feet for the type as a whole. The value of this loss will be in excess of 4 million dollars per year at harvest, and is more than 2 million dollars per year in present value terms.

HOW FARES THE ASPEN?

Aspen is an important Lake States timber type. It extends over 14 of the 52 million acres of commercial forest land in Michigan, Minnesota, and Wisconsin. Recently aspen has become very much more important commercially, as well. It made up one-half of the 4-million-cord Lake States pulpwood harvest in 1970, and its use undoubtedly will grow still larger in the future.

How fares the aspen? In most respects aspen is an easily managed pulpwood type. Reproduction is obtained by clearcutting and the root suckers that result typically are abundant and vigorous. This relatively intolerant tree expresses dominance well, and overstocking to the point of stagnation is not encountered. Thus, growth without intermediate management is reasonably good, with production of about 40 cords per acre at 50 years typical for fully stocked stands on better sites.

Diseases, however, are a serious problem, often causing large losses. Hypoxylon canker is the most important killing disease of aspen. This virulent pathogen causes mortality in 3 to 7 years after lower bole infection. It is widely distributed and evidence of the disease can be found in almost all aspen stands. An effective means of chemical or silvicultural control is yet to be identified. How serious are the losses resulting from hypoxylon canker? How urgent is a search for control? These are the questions to which this study is addressed.

LOOKING FOR HYPOXYLON INFECTION

In the summer of 1971 field crews visited 196 sample locations distributed throughout the aspen type of Michigan, Wisconsin and Minnesota. To insure representativeness, the total sample was allocated among Forest Survey units by the proportion of total aspen acreage falling in each unit. The sample locations within each unit were drawn at random from the Forest Survey aspen plots available

[1] *Michigan Agricultural Experiment Station Journal Article Number 5735. I wish to acknowledge the assistance of Timothy Flint and William Schmidt, graduate students in the Department of Forestry, Michigan State University, who collected the field data for this study, and to Gerald Anderson, Burton Essex, Allen Lundgren, and others of the North Central Forest Experiment Station. This study was financed in part through a cooperative agreement with Forest Pest Managment, Northeastern Area State and Private Forestry, USDA Forest Service.*

there. Field crews revisited these selected plots and used the survey plot center as the starting point for this infection survey.

Each sample consisted of a line of 25 circular plots 7 feet in radius and placed at 25-foot intervals. The first 20 live trees on each plot were examined and classified into four categories:

1. Aspens not fatally injured or infected.
2. Aspens with hypoxylon (*Hypoxylon pruinatum* Cke.) infections.
3. Aspens fatally infected or injured by another vector only.
4. Non-aspen tree species.

Each live aspen also was separately classified according to whether or not it had conks or target-shaped cankers. In addition, site quality was estimated by determining the height and age of three main-stand aspen dominants, and main-stand size class and species composition were noted.

THE INFECTION AND DENUDATION WE FOUND

The average percentage of live aspen trees currently infected in the Lake States aspen type is 12.1 ± 1.0 percent with a probability of 0.95. The range in observed infection rates was zero to 40 percent. Table 1 shows infection rate findings in more detail. It is clear that bigtooth aspen is far less susceptible to infection than quaking aspen. Some site and stand condition factors may also be correlated with infection rates, but further sampling and analysis will be needed to establish these.

Other disease problems were much less prevalent than hypoxylon canker. Conks were found on 1.9 percent of the aspen examined and target-shaped cankers were found on 2.5 percent.

Each of the 25 plots examined at a sample location represented the minimum area needed to support a merchantable tree at harvest. Plots where all live aspen had hypoxylon infections were plots that would be denuded, and that stand area might not support an aspen crop-tree at harvest. Plots where one or more uninfected trees exist were plots that would not be denuded by current infection, and thus no volume loss would result. We found that 5.6 ± 1.6 percent of the aspen type would be denuded by current infection with a probability of 0.95.

The amount of area lost to current infection is a function both of the rate of infection and the density of stocking. The same infection rate will cause less denudation where stocking is high than it will where

Table 1. — *Proportion of live aspen infected with hypoxylon canker, Lake States, 1971*

Item	Infection rate	Basis
	Percent	No. observations
By species:		
Predominantly bigtooth aspen	2.7	14
Mixed bigtooth and quaking aspen	7.8	25
Predominantly quaking aspen	13.7	157
By 33-year aspen site index:		
<40		
45	9.7	19
50	16.8	12
55	13.3	63
60	11.9	41
65	12.4	41
70	9.6	8
By stand size class:	8.5	12
Sapling stands (ave. d.b.h. 0-3.9 in.)	9.1	27
Pole stands (ave. d.b.h. 4.0-7.9 in.)	13.5	109
Timber stands (ave. d.b.h. 8.0 in.+)	11.0	60
By State:		
Michigan	9.5	61
Wisconsin	13.2	54
Minnesota	13.5	81
Lake States Average	12.1	196

aspen stocking is sparse. The following linear, multiple regression relationship accounted for 78 percent of the total variation in percent of area denuded:

Percent area denuded = 0.5425 (current infection rate)
— 0.0021 (No. aspen per acre)

Both determining variables are significant at the 99 percent confidence interval. Figure 1 shows expected denudation percents by current infection rate and for a range of representative aspen stocking levels.

The current average denudation rates by State are shown in this listing:

State	*Denudation Rate*
	Percent
Michigan	3.7
Wisconsin	5.9
Minnesota	6.8

The listing makes it evident that Michigan is currently experiencing the smallest proportion of area denuded, and Minnesota the greatest.

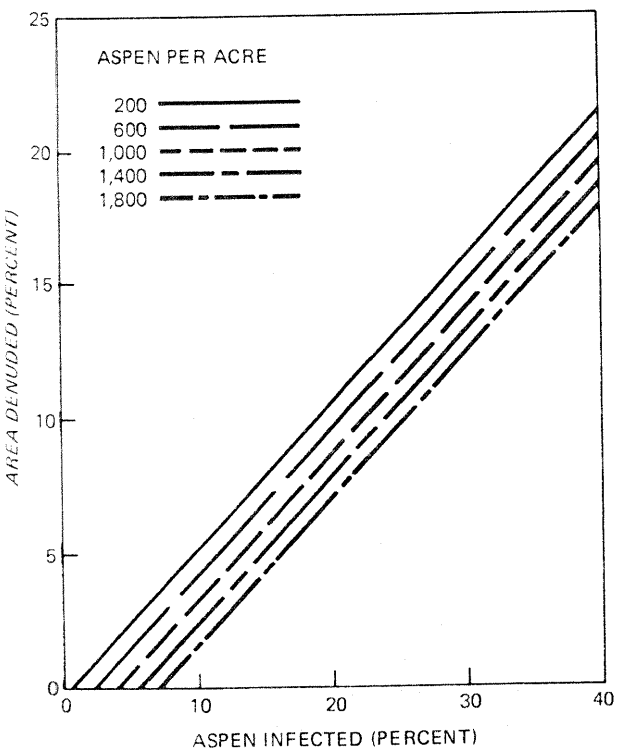

Figure 1. — *Relationship between percent area denuded, infection rate, and stocking density.*

HOW DENUDATION WAS TRANSLATED TO IMPACT

The model used to estimate volume and value impact is shown in figure 2. The loss which eventually will be occasioned by hypoxylon infection and denudation dating from a given year depends on these factors:

Volume Loss

Little or no reduction in harvest volume occurs until an area has been denuded that is approximately equal in size to that needed to support a tree of harvestable size. An aspen 8 inches in d.b.h. requires about 150 square feet of stand area — an area equivalent to a circular plot with a 7-foot radius. Denudation estimates in this study are based on the presumption that most aspen stands that are harvested at all will be harvested soon after they contain a harvestable volume of pulpwood, and that the average size of tree harvested will be approximately 8 inches in d.b.h. For the small proportion of the aspen resource that will be harvested at a larger size, this study overestimates denudation.

The percent of crop-tree areas denuded during a period, multiplied by per acre full-stocking volume at harvest, provides an estimate of the maximum volume loss per acre. Denudation in younger stands will be made up in part by restocking and especially by faster growth of surrounding aspen. This study assumes that recovery will occur at 15 percent per decade on a volume basis. Since trees with evident infection usually die within 3 to 5 years, it was assumed that the annual infection and denudation rates are one-fourth of those observed.

The full stocking volume at harvest is a function of site index and harvest age. The volumes and harvest ages assumed in this study are shown in table 2. The harvest ages are the stand ages at which the average d.b.h. of trees above 5 inches reaches 8 inches, or at which growth falls below ½ cord per acre per year, whichever age is greater. Harvest volumes are stated in cubic feet and to a 4-inch top and have been adjusted to lie between the reported yields for quaking and bigtooth aspens.

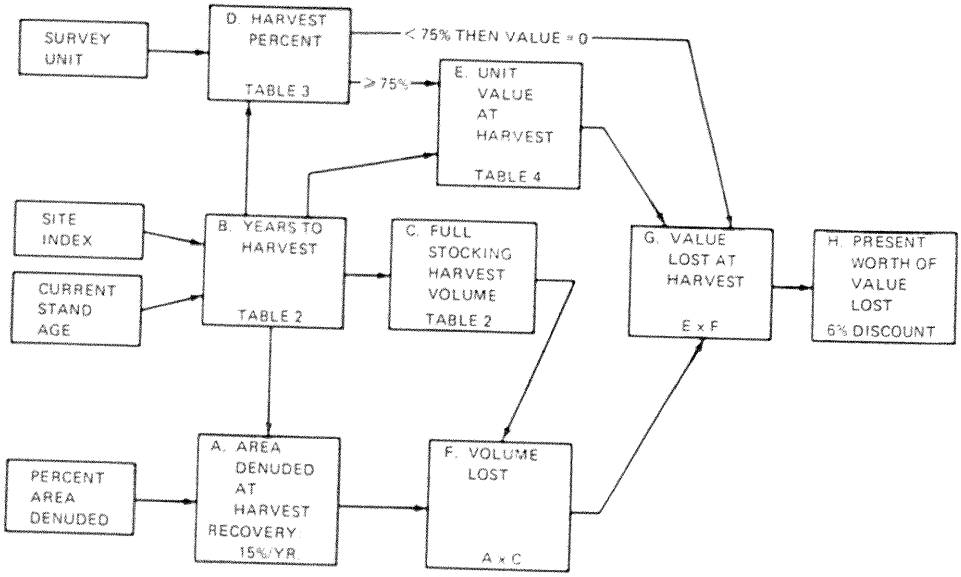

Figure 2. — *Model for estimating volume and value impacts.*

Unit Value

The value of yield losses depends on whether or not that volume would have been harvested and utilized, and if so, the income created thereby for the owner, the logger, and processor. The likelihood of harvest varies considerably from one area to another within the Lake States. Actual aspen harvest currently is less than annual growth for most Lake States Forest Survey units. A projection of these current data was used as a basis for estimating the proportion of annual growth likely to be harvested in future decades, and is shown in table 3. No economic loss is assumed in this study for survey units where harvest is expected to be less than 75 percent of the annual aspen growth during the harvest decade. Volume reductions in these instances are very likely simply to shift harvest to other acres, rather than to cause a reduction in harvest. The conversion return, or economic value, of aspen depends on how it is utilized and upon processing costs and product prices. Projections of conversion return by average stand diameter are shown in table 4.

Present Value of Losses

The present value of the economic loss was estimated by multiplying the volume loss by its expected

Table 2. — *Anticipated aspen harvest age and harvest volume*[1]

30-year site index (feet)	Expected harvest age	Expected full-stocking harvest volume (cu. ft. per acre)				
		Current stand age less than expected harvest age	Current stand age greater than expected harvest age			
			45	50	55	60
	Years					
40	40	850	900	900	850	800
45	40	1,100	1,150	1,150	1,100	1,050
50	40	1,350	1,400	1,400	1,350	1,300
55	40	1,700	1,800	1,800	1,750	1,700
60	45	2,400	--	2,650	2,650	2,600
65	45	3,200	--	3,600	3,700	3,700
70	50	3,900	--	--	4,500	4,600

1/ Adapted from Graham, Samuel A., et al. 1963. Aspens. Ann Arbor: Univ. Mich. Press. Tables 2-13, p. 70-79.

Table 3. — *Anticipated aspen harvest as a proportion of anticipated growth*[1]

State and Survey Unit	Harvest percent when years-to-harvest is: 0	5	10	15	20	25	30
Michigan:							
Eastern Upper Peninsula	66	69	73	76	80	84	88
Western Upper Peninsula	77	81	85	89	94	98	100
Northern Lower Peninsula	91	96	100	100	100	100	100
Southern Lower Peninsula	100	100	100	100	100	100	100
Minnesota:							
Lake Superior	26	27	29	30	32	33	35
Central Pine	33	35	36	38	40	42	44
Rainey River	51	54	56	59	62	65	68
Southeastern	35	37	39	41	43	45	47
Western	55	58	61	64	67	70	74
Wisconsin:							
Northeastern	95	100	100	100	100	100	100
Northwestern	76	80	84	88	92	97	100
Central	100	100	100	100	100	100	100
Southeastern	77	81	85	89	94	98	100
Southwestern	7	7	8	8	9	9	10

Areas and periods when volume losses will cause no reduction in harvest

1/ Assumes that greater utilization pressure will increase current utilization by 5 percent every 5 years.

Table 4. — *Anticipated conversion return for aspen*[1] *(In dollars per thousand cubic feet)*

50-year site index (feet)	Value when years-to-harvest is: 0	5	10	15	20	25	30
40	25	28	31	34	37	40	43
45	25	28	31	34	37	40	43
50	25	28	31	34	37	40	43
55	25	28	31	34	37	40	43
60	28	31	34	37	41	44	47
65	28	31	34	37	41	44	47
70	31	34	37	40	45	48	51

1/ Current average stumpage price is approximately $2 per 100-inch cord, which contains about 80 cubic feet. This converts to $25 per M. cu. ft. National projections of timber supply and demand indicate price increases of 73 percent by the year 2000. A straight line projection is employed. Increases in average stand d.b.h. above the 8-inch average typical of harvest from low site stands create added value because of conversion to different end products (lumber and veneer), and the lower cost of logging and conversion. An increase of 10 percent in value per inch of average d.b.h. is assumed here.

unit value, and then discounting this value from the expected harvest date to the study's base period (1971) at a 6 percent discount rate.

IMPACT FINDINGS

Table 5 shows average infection and denudation by State, and the volume and value impacts projected both on a per acre basis and for the type as a whole. The physical impact of hypoxylon is most serious in Minnesota, where infection, denudation and resulting volume losses are greatest both relatively and absolutely. However, the economic impact is concentrated in Michigan and particuarly in Wisconsin, where little excess of annual growth over cut is anticipated in the future.

The 300 million cubic feet of volume, which this study estimates will be lost each year as the result of current infection, is approximately equivalent to the annual net growth for the type (332 million cubic feet) and the "desirable" harvest level (284 million cubic feet). In other words, annual growth and utilization could be doubled if hypoxylon were eliminated. These volume impacts are based on the infection and denudation currently happening. Current hypoxylon infection and denudation may be greater or less than is typical — we have no way of knowing this. But impacts on the order of those projected in this study are probably the rule rather than the exception in most years.

It appears likely that for some time the volume of merchantable aspen added to the inventory each year will far exceed the volume harvested in Minnesota, in the eastern end of the Upper Peninsula of Michigan, and in southwestern Wisconsin. In these areas volume losses due to hypoxylon will not reduce harvests. Thus, there is little urgency for control in these areas. However, for the remaining area, where there is little or no excess of anticipated growth over anticipated harvest the situation is different. Harvest

losses are large -- 4.4 million dollars per year at time of harvest and 2.3 million dollars per year in present-value terms (table 5). So effective control could produce very substantial economic benefits.

A final word is needed regarding nontimber impacts. Aspen is a favored food of deer and beaver. Hypoxylon infection typically causes small openings that reproduce to deer browse species. Deer herds probably are favored to some extent by the disease because hypoxylon increases the amount of reachable browse. This change in aspen cover probably does not influence the beaver substantially. With regard to scenic impacts hypoxylon probably causes some reduction in attractiveness, but again, this impact is not substantial in my judgment, since extensive killings and denudations are the exception rather than the rule. Most infection is scattered in small patches and does not markedly alter the vista.

Table 5. — *Summary of current Hypoxylon infection, denudation, and impact, by State*

AVERAGE ANNUAL INFECTION, DENUDATION, AND IMPACT

State	Infection rate1/	Denudation rate1/	Harvest volume lost	Harvest value lost	Present value of losses
	Percent of trees	Percent of area	Cu. ft./acre	Cents/acre	Cents/acre
Michigan	2.4	0.9	12.3	34.2	16.1
Wisconsin	3.3	1.5	20.4	64.6	33.5
Minnesota	3.5	1.7	28.2	.0	.0
Total	3.3	1.4	21.0	30.9	15.6
TOTAL ANNUAL IMPACT FOR THE TYPE					
			Million cu. ft.	Million dollars	Million dollars
Michigan	--	--	53.2	1.436	.680
Wisconsin	--	--	93.6	2.965	1.551
Minnesota	--	--	153.7	.000	.000
Total	--	--	300.6	4.421	2.337

1/ Current infection and denudation divided by 4, the number of years of activity that current infection is assumed to represent on the average.

SELECTED ECONOMIC ASPECTS OF MANAGEMENT

Jay M. Hughes, *Director, Forest Resources Program*
USDA Cooperative State Research Service
Washington, D.C.
and
J. Douglas Brodie, *Assistant Professor*
University of Wisconsin
Madison, Wisconsin

ABSTRACT. — This paper briefly examines, from an economic point of view: (1) some characteristics of the aspen resource in general, (2) some extensive and intensive timber management applications in aspen, (3) multiple use and community impact evaluation frameworks, and (4) some research needs. Financial incentives over the near future are not favorable for more intensive aspen management, but changes in costs, prices, and values of nontimber products could change this somewhat pessimistic outlook.

All of the topics included in this Aspen Symposium have economic aspects and implications for management. The purpose of this remark is not the establishment of a pivotal role for economics and economists in aspen resource analysis. The purpose is simply to emphasize the necessarily narrow, selective, and sometimes conjectural nature of our presentation which results primarily from basing our paper on relatively limited existing data.

Our presentation is simple and straightforward. We begin with an economic overview of our aspen resource. We then identify a set of general timber production options or alternatives that seem appropriate for aspen as well as other species-type evaluations. We also consider economic evaluation frameworks that represent alternatives to the traditional single product economics analyses applied to timber growing. Finally, we have a word or two to say about some information needs that we think bear strongly on further application of economics to aspen management problems.

AN ECONOMIC VIEW OF THE ASPEN RESOURCE AND UTILIZATION OPPORTUNITIES

Aspen emerged explosively from the status of weed-tree or nonresource in the post-World War II period. Rapid exploitation over most of its range has a history of less than 25 years. Aspen is the primary species for pulpwood production and has become increasingly important in the three Lake States over the past 11 years (fig. 1). Trends have been similar in all three States; however, the proportion of production retained in-State (versus export to Wisconsin) has increased for both Michigan and Minnesota. It seems relatively certain that Lake States aspen harvests cannot continue to accelerate indefinitely, and the historical trend lines of figure 1 must flatten out as "old growth stocks" inherited from the past are liquidated, other things being equal.

Graham *et al.* (1963) projected a scarcity of harvestable aspen stands commencing in the 1975 to 1985 period. Within the relatively brief interval since this projection was published, annual aspen consumption has increased 12 percent and merchantability criteria have drifted downward, as has the accepted rotation age. In addition, early pathological deterioration and continuing high levels of harvests have continued to shift growing stock distribution to younger age classes. The net effect is that the impending hiatus in aspen availability has probably been moved ahead 5 years, but not eliminated.

There are two ways of looking at the aspen resource — as a stock or woodpile and as a flow or potential continuous yield. If the aspen resource is considered a "flow," decisions must be made as to how the following basic inputs of aspen production will be allocated: (1) land, (2) capital resources other than growing stock, (3) growing stock (allocated either to current harvest or future harvest), and (4) har-

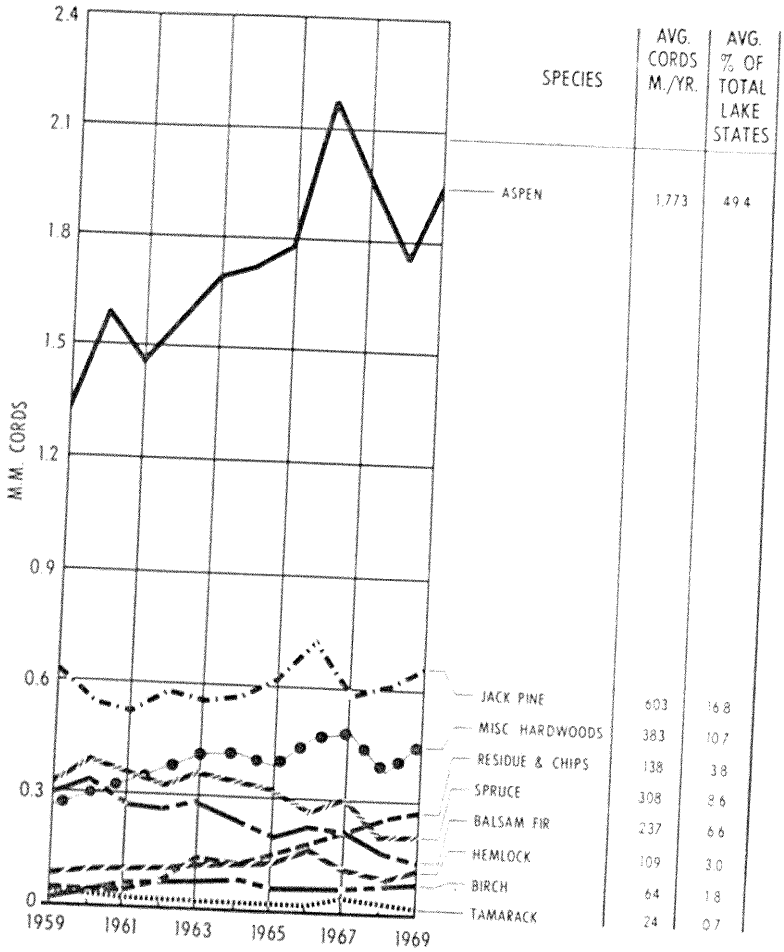

Figure 1. — *Lake States pulpwood productios by species, 1959-1969. Source: Horn (1960) and Blyth (1967).*

vested material (allocated to various end uses). Allocation of harvested material is discussed below.

Noreen and Hughes (1968) have presented a conversion-return analysis of allocation of aspen logs by diameter class to pulpwood use, lumber uses, and plywood use. The results of the study can be simplified to a comparison between pulpwood and structural products (plywood and lumber). When no return for residues was considered, 8-inch logs yielded their highest conversion return in pulpwood, and structural uses provided significantly higher returns only beyond the 10-inch diameter class. When allowance was made for residue values, however, structural uses yielded significantly higher returns in all diameter classes above 8 inches.

The above analysis is based on log diameters and not average stand diameter breast height (d.b.h.). The following factors will force these threshold diameters upwards: sorting costs, structural product producers' need for acceptable rates of return to fixed capital overtime, quality premiums that the log market will exact for "woods run" of higher diameter, and dispersion of actual d.b.h. about average stand d.b.h. and reduction of log diameters in the upper stem. If we are searching for a criterion of average stand d.b.h. to distinguish pulpwood sites from structural timber sites, including considerations of rotation or efficiency over time for production, we might suggest a "rule of thumb" criterion for a structural aspen timber site as being a site capable of producing an average d.b.h. of 10 inches in 50 to 60 years. The

most recently available aspen yield model (Ek and Brodie[1]) indicates that site class 70 will have an average d.b.h. of 8.7 inches at age 55, while site class 80 will have an average d.b.h. of 10.1 inches under similar stocking assumptions.

The above speculative analysis leads to the conclusion that only a small portion of the Lake States aspen sites (mostly in the northern counties) can be managed suitably for structural products. We note, however, that a site index 70 stand will have an average d.b.h. of 12.5 inches at age 80; and even site index 60 will have an 80-year average d.b.h. of 10.6 inches. Thus, a higher proportion of existing aspen growing stock might best be allocated to structural products, even though the second rotation harvest should probably be allocated to pulpwood.

Our discussion has dealt primarily with the aspen resource as a source of timber. The strong positive correlation between young aspen stands and grouse and deer productivity provides a direct nonmarket benefit of aspen management that may justify aspen regeneration activity on borderline commercial timber sites. Aspen timber management has a real potential to be complementary to wildlife production.

SOME TIMBER PRODUCTION OPTIONS

We are concerned here with three general classes of management options for aspen timber production: (1) extensive management or a simple "cut-and-let-grow" option with a major focus on amount of land area to allocate to aspen harvest, (2) intensive management with a focus on time and stocking control alternatives, and (3) type control and conversion options which consider not only the amount of land to allocate to aspen harvests but also the complete replacement of aspen by alternative species and by various means. These are all broad classes and we discuss only a few aspects of each below.

Extensive Management

The simple "cut-and-let-grow" option that seems to correspond to past practice, has not been challenged significantly by current economic conditions and is supported at least in part by recent research. Sorensen (1968), for example, has shown that the size of crop trees in 15-year old aspen regeneration following commercial clearcutting varies little over a wide range of initial sucker densities on good sites. This at least tends to weaken the argument for the application of intensive cultural practices such as thinning in young aspen stands to improve the size of residual trees in a given period of time. Another study,[2] concerned with the economics of young growth aspen thinning, showed that even on the best sites, given current costs and prices, it was more profitable *not* to thin than to thin. Others, however, contend that intensive management practices such as thinning will pay off and we refer to some of this argument below.

Associated with extensive management are questions of protection and stand or forest manipulation for the production of other-than-timber benefits. We would tend to argue, from a strictly financial point of view, and based upon no particular data, that the expenditure of extra funds on such practices ("extra" in the sense of more than "normal") would not yield a commensurate increase in benefits saved or produced, given current costs and prices. We would tend to argue instead that the burden of "management" should fall upon the timber harvest operation in terms of such things as adjustments in size and distribution of cutting units, slash disposal, and time sequence of harvest in stands of different ages and condition. All of these, of course, may have an impact on logging costs and, hence, on stumpage prices. Ultimately, there would be an impact on logging technology. We believe the current interest in mechanized harvesting equipment and systems is a forecast of this "ultimate" impact.

Intensive Management

Intensive management for timber production can be viewed for convenience as conscious control of the time and stocking variables of the production process. Other "intensive management" practices such as fertilization, irrigation, etc., will affect financial outcomes, to be sure. However, we believe that the

[1] *Ek, A. R., and J. D. Brodie. Yield potential of short rotation aspen. Sixth TAPPI For. Biol. Symp. Proc., Appleton, Wis., May 1-3, 1972. (In preparation.)*

[2] *Noreen, Paul A. 1968. Economic evaluation of precommercial thinning in good-site aspen. (Unpublished M.S. Report, Coll. For., Univ. Minn. 19 p.)*

primary timber management decisions are those relating to time and stocking control, *given* the entire set of other factors for a site which are usually fixed in some proportion to each other and which in turn will account for variation from site to site or stand to stand when the same time and stocking controls are applied to all sites.

Several studies in addition to those already cited have been concerned with the time and stocking aspects of aspen timber production and illustrate a continuing interest in intensive management of aspen if not an overwhelming level of research. Twenty-five years ago Zehngraff (1947) observed that precommercially thinned aspen yielded larger and sounder logs than did unthinned stands harvested at the same age. Steneker (1964), as a later example, observed that perhaps as much as 10 years can be eliminated from the rotation for aspen saw logs and veneer logs if precommercial thinning (that is, stocking control) is followed. Therefore, the results of research so far, when those like Sorensen's on the one hand and Zehngraff's and Steneker's on the other are compared, do not seem to provide clear management direction. We offer a few additional observations below, primarily from an economic vantage point.

Short Rotation Management

Time control can be of several kinds: length of time permitted for regeneration following harvest, age of stand at first thinning, time between intermediate harvests or thinnings, length of cutting cycle, and time of harvest or rotation period. We suspect that most interest in time control in intensive management of aspen is focused upon the control of rotation period because aspen: (1) is a relatively fast growing species, (2) aspen provides an increasingly large share of total roundwood consumption for such products as pulpwood especially in the lower diameter classes, and (3) growing time to maturity has a cost (interest) in financial evaluations and reduction of this cost may be the most easily accessible means for improving the economic acceptability of aspen as a fiber crop.

Inquiry into very short rotation management is in its early and extremely speculative stages. Already, however, it is divided into two different approaches with different associated speculative technologies. The first approach might be described as agronomic short-rotation management using improved genetic stock and intensive crop-tending inputs similar to agriculture. Rotations of considerably less than a decade are envisioned under this system.

The second approach might be described as "extensive short-rotation management" and involves harvest and regeneration of natural aspen stands with full utilization of small stems and branch wood. Since the analytic technique and methods of this approach are reported elsewhere[3] only major conclusions will be discussed here.

The first conclusion of note is that potentially feasible short rotations under this approach are not nearly as short as under the agronomic approach. They fall in the range of from 12 to 25 or more years because total volume is accumulating at an accelerating rate for more than a decade.

The second major conclusion is that sustained yield is not significantly reduced by these short rotations because yield functions are approximately linear over large segments of the relevant range. When this condition prevails, losses in yield from rotation shortening are counterbalanced by increases in the land area from which the harvest comes. This could have a significant effect on harvesting costs but not on available harvest volume.

A third conclusion, that should have been obvious *a priori* but required several computer simulation runs to verify, was that these short rotations are not particularly sensitive to large shifts in discount rate. A shift in discount rate from 5 to 8 percent under a particular set of assumptions resulted in rotation being lowered only from 17 to 16 years. Examination of the soil rent formula

$$\frac{Y_t}{(1.op)^t - 1}$$

indicates why this should be. The exponential term "t" does not possess the sting that it would in the conventional rotation age range of 35 to 70 years. This allows substantial variation in "p" with only a small effect on rotation.

[3] *Ek, A. R., and J. D. Brodie. Op. cit.*

Adoption of this management technique requires development of manufacturing processes that can handle the small material that develops. It also requires the development of harvesting technology that will handle the harvested material at from 75 to 50 percent of current pulpwood materials handling cost. The advantages of this system, other than those above, would include a reduced period over which harvestable stands would be subject to hazards and pathogens and thus a utilization of material currently lost. There would also be a very substantial liquidation gain if landowners cut back rapidly to the growing stock levels implied by shorter rotations. This would offset any short-term shortage of harvestable aspen and perhaps bring about more rapid utilization of deteriorating stands.

Stocking Control

"Stocking control" is a general term that includes such timber management concerns as initial stocking rates in plantation or natural stands, and residual stocking levels following thinnings or harvest cuts. It can be measured in various ways including stems per acre, basal area, and volume. Several of the studies previously cited, plus those of Pike (1953) and Day (1958), deal with stocking control. We wish to refer here, however, to only one study which has some economic inferences.[4]

Noreen compared the internal rates of return from two different thinning systems (a single precommercial thinning and a single precommercial thinning plus one commercial thinning) with no thinning in young growth aspen (thinning ages ranged from 4 to 30 years) on good aspen sites. After-thinning stocking levels were those judged by experienced forest managers to give the best results. For instance, it was assumed that 70 square feet of basal area would remain after the commercial thinnings because this level was recommended by the USDA Forest Service for aspen management. The result of this analysis was that regardless of rotation or thinning alternative considered, the "no-thinning" alternative had the highest rate of return.

The inference seems to be that at present prices and costs stocking control in aspen by thinning is not worthwhile financially. Although this analysis considered only one level of stocking and few thinning alternatives, it was based upon the best available judgment of the best apparent opportunities for aspen thinning payoff.

Time and Stocking Control

Although time control and stocking control decisions are individually important, the forest manager is more interested in the best *combination* of time and stocking levels in the timber growing process. Noreen[5] is used again to provide some economic inference.

Evaluation of rotation alternatives ranging from 20 to 55 years, for good site aspen, and no thinning, showed that rotations of 30 to 35 years yielded the highest rates of return (from 1.69 to 6.81 percent) given various cost and price assumptions. Interestingly, the short 20-year rotation required the highest price-lowest cost assumption in order to realize as much as a 1.88 percent rate of return. Thus, the best combination of time and stocking control for good site aspen in this study, using maximum rate of return as the criterion, was "no thinning" and a rotation of 30 years. This result also reflects the "high price" assumption of the study. Lower price assumptions yielded a somewhat longer rotation of 35 years (40 in the case of the high cost-low price assumption); but the best stocking control was still "no thinning."

Type Control and Conversion

We refer here to the typically most drastic attempt by man to manage the forest environment for his own purpose. Type control entails the complete replacement of any forest cover type with another type, either suddenly by some means such as shearing and planting, or perhaps slowly by single tree selection harvests in a shade intolerant forest cover type. We know of many examples of aspen stand replacement throughout the Lake States. Typically, sheared areas are planted to white spruce or red pine. Typically, too, the costs of conversion by this method are high. The rationale seems to be largely that the species presently of higher value, such as white spruce and red pine, have better prospects for long-term value yield.

We have not evaluated type conversion from an

[4] *Noreen, Paul A. Op. cit.*

[5] *Ibid.*

economic standpoint nor do we know the acreage converted throughout the aspen range. However, we think it deserves the immediate attention of solid economic analysis in view of the high initial investment, the long time period required to realize a payoff, the increasing importance of aspen as a source of wood, and the increasing importance of the aspen cover type for the production of other forest products such as wildlife.

ALTERNATIVE ECONOMIC EVALUATION FRAMEWORKS

We have focused our discussion to this point on more or less traditional timber production economics. While production economics is interwoven either directly or indirectly with all aspects of forest management, consumption and welfare foci are shifting priorities for forest management and for economics research in forestry in response to a new wave of public concern for environmental quality and its implications for economic development. We would like to mention very briefly two more or less definitive but certainly not new frameworks for economic evaluation of aspen management: (1) multiple use, and (2) community impact.

Multiple Use

We believe that multiple use management, in spite of our individual and collective hang-ups regarding precision of operational definition, is appropriate for dealing at least in part with forest environmental quality. Multiple use management explicitly recognizes the "jointness" of forestry production in the sense that whatever we do to the forest environment is likely to affect the level and quality of more than one of the several "products" of the forest. These products are valued in several ways, not only in terms of dollars but also in terms of less easily quantified values such as esthetics. Regardless of the values used, economic questions arise regarding the efficient allocation of forest and other resources to the production of these various products.

The absence of acceptable methods for making logical, objective choices between alternative forest management programs, each of which has associated with it varying levels and kinds of values, is a critical problem for administrators, managers, and researchers alike. A case in point is the production of game (e.g., deer and grouse) and timber products (pulpwood and saw logs) from aspen stands. More than dollar values are involved here. The question is: how do we use both dollar and nondollar values in making the choice between alternative combinations of timber and game products from aspen stand management?

Community Impact

"Community impact" is a broad term. It relates generally to the income and employment effects of both consumption and production activities. Perhaps of more significance, however, is the embodiment of "indirect" or "secondary" effects as well as the "direct" effects in community impact analysis. The sale of aspen pulpwood by a logger to a pulpmill yields a direct income to the logger. As the logger spends his income in his local community and elsewhere, the aspen pulpwood sale results in direct income to the grocer, the power company, the service station operator, etc. In addition, as each of these direct recipients of the logger's income make sales to the logger, they respend his income for the goods and services they require to make their sales. In this way a chain reaction of indirect income and employment effects is induced.

These indirect impacts, especially those stemming from local sales of raw timber products, are frequently much larger and therefore more meaningful to local community than the direct impacts alone. In Itasca County, Minnesota, for example, the sale of $1.00 of timber stumpage meant a total sales impact on the Itasca County economy of $3.45 (Hughes 1970). Similar results were obtained in other studies in aspen producing areas of northern Minnesota. In some instances "community impact" maximization may be at least a short-term economic objective which is more important than maximum net return or maximum internal rate of return from timber growing.

The framework of community impact analysis can also be designed to answer various questions relating to forest environmental quality. One of these is: who gets hurt by how much? This is one of the most lively questions in forest resource management today. For example, a decision to modify (perhaps increase as well as decrease) aspen timber cut to favor wildlife production and stimulate local hunting can be evaluated at least partially within a community impact framework. The direct and indirect effects of the

increase or decrease of timber harvest can be estimated for each sector of the local economy. In addition, any change in the expenditures of hunters made locally will also have direct and indirect impact which can be estimated. This example is only suggestive of the broad range of questions involving not only the size of impact stemming from alternative forest management programs, but also the incidence of impact upon various sectors of the local economy and economies outside the local area.

For the economist, the greatest information gap for aspen management is in the area of forecasting or projections of the future. Decisions must be made concerning liquidation of aspen stocks and replacement of these stocks through regeneration and management activities. In a world of certain objectives or targets, analysis is not too difficult; but this is not the sort of world that has to be faced. Fortunately the future is not completely uncertain. Aspen consumption will be maintained for the next two decades at least and we have forest inventory data on the stands that will be used to meet this consumption.

Posterity is longer than the next 20 years, however, and 1992 and beyond will have to be faced with stock distributions that will provide flexibility for meeting long-term contingencies. Regeneration is the primary immediate need and, fortunately, aspen is one of our least expensive forest types to regenerate. Aspen regeneration has the added bonus of enhanced wildlife productivity.

The information and data that the forest manager will need to meet the somewhat indefinite planning framework outlined above is improving in a relatively rapid incremental fashion. He must incorporate it incrementally into his planning process. The areas in which information is evolving and must continue to evolve are: forest inventory, regional economic supply analysis, mensuration and stand modeling, and innovative analysis of stand treatment and utilization technologies.

The most recent applications of the USDA Forest Service forest inventory techniques can make statistical information available at all levels from the individual tree to stand and regional breakdowns. This information is needed for simulation of alternative harvesting and utilization projections on the resource base. These alternative resource base projections are the foundation for regional supply studies and in fact publication of such a study should be available soon.[6]

Mensuration and stand modeling in aspen have progressed significantly from the two-variable site and merchantable volume formulations beginning at age 20. Multivariate, stand development models including site, site treatment, stocking, and growth of individual stand components are becoming available.[7] Much of this work is developed from existing data with a minimum amount of supplemental sampling.

Innovative analysis of new technologies for stand treatment and utilization is carried on by most agencies represented at this symposium. It includes analysis in genetics, silviculture, harvesting, and manufacturing.

Needed information seems to be appearing in improved form at a faster rate than ever before. Each individual segment has its role in the aspen production framework. If anything is being neglected, it is perhaps analysis of how all of these elements fit together under the overevoked and underworked systems approach. Such an approach will involve a high degree of interdisciplinary dabbling between fields. Forestry research has had a long tradition of interdisciplinary application that can, hopefully, be maintained in an age of increasing specialization.

CONCLUSIONS

A selective paper such as this one runs the risk of treating each topic too shallowly. It is far more satisfying to plumb the minutiae of fibre structure, economic rotations or DNA transfer in pollen. It is interesting to note that in being selectively economic in our outlook towards the paper, we have ended up being not particularly economic at all. Rather, we have dwelled on each aspect of the aspen production process as it eventually affects yield and man's basic requirements from his forest resource base.

From an economic point of view, however, we are somewhat pessimistic with respect to economic or

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6 *Leuschner, William A. Present and future aspen inventories in the Lake States. (Manuscript in preparation.)*

7 *Ek, A. R., and J. D. Brodie. Op. cit.*

financial incentives for practicing a much more intensive level of aspen management in the near future. Unless the price of aspen wood increases significantly, implying the development of stronger and perhaps different markets, or unless costs decrease, or unless the value (measured in appropriate terms) of other products increases so that we (all of us) are willing to pay the price of foregone timber production and increased "other product" production costs, extensive management is likely to remain the rule.

Although our long-term forecast crystal ball is dark, we do see needs for improvement of information for economic analyses. These include some improvement in growth and yield data, multiple-product multiple-value decision models, and economic forecasting techniques relating to both supply and demand.

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TRENDS AND PROSPECTS FOR WOOD PRODUCTS

Hereford Garland, *Wood Technologist*
Institute of Wood Research, Michigan Technological University
Houghton, Michigan

ABSTRACT. — Because of its excellent texture, medium density, and light color, Lake States aspen wood has an undeveloped potential for wood products. It is particularly suited for particle board, excelsior, plywood, lumber core stock, and furniture. Current utilization of the aspen resource in the Lake States is dependent upon the raw material needs of the pulp and paper industry. At least some of these needs might be satisfied as chips from residue of wood products. Further innovation is needed in the sorting and processing of the tree stems into technically superior wood components.

Because of its excellent texture, medium density, and light color, Lake States aspen wood has an undeveloped potential for wood products. It is particularly suited for particle board, excelsior, plywood, lumber core stock, and furniture. The present paper attempts to apply our current knowledge of aspen wood utilization to chart a course for expanding the use of aspen wood products.[1]

The probem of using aspen for its highest product value is shared by Federal, State, and corporate owners of the resource and the large consumers of pulpwood and other fiber products. The image of aspen simply as a pulping species should be changed and better use should be made of the larger sized logs.

This paper is addressed primarily to forest managers interested in the developing utilization techniques and the implications of these techniques for profitable forest production, and to pulpwood procurement people who may recognize the economic gains in sorting poplar wood for optimum utility and value.

UTILIZATION POTENTIAL

The use and acceptance of aspen wood depends on the recognition of its properties. Aspen is similar to higher priced basswood and has a great potential for market development. Both aspen and basswood are medium to low density woods of uniform texture and light color. For many uses they are superior to woods that have grain of distinct contrast. In small pieces, the two woods are hardly distinguishable. The uniformity of the wood structure, or lack of distinct grain, makes aspen desirable for uses where coarse grain would interfere with machining, gluing, or wearing qualities. The uniform wood structure of aspen is readily adaptable to various finishes.

The uniformity of aspen wood structure also makes it uniquely adaptable for particle board production in which the design of the particle such as a flake, is critical to the properties of the board. The formation of a "designed" flake is much more difficult with a grainy wood. The relatively low density of the aspen particle allows intimate contact under pressure and contributes to the effectiveness of both the adhesive bond and product strength. For complete treatment of the wood technology of the poplars, reference is made to the work of Lamb (1967) and Kennedy (1968).

SORTING FOR BEST USE

In order to maximize aspen utility and value, pulpwood procurement people must be willing to investigate methods of sorting out high-value bolts. Sorting the higher value sawbolts and veneer bolts during harvest, or at a concentration yard, could increase the average stumpage value and at the same time make the smaller pulpwood sticks available to the pulping

[1] *For a full treatment of aspen utilization potential see the Lake States Aspen Reports. Lake States For. Exp. Stn., 1 to 22, 250 p., illus. 1947 to 1951.*

industry at a reduced price. Of course this reduction will need to be balanced against a possible reduced pulp yield. A sign of the times about integrated timber use is the diversion of selected logs from a pulp mill woodroom to a stud mill at a western Canada location as described in a recent trade journal. Chips and residue from the sawing and veneering operations would be a further incentive in the sorting of stand-run poplar.

Optimum utilization of aspen trees, as with other hardwoods, should begin with bucking the tree stems. Yet there appears to be no appreciable aspen operation in the Lake States where log quality is considered in bucking lengths of logs or bolts. Presently, grading for various uses depends upon describing 100-inch bolts of various qualities. The traditional 100-inch bolt is dictated by handling factors for pulpwood, and is not especially well adapted to products of higher utility.

Tree-length logging and hauling would help maximize aspen utility and value. At a concentration yard the poplar stems could be cut into lengths according to product. Saw and veneer bolts could be separated from pulpwood on the basis of diameter and graded by number of "clear faces" (quarters), straightness, and bolt-end characteristics. After quality bolts for lumber or veneer are sorted out, the residual bolts could be shipped as pulpwood or chipped on site for shipment to pulp mills. Manufacturing residue would also be used.

At present some aspen saw and veneer bolts are sorted from pulpwood operations if there is a demand to justify the sorting costs. Yet much aspen suitable for veneer or lumber is converted to pulp. Rarely is stand-run poplar suitable exclusively for a sale of sawtimber. Large pulp users tend to be conservative about sorting out aspen for lumber or veneer use and changing methods of measurement. Now that weight scaling is being accepted, there should be no more problem in converting from tons of cordwood to tons of chips, board feet of lumber, or square feet of veneer than from cords or other units.

A trend toward separating aspen bolts for lumber and veneer products has been greatly aided by the use of hydraulic cylinders in logging equipment. The self-loading truck and the "clam" attachment on skidding equipment enables some loggers to "bunch" bolts of different quality and to load them for diff ent destinations. Large, specially designed machi and conveyor systems are available for handling a sorting roundwood at concentration yards.

LUMBER PROCESSING

An important anatomical feature pertinent to sa ing small logs is "juvenile wood," the wood in t region of the center or pith. Its peculiar cell structu and properties result in relatively high longitudin shrinkage. Juvenile wood on one edge or side of board can cause bowing or crooking when the boa dries. Because aspen is generally a small tree juveni wood may be expected to occur frequently.

In sawing poplar the bolts should be cut so th the pith or heart is "boxed" and does not occur o the side or edge of a board. This is particularly im portant in cutting long products such as studs whic may crook badly. Improved sawing and drying tech niques have been developed that are expected t stimulate wider use of aspen for studs and othe structural material.

For Lake States poplar a highly automated sawmi is needed that cuts narrow slabs parallel with th bark, conserving the clear wood and leaving wedge shaped residue cuttings from the center of the bol Most of the juvenile wood and center decay coul then be chipped. The question of how acceptab these chips would be at the pulpmill remains a mat ter of pulping research and economics.

Presently, most poplar lumber is sawn on conven tional sawmill equipment, usually with circular saw of heavy kerf. The disadvantage to a small diamete log is obvious. A few gangsaw operations for aspe bolts have been successful. A recent study of sawin methods has confirmed that when dimension stoc cuttings are the end products in a sawing operation sawing logs or bolts "live" can yield more clearcut tings than conventional turning to remove the high quality "jacket board" on all sides (Bousquet and Flann 1970). Such findings should be considered in the design of a specialized sawmill for poplar bolts. So-called "stud mills" have been proposed for cutting small timber such as aspen. Production costs may be low but the maximum product value may not be realized unless quality is maintained.

LUMBER USES

Because of its small size, aspen timber has had some difficulty entering the general lumber market. Its close relative, cottonwood, is recognized in the national lumber trade because it is available as large saw logs in 12- to 16-foot lengths. Aspen is normally produced in 8-foot lengths even in the larger diameters. The larger logs have become known commonly as "box bolts" because the lumber has been readily accepted by wood container manufacturers. The wood is strong enough to be used for containers of relatively low weight. Its light color gives a clean appearance and allows label printing. An added attraction for reusable boxes is its ability to wear well without splintering. Because it lacks odor when dry, aspen is the standard wood for cheese box heading in the Lake States. The strong competition of the corrugated paper container has been a depressing factor in the wood box industry.

A considerable amount of aspen, grown within easy trucking distance of metropolitan areas, is sawn into lumber for crating. In the Lake States where pine is called for light construction lumber, some poplar has been produced as standard 2 by 4 studs for house walls. Carefully manufactured, dried and graded aspen has been shown to be adequate for this use.

The uniform structure, medium density, and good gluing properties make poplar wood particularly suited for core stock. It may be overlayed with thin veneers or other surface material without contributing to "telegraphing" when pressed in the gluing operation. With modern mechanized edge-gluing equipment, aspen dimension stock cuttings as narrow as about 1½ inches may be used in this product. Random-width cuttings are obtainable from the small logs typical of poplar.

The utilization of poplar lumber for cabinetry and furniture is a small, but growing industry in the Lake States. Here again, uniformity of structure and good strength-density relationship are plus factors. Poplar presents a subdued grain surface that is adaptable to a variety of hardwood finishes. Machining aspen wood for uses such as furniture parts is no more difficult than machining many of the conventional furniture woods, but it requires careful consideration of machine-setting and knife grinding. Figure 1 shows a furniture group produced from poplar.

In many of its properties, poplar is similar to the soft western pines. Lake States aspen has been used successfully in the experimental production of louvres and window sash. But lack of sufficient lumber in comparison with western pine prevents wider use of poplar for high volume products such as window sash.

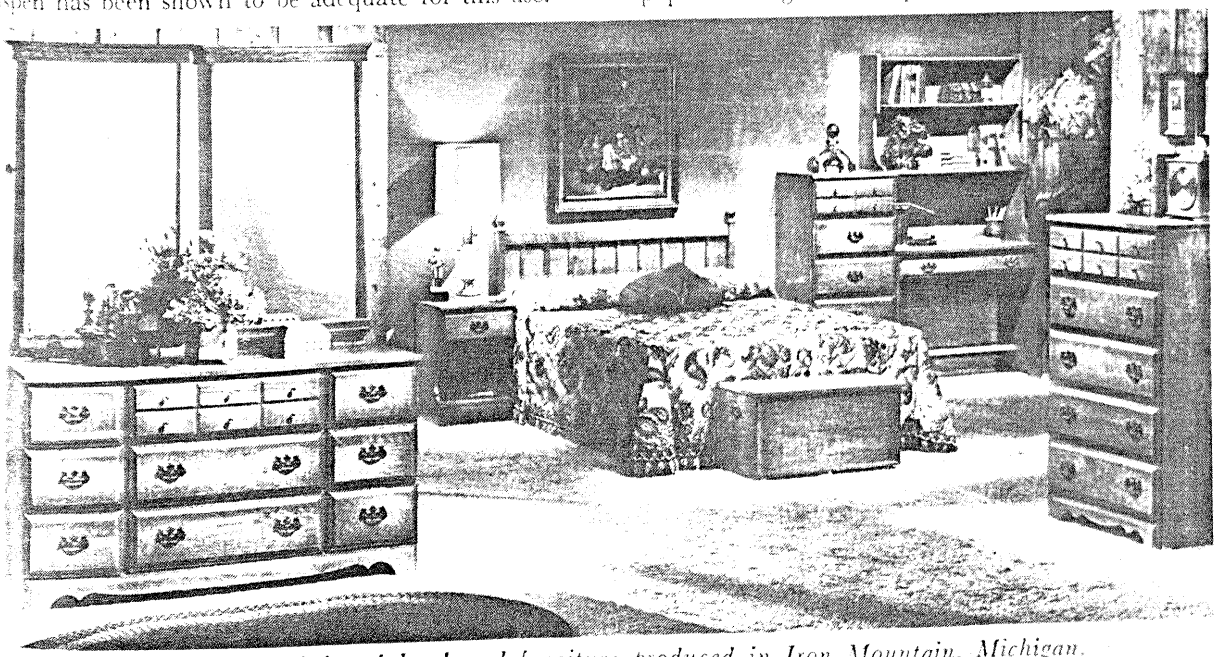

Figure 1.—*Suite of hardwood furniture produced in Iron Mountain, Michigan. The hardwood used here is poplar. This is an outstanding example of the utilization potential of the wood.*

PLYWOOD

Although poplar plywood production has become well established in Canada, there is only a single aspen veneer and plywood plant in the Lake States. Yet the product has found acceptance in a market that has been dominated by West Coast woods and, more recently, southern pine. A key to this development has been the adaptation of special manufacturing equipment for small diameter bolts. The properties of poplar wood are uniquely suited for plywood in many applications. Its uniformity of structure has made it well established as a base for overlaying thin sheet materials. It is a preferred wood for matches made from veneer. Further progress in the mechanization of jointing veneer sheets, both edgewise and endwise, could lead to the acceptance of relatively small, clear, poplar veneer bolts, and make raw material more available.

EXCELSIOR AND PARTICLE BOARD

A market for aspen excelsior wood is well established in the Lake States. Uniformity of wood structure makes for uniformity of the excelsior strands and uniformity of product. Innovative engineering and usage can lead to an expansion of markets. Some traditional uses for excelsior have been displaced but excelsior padding is still unique in absorbing shocks.

Excelsior has recently been used as a roadside binder. The strands have a special ability to attach to soil particles. A developing use for excelsior is in evaporator pads for humidity and temperature control equipment. Poplar has displaced basswood as the favored wood for excelsior because of the superior mechanical properties of its strands. Fire-resistant structural panels, made from excelsior with Portland cement or other inorganic binders, have been used as structural products. The uniformity of aspen wood structure helps create a panel product of uniform properties. The entire roof of the Forestry-Institute of Wood Research building at Michigan Tech is composed of excelsior board spanning laminated wood beams.

Much experimental work has been done on aspen for particle boards. Again, aspen's uniformity of structure makes it possible to design a particle of constant properties. Although much of the particle board industry uses non-uniform or hammer-milled particles, some boards with designed-flake particles are pr duced that have unique structural properties. Asp flake board production has been successfully intr duced in Canada and is being expanded in the La States. A specialized particle board designed as a exterior panel is now in production in Minnesot Further technical progress in the design of flakes an their orientation in board formation may be expecte

THE WOOD IS "POPLAR"

The use of "aspen" and "poplar" interchangab and alternately in this paper is purposeful. To ga acceptance as a wood of good technical qualiti comparable to basswood, the lumber we know a "aspen" (trembling aspen and bigtooth aspen) shoul be identified as "poplar," from the botanical nam *Populus tremuloides* and *Populus grandidentata*. Th demeaning term "popple" should be avoided. As Ga land (1946) suggested, the wood might be calle white poplar to distinguish it from the yellow-popla available in the lumber market from the souther United States. It is of interest that yellow-poplar wa probably so named by early settlers because the woo of the tuliptree has the same low density and unifor texture that they associated with the true poplars i Europe. One Lake States producer of aspen lumb and dimension stock already uses the name "norther poplar." Leadership in improving the image of aspe wood products should be shared by those foreste charged with the management and improvement o the large Lake States timber resource.

The Canadian industry and agencies have wisel grouped the woods of most species of *Populus* unde the common name "poplar" (Kennedy 1968). Th Forest Products Laboratories Division, Canadian For estry Branch, has given priority to the common nam "poplar" (Jenkins 1951). However, the U.S. Fores Products Laboratory (USDA Forest Service 1955 uses the term "aspen," but indicates that "poplar" o "popple" is in fairly common use in trade practic in the United States.

CONCLUSIONS

We can expect the use of aspen wood products t increase because aspen is relatively abundant and i has characteristics that make it suitable for a varie of products.

Although the pulp and paper industries will continue to be important consumers of aspen, improved appreciation of aspen wood products should divert more aspen logs into use for higher value products. This trend is already evident, of course, but improved technology in veneer and lumber utilization may be expected to make harvesting aspen for an integrated market the accepted practice.

This will mean that suitable logs will be sold to veneer mills where these are available. Other large logs will go to dimension stock plants where primary products will be parts and panels for furniture and cabinets. Secondary products may be pallet parts, box shook, structural lumber, or crating material. Only the smaller roundwood would be used for pulp chips or particle board.

Historically, the paper industry has been able to adapt itself to progressively less critical raw material specifications through research and development. Chips and residue from manufacturing processes will supplement the traditional pulp to an increasing extent.

Improved utilization technology will help to offset the present aspen surplus. At the same time the increased demand for higher quality will present a new challenge to timber management research.

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PROSPECTS FOR USE IN FIBER PRODUCTS

Richard J. Auchter, *Assistant Director*
Forest Products Laboratory,[1] *USDA Forest Service*
Madison, Wisconsin

ABSTRACT. — About 85 percent of the operating pulpmills in the Lake States use some aspen. In recent years the aspen percentage has varied between 45 and 50 percent of all pulpwood use. Pollution abatement orders may result in some changes in pulpwood use. Aspen has good credentials for use in fiber products. It is light colored, making its use for groundwood pulp attractive. It is readily pulped by any of the commercial processes, and is a raw material most often used in process developments because it is easily pulped. Aspen fiber morphology is excellent. The length-to-diameter ratio and the thin-to-medium-thick walled fibers are particularly suited to enhancing fine paper structure. Its low density is attractive to fiberboard production. The relative low yield per unit cost for aspen probably restricts potential expanded use.

Within the past 25 years we have seen a tremendous increase in the use of all types of hardwoods for fiber product manufacture. While a cost advantage may have been the first and perhaps still is the foremost incentive, certain quality gains were realized so that today hardwood fibers are essential to the satisfactory performance of many fiber products.

In the northern United States aspen has since the early 1940's been the major factor in the remarkable growth in hardwood consumption for pulping.

Recent statistics on aspen use in the Lake States illustrate its importance and availability. Nearly 85 percent of the pulpmills operating in this area use some aspen, and this use comprises some 45 to 50 percent of all the pulpwood consumed (table 1). This speaks well for aspen's use in fiber products since it is estimated to make up about 30 percent of the timber volume.

We are all aware that pressures for pollution abatement are causing wide-scale reevaluations by the fiber products industry. It is too early to attempt to analyze what this may mean for aspen.

Aspen and poplar species in general have been the subject of extensive research throughout the world (Brown, Seager, and Weiner 1957; Roth and Weiner 1964, Weiner and Roth 1970). Much of this research is related to growth, but the general ease in processing and the quality of the resulting fibers and fiber products have made these species somewhat of a standard in the control and evaluation of new products and processes.

WOOD PREPARATION

When aspen first entered pulpwood markets, most was sap-peeled in the woods before shipment. In recent years, preparation has changed dramatically and many pulpmills now practice "hot logging," debark at the mill, and store a limited time. Perhaps the most important factors in the change were the general rise in storage costs and a significant brightness loss resulting from extended storage of peeled logs. Prolonged storage is still practiced when the wood is used in the sulfite or bisulfite process for alleviating potential pitch problems. Other factors were the limited labor market and the lack of accepted portable debarkers. Today we find year-round harvesting and preparation operations for aspen with debarking both in the woods and at the mill.

For debarking at the mill site, mechanical and

[1] *Maintained at Madison, Wis., in cooperation with the University of Wisconsin.*

Table. 1 — *Lake States pulpwood production*
(In thousands of rough cords)

Kind of pulpwood	1965	1967	1968	1969	1970
Hardwood					
Aspen (roundwood)	1,780	1,976	1,753	1,963	1,966
Other miscellaneous (roundwood)	444	539	449	555	658
Residues	8	195	219	259	302
Softwood					
Roundwood	1,268	1,235	1,091	1,139	1,313
Residues	31	20	39	27	46
Total production	3,531	3,965	3,551	3,943	4,285
	Percent	Percent	Percent	Percent	Percent
Aspen	50	50	50	50	46

drum debarkers or combinations thereof are used. Wood cut and delivered during the sap peeling season cleans up quite satisfactorily in one pass, but multiple passes are required for tight-bark seasons. Some operators have found that series installation of debarkers has advantages over recycle systems.

Portable debarking equipment has been added to some woods operations and concentration yards away from the mill site have been developed. New forestry and harvesting practices for optimum management of our wood resource will no doubt force a growth in these types of systems (Benson and Peckham 1968).

Whole tree utilization has potential in the fiber products field. Bark-chip separation techniques will be required for some products. Various methods are under investigation and it is expected that alternatives will be available for both the processor and the user of the wood.

Aspen, when improperly debarked, has been known to cause some operating problems. Perhaps the most troublesome of these is the filling of paper machine wire caused by deposits of stone cells from the inner bark on the wire, a problem similar to the filling caused by resinous woods.

PULPING BY COMMERCIAL METHODS

Pulping, the separation of wood into fibrous elements, is accomplished by mechanical means, by chemical removal of the lignin and incrustants, or by combinations of these two procedures. In each case, the pulp characteristics needed for a particular wood fiber product along with economic considerations determine the choice of the process — groundwood, chemimechanical, semichemical, sulfite, or kraft.

Aspen is readily pulped by any of these commercial processes (Brunson 1964). In fact, it is the wood most often used in development work because of the general feeling that if you cannot pulp aspen with the technique under development, you most likely do not have a viable plan or program. Processing conditions are not uniform from mill to mill for any of the processes, but can be controlled at an optimum for each pulp and fiber product situation. For the optimum, a wood specification such as percentage of rot, size, brightness, or other wood factor could be included. Table 2 gives estimated pulp yields of different species for each of the commercial processes.

The data demonstrates quite clearly the yield advantages of the higher density woods and the importance of including cost in the calculations so that yield per unit cost can be the comparable unit.

Groundwood

Two procedures are available for producing groundwood pulps, which in 1970 accounted for almost 4½ million tons of production in the United States, of which aspen approached 10 percent.

Table 2. — *Estimated yields of pulp for various wood species*

Species	Ovendry wood	Pulping processes					
		Groundwood	Chemimechanical	Semichemical		Sulfite	Kraft
				80 percent yield	60 percent yield		
	Lbs./cord	Cords/ton	Cords/ton	Cords/ton	Cords/ton	Cords/ton	Cords/ton
Aspen	1,825	1.08	1.15	1.31	1.62	1.88	1.97
Black spruce	1,990	.99	1.06	--	--	1.90	1.96
Hemlock	1,990	.99	1.06	--	--	1.95	2.05
Southern pine	2,405	.83	--	--	--	--	1.66
Birch	2,490	--	.85	.96	.83	1.46	1.39
Beech	2,905	--	.76	1.18	1.02	1.54	1.41

The conventional stone grinding process involves holding logs under specified pressures against a rotating grinding wheel of a designated grit size, structure, and surface pattern. Bundles of fibers, individual fibers, and parts of fibers are separated from the log and further ground to form a pulp of desired fiber size distribution and strength. Low-density woods such as aspen are best suited to this process for the production of optimum groundwood quality (Hyttinen, Martin, and Keller 1960; Perry and Canty 1971).

In recent years, a second method for groundwood pulp manufacture has come into significant use. This is the refiner groundwood process which developed primarily as a result of the availability of chips from sawmills or other residue sources (Allan, Skeet, and Forgacs 1968). In this process, the wood chips are reduced to fiber and fiber fragments by refining in a series of attrition mills, commonly called disc mills. The resulting pulps are known by a variety of names — refiner groundwood, disc woodpulp, super groundwood (Richardson and Le Mahieu 1965), and others.

Although the two groundwood pulps are used in similar paper grades, the refiner pulp is usually superior in both tear and bonding strengths, has more long fibers, is poorer by varying degrees in opacity and brightness factors, and usually requires the papermaker to adapt his machine to a change in runnability.

Aspen groundwoods can produce the paper with highest printing quality of any groundwoods and their somewhat lower strength does not materially affect runnability factors on either the paper machine or the printing press.

Chemimechanical

Chemimechanical pulps are the result of a very mild chemical action to delignify and soften wood chips for subsequent refining in a disc mill (Leas 1968) at yield ranges of 80 to 95 percent. Steam treated pulps characterized by those from the Masonite and Asplund process are included in this category.

The chemical and steam treatments or combinations of the two permit more effective fiberizing and also allow the use of the higher density hardwoods. Certain physical properties are enhanced. These pulps have some use for fine paper but are most used in coarse papers and in many kinds of fiberboard (Fahey and Steinmetz 1971). In this latter category, the low density of aspen is an advantageous factor, especially for the low and medium density fiberboard field. Growth rate in the fiberboard market approaches 10 percent per year.

Semichemical

Semichemical pulps (Vamos, Lengyel, and Mero 1964; Van Eychen 1968) differ from the chemimechanical types by yielding less — 60 to 80 percent. The chemical treatment is somewhat more severe and the subsequent fiberizing requires less power. Some 3½ million tons of semichemical pulps were produced in the United States in 1970 using all types of hardwoods but with negligible aspen use.

Aspen pulpwood, however, is suitable for this process and the resulting pulps are usable in both fine and coarse paper. Almost all of the semichemical pulp tonnage goes into coarse paper grades where the yield per unit cost advantage of the higher density hard-

woods limits aspen use. In the fine papers, kraft and sulfite pulps are preferred.

Sulfite and Kraft

These processes together with bleaching delignify pulps completely and make them suitable for fine paper. The aspen pulp fibers resulting from these processes have special quality characteristics that make them particularly suitable for fine paper structure. They have thin- to medium-thick walls and a length to diameter ratio in excess of 30. While vessel elements are numerous, their diameter is well below that which results in the well-known and disastrous fiber pick problem associated with printing papers containing oak pulp. Thus the fine papermakers, especially those using sulfite pulps, have good reasons to want aspen in their wood procurement plan.

OTHER PULPING METHODS

New pulping methods arise from laboratory and pilot investigations but usually fail to replace those just presented for economic or pulp quality reasons, or both.

Solvent pulping is routinely offered for consideration as a commercial process. A goodly number of solvents together with a hydrolysis reaction will remove lignin from wood, but the processes remain unattractive despite steady promotion in isolated cases.

In general, the commercial potential for new pulping methods must be judged on the basis of the quality obtainable in relation to present methods and the pollution abatement technology economically available for these processes.

It is highly probable that if and when a new pulping process is put through the paces of pilot planting and commercial evaluation, aspen pulpwood would be one of the first wood species to be used.

SUMMARY AND CONCLUSIONS

In summary then, we know that aspen is available and is readily pulped by any of the commercial processes now in use. This fact strongly suggests that if and when pulping processes are changed, aspen will still be a readily usable source of pulp.

The bulk of the aspen pulpwood produced in the Lake States is used in the groundwood, chemimechanical, and sulfite processes. Aspen pulp in these processes provides the pulp quality needed at an economic advantage over other species.

The groundwood pulps are used mostly in printing paper grades. Here aspen provides highest printing quality and opacity without sacrificing runnability on either the paper machine or printing presses. The publication paper segment of the industry recently suffered production cuts but should recover with the general business upturn expected. Small quantities of aspen groundwood are used in tissue at some expense in quality but with economic advantage. This must never be considered a significant outlet.

Chemimechanical pulps are used principally in fiberboards and to a very limited degree in fine papers. In fiberboard, the low density of aspen is an important factor for the low and medium density products. The fiberboard market is expanding at a 5 to 10 percent rate per year.

Aspen is used in sulfite pulpmills for the production of pulps for fine paper grades. Sulfite pulping, however, is in decline and such mills are being shut down. Modifications of sulfite pulping with recovery systems are operating and planned for the Lake States. The real future of this outlet, however, is still cloudy and unpredictable.

Therefore aspen must look to groundwood and chemimechanical pulping for its future. Its advantageous fiber morphology, as shown on table 3, makes it a desirable wood fiber, but its low density is a serious economic disadvantage that limits expansion to other processes and paper grades.

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Table 3. — *Physical and chemical characteristics of five pulpwoods*[1]

Species	Morphology							Cellulose	Lignin	Hemi-cellulose	Density
	Fiber length	Vessel length	Fiber width	Wall thickness	Fiber volume	Vessel volume	Ray volume				
	Mm.	Mm.	Microns	Microns	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Aspen	0.95	0.55	18-40	2.2	53	33	14	53	16	31	22
Birch	1.20	.95	20-36	2.5	66	21	11	41	19	40	35
Maple	.70	.35	16-30	2.8	61	21	18	41	24	35	35
Spruce	3.20	--	28-40	2.9	93	--	6	44	28	28	24
Southern pine	3.50	--	35-45	3.8	90	--	10	41	29	30	30

1/ Sources of data: Forest Products Laboratory, Rydholm (1965), Joint Textbook Committee of The Paper Industry (1969), Marton and Alexander (1964).

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WOOD AND FIBER PRODUCTION FROM SHORT ROTATION STANDS

Dean W. Einspahr, *Senior Research Associate*
The Institute of Paper Chemistry
Appleton, Wisconsin

ABSTRACT. — Growing native and improved aspen on short rotations is recommended. Information on young sucker stands indicate that by using short rotations of 10 to 20 years and complete tree, chipping-in-the-woods harvesting, total annual volume production can be more than doubled. Additional major increases in volume production can be expected through the use of genetically improved trees, fertilization, and irrigation. Wood and pulp quality are expected to decrease only slightly from large-scale use of short rotation aspen.

For a number of years I have had the philosophy that "competition," not love, makes the world go around and I think that this concept will particularly apply to Lake States forestry in the 1980's and 1990's. Forests, as a source of woody raw material and forest management as many of us know it, will survive in the Lake States region only if we remain competitive. A major increase in both hardwood and conifer requirements is predicted. Hardwood needs, for example, are expected to increase by 400 percent by the year 2000 (USDA Forest Service 1965a). I am not naive enough to believe that we can grow red pine and jack pine rapidly enough to compete with southern pine and increase our share of that market, but I do feel that there is a possibility that we can remain competitive in producing hardwood fiber, particularly aspen.

The solutions most often suggested for meeting our raw material requirements include improved utilization, intensive forestry, and the use of genetically improved trees. The concept of short rotation aspen forestry encourages the use of all three approaches and for this reason is obviously not new. The objective of this paper is to present you with data indicating that a system of short-rotation forestry will work.

SYSTEM REQUIREMENTS

To make a short rotation cellulose system economically and biologically feasible requires the use of species that: (1) reproduce easily, (2) exhibit rapid juvenile growth, (3) have form and natural pruning that facilitates mechanical harvesting, (4) will respond to intensive management practices, and (5) have suitable juvenile wood and pulp quality. Such a system also requires an efficient method of harvesting and complete utilization of small-size trees.

SILVICULTURAL CHARACTERISTICS

The silvicultural characteristics of Lake States aspen, bigtooth and quaking aspen (*Populus tremuloides* and *P. grandidentata*), is well documented (USDA Forest Service 1965b). Aspen, particularly quaking aspen, is widely distributed geographically and has the ability to grow on a wide variety of upland soil types. Growth and development of aspen is strongly influenced by soil conditions, and aspen and aspen hybrids are expected to respond to intensive silvicultural procedures aimed at improving site quality. Noted for its vigorous production of root suckers, aspen rapidly occupies an area after being cut and develops into densely stocked stands containing trees with good straightness, good natural pruning, and narrow crowns. Also of considerable importance is the ability of aspen stands to develop, once established, with a minimum of silvicultural treatment.

SUCKERING AND VOLUME GROWTH

Rapid volume growth is essential to any short rotation system. In the case of aspen, the key to the rapid growth of juvenile stands is the vigorous suck-

ering of aspen and its ability to completely occupy a site within 2 to 3 years after harvesting. Sucker numbers, the first year after cutting, may run as high as 40,000 stems per acre. Rapid thinning occurs but stem numbers may still be as high as 14,000 at age 6, 8,000 at age 9 and 2,200 at age 23 (table 1). Height growth is normally rapid and is influenced by site quality. Diameter growth is usually quite slow but because of the large numbers of stems per acre, total volume growth is considerable.

The average volume growth for commercial forest lands in the Lake States region is estimated to be only 22 cubic feet/acre/year (USDA Forest Service 1965a). Published total volume growth data for aspen stands less than 20 years of age are extremely scarce. Information available indicates volume growth from unmanaged young sucker stands varies from 25 to 106 cubic feet per acre per year (table 1). Site quality on these stands ranged from poor to medium (estimated age 30 site index from 30 to 50); aspen growing on the better hardwood sites were not included. There is considerable evidence to show that by completely utilizing young aspen sucker stands (age 15 to 20 years), the harvested volume/acre/year will be approximately double the volume obtained by a conventional pulpwood harvest at age 40 (Benson and Einspahr 1972). The increased production appears to be due to rapid juvenile growth, complete [illegible]ation, utilization of virtually all the trees on an area, and the salvaging of volume growth that normally would be lost to disease and insects.

Under certain management situations it may be desirable to plant genetically improved aspen. To use improved aspen in the described coppicing system it is recommended that improved seedlings be planted at wide spacings (minimum of 80 square feet per tree). After 5 or more years, the planting could be cut back and in this way a sucker stand of the most vigorous clones established. Good volume growth is being obtained from plantings of some of the better materials presently available (table 2, fig. 1). The data illustrate the influence of age and spacing on total volume growth of young aspen plantings and indicate some of the alternatives available to the forest manager when establishing improved aspen. Suckering data on several of the materials listed in table 2 indicate that, after 8 years, annual volume growth on the first rotation of suckers will be 10 to 30 percent better than for the original planting (fig. 2).

Preliminary growth chamber studies with aspen seedlings and field studies involving both seedling and young sucker stands indicate moderate growth response (15-30 percent) can be expected from fertilization treatments. In those situations where it is feasible to both fertilize and irrigate, volume growth increases in excess of 100 percent appear possible (Einspahr *et al.* 1972a).

Table 1. — *Age, trees per acre, and volume of unmanaged young sucker stands*

Location	Age	Trees per acre	Total volume per acre	Average volume growth per acre per year	
	Years	Number	Cu. ft.	Cu. ft.	2/ Cds.
N. Wisconsin	6	14,463	151	25	0.29
N. Wisconsin	9	8,659	272	30	.35
N. Wisconsin	12	1,900	650	54	.64
Manitoba	13	7,695	1,373	106	1.25
Manitoba	14	5,990	830	59	.69
N. Wisconsin	15	2,200	1,379	92	1.08
N. Wisconsin	18	1,700	1,770	98	1.15
Manitoba	19	2,464	1,240	65	.76
Manitoba	23	2,226	2,082	91	1.07

1/ N. Wisconsin data from The Institute of Paper Chemistry, 13-year-old Manitoba data from Bella and Jarvis (1967) and the 14-, 19-, and 23-year-old Manitoba data from Steneker (1964).

2/ Based on 85 cubic feet per cord.

Table 2. — *Age, density, and volume of improved aspen in plantations*

Type[2]	Age	Trees per acre	Total volume per acre	Average volume growth per acre per year[3]	
	Years	Number[4]	Cu. ft.	Cu. ft.	Cds.
Triploid hybrid aspen (2)	5	538 (9x9)	76	15	0.18
Quaking aspen progeny (14)	5	2,420 (3x6)	211	42	.49
Quaking aspen progeny (2)	10	538 (9x9)	503	50	.59
Triploid aspen (1)	10	538 (9x9)	613	61	.72
Quaking aspen progeny (7)	10	1,210 (6x6)	1,075	107	1.26
Triploid hybrid aspen (2)	10	538 (9x9)	1,118	112	1.32
Quaking aspen hybrid (1)	10	538 (9x9)	1,300	130	1.53
Bigtooth aspen hybrid (1)	10	538 (9x9)	1,905	190	2.24
Triploid aspen (1)	13	538 (9x9)	1,361	105	1.24
Triploid hybrid aspen (2)	13	538 (9x9)	2,577	198	2.33

1 Test plantings have been adjusted to a standard 90 percent survival to make comparisons possible. Since actual survival for most was over 90 percent, the growth figures are conservative.

2 Number of progeny groups averaged is in parentheses.

3 Bark-free volume growth; based on 85 cubic feet per cord.

4 Spacing in feet given in parentheses.

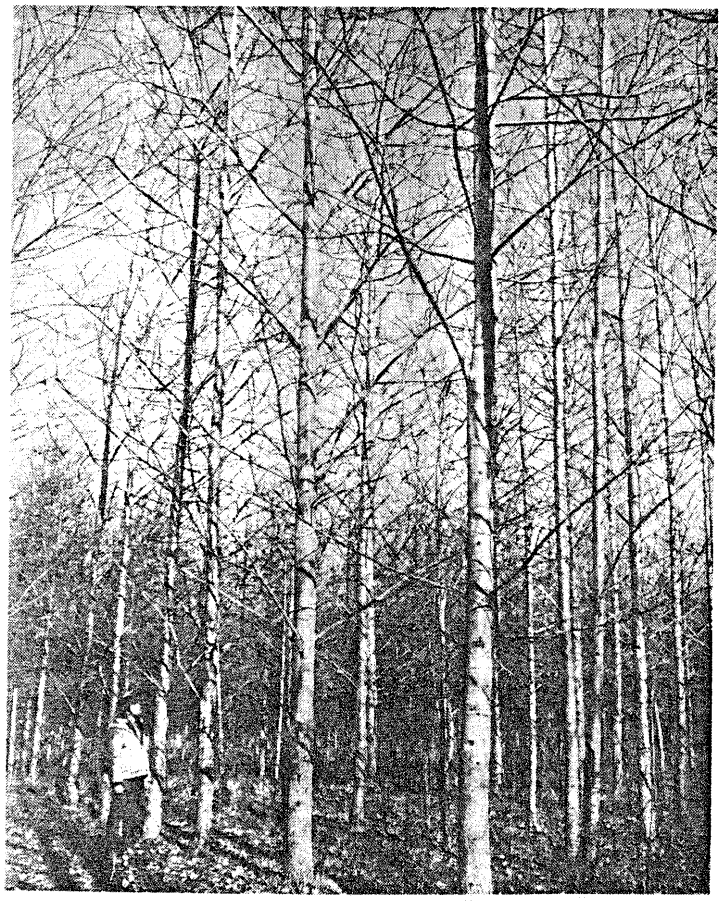

Figure 1. — *A triploid hybrid aspen planting that at age 13 has a mean annual increment of 198 cu. ft./acre/year. The planting is growing on a sandy soil in northern Wisconsin.*

Figure 2. — *Eight-year-old triploid hybrid suckers that have a mean annual increment of 120 cu. ft./acre/year. The sucker stand is growing on a sandy site in northern Wisconsin.*

WOOD QUALITY

Specific gravity, fiber length, and levels of lignin and extractives are important when considering wood as a raw material for papermaking. Characteristically, juvenile wood has less desirable wood properties than mature wood and the wood of aspen is no exception. The question then becomes, at what age do the overall wood properties improve to the point that the wood is suitable for use by the pulp and paper industry? Table 3 summarizes wood quality data from several studies involving juvenile aspen, and table 4 provides tentative estimates of wood quality/age relationships for quaking aspen. Slight specific gravity decreases and modest fiber length increases have been observed on rapidly growing aspen. The trends given in table 4 are for native sucker stands growing at average growth rates. Specific gravity appears to be little influenced by tree age in trees from ages 5 to 30 years. Tree-to-tree variation within age classes appears to be as great as the differences observed between trees of different ages.

Fiber length, on the other hand, appears to be strongly influenced by age and location within a tree (Einspahr *et al.* 1972b). Observations made on aspen pulps from numerous sources indicate that pulp from age 5 trees will have approximately 40 percent shorter fiber length than age 30 trees (table 4). Ten-year-old trees are expected to have fiber length about 80 percent of normal and by age 15 it has been estimated that pulp fiber length will be only 8 to 10 percent shorter than at age 30. Genetic improvement of fiber length has been one of the goals of aspen tree improvement work. Triploid hybrid aspen presently available have at age 10 pulp fiber lengths greater than 30-year-old native aspen. Use of such materials would make possible shortening the rotation age without any loss in fiber length.

Levels of lignin and extractives are important because they provide estimates of maximum possible pulp yield and suggest, in the case of extractives, possible paper machine pitch problems. Lignin levels in young aspen are consistently less than those for mature aspen, but overall differences between age 10 and age 30 are relatively small (18 *vs.* 19 percent) (table 4). Five-year-old aspen often exhibit high levels of extractives but by age 10 extractive levels appear to be near normal. At rotation ages of greater than 10 years, no extractive problems are anticipated.

PULP QUALITY

Pulp quality of juvenile aspen has also been investigated, although not as extensively as wood quality. The amount and type of pulping data available for review has resulted in a less well-defined "age" relationship than was evident for wood properties. Pulp yield, based upon age 5 micropulping information, indicates yield of extremely young aspen will be as much as 4 percent lower (48 *vs.* 52 percent) than 30-year-old aspen. Ten-year-old diploid aspen,

Table 3. — *Variation in quaking aspen wood quality*

Source and type data	Tree age	Specific gravity	Fiber length wood[1/]	Lignin	Extractives
	Years		Millimeters	Percent	Percent
Aspen Heritability Study[2/]					
1958 plantings	5	0.37	0.63 (3-5)	18.5	3.7
1959 plantings	5	.37	.63 (3-5)	17.9	4.7
1960 plantings	5	.37	.59 (3-5)	17.8	4.2
Micropulping Study[3/]					
Diploid families	5	.37	.53 (5)	17.8	6.8
Triploid clones	5	.36	.61 (5)	17.2	6.3
Triploid hybrid families	5	.40	.70 (5)	17.2	5.4
Fertilizer/Irrigation Pulping[4/]					
Control	9	.33	.66 (7-9)	17.5	1.5
Fertilizer (F)	9	.33	.68 (7-9)	17.4	5.4
Water (W)	9	.32	.72 (7-9)	17.6	2.4
F + W	9	.30	.68 (7-9)	16.7	4.9
Whole Tree Pulping Study[5/]					
Diploid families	10	.35	.86 (9-10)	18.0	3.4
Triploid clones	10	.34	.96 (9-10)	18.4	3.3
Triploid hybrid families	10	.42	.99 (9-10)	18.0	3.5
Mature diploid	33	.35	.97 (30)	18.9	3.4
Whole Tree Clonal Study[6/]					
Mature diploid	30	.40	.87 (30)	--	--

1/ Fiber length based upon annual rings indicated by the numbers in parentheses.
2/ Einspahr *et al.* (1967).
3/ Einspahr *et al.* (1968).
4/ Einspahr *et al.* (1972b).
5/ Einspahr *et al.* (1970).
6/ Buijtenen *et al.* (1962).

Table 4. — *Estimated wood quality/age relationships*

Tree age (years)	Specific gravity[1/]		Fiber length: Pulp		Fiber length: Wood[2/]		Lignin	Extractives
		Percent	Mm.	Percent	Mm.	Percent	Percent	Percent
5	0.37	97	0.50	57	0.73	69	17.7	5.2
10	.37	97	.71	82	.85	80	18.0	3.5
15	.37	97	.80	92	.94	89	18.2	3.5
20	.38	100	.85	98	1.00	94	18.5	3.4
30	.38	100	.87	100	1.06	100	19.0	3.4

1/ Specific gravity estimates based upon b.h. disk samples, dry weight ÷ green volume. Percentages were obtained by calling age 30 trees 100 percent.

2/ Values taken from fiber length/age curve prepared from b.h. wood samples. Percentages were obtained by calling age 30 trees 100 percent.

based upon limited data, are expected to have pulp yields about 2 to 2½ percent lower than 30-year-old aspen. The yield of puckerbrush chips (Chase *et al.* 1971) of unknown tree age was lower than that of the other studies reported and appears, in part, to reflect differences in cooking conditions and type of chip sample employed.

Zero-span tensile strength, which is considered a measure of fiber strength, appears to be about the same for young aspen as for mature aspen. Tear, burst, and tensile strength (breaking length) seems to have been little affected by tree age. Although based upon a limited amount of data, it appears that pulp of 10-year-old trees can be used successfully to replace pulp from mature aspen. Chase and his associates (1971) drew similar conclusions in their study of Maine aspen puckerbrush chips.

HARVESTING AND DEBARKING PROBLEMS

Important to the short rotation concept is the availability of an efficient method for harvesting and debarking small-sized trees. The method most often suggested is to chip the material in the woods and then segregate the wood and bark mixture after chipping. Such a procedure is already a reality and makes it possible to utilize the entire stem plus branches and also allows the bulk handling of the chips from the woods to the mill. Recent "chipping in the woods" demonstrations in northern hardwoods have added considerable impetus to the short rotation concept (Paper Trade Journal 1971). The harvesting system employs a feller buncher, skidders, and a high capacity truck-mounted chipper. The system essentially doubles the yield of wood chips from an acre of northern hardwood land by utilizing "nonmerchantable" trees and by utilizing all trees more completely. Production rates in excess of 400 tons (green weight) of chips per 8-hour day are attained with a 6-man crew. The rapid rate of production is the result of chipping the trees prior to debarking and the ability of the chipper to handle multiple stems. Additional technological advances are expected which will put the short rotation concept in an even more favorable economic position.

Bark, a perennial problem to the forester and papermaker, offers an interesting challenge to short rotation forestry. Research on aspen wood bark separation and segregation indicates that aspen bark may well be one of the easiest to handle and can be separated by several different techniques. One approach is to pulp the bark right along with the wood (Chase *et al.* 1971). Another approach is the use of the compression debarking technique developed by Blanchard[1] and described by Blackford (1961, 1965) and recently modified and demonstrated by the North Central Forest Experiment Station's Forest Engineering Laboratory in Houghton, Michigan. Still another promising approach is a water flotation procedure described by Einspahr *et al.* (1968) that depends upon specific gravity and moisture content differences between bark and wood to cause segregation of bark and wood mixtures. Also very promising is the procedure described and patented by Lloyd *et al.*[2] which employs a combination of bark compression, screening, and water flotation and is expected to handle wood/bark chip mixtures under a variety of conditions.

SUMMARY

Volume growth of juvenile native aspen is rapid. Increased growth is expected from use of genetically improved trees and through intensive silviculture. Wood and pulp quality for trees 10 years of age and older appears to be adequate for a variety of products. Efficient bark segregation procedures are available. All that appears to be required is a little courage on the part of forest managers.

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[1] *Blanchard, F. G. U.S. Patent 3,070,318, 1962.*

[2] *Lloyd, W. D., Robert E. Lee, and Kimberly-Clark Corporation. Treatment of hardwood chips for bark and wood separation. U.S. Patent 3,337,139. Aug. 22, 1967.*

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YOUTH, MATURITY, AND OLD AGE

James S. Fralish, *Assistant Professor*
Department of Forestry, Southern Illinois University
Carbondale, Illinois

ABSTRACT. — Aspen ecology is examined in mature, regenerating, and overmature stands. Investigations in mature stands indicate that aspen growth is controlled primarily by soil water-holding capacity (texture), water table depth, and exposure to wind. These same factors control the rate of aspen conversion but the availability of seed must also be considered. Aspen seedling and sampling densities may be influenced by competing vegetation, site treatment after harvesting, and drainage. Deteriorating (overmature) stands are becoming common, can be regenerated, and should now be considered in forest management planning.

The present aspen forest in northern Wisconsin began with the timber harvesting and extensive fires of the early 1900's, but it was not until the 1950's that aspen was recognized as an important tree species. Then with large areas of aspen forest nearing maturity and providing a supply of pulpwood, aspen suddenly became an economically desirable forest species. Most northern pulpmills now use aspen pulpwood to the near exclusion of other species. In addition, it is recognized as an important food for deer and grouse.

The end of the first aspen forest in Wisconsin is approaching as stands continue to be harvested. In the second aspen forest, which has already begun, there are substantial changes that will have a bearing on the economics and operation of the industries that depend on aspen. The present paper summarizes the author's investigations on the ecology of quaking aspen in north-central Wisconsin as it may affect future aspen silviculture, management and supply.

Because geographic conditions vary greatly and the ecological considerations may be applicable to other States and regions, a brief review of the climatic and soil conditions is necessary. Within the counties of Langlade, Lincoln, Oneida, Vilas, Sawyer and Price, a climatic gradient exists from southeast (Lincoln County) to northwest (Sawyer County); the average growing season temperature decreases from 68.6° F. to 66.6° F.; the growing season precipitation increases from 14.7 inches to 16.1 inches; and the growing season length decreases from 130 to 107 days (U.S. Department of Agriculture 1941).

Upland soils of the area are classes as Spodosols (weak Podzols intergrading to Gray Brown Podzolics) with an albic (A_2) horizon near the surface and an underlying spodic (B_{hir}) horizon. Soil textures range from coarse sand to fine silt loam depending on the initial material. Soils formed in glacial outwash (Crivitz, Hiawatha, and Vilas series) range from sand to light sandy loam, and from heavy sandy loam to loam for soils formed in glacial till (Elderon, Iron River, and Pence series). These soils are well to excessively drained but often have water tables in the lower part of the rooting zone. Soils formed in loess have silt loam textures; a mottled fragipan at a depth of 12 to 22 inches usually restricts root growth and slows the rate of percolation through the profile. These soils are moderately well and well-drained on slopes and ridge tops (Goodman, Lynne, and Stambaugh series), and somewhat poorly drained in depressional areas (Clifford series). In this paper, soils formed in glacial outwash, glacial till and loess will be referred to as coarse-, medium-, and fine-textured soils respectively.

MATURE STANDS

Growth

Past studies (Kittredge 1938, Stoeckeler 1948, [illegible]; Wilde and Pronin 1950; Voigt, Heinselman, and Zasada 1957; Meyer 1956; Strothmann 1960; Graham, Harrison, and Westell 1963) have frequently related aspen growth rates to some characteristic of soil (texture, horizon thickness, stoniness, pH, cation exchange capacity and organic matter and nutrient levels) or of site (slope, aspect and topographic position). In the northern Wisconsin study[1] aspen site index was related to some of the above soil and site factors as well as additional factors that proved to be quite important. The following paragraphs on aspen growth summarize the results of that study.

Aspen site index is strongly influenced by soil texture. As the percentage of silt increases from 5 to 90 percent, average site index (age 50) increases from 69 to 85 (fig. 1). A similar relationship exists with decreases in the percentage of sand from 95 to 5 percent. In general, stands on coarse-, medium-, and fine-textured soils have site indices that range from 66 to 72, 72 to 78 and 78 to 85 respectively; however, the influence of other site factors (e.g., water table depth) will cause considerable overlap between ranges. These relationships agree closely with those from other previously cited studies.

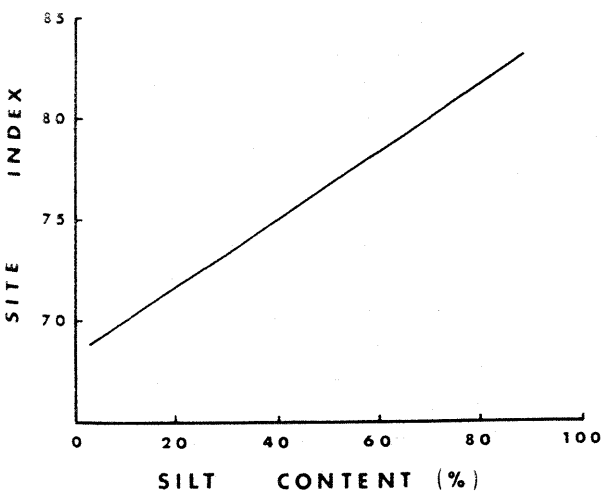

Figure 1. — *Relationship of aspen site index to silt content of the soil.*

Moreover, for growth to occur, a tree must utilize the primary substances obtained from soil — water and nutrients. Thus, using a formula developed by Auclair and Cottam (1971) the available water-holding capacity of the soil was calculated for each stand. The average water storage capacity in inches per foot of soil depth for coarse-, medium-, and fine-textured soils is approximately 1.50, 2.50 and 4.0 respectively. Statistically, the relationship between site index and available water-holding capacity is very strong (r. = 0.658) and indicates that growth is controlled by available soil water.

Because soil water is of major importance, it is relatively easy to understand how other soil factors affect aspen growth. The stoniness of the soil affects aspen growth by decreasing the water-holding capacity of the soil by decreasing the amount of space where water can be held. A soil that is 25 percent stone will have a site index that is at least five feet lower than for a nonstoney soil, other factors being equal.

A water table within the rooting zone will increase aspen growth by providing additional amounts of available water. However, the relationship between site index and water table depth is not linear (fig. 2). Water tables between 3 and 8 feet in depth will greatly increase aspen growth, particularly in the coarse- and medium-textured soils. Water tables deeper than 8 feet will have little effect on growth because few roots penetrate to that soil depth. Water

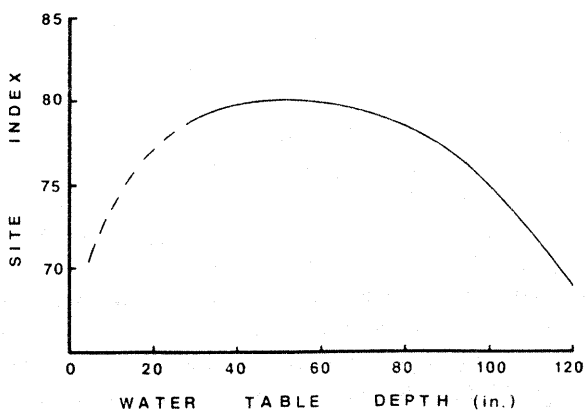

Figure 2. — *Relationship of aspen site index to water table depth.*

[1] *Fralish, James S. 1969. Site indices and rate of conversion in northern Wisconsin quaking aspen. Ph.D. dissertation. Univ. of Wisconsin, Madison.*

tables less than 2 feet in depth will decrease aspen growth because of decreased space and air that is necessary for roots to develop and support a large tree.

Subsurface horizons of substantially finer texture are particularly important on coarse-textured soils that seldom can retain enough water for maximum aspen growth. These horizons influence aspen growth in a manner similar to that of a water table. They prevent water from being lost from the rooting zone, and, if they are not restrictive to root growth, will substantially increase aspen site index.

The effect of the water table on aspen growth becomes less important on the fine-textured soils (fig. 3), because sufficient water for growth is already held by soil particles. In addition, the shallow fragipan slows the rate of water movement through the profile. However, when water accumulates on or near the surface, as in the poorly drained silt loam soils, site index may be very low (less than 40).

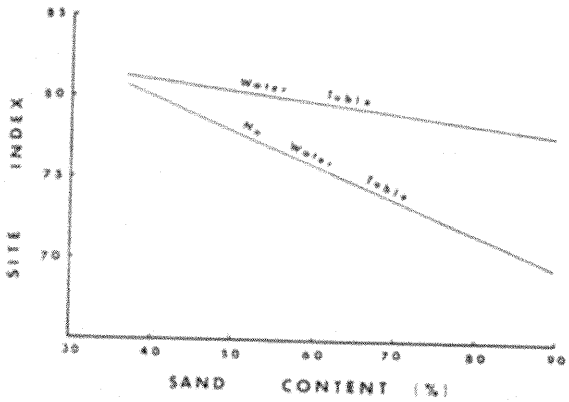

Figure 3. — *Relationship of aspen site index to water table depth and sand content of the soil.*

If aspen growth is primarily dependent on soil water, then will site factors that increase the rate of water loss from a site or tree (evaporation or transpiration) affect growth? The answer is an unqualified yes; because of more rapid soil water depletion, there will be more frequent periods of longer duration when water is unavailable to the tree. Most of the previous site studies on aspen have investigated aspect, slope, and topographic position. Stands located on south, southwest, and west aspects, on steep slopes, or on ridge tops tend to have lower site indices because of increased evapotranspiration or runoff rates.

Wind is an additional factor that has been usually overlooked in most aspen studies but it is important because wind also affects evapotranspiration rates. Exposure to wind is nearly as important in influencing aspen growth as soil water-holding capacity and water table depth. Isolated stands and stands located on ridge tops have lower site indices because of higher internal wind velocities than stands on middle slopes or stands protected by forest on two or more sides, particularly the south, southwest, and west sides. In general, protected stands whether in valleys, between ridges, or surrounded by forest, have higher site indices than unprotected stands, other factors being equal.

Soil nutrient levels have very little effect on aspen growth in northern Wisconsin; similar results for Wisconsin aspen were obtained by Stoeckeler (1960). However, Voigt and others (1957) and Stoeckeler (1960) found that site indices increased as levels of phosphorus, potassium, calcium, and magnesium increased in Minnesota soils.

Compositional Changes

Shade intolerant species such as aspen eventually will be replaced by shade tolerant species that form a more stable forest community. In the northern Wisconsin study,[2] the environmental factors that control growth, soil water-holding capacity, water table depth, and exposure, also were found to control the species composition of stands replacing the present aspen stands. However, the presence or absence of a seed source may also have a significant effect. The following paragraphs on compositional changes in aspen stands summarize the results of the above study.

On coarse-textured soils (Crivitz, Hiawatha, and Vilas series), rapid aspen succession is not a problem. At present, 70 percent of the aspen stands do not have any or have very light understories. Hardwood species such as sugar maple, white ash, basswood, and American elm rarely grow on these soils because of their droughty nature. In 30 percent of the study stands there are up to 150 stems per acre of red maple, white birch, and red oak.

If mature white pine trees are present within a 10-chain radius of a stand generally there will be

[2] *Ibid.*

white pine in the understory. However, even with an adjacent white pine seed source, the present white pine understories are not dense, having an average of only 135 stems per acre.

After aspen stands are clearcut on coarse-textured soils at the end of the present rotation, aspen suckers sufficient to form another stand will grow through the low density pine and/or hardwood understory which averages less than 200 stems per acre for all stands investigated. A few mixed stands of aspen-hardwood or aspen-hardwood-pine may result but the problem of aspen conversion may be more serious in one or two rotations when the understories are better developed.

On medium-textured sandy loam and loam soils (Elderon, Iron River, and Pence series), white pine and northern hardwood species also may be found in mixture or separately in the understory. The proportion of pine and hardwood in the understory usually depends on the availability of seed from adjacent seed sources. In general, aspen stands on the medium-textured soils exhibit moderate conversion rates. Therefore, changes in the acreage and volume of aspen on these soils can be expected.

After a clearcut of stands on the medium-textured soils, approximately 25 percent of the sites will immediately convert to the northern hardwood or northern hardwood-white pine forest type, and another 45 percent of the new stands will be some combination of aspen, northern hardwood, and pine. Approximately 30 percent of the stands will regenerate to relatively pure stands of aspen.

Stands on the moderately well-drained and well-drained fine-textured silt loam soils (Goodman, Lynne, and Stambaugh series), are rapidly converting to the northern hardwood forest type. These soils have high water holding capacities and are rapidly invaded by sugar maple, red maple, yellow birch, white ash, green ash, American elm and red elm. White pine is usually not a component of the forest understory in many parts of north-central Wisconsin. White pine of any size is noticeably absent, particularly in the Newwood River area of Lincoln County and parts of Price and Sawyer Counties. Surveyor's records indicate that white pine was once a component of the forest in these areas, but apparently it was eliminated during the cutting and fires of the early 1900's.

After aspen stands are clearcut on the silt loam soils, 45 percent of the sites will immediately convert to the northern hardwood forest type and another 45 percent will convert to some combination of aspen and hardwood. Approximately 10 percent of the sites will remain in pure aspen. At the end of the next rotation, aspen will not be an important species on the fine-textured soils unless drastic methods are used to maintain it.

YOUTH

Foresters recently entered a new phase in aspen management when the vast areas of mature stands began to be replaced by young stands of aspen or northern hardwoods. Management problems and procedures for these young aspen stands are considerably different than those for mature stands and several questions need to be answered.

How does reproduction density vary with the soil texture, amount of overstory remaining, or understory density? How effective is site treatment in removing competing species and maintaining aspen? Do the results of site treatment vary with the soil texture and drainage?

In north-central Wisconsin, clearcut aspen stands on coarse-textured loamy sand and fine-textured silt loam soils were studied in an attempt to answer these questions (Fralish and Loucks 1968; Fralish 1971). Approximately one-half of the clearcut stands investigated had been subsequently treated (cleared) by a bulldozer and a K-G blade or disk. Generally the data for clearcut but untreated stands on silt loam soil are for stands that are slowly changing in composition; rapidly converting stands were more difficult to locate since, after cutting, these stands immediately converted to northern hardwood species.

In general, a few small trees remained after harvesting operations in clearcut stands; on a per acre basis only 51 and 44 trees ($\geq$ 3.5 inches) remained standing on loamy sand and silt loam soils respectively (table 1). Aspen reproduction did not appear to be affected by this low number of overstory trees, although larger numbers could increase competition and reduce the number and growth of suckers. Stands that were both clearcut and treated by bulldozing had no overstory trees and the brush and hardwood understory common to fine-textured soil was also absent.

Table 1. — *Density of residual trees in 3- and 4-year-old stands after clearcutting and in overmature stands on loamy sand and silt loam soils (stems/acre ≥ 3.5 in. d.b.h.)*

Species	3- and 4-year-old stands		Overmature stands	
	Loamy sand	Silt loam	Loamy sand	Silt loam
Aspen	15	38	115	138
Pine	8	0	3	1
Northern hardwoods	2	6	1	93
Red maple	10	0	7	1
White birch	14	0	7	11
Miscellaneous	2	0	2	10
Total	51	44	135	254

The average number of aspen seedling and sapling stems per acre for 3- and 4-year-old clearcut stands on loamy sand soils (Crivitz, Hiawatha, Vilas series) varied between 12,700 and 13,700 on both treated and untreated sites (table 2). In 1-year-old stands, there are probably 16,000 to 18,000 stems per acre. The data indicate that lack of aspen reproduction is not a problem on sandy soils even where the former stand was mixed aspen and jack pine. In stands investigated disking had been employed to stimulate jack pine reproduction rather than aspen; at present aspen dominates these sites.

After stands were harvested on moderately well and well-drained silt loam soils (Goodman, Lynne, and Stambaugh series), aspen reproduction developed quickly and in high numbers (approximately 18,000 stems per acre in 1-year-old stands)if hazel and northern hardwoods were absent from the site. Very few of these stems were browsed by deer. In 3- and 4-year-old stands, aspen density decreased to 12,352 stems per acre (table 2) indicating a high mortality rate due to intense interspecific competition.

However, aspen suckers developed rather slowly and in lower numbers (approximately 5,600 stems per acre in 1-year-old stands) on fine-textured soil if heavy hazel was present on the site. Approximately 50 to 60 percent of these stems were browsed by deer. Moreover, suckers apparently continued to develop; at age 4 there were 8,162 stems per acre. Hazel definitely reduces aspen suckering but does not compete sufficiently to prevent a new stand from developing. Where hazel is very dense, prescribed burning can probably be used to reduce competition.

Table 2. — *Density of seedlings and saplings in 3- and 4-year-old stands after clearcutting and in overmature stands on loamy sand and silt loam soils (stems/acre < 3.5 in. d.b.h.)*

Species	3- and 4-year-old stands						Overmature stands	
	Clearcut			Clearcut and treated				
	Sand	Silt 1/	Silt 2/	Sand	Silt 1/	Silt 2/	Sand	Silt
Aspen	13,647	12,352	8,162	12,766	10,764	8,084	1,602	728
Pine	3/358	0	0	3/233**	0	0	3/116*	0
N. hardwoods	0	48	24	0	80	20	2	1,537
Red maple	80	812	266	542	40	20	245	309
Red oak	132	0	0	60	0	0	206	2
Willow	220	1,820	602	873	880	5,408	129	297
Miscellaneous	362	912	196	461	1,992	128	534	174
Total	14,799	15,944	9,250	14,935	13,752	13,660	2,834	2,045

1/ No understory competition.
2/ Heavy brush competition.
3/ Moderately well-drained soils.
4/ Somewhat poorly drained soils.
5/ White pine.
6/ Jack pine.

Dense advanced hardwood reproduction prevents aspen suckering. As previously mentioned, the clearcut but untreated stands on silt loam soils generally had low numbers of advanced hardwood reproduction and, therefore, had high numbers of aspen suckers. On sites where large numbers (500 or more per acre) of hardwood stems are present, the conversion rate is rapid and the site must be treated if aspen is to be maintained. The treated sites are now covered with well-stocked young aspen stands (table 2) but without treatment aspen would have been excluded as the sites were stocked with advanced hardwood reproduction after clearcutting but prior to treatment.

On somewhat poorly drained silt loam soils (Clifford series), the treated sites had approximately 18,000 stems per acre at age one, but at age four only 8,084 stems remained and most of these stems were located on small raised mounds. The surrounding lower and more poorly drained areas were nearly devoid of aspen reproduction. Therefore, it appears that sites with somewhat restricted drainage should not be treated but be allowed to convert to northern hardwoods.

Other species such as black cherry, red maple, white birch, juneberry, and pin cherry are found in nearly all stands. Only willow showed a relationship between density and soil texture or site treatment (table 2). Willow has a much higher density on the silt loam soil, especially on the treated sites. These higher densities reflect not only the more favorable moisture conditions but also the stimulating effect of site disturbance.

OLD AGE

The phenomenon of aspen stand deterioration (natural breakup) is a relatively new problem in forest management (Fralish and Loucks 1968; Fralish 1971). It should not be assumed to occur with the same frequency or at the same stand age throughout the geographic range of aspen. Some evidence indicates that natural breakup varies with climatic conditions.

In central Wisconsin maximum stand age ranges from 25 to 35 years (Portage County), while 75 miles to the north (Lincoln County) maximum stand age ranges from 45 to 50 years. In Sawyer County, 100 miles northwest of Lincoln County, maximum stand ages range from 55 to 60 years. Aspen stand ages in northern Minnesota may reach 100 years (Zehngraff 1947). Although other climatic factors may be influencing maximum stand age, there is some correspondence to summer temperatures. Mean July temperatures for these four geographic areas are 71° F., 69° F., 67° F., and 63° F. respectively (U.S. Department of Agriculture 1941).

Deterioration appears to follow a definite pattern in each stand. During the ages of rapid growth the even-aged condition of the stands creates severe competition for light and moisture. As less vigorous, slower growing individuals die, openings are created that are rapidly closed through radial crown growth of faster growing individuals. Because of the closely packed canopy and even-aged condition, the trees become dependent on a continuous canopy to prevent exposure and breakage by wind.

Growth slows as maturity is reached, thus when individual trees die, the canopy holes cannot be closed as during earlier periods of rapid growth. As the canopy becomes more open, the frequency of breakage increases. Moreover, the open canopy exposes the stand to the stresses of increased wind, sunlight, and evaporation. Aspen physiology is not designed to tolerate these sudden stresses and the tree usually dies, or becomes less vigorous and thus more susceptible to disease and insect attack which further increases the frequency of breakage. The entire process of deterioration may take no longer than three or four years.

In mature stands, aspen density may average from 300 to 400 trees per acre. In deteriorating stands, aspen density ranges from 115 to 138 trees per acre (table 1) and is decreasing. The stands are relatively open and the trees often, but not always, show evidence of heartrot.

Overmature stands on loamy sand soil have low numbers of aspen seedlings and saplings because suckering is inhibited by the remaining overstory (table 2). The stem densities of other species are also low so that these sites are converting to open, nonproductive forest and brush, primarily uneven-aged aspen, *Rubus*, and related species. However, as long as a few live aspen trees per acre remain, such stands can probably be regenerated through the removal of the overstory and disking to stimulate suckering. In some cases, it may be preferable to refrain from treating such areas in order to create a natural opening for wildlife.

Where aspen stands deteriorate on fine textured soils, generally hardwoods will occupy the site because an overstory remains to inhibit aspen suckering and there is severe competition from the hardwood understory. Site treatment to remove the overstory and hardwood understory will probably regenerate the aspen; however, more research needs to be done on deteriorating stands.

MANAGEMENT IMPLICATIONS

The ecological relationships between quaking aspen, soil and site characteristics, and associated vegetation have both long and short management implications to land managers. The relationship between site index and conversion rate, both of which increase on the fine-textured silt loam soils, is important. The best aspen sites are being lost to the northern hardwood types, thus as conversion continues the total volume and acreage of aspen will decline drastically. Average aspen growth and volume per acre can be expected to decrease because only the poorer sites will remain in aspen.

Perhaps management should consider the economics of using more hardwood pulp as opposed to the continued use of aspen pulp. Hardwood species are slower growing, but no effort is needed to maintain them on silt loam soil. Maintenance of aspen through site treatment methods results in increased costs, but aspen is faster growing and at present mills are equipped to handle aspen pulp. Because the greatest conversion to hardwood will occur at the end of the present rotation, these economic evaluations should be made immediately.

However, site treatment to regenerate aspen must be judiciously applied. Poor aspen sites that are converting to northern hardwoods on somewhat poorly drained fine-textured soil should be permitted to continue. On coarse-textured soils, site treatment should not even be considered. In areas where overmature stands are common, regenerating these stands may be necessary especially with the reduction in aspen acreages in the years ahead. In general, it appears that foresters will have to do some precise management planning.

Finally, foresters should not limit the types of site treatment methods that can be employed to regenerate aspen. At present, only mechanical methods have been attempted and found satisfactory. However, the present aspen forests were the result of cutting and fire, thus prescribed burning should be investigated as a possible management tool.

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NATURAL SUCCESSION IN NORTH-CENTRAL MINNESOTA

Henry L. Hansen, *Professor*
University of Minnesota, St. Paul, Minnesota
and
Vilis Kurmis, *Research Associate*
University of Minnesota, St. Paul, Minnesota

ABSTRACT.— A large area of aspen forest in Minnesota will not be harvested, and the nature of the succeeding forest will depend on natural successional processes. These changes have great significance for future wood supplies and deer and grouse habitat. This study examines the nature of forest succession in north-central Minnesota and describes variations in stand composition that will occur under different site conditions. Three broad lines of succession are described leading to stands of tolerant hardwoods, mixed oak with dense shrub understories, and "shrubwood."

THE PROBLEM

The aspen type covers 13½ million acres, approximately a quarter of the commercial forest land in the Lake States. In Minnesota it is the State's largest forest type, occupying over 5 million acres. Most of this type is in the older age classes, between 30 and 60 years. Using timber management projections by Lundgren[1] it appears that the present two million cord annual cut of this species will increase by an area equivalent to about 5 thousand acres per year. However, even with this increasingly large acreage cut there is a considerable present underutilization of the aspen type, and a vast area in excess of two million acres will not be harvested and will be subject to "natural" successional processes. This is particularly true in Minnesota where the ratio of utilization to acreage and growth is lower.[2]

The great capacity of aspen to sucker from shallow lateral roots following logging or fire is well known. Harvested stands, particularly if clearcut, seldom pose regeneration problems unless conversion to other species is desired. However, what succeeds the aspen on the large uncut areas is of great importance to the wood-based industry of Minnesota and the Lake States. In addition, the great value of this type for deer, moose, and grouse habitat make a knowledge of the successional processes of even greater concern.

This report considers the successional processes and site interrelationships of aspen stands in Minnesota under relatively undisturbed conditions. It considers projections in time assuming the stands studied will not be logged or burned but subject to "normal" attrition by insects, disease, old age, and wind.

THE STUDY AREA

The study was conducted in Itasca State Park in north-central Minnesota. This area was selected because it has been subject to a minimum of disturbance by logging or fire for the life span of the existing aspen stands. Itasca State Park covers approximately 33,000 acres and contains elements of the mixed conifer-hardwood, deciduous, and boreal forests with influence of prairie conditions to the west. The climate is typically continental. Surficial geology reflects a complicated glacial history and the effects of the movements of three ice lobes. Soils have developed on tills and outwash of gray drift origins. They belong mainly to the Nebish-Rockwood and Menahga-Marquette soil associations and vary widely in soil texture.

SAMPLING AND METHODS

An attempt was made to sample the entire range of ecological conditions prevailing in the area. From a preliminary survey representing all major upland

[1] *Lundgren, Allen L. Timber management: projections for the 70's. (Unpublished paper for A Symposium on the White-tailed Deer. 1971.)*

[2] *See Leuschner, William A. Projections of inventories in the Lake States. p. 10-15.*

cover types, 36 stands were selected as representative of the upland site spectrum (Kurmis).[3] Intensive plant and soils data were collected on these stands. In addition, 25 aspen stands were added to intensify the sampling of this cover type; another 27 stands included lowland types not in the original survey. This total of 88 stands represented all major forest cover types and included 35 aspen stands. The basic data collected included tree diameters, ages, and heights, shrub understory characteristics, soil profile descriptions, and plant lists of woody and herbaceous species.

Prediction of current successional trends in forest stands require a knowledge of the species composition of the present stands, the role played by each species, and the site characteristics. Data on species composition were obtained from the field studies for individual stands. Since aspen is a transient type on a great range of site conditions, succession to other types can be expected to vary depending on site.

To provide the necessary framework of site or ecological characteristics, the method of synecological coordinates was used. This method was formalized by Bakuzis[4] and is described by Bakuzis and Hansen (1959). Briefly, it is based on a knowledge of the behavior of individual plant species in nature under conditions of competition with respect to moisture, nutrient, heat, and light factor complexes. Individual species are given relative values from 1 to 5 according to their prevailing occurrence at different intensities of the factor complexes. Species occurring at the lowest intensity of the factor complex are assigned a value of 1 for that factor and those associated with the highest intensity are rated 5. A species such as jack pine with high light requirements has a value of 5 for light. Tamarack, confined in natural stands to the wettest sites, has a value of 5 for moisture. Community values are computed as averages of the values of all species in the community. These values were determined for all stands studied. The edaphic complex as described by the moisture-nutrient value was considered to provide the basic framework for examining the successional patterns of the aspen stands.

Each stand was classified by its cover type using preponderance of basal area by species as the basis. Ten cover types were recognized (upper diagram, fig. 1). The stands were analyzed as to their community values. Each stand was then plotted by its pair of moisture and nutrient values to produce the total distribution pattern (fig. 1). Eight site units representing combinations of different moisture and nutrient levels were identified as being ecologically meaningful.

LITERATURE REVIEW

While numerous studies of forest succession have been made in Itasca State Park and elsewhere in Minnesota, two are considered particularly relevant to this report. Heinselman (1954) investigated natural conversion in the aspen-birch type in the Lake States using the character of the "invading cover type" as indicative of the developing forest types. He defined 5 "ecological regions" in the aspen-birch type distribution in the Lake States. The Itasca State Park area was located in an oak-pine-hardwood belt. Heinselman predicted that about a fourth of the total Lake States aspen area would convert primarily to northern hardwoods and balsam fir in 30 to 50 years. In over half the aspen area there was no appreciable present indication of conversion. He estimated complete conversion to be in process on over 40 percent of the type in Wisconsin and Upper Michigan but on only 20 percent in Minnesota.

Ness[5] described the aspen type in Itasca State Park in connection with his research on the comparative dynamics of upland forest communities. While aspen currently covers almost half the total park acreage, Ness predicts the structural disintegration and overmaturity of most of the aspen cover type in 30 to 40 years. In few instances does aspen appear capable of predominance in the next generation stand overstory.

[3] *Kurmis, V. Dynamics of advance reproduction in upland forest communities in Itasca State Park, Minnesota. (Unpublished Ph.D. thesis, University of Minnesota, 166 p. 1969.)*

[4] *Bakuzis, E. V. Synecological coordinates in forest classification and in regeneration studies. (Unpublished Ph.D. thesis, University of Minnesota, 242 p. 1959.)*

[5] *Ness, D. D. Comparative dynamics of upland forest communities in Itasca State Park, Minnesota. (Unpublished Ph.D. thesis, University of Minnesota, 447 p. 1971.)*

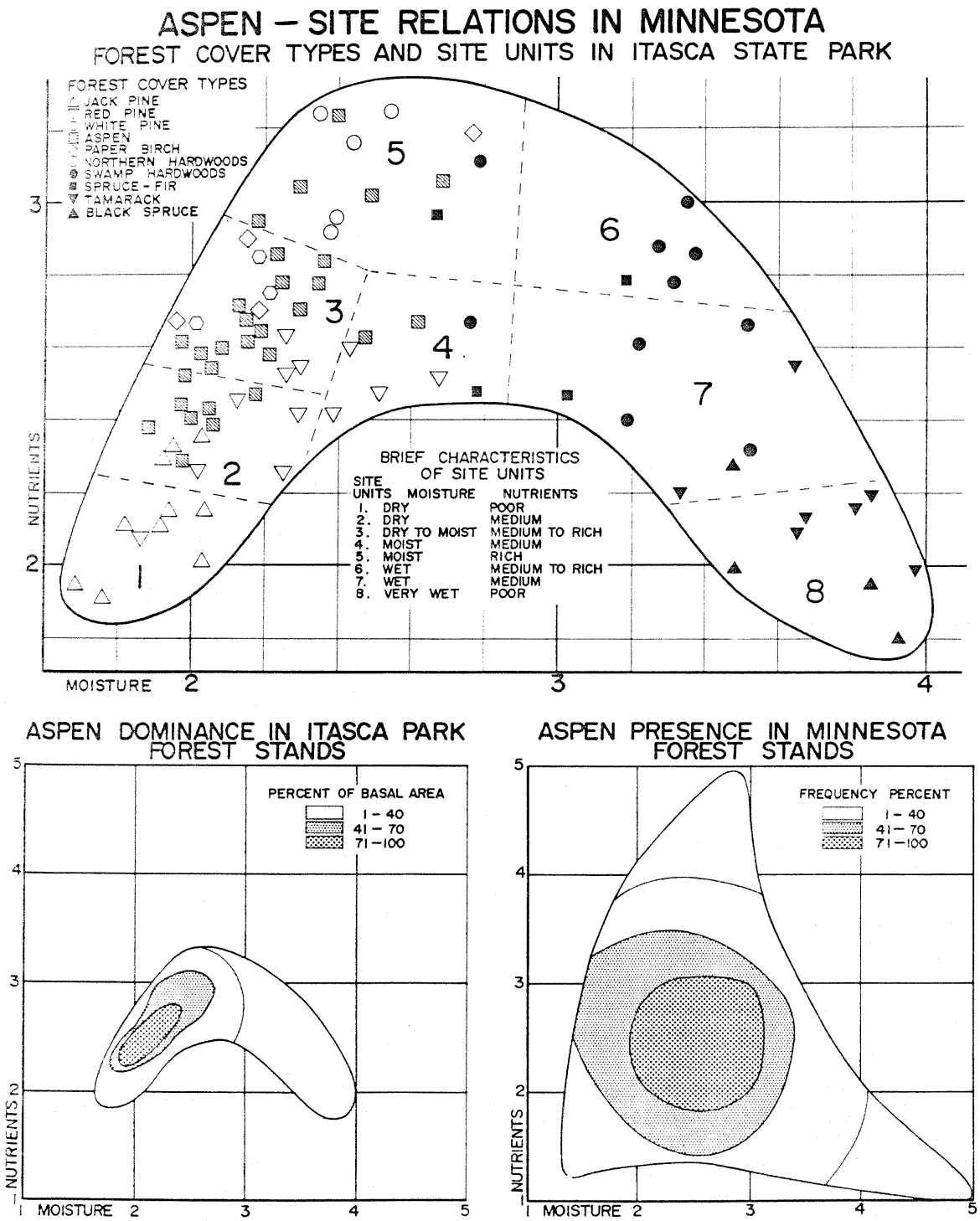

Figure 1. — *Aspen distribution and site relationships in moisture-nutrient coordinates.*

Ness postulates a disintegration within 30 to 40 years of most of the existing aspen overstory and the concommitant development of a vigorous shrub understory and invasion by more shade tolerant hardwoods. For eight of 10 aspen stands studied succession to either transitional northern hardwoods or a "shrubwood" within 50 years was projected.

THE DATA

The pattern of relationships between cover types and site units for all 88 stands was indicated by positioning the various cover types in the edaphic (moisture-nutrient) field (upper diagram, fig. 1). For example, all jack pine stands fall in site units 1 (dry, nutrient-poor) or 2 (dry, medium nutrient).

The distribution of aspen within the total forest site complex in Itasca State Park is shown in the lower left diagram in figure 1. Aspen dominance in each stands is indicated by its percent composition of the total stand basal area. In general, aspen tends to dominate on dry to moist, medium-nutrient sites. It has little dominance on the dry, nutrient-poor sites, and is almost absent from the richest sites. It is totally absent at any nutrient level on wet or very wet sites.

Presence of aspen on the entire range of forest sites in Minnesota is plotted in the lower right diagram in figure 1. This refers to the percent of all stands in any portion of the edaphic field which contain aspen. Again, aspen occurs most frequently on dry to moist sites of medium nutrient levels. It is absent or rare on the driest, richest, and wettest sites.

The basal area distribution and intensity of occurrence of each tree species was studied (fig. 2). Each tree species was grouped into three size categories: tree (over 4 inches d.b.h.), sapling (1.0 to 3.9 inches d.b.h.), and seedling (under 1.0 inch d.b.h). These patterns help clarify the competitional characteristics of some of the species. For example, red maple trees are shown to be confined to the moister and richer sites although smaller saplings and seedlings are found on drier and poorer sites. Ironwood occurring on similar sites is shown to be an understory species with little tree-sized representation.

Patterns of shrub species' occurrence and abundance under aspen stand overstories can be seen in figure 3.

OBSERVATIONS AND CONCLUSIONS

Distribution Patterns of Characteristic Species

All sizes (tree, sapling, seedling), of quaking aspen were found to occur over the same range of sites except that no saplings were found in aspen communities on nutrient-rich sites (fig. 2). These sites are characterized by early and severe competition from tolerant species. This means no reproduction survival and the early elimination of suppressed trees. In the sapling class (less than 4 inches at d.b.h.) there are some old, suppressed trees that have never attained tree size. This may also be true with some other intolerant species such as bigtooth aspen and paper birch. Thus, the significance of the presence of saplings of these species may be overrated in terms of community succession.

Northern red oak is a common aspen stand component. It has a wide distribution, especially in the seedling stage, from dry, nutrient-poor to moist, nutrient-rich sites. However, reproduction is less frequent on dry, nutrient-poor sites. Red oak reproduction competes well on dry to moist, medium-nutrient sites with high shrub densities. Saplings are lacking on rich sites. The distribution of bur oak is narrower than that of red oak. Bur oak trees, saplings, and seedlings are largely lacking in aspen stands on dry, nutrient-poor and moist, nutrient-rich sites.

Red maple is considered a subclimax species, and it functions as an intermediate in many forest stands. It is most commonly found in the understory. The occurrence of red maple in tree sizes is sporadic in aspen stands. Saplings are widespread. Reproduction is most abundant in aspen stands on better sites and sometimes exceeds 10,000 seedlings per acre. Red maple is able to compete successfully with shrub and ground cover species. Its growth rate under conditions of strong shrub competition is similar to that of red oak. Sugar maple is commonly a constituent of old aspen stands on better sites. Trees, saplings, and seedlings are well represented. Sugar maple reproduction is able to withstand complete suppression for several years and still respond strongly to release.

White pine is present in some aspen stands as old, scattered veterans. Seedlings may be quite numerous on better sites; however, inadequate light, deer browse, and blister rust account for the lack of saplings in aspen stands.

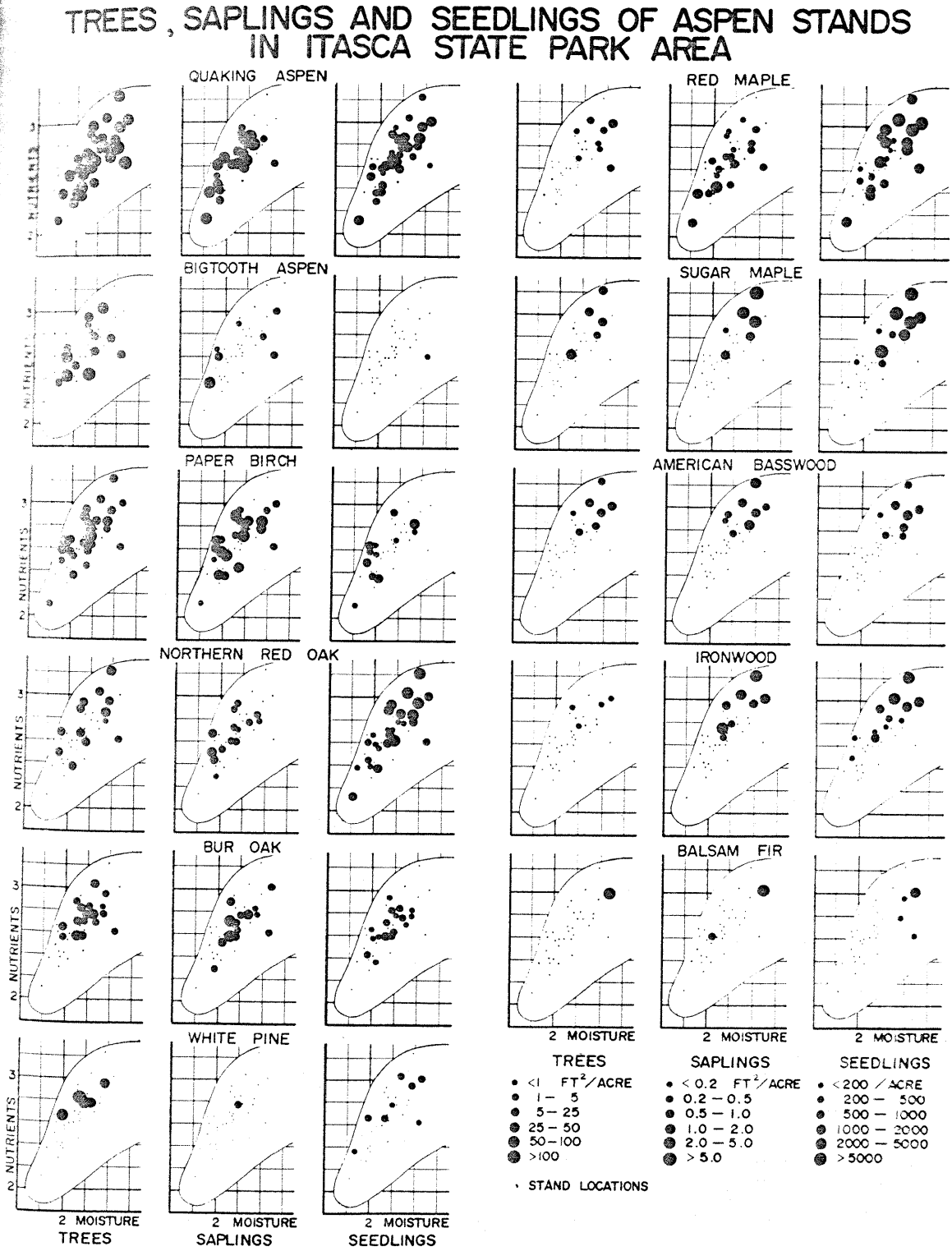

Figure 2. — *Distribution of aspen and its associated species as measured by basal area of trees, saplings, and numbers of stems of seedlings in moisture-nutrient coordinates.*

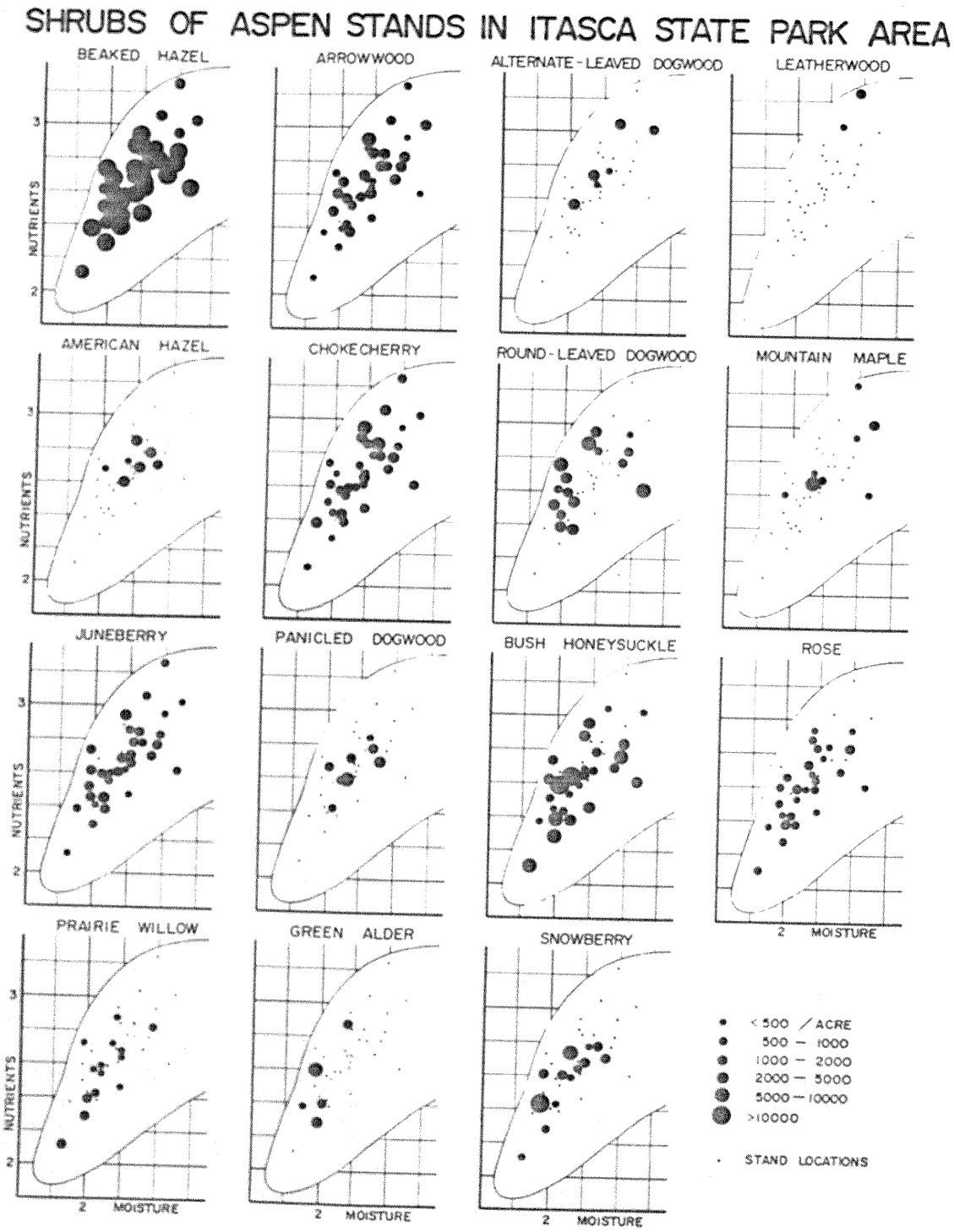

Figure 3. — *Shrub distribution in aspen stands in moisture-nutrient coordinates.*

Being a boreal species, balsam fir is on the southwestern edge of its natural range. In the Itasca State Park area it tends to occupy moist and cool sites. It is largely lacking in aspen stands. Reproduction is only found on moist, medium-nutrient sites in places adjacent to wet areas (fig. 2).

Shrubs are generally distributed over the total range of aspen stands. The greatest abundance and diversity of shrubs occur on dry to moist, medium-nutrient sites with beaked hazel predominating (fig. 3).

Successional Trends

Succession in forest stands will be toward the most tolerant species capable of invading, establishing, and regenerating under the site conditions present. Aspen is an intolerant species of well-known transient character in the absence of disturbance, and most of its associates except jack pine, paper birch, and bigtooth aspen have greater shade tolerance. What succeeds a present aspen stand will depend on the relative tolerance of any associated species, and their affinity for the various site characteristics. These relationships for forest stands in the Itasca State Park area are shown in upper figure 1 and figure 2.

Succession in Pure Aspen Stands

Where no other species are associated with the aspen, succession under natural conditions will depend on the nature of the final breakdown process. If the stand is subject to drastic blowdown, it is possible for a considerable number of suckers to regenerate a second stand of aspen. However, in most instances a more gradual deterioration will result in a limited stand of aspen with a greatly increased brush component, the "shrubwood" described by Ness.[5] This will happen because several brush species, especially beaked hazel in this area (fig. 3), are aggressively present over the total range of site occupied by aspen stands.

Succession of Aspen with Intolerant Associates

When aspen is mixed with paper birch, red pine or jack pine, species of essentially equal intolerance, the nature of the second stand will depend on the relative longevity of the species involved. The pines and paper birch have normal lifespans exceeding that of aspen and can be expected to outlive it. However, since these species like aspen are transient in the absence of disturbance, they will in turn be replaced by a shrubwood type, characterized by a distinct shrub canopy with occasional trees in various states of maturity.

Succession of Aspen with Xeric Hardwood Associates

The two oaks, northern red and bur, occur in many aspen stands to the extent of 25 to 50 or more square feet of basal area plus a considerable number of saplings and seedlings (fig. 2). These species have greater longevity and tolerance than the aspen and will form the second stand, the stocking depending on their current abundance and age structure. Such stands can be expected to continue to have a dense shrub understory.

Succession of Aspen with Tolerant Hardwood Associates

The tolerant hardwoods in this area include sugar maple, basswood (*Tilia americana*), ironwood, and red maple. These species, except for red maple, are largely confined to site unit 5 (moist, rich) (figs. 1 and 2). In aspen stands on those site conditions succession is inevitably to these climax species. The degree of stocking of the regenerated hardwood stand will vary, but the ability of these species to regenerate under their own cover will promote more complete stocking in time. The shrub layer in these stands will be sparse or absent and consist of scattered leatherwood, alternate-leaved dogwood, and occasional other species (fig. 3).

Succession of Aspen with Spruce and Balsam Fir Associates

It should be noted that white spruce and balsam fir are only infrequent associates in the aspen type in this area. Balsam fir is at the southwestern fringe of its range and it does not appear capable of assuming the role of a dominant climax species as it does

in the boreal region. It reproduces with some abundance under aspen overstories on moist sites (fig. 2). However, in only one aspen stand was it found to reach the overstory position. Permanent plots in this area indicate that as the overstory breaks up, balsam fir tends to disappear in favor of brush or hardwoods except on wet microsites.

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SILVICS AND ECOLOGY IN CANADA

J. S. Maini, *Program Coordinator, Tree Biology*
Canadian Forestry Service
Ottawa, Ontario

ABSTRACT. — Aspens are widely distributed and grow under a wide range of ecological conditions in Canada. The most productive aspen stands in Canada are located north of the height of land where rivers flow toward Hudson Bay. Formation of clones, due to repeated vegetative propagation, is silviculturally the most significant feature of aspen stands. Clones vary in their suckering ability, phenology, growth vigour, form, and disease susceptibility. High grading of superior clones is detrimental to the future of aspen resource; clearcutting is recommended to ensure adequate regeneration and to conserve a broad genetic pool.

Poplars in Canada constitute 54 percent of all merchantable hardwoods, or about 9 percent of the total net merchantable forest resource. Of the eight poplar species native to Canada, trembling aspen and largetooth aspen are among the five suitable for commercial use (Fitzpatrick and Stewart 1968). These two aspen species, comprising approximately 30 percent of the poplar resource in Canada, occur in unmanaged stands, many of which are overmature and decadent.

In spite of the wide distribution and abundance of poplars in Canada, only 5 percent of the estimated allowable annual cut is used; this underutilization is attributed partly to easy availability of conifers in areas closer to mills and partly to certain biological features of the species. However, interest in utilization and management of aspens is increasing not only because of the expected increase in the demand for forest products but also because of the wide ecological amplitude and fast growth rate of aspen.

Various biological aspects of aspens in Canada have been described in recent reports (Maini and Cayford 1968, Shoup *et al.* 1968). This report deals with the silvics and ecology of aspens in Canada, with emphasis on the features considered significant in the management of natural stands.

TAXONOMY

Only two species of aspen belonging to Section Leuce of the genus *Populus*, namely trembling aspen and largetooth aspen, are native to Canada and the United States. Detailed taxonomic descriptions of these two aspens, which are widely distributed in Canada (fig. 1), have been presented by Maini (1968). Among poplars, these species may be easily recognized in the field by the following morphological characteristics:

Leafy Condition in Summer

1. Leaf orbicular to broadly ovate or elliptical, glandless. Buds not resinous; leafstalk, at least in upper part, flattened in vertical plane, about ¾ length of blade . . . . . Aspens 2
Leaf narrow, lanceolate to ovate, fine-toothed. Leaf stalk about ¾ length of leaf blade, flattened on top. Buds resinous. . . . . Cottonwood and Balsam Poplar

2. Leaf coarsely sinuate-toothed; usually 10 or fewer teeth each side. Buds grayish downy. . . . . Largetooth Aspen
Leaf finely serrated to crenate; usually 15 or more teeth each side. . . . . Trembling Aspen

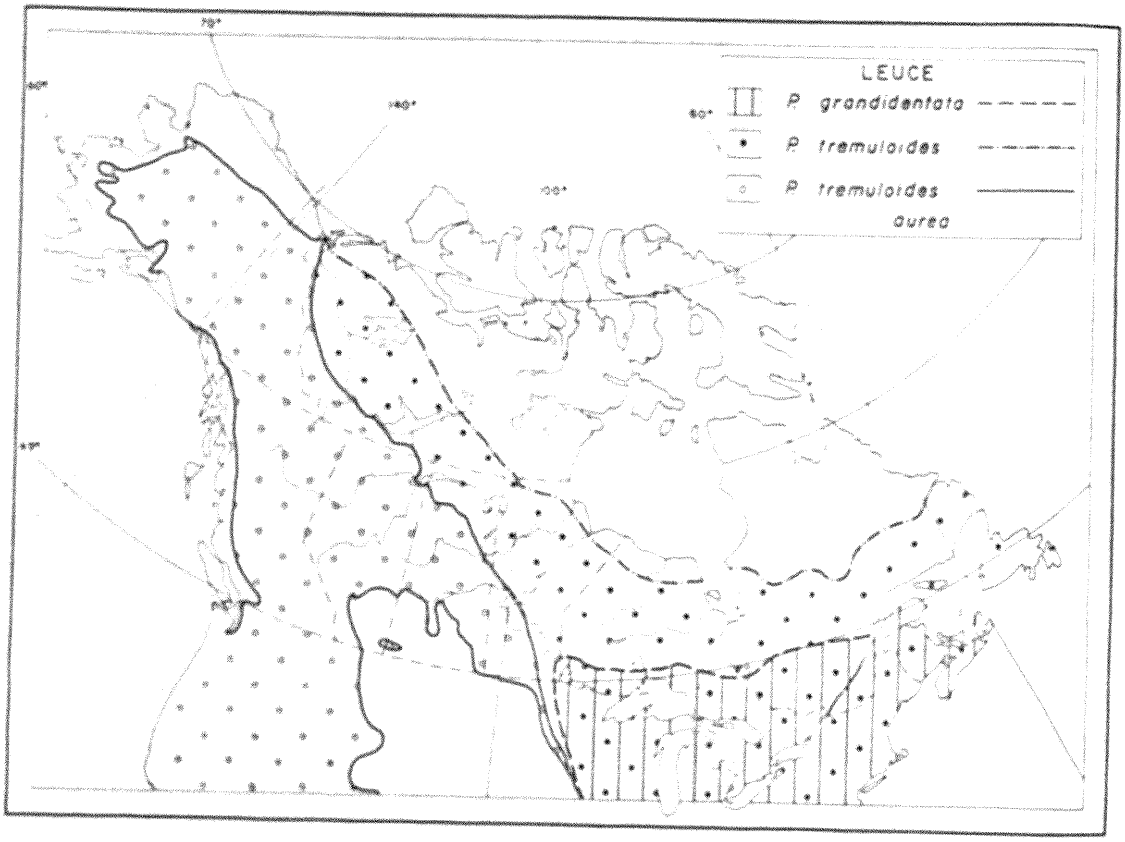

Figure 1.—*Distribution of* Populus tremuloides, P. tremuloides aurea, *and* P. grandidentata *in Canada (after Maini 1968).*

There is considerable variation in the size and shape of leaves borne on short, slow-growing lateral shoots and of leaves on vigorously growing long shoots, stem sprouts, and suckers. Only leaves borne on short shoots are reliable for species identification.

Leafless Condition in Winter

1. Buds nonresinous . . . . . Aspens 2
Buds resinous . . . . Cottonwoods and Balsam Poplars

2. Buds glabrous, brown, the terminal longer than the subjacent lateral bud. Smooth bark white, gray, or pale green, roots pale brown . . . . Trembling Aspen
Buds grayish downy, the terminal and subjacent lateral buds of almost equal length. Smooth bark greenish yellow; roots dark reddish brown.
. . . . Largetooth Aspen

A number of forms and varieties of tremb aspen have been reported in Canada (Maini 196 these distinctions, however, are not made from a s cultural viewpoint, and even the two aspen spec are usually treated in similar fashion.

ECOLOGICAL LIFE HISTORY

Phenology

Aspens are normally dioecious (i.e., male and female flowers are separate and borne on differ plants); some floral abnormalities, however, h been reported (Maini and Coupland 1964). Flo buds of aspens swell and extend before the leaf b and in western Canada the female plants flower leaf earlier than the male plants. In southern Cana the aspens flower in early April and leaf in ea May. These phenological events are delayed no

ards and their timing appears to be determined by temperature. In Ontario, flowering, leafing, and seed dispersal occur about 10 days later in largetooth aspen than in trembling aspen. The considerable variation in the phenology of different clones helps differentiate various clones.

Sexual Reproduction

Aspens start flowering at about 10 years of age and mature trees produce adequate seed crops annually. Good seed crops may be expected every 2 years. During an "average year," for example, a 23-year-old, 33-foot-tall trembling aspen in southern Ontario produced 1.6 million seeds. The seeds are light (2.5 million trembling aspen seeds weigh 1 pound), pear-shaped, and have a tuft of long silky hair attached to the narrow end, enabling them to disperse over long distances. In spite of the enormous quantities of aspen seed produced annually and the ease of germination under controlled conditions (e.g., 80 to 95 percent at room temperature), establishment resulting from seeds under natural conditions is uncommon for the following reasons (Maini 1960, 1968):

1. Short seed viability.
2. The presence of a water-soluble germination and growth inhibitor in seed hair.
3. The occurrence of unfavorable moisture conditions during seed dispersal on upland sites that aspens usually inhabit.
4. The susceptibility of seedlings to high temperatures that occur on soil surface blackened by fire.
5. The susceptibility of seedlings to fungal attack.
6. The adverse influence of diurnal temperature fluctuations on initial seedling growth.
7. The unfavorable chemical nature of some substrates on which the seeds are likely to fall.

Asexual Reproduction

Rooting of aspen stem cuttings is extremely difficult and one of the major obstacles to mass multiplication of the desirable genotypes. Sprouts from stump and root collar are uncommon, although sprouts from the latter occur somewhat more frequently in largetooth aspen than in trembling aspen.

The most common mode of aspen reproduction is the formation of adventitious shoots on roots (suckers). Suckering following logging in aspen stands has been attributed to isolation-induced increase in soil temperature (Maini 1968) and to relief from the apical dominance effect.[1] Repeated vegetative reproduction of dioecious aspens has resulted in the formation of male and female clones that range from a few to several hundred trees (Maini 1968) and occupy 0.01 to 3.80 acres of land.[1] From a silvicultural viewpoint, the development of clones is perhaps the most significant biological feature of aspen stands. While a single clone may occupy a particular land surface to the exclusion of others, intermixing of clones is common.

Trembling aspen suckers are borne on roots that range from 0.2 to 2.0 inches in thickness and are located in the upper 2 inches of soil (range: 1.0 to 4.0 inches). The sucker-bearing roots on largetooth aspen range from 0.2 to 4.5 inches in thickness and penetrate to a depth of 3 inches in the mineral soil (range: 1.0 to 7.0 inches).

Although under natural conditions suckering is profuse after various types of disturbances, aging aspen stands reportedly decrease in suckering capacity. The pattern of spatial distribution of clones and the physiology and ecology of root-suckering have been studied under controlled environmental and the field conditions. The studies show a significant clonal variation in suckering capacity (fig. 2), optimum temperature for suckering, and the rate of suckering in the two species of aspen (Maini 1967), and the rootability of newly formed suckers.[1] In the controlled environment, root cuttings from clones that sprouted the most suckers produced the most large suckers. No significant correlation, however, could be established between the size of the clones (from which the root cuttings had been sampled) and the sucker growth or the rooting ability of these root cuttings; clone size was also not related to the soil moisture and the nutrient level of the various sites.[1] Considerable clonal variation in disease susceptibility has also been reported (Wall 1969). The foregoing features indicate that the natural stands of aspen are genetically and ecologically very diverse.

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[1] *Steneker, G. A. Structure, size, and development of trembling aspen (*Populus tremuloides *Michx.) clones in Manitoba. (Unpublished report, 157 p. 1972.)*

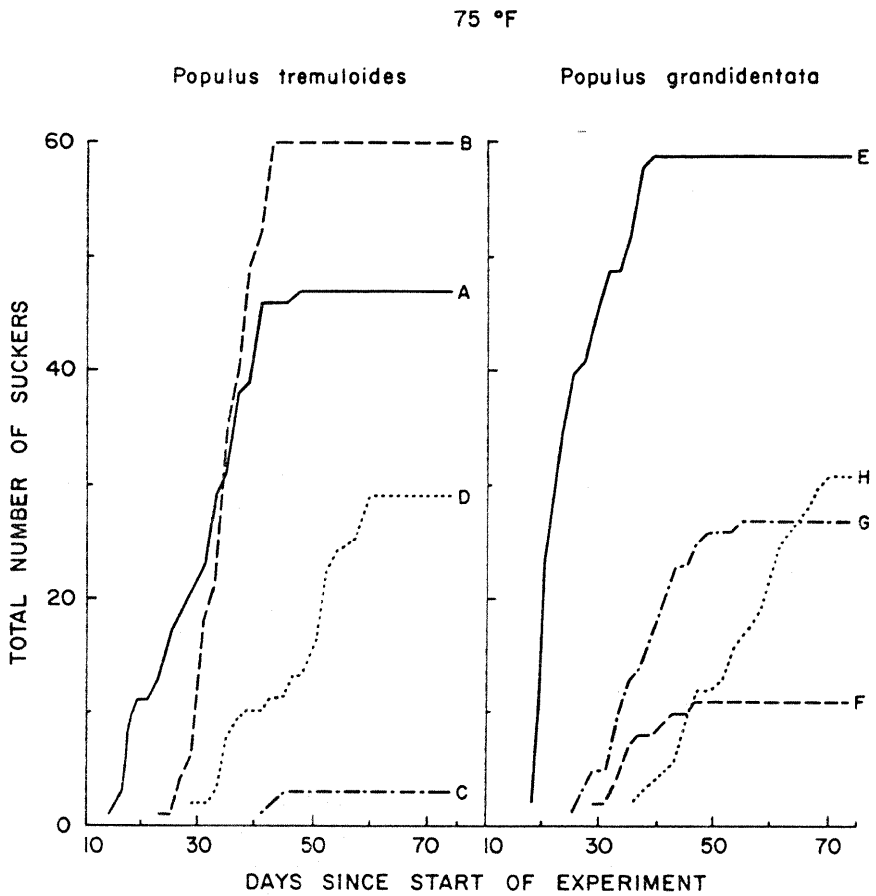

Figure 2.— *Variation in sucker formation on root cuttings obtained from four clones of* Populus tremuloides *and* P. grandidentata, *maintained at 75° F.*

EARLY GROWTH

Stem Growth

Aspens are intolerant to shade and require full sunlight for optimum growth. The suckers may originate singly or in a clump and the height of the dominant shoot in a clump increases with the number of suckers in the clump (Maini 1968). Suckers that initially have a rapid growth rate tend to maintain their dominance (Pollard 1971).

Height growth of young plants was not adversely affected when subjected to various degrees of defoliation, branch pruning, and debudding (Maini 1966, Pollard 1970); these observations suggest that a young stand of aspen suckers may be lightly browsed without any detrimental effects to the future crop.

There is considerable clonal variation in the phe ology, growth rate, form, branching habit, and d ease susceptibility. Studies by Vaartaja (1960) ha demonstrated the occurrence of photoperiod ecotyp in trembling aspen — a feature that one would expe to occur in a widely distributed species.

Root Growth

Information on initial root growth is scanty due the paucity of seedlings in nature. However, m new roots develop near the base of suckers and spre laterally in the upper soil layers. Trees of suck origin can be distinguished from seedlings by a thic ening that develops on the distal side of the pare root adjacent to the sucker (Maini 1968). The ro system of aspens extends 40 feet or more from t stem base, that of largetooth being located a fe

reaches deeper than that of the trembling aspen; the former is also less profusely branched and has fewer adventitious roots. Recently Zufa (1971) has successfully rooted aspen by planting succulent suckers in a suitable rooting medium maintained under high humidity.

STAND DEVELOPMENT AND MANAGEMENT

The intolerant aspens have many features characteristic of a pioneer species. However, most aspen regeneration on cutover and burned forest land is vegetative; i.e., from root suckers. The abundance of aspens in disturbed forest land, which is indicative of their ecologic significance, is determined by the proportion of aspen in the logged or burned forest and the magnitude of disturbance.

A fully stocked stand of aspen, when clearcut (or burned), produces up to 40,000 suckers per acre. However, mortality in young sucker-stands is high and by 30 years of age, the number is reduced to 1,000 to 1,500 stems; at maturity (70+ years), the stocking ranges from 300 to 400 trees per acre. Regeneration of aspen following removal of apparently pure conifer stands is usually from the roots of a few widely scattered individuals.

Aspens grow under a wide range of ecological conditions and are found associated with almost all native trees of Canada. Depending on stand history, the two aspens occur in extensive pure stands, in mixed stands of the two aspen species, in association with conifers, particularly spruce and pine, and with other hardwoods, commonly paper birch. Shrubs and herbs commonly associated with aspen and competing with aspen regeneration include *Symphoricarpos, Corylus, Alnus, Prunus, Salix, Lonicera, Vibernum* and *Pteridium* (Maini 1968).

In one investigation, the height growth of dominant trembling aspen trees was measured in 96 mature stands, located in an approximately 750-mile long south-north transect, extending from 49° and 50° N. latitude (fig. 3). In the south, height growth

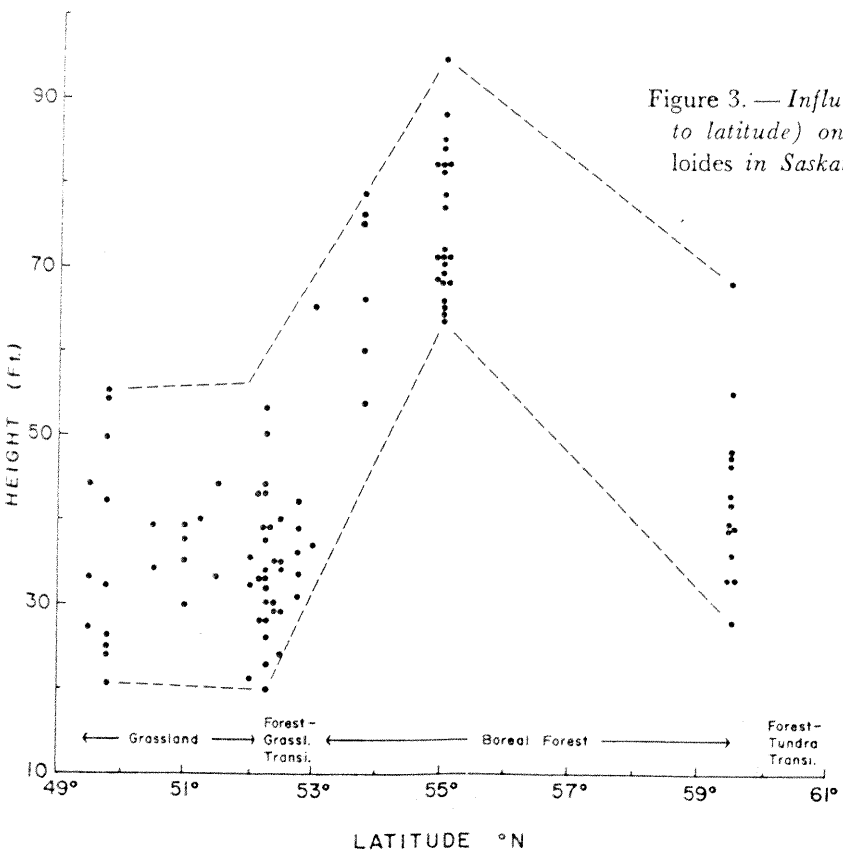

Figure 3. — *Influence of climatic gradient (as related to latitude) on height growth of* Populus tremuloides *in Saskatchewan (from Maini 1968).*

was apparently limited by inadequate moisture and in the north by unfavorable temperature and edaphic conditions. In Canada, optimum growth of trembling aspen is attained north of the height of land where rivers flow toward Hudson Bay; it is interesting to note that the "Major Poplar Area" in Canada (fig. 4) described by Fitzpatrick and Stewart (1968) also lies in this geographical region.

Several silvicultural techniques have been applied to stimulate aspen suckering and to control competition from associated vegetation. The relative effectiveness of the various treatments has been evaluated by using a "Reproductive Index" (Maini and Horton 1966). Considering the great microenvironmental variations that occur in the surface soils following disturbance in an aspen stand and the tremendous intraspecific variation in the ecologic requirements of aspens, it is not surprising that many clones continue to perpetuate in a given area. Consequently, aspens have been regarded as weed species, sometimes difficult to eliminate.

Many aspen stands are overmature and decadent. Economic considerations necessitate high grading of clones that have superior growth and low incidence of disease and other defects. This practice is expected to lower the quality of future aspen stands because these clones do not reproduce adequately under a partial canopy. And unless they produce suckers, most of these superior aspen clones decay within 3 to years after cutting, and so the inferior clones would be perpetuated when the remaining tree canopy is eventually removed by logging or natural fire. The influence of high grading on impoverishment of gene pool is much more serious in species that reproduce predominantly by vegetative means than those that reproduce by seeds. Therefore, clearcutting is essential to obtain good regeneration of aspens and to conserve a broad genetic base.

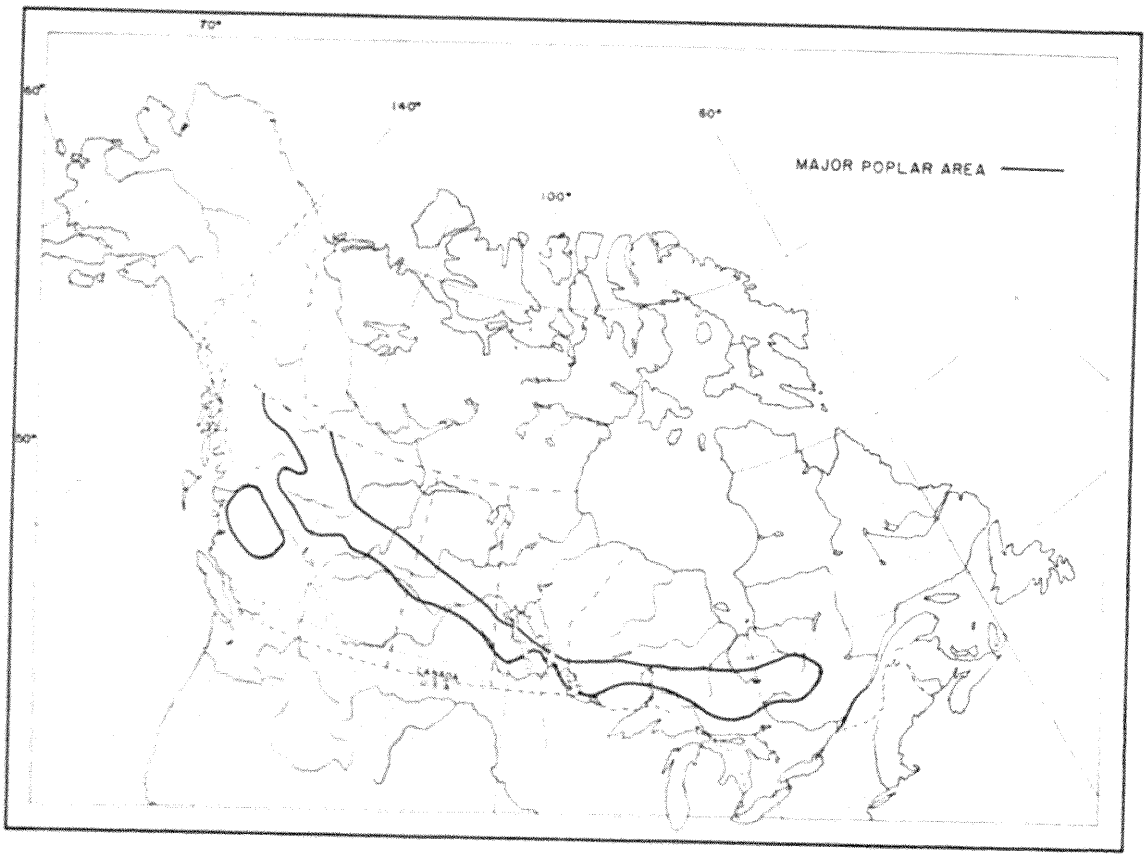

Figure 4. — *Major area of poplar volume, mostly aspens, in Canada (after Fitzpatrick and Stewart 1968).*

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DISEASES

Gerald W. Anderson, *Principal Plant Pathologist*
North Central Forest Experiment Station

ABSTRACT. — Reviews literature on the diseases of quaking aspen. Emphasis is placed on the Eastern United States and Canada; related problems in other areas are also included. The future impact of aspen diseases is discussed.

A number of diseases attack aspen throughout its broad range in North America. These diseases in aggregate damage all parts of the tree from roots to foliage. Although many pathogens attack aspen, the major impact results from attacks by relatively few parasitic fungi. Of these, the most important cause various decays and stains that greatly reduce merchantable volumes, especially in older stands. Although they do not normally kill the host tree, these pathogens impose a pathological rotation on aspen producers who must harvest early to minimize losses. The next most important group of pathogens causes cankers on the main bole of the tree. These kill directly by girdling the stem, as well as indirectly by weakening the tissues and predisposing the trees to breakage by wind. Other pathogens, such as leaf-spotting organisms, do some damage but usually are unimportant. The root pathogens have not been investigated to any great extent and, as a consequence, are relatively little known. However, they are not believed to cause any great damage to the aspen type.

Much has been written on the diseases of aspen. Some articles deal with *Populus* in general on a worldwide basis (Berbee 1964, Farmer and McKnight 1967); others are more restrictive in that they deal with limited regions or certain species (Davidson and Prentice 1968, Graham *et al.* 1963, Hepting 1971). The present account will apply primarily to *Populus tremuloides* in the Eastern United States and Canada.

STEM DISEASES

Among the many stem pathogens, those that cause stain and decay have the greatest direct impact on wood production. Because of them it is necess to impose pathological rotation ages as low as 35 40 years in some areas. Canker-producing fungi, to can cause serious damage to aspen stands. Althou these fungi are normally confined to local areas of t stem, the entire tree is killed when the bole is girdl by them. Because aspen wood is quickly degraded, t trees killed in this way are usually lost. Most of t other stem diseases of aspen are of lesser consequenc

Stain and Decay

Stain is a very common defect in the stems of aspe trees. Several conditions are said to be associated wi stain; some involve micro-organisms while others d not. Although organisms are frequently associate with discoloration, their role is not understood. Di coloration, which develops in the absence of micro organisms, has been little studied, and it is not know if pigment production can continue for any length o time. Apparently wounding, which exposes the xylem to the atmosphere, results in pigment productio around the wound (Sucoff *et al.* 1967). Xylem killed without being exposed to the atmosphere does no discolor.

Associated with decay columns in aspen are zone of discoloration of varying intensity. Considerabl portions of the stem are often discolored. Although the strength of affected tissues is not reduced greatl in the initial stages of decay, the discolored wood increases manufacturing costs for color-sensitive products.

Aspen tissues are known to harbor a number of

different organisms. From xylary tissues, a variety of fungi and bacteria has been identified (Good and Nelson 1962, Thomas *et al.* 1960). Apparently, these different organisms interact in such a way as to follow one another in a successional manner, suggesting that one acts as a precursor for the next. A strong case for the concept of fungal succession in wood was made by Shigo (1967), and a good account of the successional appearance of various organisms in aspen was presented by Etheridge (1961). He found that bacteria were the first organisms to appear, followed by *Cytospora* spp., *Phoma* spp., and *Libertella* spp. Two wood decay fungi, *Corticium polygonium* and *Polyporus adustus,* preceded the common decay fungus, *Fomes igniarius.*

Though stains are very plentiful and occasion much volume loss, the decay-causing organisms are responsible for the greatest volume loss in the aspen type. The bulk of the damage has been attributed to *F. igniarius.* Early in this century there were reports of damage by this fungus to aspens in New England (Weigle and Frothingham 1911) and the Rocky Mountain area (Von Schrenk and Spaulding 1909).

F. igniarius is worldwide in its distribution, and on aspen it is known throughout the United States and Canada. In some locations more than 50 percent of the trees on sample plots have been infected (Basham and Morawski 1964, Thomas *et al.* 1960). It is reported to be so prevalent as to mask or conceal rot caused by other fungi (Schmitz and Jackson 1927). Fruiting bodies (fig. 1) are regarded as the most reliable external indication of decay (Basham 1960), and some pathologists have attempted to estimate decay losses in individual trees on the basis of sporophore presence (Hinds 1963, Horton and Hendee 1934, Riley and Bier 1936). Other studies have related damage to tree age (Meinecke 1929, Riley 1952), height (Brown 1934), and diameter (Basham 1960). Evidence conflicts as to the relation between site quality and decay (Wagener and Davidson 1954): both positive correlation (Davidson *et al.* 1959) and negative correlation (Brown 1934) have been reported. Apparently, hosts vary in susceptibility to decay by *F. igniarius* because incidence of this pathogen varied significantly among different aspen clones (Wall 1969). Clone had a greater effect than site on decay incidence.

Few reports agree on which fungus causes the next

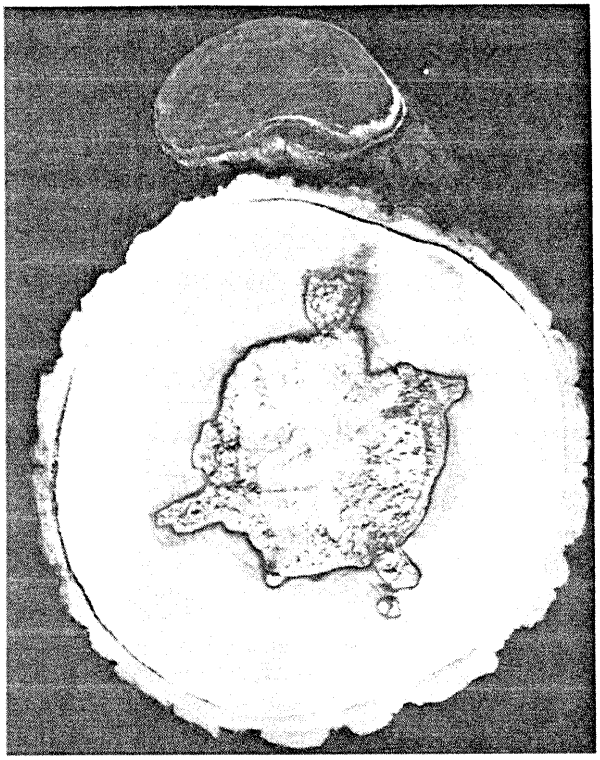

Figure 1. — *Cross section of aspen infected by* Fomes igniarius.

greatest amount of damage after *F. igniarius.* Basham (1958) isolated *Radulum casearium, Corticium polygonium,* and *Pholiota adiposa* most frequently from yellow stringy trunk rot in the Upper Pic Region of Ontario. From butt rot in the same region, he isolated *Pholiota spectabilis, Armillaria mellea, Radulum casearium, Pholiota adiposa,* and *Collybia velutipes.* In northern Michigan and Wisconsin, Anderson and Prielipp[1] found *R. casearium* and *A. mellea* to be the most abundant decay-causing fungi on aspen. In Colorado, Davidson *et al.* (1959) isolated *Crytochaete polygonia* most frequently even though *F. igniarius* caused the greatest volume loss.

Cankers

Cankers are among the most common disease problems on aspen. Although there have been few comprehensive assessments of the damage caused by

[1] *Anderson, Gerald W., and Prielipp, Donald O. Decay and stain of quaking aspen in northern Michigan and Wisconsin. (Unpublished manuscript.)*

the many different canker-producing organisms, their impact is considerable. Some canker-causing fungi produce slow-growing, persistent infections; others become established and kill the host within a relatively short time. Regardless of their rate of action, the net effect is loss of part or all of the diseased stem for most purposes.

Because many cankers are similar in appearance, the task of distinguishing between the various canker types on aspen can be difficult. Where several similar types occur in the same geographic area, it can be next to impossible to differentiate them in the field (table 1). Often identification can be made only by isolating the causal organism and demonstrating its pathogenicity by inoculating healthy trees.

Hypoxylon Canker

In many areas hypoxylon canker is regarded as the most serious aspen disease. It has been reported from a number of locations throughout most of the range of quaking aspen in the United States and Canada, but it has not been found in Alaska and adjacent portions of the Yukon territory. The disease occurs, too, on *P. tremula* in Czechoslovakia and Russia.

It has been estimated that this disease kills 1 to 2 percent of the aspen each year (Anderson 1964). Caused by *Hypoxylon mammatum (H. pruinatum)*, this canker disease is manifested by rapid invasion and early death of host tissues. While callous tissue may form along the margin of some cankers, and occasionally a tree will appear to recover from infection, in the vast majority of cases, once established, the fungus overwhelms the defense mechanism of host (fig. 2). Mortality occurs as a result of girdling or wind breakage at the point of infec

Figure 2. — *Hypoxylon canker on aspen at the of a dead branch.*

Table 1. — *Summary of poplar canker diseases, causal organisms, and major areas of occurrence.*

Canker	Fungus	Main region
Hypoxylon canker	H. mammatum	Rocky Mtns., Lake States, Canada
Cytospora canker	C. chrysosperma	United States and Canada, general
Dothichiza canker	D. populea	Widespread
Sooty-bark canker	Cenangium singulare	Rocky Mountains
Neofabraea canker	N. populi	Canada
Nectria canker	N. galligena	United States and Canada
Shoot blight	Venturia spp.	Canada and northern United States
Ceratocystis canker	C. fimbriata	Minnesota
Pezicula canker	P. ocellata	Canada

Adapted from: Hepting, George H. Diseases of forest and shade trees of the United States. USDA Forest Serv. Agr. Handb. 382: 393. 1971.

Although the mode of infection is not known, canker infections first appear as slightly depressed to yellowish areas in the host bark (Bier 1940). Usually they are associated with branch stubs or other abnormalities. It has been reported that insects are instrumental in transmission of the fungus by creating infection courts (Graham *et al.* 1963) and that insect control would reduce infection (Graham and Harrison 1954). However, other investigators report no association between insects and canker distribution (Ewan 1959).

Canker prevalence and host density are correlated; low-density stands have proportionally more infection than high-density stands (Anderson and Anderson 1958). Prevalence also has been related to age of the host and geographic location (Anderson and Anderson 1959). Stand composition, too, has been suggested as being related to canker prevalence, but the association is not clear. Evidence has been presented to show that new infections are established in a "wave year" pattern (Schmiege and Anderson 1960). Whether environmental factors or vectors occasion this phenomenon is unknown.

To minimize losses due to hypoxylon canker, the forest manager should maintain fully stocked stands. Stands in large blocks are preferred to reduce edge effect around margins where hypoxylon canker infection is frequently high. In addition, pure stands should be encouraged. Sanitational removal of infected stems seems of little value.

Nectria and Ceratocystis Cankers

Nectria and Ceratocystis cankers are being discussed together here because of confusion that exists as regards their pathogenicity on aspen. Historically, target-shaped cankers on aspens have been called Nectria cankers (fig. 3) and are assumed to be caused by *N. galligena* even though the conspicuous reddish-colored perithecia borne by this fungus have seldom been observed on aspens. Recently, investigators have begun questioning this assumption and suggesting that some other fungi may be involved. Accordingly, isolation and inoculation work have been done to clarify the matter (Manion and French 1967, Wood and French 1963). It has been shown that *Ceratocystis* spp. are associated with infections of this type. *C. fimbriata* has been recovered from these cankers in a number of locations — Manitoba and Saskatchewan (Zalasky 1965), Colorado (Hinds 1964), Minnesota (Campbell 1960, Hinds and Anderson 1970), and Pennsylvania (Wood 1964). These cankers seldom cause mortality but do cause volume losses.

Figure 3. — *"Nectria" canker on quaking aspen.*

Although definite associations have been made between cankers and apparent causal organisms, additional data are needed to establish conclusively the primary pathogen. Further work being planned or underway may clarify this situation and identify the organism responsible for causing these "nectria"-type cankers. While it is too early to assess this work, it may be that more than one fungus is involved.

Cenagium Cankers

A prominent sooty-bark canker of aspen in the Central Rocky Mountains is caused by *Cenangium singulare* (Davidson and Cash 1956). It is common in Colorado where it does a great deal of damage (Hinds 1964). Infection apparently takes place through fresh wounds (Hinds 1962). Symptoms in-

clude a blackened bark that remains intact over the infected area. Vertical spread is rapid, and cankers 15 feet in length have been reported. Limited sporulation may occur after 3 to 5 years but becomes most abundant after the tree is killed. The fungus has been found on aspen in a number of locations in Minnesota (Hinds and Anderson 1970); but in these areas it appeared to be saprophytic on the bark. Why the fungus does not cause damaging perennial cankers in Minnesota, as in Colorado, is unknown.

Cytospora Canker

Cytospora chrysosperma and its perfect stage, *Valsa sordida*, occur throughout the world. This fungus can cause canker on aspen (Schreiner 1931) but is not regarded as a primary pathogen (Christensen 1940). The fungus is a normal inhabitant of aspen bark and causes cankers only after the host has been stressed (Long 1918). Fire, drought, frost, leaf diseases, and off-site location have been mentioned as factors that predispose trees to infection (Povah 1921, Treshow and Harward 1965). Reducing the water content of the host tissues also increases its susceptibility (Müller-Stoll and Hartmann 1950). It is suggested that this may operate partly through the mechanism of tannin deposition (Bloomberg and Farris 1963).

The disease is most serious on young trees, transplants, and aspen hybrid material (Bloomberg 1962, Huppel 1964). Cankers appear as sunken brown areas that eventually girdle the stem. On older stems with rough bark, cankers are difficult to identify until spore tendrils appear (Boyce 1961). Maintaining trees in a normal vigorous condition is the best means of avoiding losses from this fungus.

Dothichiza Canker

Dothichiza canker, caused by *D. populea*, occurs in the eastern United States and Canada (Waterman 1957). This appears to be an endemic disease that infects a number of poplars and their hybrids. Infection has been found on quaking and bigtooth aspen (Honey 1944). It is regarded as a disease of young or weakened trees and trees growing in plantations. The disease has not been reported in vigorous natural stands. In Europe, where the fungus is common, it is considered one of the most dangerous pathogens of poplar plantations.

Neofabraea Canker

A little-known disease, Neofabraea canker, caused by *N. populi*, has been reported from Ontario (Thompson 1939). Thus far, it has not been found in the United States. Only young trees are infected and these on the lower bole. Cankers may be up to 6 inches long, with spores produced on the bark surface.

Wetwood

Wetwood is a condition in which the central heartwood of the tree has a darker color, higher pH, and is more moist than in a normal tree. Little-known bacteria are associated with this condition (Hartley and Davidson 1950). An isolate of *Corynebacterium humiferum* obtained from *Populus nigra* has been transferred successfully to *P. tremuloides* (Seliskar 1952), suggesting that a bacterium may have more than one host. No estimate of the amount of damage resulting from wetwood infection of aspen is available, but for some uses the discoloration associated with this condition probably causes increased processing costs. Losses also result from tissue collapse, which often occurs when these infected materials are being dried.

Rough Bark

The surface of normal healthy aspen stems remains smooth even as the tree grows and increases in girth. However, because of injuries, most stem surfaces are broken and fissured, a condition that is referred to as rough bark. Fungi, lichens, and mechanical wounding can initiate this condition, which is manifested as rough bands of varying width that extend all or part way around the stem. *Diplodia (Macrophoma) tumefaciens* is reported to be the primary cause of rough bark (Kaufert 1937, Zalasky 1964). Infected trees are not known to suffer from reduced growth or loss of vigor.

LEAF DISEASES

In most areas, leaf diseases are not considered important in aspen management (Christensen *et al.* 1951). While a number of fungi infect aspen leaves, they do not have significant impact on fiber production. In the future, however, if the supply of aspen becomes more critical or management practices are

odified so that younger and thus smaller stems are ilized, the impact from foliar diseases may be ewed differently. At present there are no known ontrols for these pathogens.

Leaf Spots

As might be expected with a tree having such wide ographical distribution, a number of leaf diseases tack aspen. One of the most prevalent is a leaf spot sed by *Marssonina populi*. Under epidemic condi-ons it can cause premature defoliation. Repeated tack reduces growth and may cause dieback (Mielke 957). Apparently aspen has a wide range of suscept-ility to infection: some clones are heavily attacked hile others in the same vicinity have little or no fection.

Another common leaf disease caused by *Venturia emulae* (Dance 1959) is manifested as angular black ots that increase in size until the leaf dies. A similar sease on balsam poplars is caused by *V. populina* Dance 1961). The fungus is able to grow through e leaf petiole into the stem and damage tissues neath. If infection occurs at the top of a tree, it can l and darken the shoot, which withers and becomes nt (fig. 4). This "shepherd's crook," as it is some-nes called, is common, particularly in younger nds. A similar leaf disease syndrome in Wisconsin s been attributed to *Colletotrichum gloeosporioides* Marks *et al.* 1965).

The "ink spot" disease of aspen foliage is common some areas (Pomerleau 1940). This disease is used by two or more species of *Ciborinia (Sclero-ia)*. The infected spots on the leaves turn black ring the summer, and this material falls free, leav-g a hole in the leaf. Although small trees may be ed by heavy infection, older trees normally survive.

Another leaf spot of aspen is caused by *Septoria siva* (Thompson 1941), a fungus that also incites n cankers on hybrid poplars. The symptoms are crete necrotic lesions. Spores are produced on both f surfaces throughout the growing season.

Leaf Rust

Several leaf rust fungi belonging to the genus *Melampsora* have been reported on *Populus*. One of

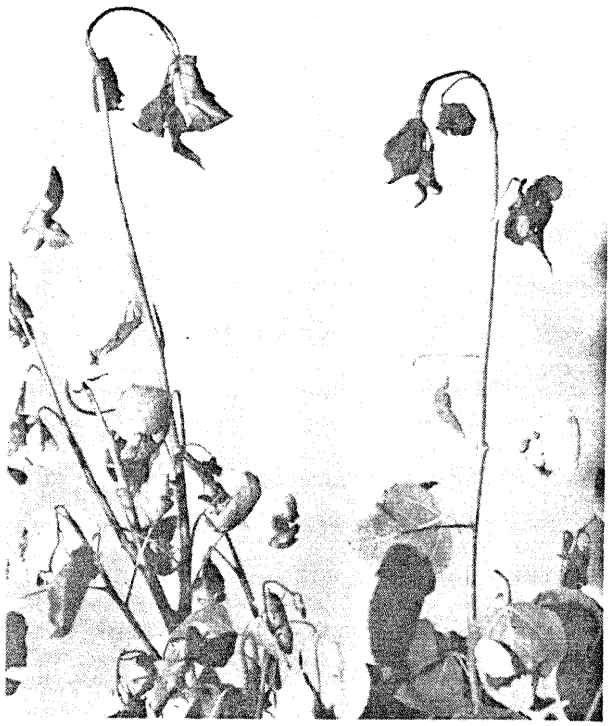

Figure 4. — *Venturia tremulae infection on aspen, a disease that is particularly damaging to young trees.*

the most common, *M. medusae*, has been reported on aspen throughout much of the United States east of the Rocky Mountains (Anon. 1960). *M. abietis-canadensis* occurs in the New England area and westward and *M. albertensis* is reported from New Mexico northward through Canada to Alaska. These fungi have life cycles that include aspen and a coniferous host. Although they can cause discoloration and death of quaking aspen leaf tissue, they more commonly damage hybrid aspens.

Powdery Mildew

Although little mentioned in the literature, powdery mildew does occur on aspen. *Erysiphe cichoracearum* is common in the West (Meinecke 1929) and *Uncinula salicis* is reported to be widespread (Anon. 1960). While infection by these organisms can be quite conspicuous on the leaves, any damage resulting is probably of minor importance.

Leaf Virus

An innocuous leaf-spotting disease of aspens that may be virus-caused occurs in Canada (Boyer 1962, Boyer and Navratil 1970). Electron microscopy has revealed some virus-like aggregates in these tissues. The disease has been transmitted by insects and by budding. Initial symptoms are chlorotic spots that become raised, turn brown, and collapse. Red pigments frequently develop in and around the lesion before the tissue dies. The affected leaves are often distorted from mechanical stress on the remaining living tissue.

FLORAL DISEASES

Catkin Deformity

A catkin deformity, caused by *Taphrina johansonii*, occurs on aspen east of the Great Plains (Anon. 1960). The disease is manifested by carpel enlargement. Because aspen is normally regenerated by root suckering, this disease is of little consequence except to plant breeders who are concerned with aspen seed production.

ROOT DISEASES

Very little is known about the root diseases of aspen, probably more from lack of study than freedom from diseases. Undoubtedly, some of the decay fungi that have been reported to cause damage in aspen stems can cause root damage too. *Armillaria mellea* is one of the few fungi reported to cause root rot on aspen (Schmitz and Jackson 1927). Some mycorrhizal fungi (*Cenococcum graniforme*, *Leccinum aurantiacum*, and *L. scabrum*) have been reported on aspen roots (Trappe 1962). Nothing is known about the effects of soil compaction, but this undoubtedly would affect root development.

NONBIOTIC

Weather

Within its primary range, aspen is little affected by normal climatic conditions. Damage does result, however, from extreme weather. Strong wind and wet, heavy snow or sleet can break branches or whole trees. Hail storms may produce bark bruises that could serve as infection courts for pathogenic organisms. Pronounced drought may reduce growth, but probably does not cause death except for very small trees under unusually severe conditions. Frost crack and sunscald are found in many areas. The latter is particularly noticeable in recently disturbed locations where sunlight strikes previously protected stems.

Fire

Fire favors aspen establishment by reducing competition through killing of the overstory and stimulating suckering. Subsequent fires, however, can injure or kill established stands. Repeated burning can reduce aspen site index by 6 to 25 feet and make such reburned areas nonproductive for future aspen management (Stoeckeler 1948).

FUTURE OUTLOOK

None of the presently known aspen diseases are of the catastrophic type likely to assume epidemic proportions. Therefore, aspen diseases probably will continue to exert the same impact as in recent years. The exception would be if a foreign pathogen to which aspen had little inherent resistance were introduced into North America. Barring that eventuality, it should be possible to predict reasonably well the types of losses that will occur.

In the future we may find that leaf diseases cause more damage than is assumed at present. Our present assumptions in this regard are not well substantiated, and further research might demonstrate that these diseases are important. This could be true especially if short rotation with mechanized harvesting is practiced. Root problems, too, might be important. Thus far they have not been investigated to any extent.

Perhaps the greatest long-term impact from aspen diseases will be on distribution of the type itself. In some areas growth of aspen now exceeds harvest. Where there is also a disproportionate amount of the type at or near the pathological rotation age, it is only a matter of time before much of this material will be too decadent for economical harvest. When that happens and owners disregard these stands in future management plans, the trees will continue to increase in diameter and height while decay is destroying additional wood fiber. Eventually some of these trees may reach 100 or more years of age. Because the stands will open gradually, the result may be type conversion, since the understory of other species often will

take over the site. For that reason, we are in danger of losing untold acres of aspen type unless we can increase the rate of harvest or raise the pathological rotation age by reducing the impact of disease.

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INSECTS

Harold O. Batzer, *Principal Insect Ecologist*
North Central Forest Experiment Station

ABSTRACT.— Insects influence the aspen forest through defoliation, boring, girdling, gall making, and sucking plant juices. The impact is not well understood but in some cases may be beneficial. The most prominent insects are the forest tent caterpillar, the large aspen tortrix, the poplar borer, and the insects attacking aspen suckers. An increased awareness of the many kinds of insects found throughout the life of an aspen stand will improve the forester's management decisions.

Aspens are host to a wide variety of insects. Davidson and Prentice (1968) report the Canadian Forest Insect and Disease Survey has recorded at least 300 species on trembling aspen alone. Many of these apparently have little impact upon the aspen forest, but the role of some is not yet understood. Some are obviously deleterious; others may be beneficial. I shall discuss only those that are most frequently encountered or that severely damage aspen trees. For more detail, see Graham *et al.* (1963) and Shoup *et al.* (1968).

DEFOLIATORS

The foliage-feeding insects of aspen belong mainly to the orders Lepidoptera (moths and butterflies) and Coleoptera (beetles). The most spectacular defoliator of aspen is the forest tent caterpillar, *Malacosoma disstria* (Hübner). This native insect has defoliated aspens and other broadleaved species over areas as large as 100,000 square miles (Davidson and Prentice 1968). Its estimated impact on the aspen ecosystem ranks above all forest insects in the north-central United States (Addy *et al.* 1971). Outbreak patterns have been described by Hodson (1941), Hildahl and Reeks (1960), and Sippel (1962). High populations appear suddenly at approximately 10-year intervals following an increase in annual cyclonic passages (Wellington 1952). These outbreaks normally persist for 2 to 3 years. However, heavy infestations have occurred in the same stands for 6 consecutive years in the International Falls, Minnesota, area (Witter *et al.* 1972) and for 7 years in Alberta (Shepherd and Brown 1971). Outbreaks may end as abruptly as they began; decline has been attributed to low hatch due to frost, starvation of larvae after hatch due to frozen foliage, and freezing (Prentice 1954, Blais *et al.* 1955, Hildahl and Reeks 1960, Gautreau 1964, Smith and Raske 1968). Starvation may occur when the number of insects increases so rapidly as to exhaust the food supply before caterpillars are fully grown.

Complete defoliation of the aspens as well as the understory shrubs commonly occurs in June. Heavily defoliated trees refoliate by the end of July. Tree mortality has not been widespread. Locally, stands may sustain 20- to 80-percent mortality on poor sites during drought years (Duncan and Hodson 1958, Barter and Cameron 1955, Ghent 1958), but more commonly some branch mortality and reduced diameter growth occur (Batzer *et al.* 1954, Hildahl and Reeks 1960, Rose 1958, Dils and Day 1950). Growth may be reduced about 2 cords per acre (Hildahl and Reeks 1960, Duncan and Hodson 1958). Growth is significantly reduced 1 year beyond the cessation of defoliation, but the third year after defoliation in stands heavily defoliated 3 successive years growth on dominants increased. *Hypoxylon* and *Nectria* fungus infections increased with intensity of defoliation (Churchill *et al.* 1964). During outbreaks the large numbers of caterpillars and the denuded trees are a nuisance in resort areas. However, the effects of forest tent caterpillar outbreaks are not entirely negative. Where there are understory conifers such as balsam fir, heavy defoliation of the overtopping aspen has resulted in a 20-percent increase in radial growth of the balsam fir (Froelich *et al.* 1955).

More than 40 species of insect parasites attack the forest tent caterpillar. One of the flesh flies, *Sarcophaga aldrichi* Parker, is the most abundant; living maggots are deposited on cocoons and bore into the body of the caterpillar prepupae or pupae. The small

tent caterpillar larvae are susceptible to nuclear and cytoplasmic polyhedrosis viruses (Bird 1969), and epizootics in forest tent caterpillar populations have been introduced artificially (Stairs 1965).

Another defoliator found in outbreaks over large areas is the large aspen tortrix, *Choristoneura conflictana* (Walker). Infestations covering 10,000 square miles have occurred in Manitoba, Saskatchewan, and interior Alaska, and nearly 2 million acres of gross land area in Minnesota. Feeding by the tortrix larvae is first noticeable in spring, although some inconspicuous skeletonizing occurs soon after hatching in August just before hibernation. Spring feeding may destroy the buds when populations are high, but generally defoliation takes place in May and June when larvae feed openly on leaves tied together by webbing. The life history of the large aspen tortrix is described by Prentice (1955), Wickman (1963), and Beckwith (1968). Although this insect will feed upon a number of broadleaved trees, large increases in populations require a diet of quaking aspen (Beckwith 1970). Outbreaks normally collapse in 2 to 3 years in any particular area. Little mortality of aspen has been reported from large aspen tortrix defoliation, the principal effect being growth reduction. Tortrix larvae are fed upon by a variety of warblers and grosbeaks. Many species of parasites attack the large aspen tortrix. Hibernating larvae may be infected by a fungus and larger larvae may be attacked by virus (Beach 1970).

A leaf tier often associated with large aspen tortrix infestations is *Sciaphila duplex* (Walsingham) (McGregor 1967). Other aspen leaf tiers are *Epinotia criddleana* Kearfott (Kusch 1967), *Anacampsis innocuella* (Zeller) (Miller 1955), *Pseudexentera oregonana* Walsingham (Wong and Melvin 1967), *Compsolechia niveopulvella* (Chambers) (Henson 1958), and *Enargia decolor* Walker (Beach 1970), to name but a few. Other lepidopterous defoliators of aspen are the Bruce spanworm (*Operophtera bruceata* Hulst) (Brown 1962) and *Lobophora nivigerata* Walker (Smereka 1960). Lindquist and Miller (1969) have a key to common lepidopterous larvae feeding on aspen.

Three species of leaf-rolling sawflies belonging to the genus *Pontania* are found in some local outbreaks in the Lake States. The pale green larvae fold the leaf margin and the injured portion becomes blackened (Christensen *et al.* 1951), other sawflies of the genus *Platycampus* Schiodte chew holes in leaves (Wong 1957). As with the previously mentioned defoliators, the main effect is the reduction of growth.

Although their feeding characteristics are different from the defoliators mentioned so far, the lepidopterous leaf miners reduce the photosynthetic area of leaves. The more common of these are the aspen leaf miner *Phyllocnistis populiella* (Chambers) (Condrashoff 1964), which produces meandering mines in the epidermal layers of the leaf surface, and the aspen blotch miners *Lithocolletis tremuloidiella* (Braun) and *L. Salicifoliella* Chambers, which cause irregularly shaped blotchy mines (MacAloney and Ewan 1964, Martin 1956). Similar injury is caused by a leaf-mining sawfly *Micra populifoliella* (Townsend) (Underwood and Titus 1968). Heavy attack may cause premature dropping of the foliage.

Beetles that defoliate aspens are the aspen leaf beetle *Chrysomella crotchi* Brown (Smereka 1965), the cottonwood leaf beetle *C. scripta* F., and the introduced species *C. tremulae* (F.) and *C. interrupta* F. (Christensen *et al.* 1951). These have feeding habits similar to the American aspen beetle *Gonioctena americana* (Schaeffer) (Rose and Smereka 1959) and the gray willow leaf beetle (*Galerucella decora* Say) (Davidson and Prentice 1968). Leaf beetle larvae skeletonize the lower surface of leaves. The adults are general feeders.

BORERS

The wood-boring insects that attack aspen are principally beetles belonging to the families Cerambycidae (roundheaded borers or longhorned beetles) and Buprestidae (flatheaded borers or metallic beetles). Some borers found in aspens belong to other orders, such as a clear-wing moth of the genus *Aegeria* and a twig-boring sawfly, *Janus abbreviatus* (Say).

The most serious wood borer in aspen is the poplar borer, *Saperda calcarata* Say. The larva of this largest of all North American members of the genus produces tunnels. As a result, wind breakage increases and lumber and veneer are degraded. As much as 64 percent of all mature trembling aspen may be attacked (Graham *et al.* 1963). The tunnels serve as infection courts for wood-rotting fungi, and in Michigan most hypoxylon cankers were associated with

popular borer and other borer attack (Graham and Harrison 1954). Successful borer activity is evidenced by the accumulation of ejected fibrous frass and masses of varnish-like dried sap on the bole beneath the ejection openings.

Poplar borer numbers seem to increase during dry years (Graham and Mason 1958). Successful attacks are always concentrated in individual trees or small groups of trees distributed unevenly throughout the stand. Inasmuch as no differences have been observed in growth rate or size between adjacent attacked and unattacked trees, Peterson (1948) has suggested that initial attack occurs randomly, and successive generations attack the same tree. Graham *et al.* (1963) reported that certain trees growing in exposed positions are likely to be attacked several times during years when beetles are especially numerous. Borer infestations tend to vary directly with stem diameter and inversely with stocking (Ewan 1960). Periodic removal of infested trees proved worse than no cutting because the reduction in stand density resulted in more infestations (Peterson 1948). Apparently, the best practice would be to maintain well-stocked stands and clearcut them at maturity.

The root-boring saperda, *Saperda calcarata adscerca* Felt and Joutel, feeds on the phloem and surface of the sapwood on the trunk near the ground (Graham *et al.* 1963). This may be the same species reported by Wong *et al.* (1963) in Manitoba and Saskatchewan.

Several other roundheaded borers commonly occur in sucker stands and on branches of larger trees. The poplar gall saperda, *Saperda inornata* Say, produces globose galls as a result of oviposition incisions in the bark (Nord *et al.* 1972a). As a result of the larvae boring into the wood, growth ceases and susceptibility to wind breakage increases. Another longhorned beetle, the poplar branch borer, *Oberia schaumi* LeConte, attacks larger suckers as well as tree limbs (Nord *et al.* 1972b). Site quality appears not to be significant in attack by these insects. The recommended practice to minimize damage by these beetles is to achieve and maintain maximum density of vigorous aspen regeneration (Myers *et al.* 1968).

The bronze poplar borer *Agrilus liragus* Barter and Brown, one of the flatheaded borers, often weakens and kills aspen by attacking the branches and stem (Barter 1965). The zigzag galleries disrupt the normal translocation of nutrients. Any weakening factor such as forest tent caterpillar defoliation, hypoxylon canker, wind damage, suppression, etc. increases a tree's susceptibility to attack and enhances borer survival. Graham and Harrison (1954) maintain that *Agrilus* beetles are beneficial because they attack weakened trees and thin the stand.

Another *Agrilus* beetle is the aspen root girdler, *Agrilus horni* Kerremans. The larva bores from the bark on the trunk near the ground to the root, then back to the stem, making a spiral gallery that girdles the sucker (Nord *et al.* 1965).

Several other Buprestids attacking aspen are the flatheaded appletree borer *Chrysobothris femorata* (Olivier), the Pacific flatheaded borer *C. mali Horn*, and the flatheaded aspen borers *Dicerca callosa* Casey, *D. tenebrica* Kirby, *D. divaricata* (Say), and *Poecilonota cyanipes* (Say). These insects are not serious pests in well-managed stands.

The poplar and willow borer *Sternochetus lapathi* (L.) is a weevil that riddles the stem with galleries when young larvae bore from the outer sapwood toward the center of the stem. Broken places in the bark through which the larvae push their frass and knotty gall-like swellings are characteristic of attack. Planted trees are particularly susceptible. This insect is found from the east to the west coasts of North America on both sides of the Canadian-U.S. border (Harris and Coppel 1967).

SUCKING INSECTS

Two common galls on aspens are caused by aphids. The poplar vagabond aphid *Mordwilkoja vagabunda* (Walsh) causes a peculiar curled and twisted convolution of leaves up to 2 inches in diameter at the tips of twigs. Another large gall caused by mites commonly follows severe infestations by the forest tent caterpillar. Poplar petiolegall and twiggall aphids of the genus *Pemphigus* produce swellings on leaf petioles of aspens. The speckled poplar aphid, *Chaitophorus populifoliae* (Fitch), and the spotted poplar aphid, *Aphis maculatae* Oestlund, are commonly found on expanding leaves of aspen suckers. Heavy populations may cause increased forking of the stem (Osgood 1963). A common aphid on bigtooth aspen

tent caterpillar [illegible] Sanders [illegible] cytoplastic [illegible] epizootics [illegible] been introduced [illegible] to the [illegible] *opis*, [illegible] Another [illegible] ves [illegible] a [illegible] ects [illegible] familiar [illegible] limited to [illegible] from excessive [illegible]

[illegible] weakening factor [illegible] defoliation, hypoxylon [illegible] etc. increases a [illegible] borer [illegible] maintain that [illegible] they attack [illegible] disrupt the normal [illegible]

[illegible]NCLUSION

[illegible] not discussed here may occasionally [illegible] aspen stands. However, even where the [illegible] ecology of insects are known, the role [illegible] throughout the life of the stand is not well understood. Some may attract more attention than they deserve, while others may deserve more attention than they command. The impact of some of the more prominent insects of aspen (such as the forest tent caterpillar, the large aspen tortrix, the poplar borer, and the many insects attacking aspen suckers) needs to be quantified. An increased awareness of the many kinds of insects found in aspen forests and their interactions with the trees, shrubs, herbs, and other biota, along with the management objectives, should improve the forester's ability to decide his course of action.

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BREEDING AND ESTABLISHMENT — AND PROMISING HYBRIDS

Miles K. Benson, *Research Fellow*
The Institute of Paper Chemistry
Appleton, Wisconsin

ABSTRACT. — Methods for breeding aspen and for successful plantation establishment, and several promising aspen hybrids are described. By cutting flowering branches from aspen in the winter and forcing them indoors in ice water, 150 to 300 seeds per catkin pollinated can be produced. Establishing aspen plants requires minimizing sod competition. Mechanical cultivation (the only method found satisfactory) produced 2-year average heights of 8 feet for some planted materials. Improved materials of native aspens, *Populus tremuloides* Michx. and *P. grandidentata* Michx., are described as well as native aspens hybridized with Asiatic and European aspens. The more promising interspecific hybrids described include *P. tremuloides* crossed with either *P. tremula* L. (diploid or tetraploid) or *P. davidiana* Dode, and *P. grandidentata* crossed with either *P. alba* L. or *P.* x *canescens* Sm.

Breeding work with aspens (section Leuce) in North America has been a novelty until recent years. The earliest work was done by such pioneers as Dr. Carl Heimburger, Dr. Scott Pauley, Dr. Ernest Schreiner, and Dr. Philip Joranson at a time when aspens were considered weeds. Most of the work by the above-named men included work with poplars to a greater or lesser degree. The foresight of these pioneers is still not fully appreciated by the practical field man.

The program on which this paper is based originated with work by Joranson at Beloit College in 1953. In 1954 Dr. Joranson moved to The Institute of Paper Chemistry, where an industry-sponsored research program for the improvement of aspens in the Lake States was initiated. The program continued under Joranson's direction until 1959, and has since been directed by Dr. Dean W. Einspahr. Of the current aspen breeding programs, the program at The Institute of Paper Chemistry and that at the Southern Research Station, Maple, Ontario, Canada, (now under the direction of Dr. Louis Zufa who succeeds the retired Dr. Carl Heimburger) are the most comprehensive and active in North America.

The worth of aspen should have been fairly well defined in the previous papers submitted to this symposium. The purpose of this paper then is to take the reader from the germ cell to the established tree in the field. To do this the author draws heavily on his experiences since 1960 with The Institute of Paper Chemistry (IPC). A number of publications (International: FAO, International Poplar Commission 1958; Strothmann and Zasada 1957; Slabaugh 1957; Farmer and McKnight 1967; Einspahr and Winton 1972) have been published containing considerable information on the life cycle and breeding of aspen. Because of the nature of this paper and the previously mentioned publications, the author has chosen a general approach and refers the student of the subject to the more detailed papers.

BREEDING OBJECTIVES

Basically, the objective of all *Populus* spp. breeding programs is to produce more wood per unit area in a given time, and of a quality either comparable to or better than that presently produced. There are a number of approaches available to achieve this goal. One of the approaches often considered first is developing materials with hybrid vigor; i.e., progeny with characteristics better than either parent. Hybrid vigor is a phenomenon that can occur for either intra- or interspecific crosses. While growth rate is the characteristic most commonly thought of for hybrid vigor,

characteristics such as specific gravity and form are of equal importance. Another approach is to find trees that require less growing space than the presently produced: thus, more stems and more volume can be produced per unit area. Breeding for disease and insect resistance, photosynthetic efficiency, maximum response to intensive silvicultural practices such as fertilizing and irrigating are other approaches that can be followed. In truth, few breeding programs exist without all of these approaches woven into their basic plan. The difference in choice of approach is generally a matter of emphasis or priorities.

The factor of polyploidy is employed and given high emphasis at The Institute of Paper Chemistry. Exaggerated, genetically controlled characteristics can be obtained in some plants by changing the number of chromosome (rodlike bodies in the cell nucleus which contain the genes, the units of inheritance) sets. In aspen, the cell nucleus normally contains two sets of 19. It has been found that aspen with three sets per cell (triploids) usually have better growth and longer fibers. Triploid quaking aspen have been found occurring naturally (van Buijtenen *et al.* 1957) and triploid aspen hybrids have been produced (Benson and Einspahr 1967) artificially (fig. 1).

Suckering ability of the developed material is an important consideration in the IPC program. One of the more important benefits of aspen is its ability to regenerate and produce a fully stocked stand after harvest (fig. 2). Materials that sucker well should not only give adequate restocking but should continually improve the stand through natural selection. The stronger, faster growing clones that are more resistant to insect and disease problems and better suited to the site should dominate the stand more and more with each harvest and regeneration.

SEED PRODUCTION

Briefly, the aspens are dioecious, and have a 1-to-1 sex ratio with the males flowering more frequently and abundantly than the females. Abnormalities such as bisexuality, perfect flowers, and late flowering have been observed. In the Lake States the flower buds apparently are initiated in May and June and are dormant through most of the winter. Flowering begins in the early spring before leaf flush. Quaking aspen begins flowering anywhere from late March through mid-April, depending on the latitude. Bigtooth aspen, generally follows about 2 weeks behind quaking aspen in the same locality. Pollination begins about 2 weeks after the flowering, with seed fall occurring when the leaves are fully expanded (4 to 5 weeks after pollination).

The seeds are attached to hairs, facilitating seed dissemination by the wind. The seed size can be likened to coarse ground pepper, with about 7,500 seeds per gram for quaking aspen and about 10,700 seeds per gram for bigtooth aspen. Seed germination is high, but the exacting requirements for mineral soil, adequate light, and moisture greatly limit natural regeneration through seeding.

In artificial seed production a cut-branch technique is generally used. In the Lake States the procedure can be started after mid-January for quaking aspen, but should not be started before February for bigtooth aspen. The technique involves forcing flower buds on bundles of cut branches (2 to 3 feet long) to flower by putting the branch bases into a vase of ice water. The bundles are kept in the greenhouse at 65° F. with normal light (daylight). The branches are clipped and the ice water changed daily to prevent vascular plugging of the stems. In this condition the male flowers should shed pollen and the female flowers should become receptive in 7 to 11 days. The female flower buds are generally forced a week later than the males to assure pollen availability for receptive females. During the periods of pollen shed and female receptivity each bundle is kept isolated from all but one pollen source.

When the male catkins are ripe they are collected and allowed to dry at room temperature for 24 hours in paper boxes. After drying the pollen is extracted by shaking the catkins over a 100-mesh screen, which holds back the debris and allows the pollen to pass through. The pollen is put in a cotton-stoppered vial and stored at 40° F. over calcium chloride until it is to be used. When the pistils of the female flowers are brightest red or pink, depending on the species, the specified pollen is applied directly to the filament with a camel hair brush. Filaments dry up within a day if the timing is right; otherwise, a second pollination may be necessary 1 to 2 days later. After the filaments have dried up, the bundle can be washed

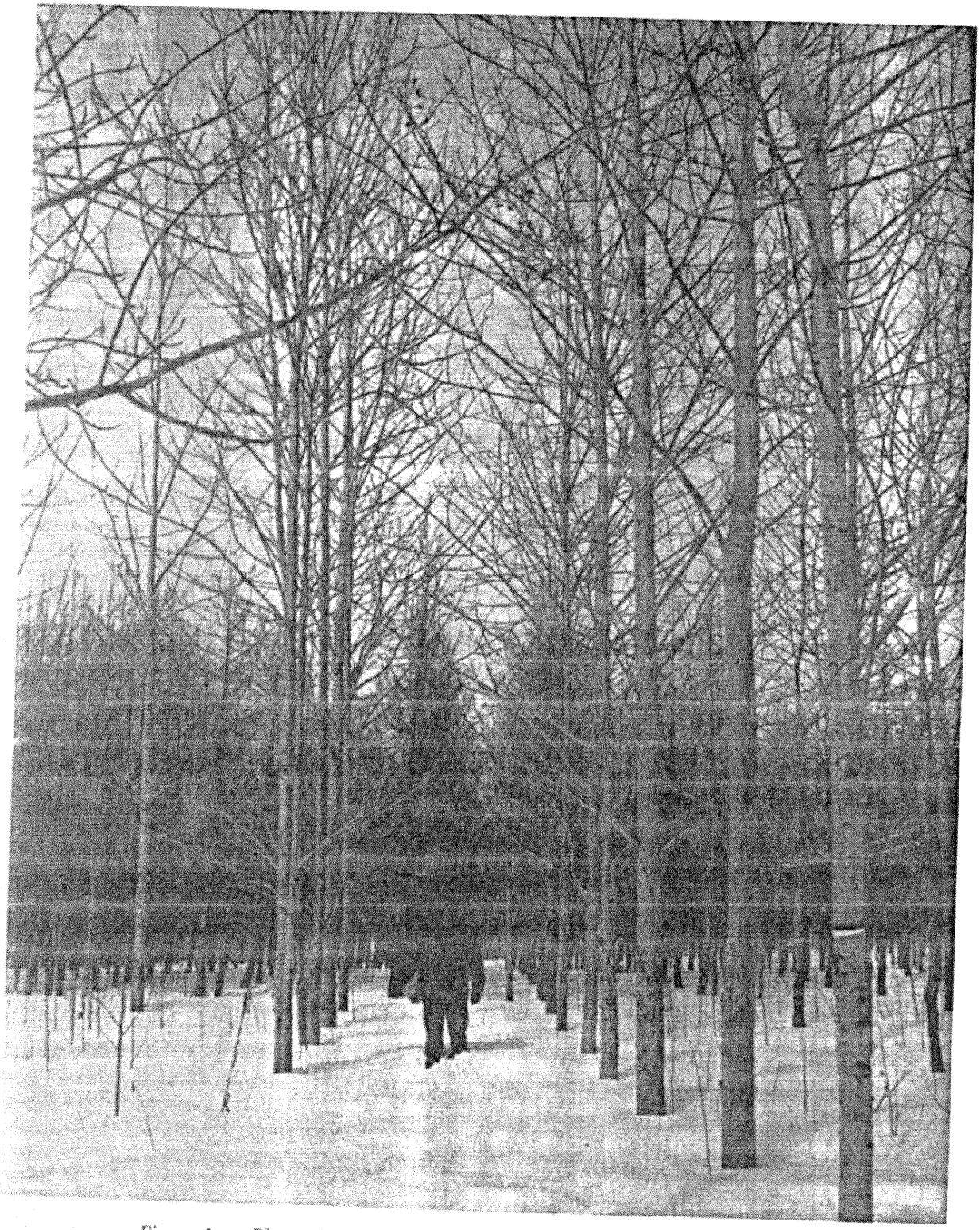

Figure 1. — *Pictured are triploid progeny of* P. tremuloides *Michx. (diploid) x* P. tremula *L. (tetraploid). At 13 years the trees at a 9 by 9-foot spacing averaged 51 feet in height and 6.0 inches d.b.h.*

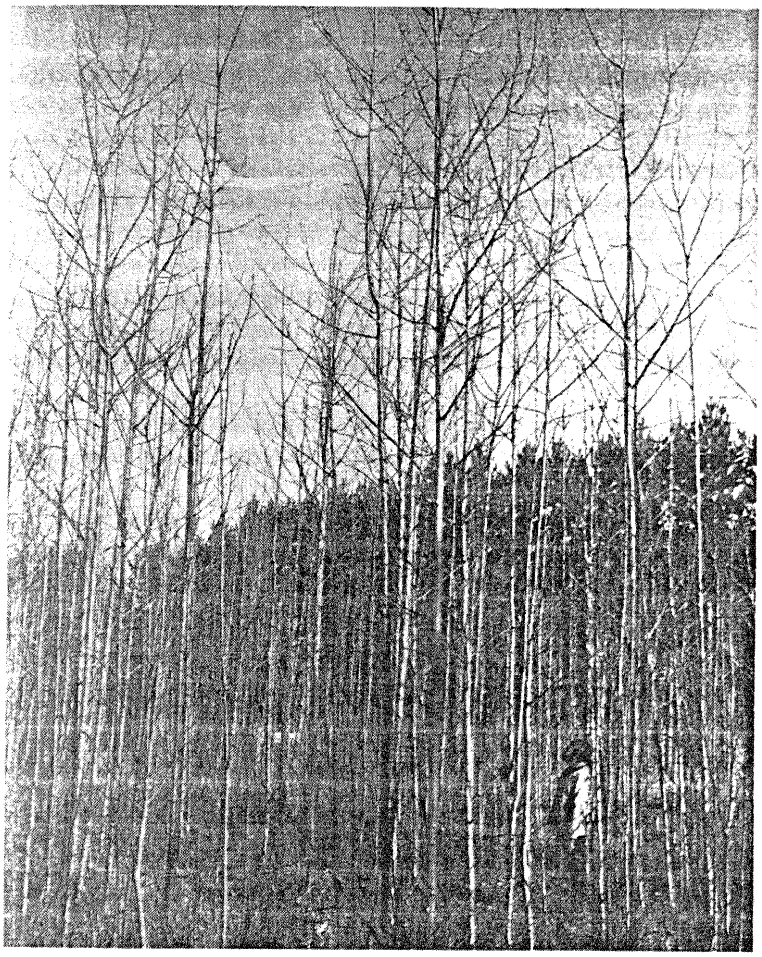

Figure 2. — *The suckering ability of quaking aspen is illustrated in this photo. The material is 8-year-old suckers from a planting cut back at 5 years. The suckers average 15.5 feet in height, 1.1 inches d.b.h. and 4,230 stems per acre.*

with a water spray and removed from isolation until seed is shed.

Seed shed begins about 21 days after pollination. During the shedding each cross is kept isolated from the other shedding crosses: Seed and cotton are collected with a vacuum cleaner and the seeds kept refrigerated a 40° F. over calcium chloride until the seed is ready to be sown. The seed is cleaned by tumbling the cotton with air in a glass jar over soil screens (Harder 1970). If a series of screens is used, the seed can be classified to size in the same operation. Seed production varies between females and type of cross. Up to 700 seeds per catkin pollinated have been produced using this procedure although the average production is closer to 150 to 300 seeds per catkin pollinated.

All the aspens may be artificially crossed using the above technique. In ease of handling, the females of the native and exotic species may be ranked as follows: *P. tremuloides* Michx., *P.* x *canescens* Sm., and *P. tremula* L. with ease; *P. alba* L. less easily; and *P. grandidentata* Michx. with great difficulty. It is most difficult to judge when *P. alba* L. is receptive because its filaments have a lighter color. It also produces fewer seeds per catkins pollinated *P. grandidentata* Michx. is more sensitive than the other species, takes slightly longer to produce seed, loses catkins easily, and produces smaller seed.

SEEDLING PRODUCTION

At The Institute of Paper Chemistry aspens have been raised routinely from seed to plantable size (2 to 4 feet depending on the material and conditions) in a single season since 1959. Plantable seedlings also have been raised at a commercial nursery (Benson and Dubey 1972) using essentially commercial techniques. Critical steps are proper seed storage (40° F. over calcium chloride) until the hour of seeding, fumigating the seedbeds with methyl bromide, maintaining a moist seedbed the first 2 weeks after seeding, and periodic application of captan through the first 8 weeks to prevent damping-off infections. The seedlings are cut back to 1 foot and lifted in the fall when dormant, then heeled-in in a sand bed in an unheated building. The seedlings can then be taken from the sand in the spring and bundled for transport to the planting site.

ESTABLISHMENT OF PLANTINGS

Establishment problems for aspen are similar those described by Schreiner (1945) for pop plantings. In old fields eliminating sod prior to plan ing and controlling it during the first 2 years is esse tial to good establishment (fig. 3). With good sod co trol during the first 2 years, average heights of 8 fe and more can be obtained; without it, average heig of more than 3 feet are seldom obtained. The on method demonstrated to date that gives uniform good control of competing vegetation is mechanic cultivation. For all-around control after plantin rototilling works best; cultivation with a spring toot disk, or quack digger can work almost as well if cult vation is timed properly for the most effective wee kill.

A number of herbicides have been tried in bot

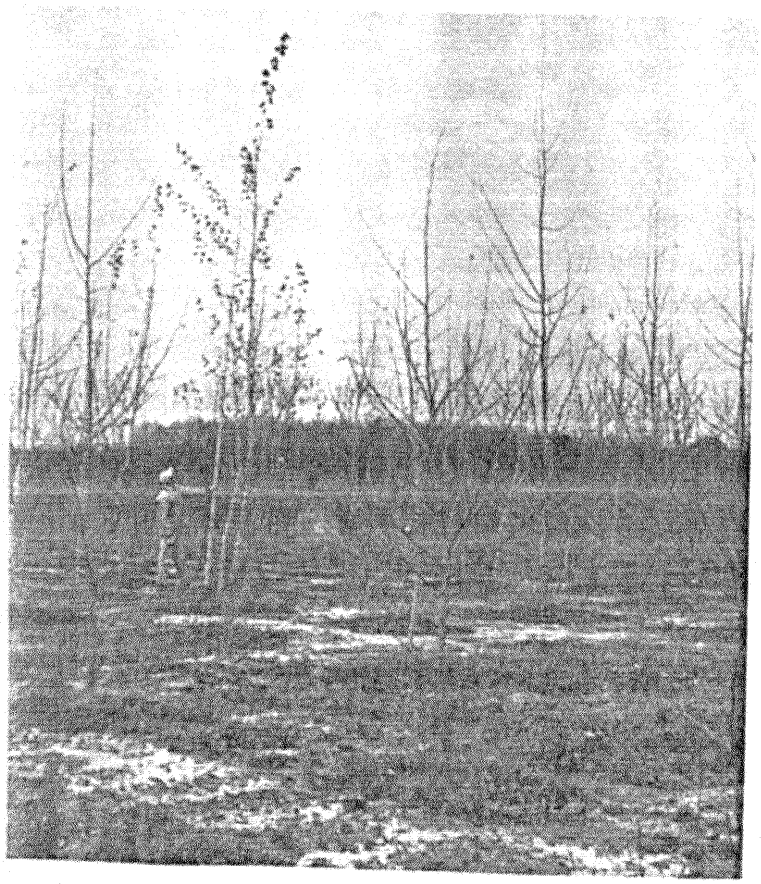

Figure 3. — *Good cultivation during the first 2 years is shown in this 4-year-old plantation. In the background are several* P. grandidentata *Michx. x* P. x canescens *Sm. individuals that are 28 feet tall. The smaller trees in the foreground are better-than-average planted bigtooth aspen, demonstrating the difficulty of establishing bigtooth.*

and industrial plantings but none have controlled the vegetation consistently without hurting the

Planting in a trench (machine with scalpers) has been tried with poor results. Aspen plantings cultivated have become established after 5 years at 25 to 50 percent stocking. The trees in these plantings are bushy and poorly formed due to deer browsing and insect and disease attacks. The trees eventually reach a size where cutting back will result in a reasonably well-stocked sucker stand. Following the "no cultivation" practice can only result in the first planting being a biological and fiscal disaster with the newly formed sucker stand established at the cost of a noncommercial or minimum production harvest. The cost of mechanical cultivation at times seems too high to be profitable; however, with imagination, successful ways such as spacing adjustment or intercropping can be found to reduce the cost to reasonable levels. On light soils deep-planting from 4 to 12 inches above the root collar has resulted in no adverse establishment effects and in dry years has benefited survival and growth.

Aspen plantings have been made in clearcut northern hardwood stands. Growth of the aspen in these areas was observed, during the first 5 years, to be better than uncultivated aspen planted in plowed fields but considerably poorer than well-cultivated aspen plantations. Aspen also grew better than the hardwood regeneration on the cutover area. When planted in areas that developed into aspen sucker stands, the planted aspen tended to be codominant or suppressed, depending on the available growing space. This was better growth than anticipated under these conditions, as planted aspen have a much lower food reserve and less root system available than sucker growing on the root systems of harvested mature trees. The critical factors for establishment of aspen on either old fields or clearcut areas are pressures of deer browsing and herbaceous competition.

PROMISING MATERIALS

It is ironic that people tend to object to interracial marriages of their own kind but generally think of interspecific hybridization as a method to produce the most improvement in plant or animal breeding. The truth is that discretion is needed in either situation.

Intraspecific Hybrids

In the IPC program about two-thirds of the aspen breeding work concerns intraspecific (within species) crossing. A large portion of these crosses are made to evaluate selected trees as parents, evaluating both their breeding performance and the performance of their progeny. Good combinations can be repeated, superior individuals within a progeny group can be used and evaluated as parents, and parents with proven ability to produce good offspring are used in further crossing work, either intraspecific or interspecific.

Of the intraspecific crosses the bigtooth aspen are the least impressive. This is primarily due to the difficulty of establishing the material in plantings (fig. 3). They prefer sandier soils and have slow early growth, 2 feet per year for the better materials under good cultivation. No crosses of bigtooth aspen have yet been found that can be recommended for planting.

Quaking aspen crosses prefer fresher, richer soils of medium texture and respond well to cultivation, the better materials growing 3 to 3½ feet per year. Several promising quaking aspen crosses have been developed. While the progeny of these crosses do not have the growth rate of the best interspecific hybrids, they offer somewhat more uniform growth and establishment, have better suckering ability than any of the materials tested, and, being native, offer more predictable estimates of risk due to damage by insects, disease, or other factors. The potential available using quaking aspen intraspecific crosses has been undersold; considerable gains can be made using improved materials of this kind.

Several exotic intraspecific crosses have been made, primarily to broaden the base of breeding stock available locally. None of the exotic species are considered as possible answers for improved progeny groups, although certain individuals may rate consideration for clonal propagation. *P. alba* L. is too poorly formed, being generally branchy with crooked boles. *P.* x *canescens* Sm. is too variable, perhaps due to its supposed origin as a natural interspecific hybrid. *P. tremula* L. generally has shown less vigor than the native quaking aspen and is not considered desirable for this reason.

Bigtooth Aspen Interspecific Hybrids

Perhaps the best known interspecific aspen hybrid in the Lake States area is *P. grandidentata* Michx. x *P. alba* L., due to the publicity given Iowa hybrids (McComb and Hanson 1954). Several naturally occurring hybrids of this type have been found and many are being tested clonally with hybrids from controlled crosses. Twenty-six crosses of this type have been made at The Institute of Paper Chemistry and 12 were successfully outplanted. Seed production is low for this type of cross. Their growth is superior to native aspen on dry, sandy soils (fig. 4), but their vigor is maximized on fertile, fresh soils. The wood quality of these materials is similar to native aspen but the suckering ability is not as good. While branc ness is excessive and bole straightness is generally po for this material, it can be accepted due to the ga in vigor. A number of plantings have been made the United States and Canada with vigor obvious most areas. A dieback of this material was noted Heimburger (1968) in the Canadian plantings. Su scald has been the most prevalent malady in the IP plantings, but so far has not been great enough discredit the material. The hypoxylon canker, *Hy poxylon pruinatum*, has been occasionally observe on trees of this material. While deer will browse th hybrid, they seem to prefer native aspens. Anoth plus for this type of hybrid is that dormant cuttin can be rooted with an average success of 35 percen

Figure 4.—*Pictured is a 10-year-old planting of* P. alba *L. x* P. grandidentata *Michx. progeny growing at a 9 by 9-foot spacing on a dry, sandy soil. The planting averages 41.5 feet in height and 5.3 inches d.b.h.*

P. grandidentata x *P.* x *canescens* Sm. is an interspecies hybrid, not as well known as "alba x bigtooth," that has exceptional promise (fig. 3). Forty-eight crosses of this type have been made in the IPC program and 33 successfully outplanted. This material exhibits better form than the "alba x bigtooth" hybrids and seems to have similar vigor. Trees growing on dry, sandy soils have reached 28 feet in 4 years. Suckering ability is still unknown, but it is expected to be similar to that of the "alba x bigtooth." No major insect or disease problems have been observed on this material as yet.

Some interspecific crosses have been made between bigtooth aspen and some Asiatic aspen. In the case of the combination with *P. sieboldii* Miq., the crosses did not produce seeds successfully. Crosses for this type of hybrid were only made in one season and have not been repeated since, so it has not been well tested. Three crosses with *P. davidiana* Dode were made and two were successful and outplanted. While these crosses grew well, one exhibited an extreme susceptibility to hypoxylon canker. The above-mentioned Asiatic aspen are supposedly linked to European trembling aspen, *P. tremula* L.

Quaking Aspen Interspecific Hybrids

Several interspecific hybrids using quaking aspen as one of the parents have been produced. They generally grow best on sites similar to those utilized best by quaking aspen. *P. tremuloides* Michx. *P. tremula* L. is one combination that has done well in Europe (International Poplar Commission: FAO International 1958), Canada (Zufa 1969), and in IPC plantings. This material grows slightly faster and is more robust than quaking aspen growing on the same site. The suckering ability and wood quality of these materials is not well tested under the IPC program yet, but there is evidence that both qualities are at least as good as in the native quaking aspen.

Crosses of *P. tremuloides* Michx. with the two Asiatic aspen have been made and tested. Pollen from *P. sieboldii* Miq. was imported and used with quaking aspen. Good results were obtained in the breeding work and nursery production with this cross, but the field plantings were poor. The initial growth and survival was good, but by the end of the second season the material began to show an extreme susceptibiliy to *Agrilus hornii*, a root-boring Agrilus, and by the sixth year 63 percent of the trees survived and were stunted. Hypoxylon cankers were observed on some of the survivors. This cross was not repeated so it cannot be said whether this was typical behavior. Four crosses have been made on quaking aspen with pollen from *P. davidiana* Dode. Two of the crosses resulted in superior outplantings and two failed as outplantings. The failures were due to selective infestation by *Agrilus hornii*. In this case it can be assumed the particular parent combination was a factor. The two successful crosses were outplanted on more than one site and have shown impressive field performance — impressive enough to encourage their future use and to investigate this cross more thoroughly.

One triploid hybrid, *P. tremuloides* Michx. x *P. tremula* L., *4n*, has been very successful (fig. 1). The material grows similarly to quaking aspen through the first few years and then proceeds at a faster rate, producing taller, more robust trees. The material has shown specific gravities and fiber lengths greater than those of native quaking aspen (Einspahr *et al.* 1968). It also has excellent suckering ability, perhaps better than quaking aspen. Tests are presently under way to distinguish the gains due to triploidy from those due to interspecific hybridizations.

Twenty-five crosses between *P. tremuloides* Michx. and *P.* x *canescens* Sm. have been made with 17 successfully outplanted. This material is characterized by high vigor, ability to grow on several sites, and some drought resistance. Because most of the outplantings of this material are young, characteristics of larger trees are not certain. It is suspected these materials will tend toward branchiness and poor bole form.

Quaking aspen has also been crossed with *P. alba* L., but this cross, while vigorous, is generally considered poorer than the "alba x bigtooth" because of its greater branchiness and poorer bole form.

The above-mentioned aspen hybrid evaluations are primarily confined to IPC plantings. A number of other types of crosses — those with three species combined, back crosses, and crosses with species in other *Populus* sections not as closely related to the aspen — have been made but are generally not exceptional in vigor or form. As more of these types of crosses are tried, better results may be obtained. It should also be restated that for the previously mentioned aspen

hybrids parent combinations are very important and that superior hybrid progeny groups or single clones may be developed from any of the mentioned hybrids. The heterogeneity of aspen allows a wide range of results in aspen breeding work, ranging from frustrating ones to those with considerable promise.

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REGENERATION: BIOTIC AND SILVICULTURAL FACTORS

D. A. Perala, *Associate Silviculturist*
Northern Conifers Laboratory, North Central Forest Experiment Station
Grand Rapids, Minnesota

ABSTRACT. — Vegetative regeneration by suckering can be successful in harvested aspen stands only if competition from residual vegetation is largely eliminated. Mechanized timber harvest can best create the site conditions necessary for successful and complete aspen regeneration. Prescribed burning or release by aerial spraying of herbicides also are effective tools.

The North American aspens, trembling and bigtooth, can be regenerated by seeding, stem and root cuttings, and even from tissue cultures (Winton 1968) but by far the least expensive, most practical and reliable method is vegetative regeneration by root sprouts or suckers.

VEGETATIVE REGENERATION AND THE CLONAL CONCEPT

The spreading cord-like lateral roots of aspen usually produce a great number of suckers when the parent tree is killed and the forest floor warmed by insolation (Farmer 1962, Maini and Horton 1966a). Following harvest of a well-stocked aspen stand, as many as 60,000 suckers may be regenerated per acre. All suckers growing from the roots of the same parent belong to a genetically distinct group or clone, and each stand consists of several clones. Excavation of one trembling aspen stand showed that about 70 percent of the suckers were located on seven different root systems with as many as 15 suckers on the same root system (Barnes 1966). Repeated destruction of a stand at intervals of several years will result in engagement of some clones and intermingling according to their ability to compete with one another (Barnes 1966).

Most suckers arise from roots averaging about ½ inch in diameter which, for trembling aspen, lie within an inch of the soil surface, and for bigtooth aspen, within 3 inches (Sandberg and Schneider 1953, Farmer 1962). Suckers may originate more than 80 feet from the parent stump (Graham *et al.* 1963).

Drawing on the parent roots for nutrition, aspen suckers develop rapidly and dominants commonly grow 4 to 5 feet their first year. Young suckers soon produce adventitious roots, and in many cases develop independently if the parent root system decays (Sandberg and Schneider 1953). However, functional root connections occur between aspens up to 65 years of age (Quaite 1953, De Byle 1964, Maini 1968). The distal parent root thickens with time indicating its greater contribution to sucker growth than the proximal root which remains relatively unchanged (Day 1944). It is not until about age 25 when the adventitious roots of bigtooth aspen become more important than the parent root to sucker growth (Zahner and De Byle 1965).

GENETIC VARIABILITY OF CLONES

Aspen clones vary considerably in genetic traits such as leaf morphology and seasonal coloring, stem form, branching habit, growth rates, bark characteristics, sex, and phenology (Barnes 1966). Stems of recognizable single clones may cover from 0.05 to 35 acres (Blake 1964, Barnes 1966). The clone concept is of great importance in interpreting research results for aspen management since genetic variation also greatly affects suckering capacity and may mask variation in suckering due to site index or stand age, for example. Six clones of bigtooth aspen varied sevenfold in numbers of suckers produced after clearcutting (Garrett and Zahner 1964). Other bigtooth and trembling aspen clones varied fourfold in sucker numbers (Farmer 1962) and even up to twentyfold depending on temperature regime (Maini 1967).

Variability in initial growth and survival of suckers may be due to clonal variability of root carbohydrates (Tew 1970, Schier and Johnston 1971).

Variability in suckering under different ecological conditions could be an important tool in management efforts to increase the area of desirable clones. For example, partial cutting may leave a site cooler than clearcutting would, thus favoring suckering of one clone over another. After regeneration is achieved, a clearcut of the remaining stand would allow sucker development of the preferred clone.

STAND FACTORS INFLUENCING SUCKERING

Suckering generally increases as the density of the parent aspen stand harvested increases, whether density is expressed in number of trees, basal area, or volume (Stoeckeler and Macon 1956, Graham *et al.* 1963). Some trembling aspen stands have regenerated satisfactorily in northern Minnesota where stocking was only 20 square feet of basal area per acre.[1]

Sucker stocking generally decreases as density of the residual overstory increases. Aspen suckers are intolerant of shade and require full sunlight to develop. Stoeckeler and Macon (1956) found sucker numbers increased twentyfold when the overstory decreased from 100 square feet basal area per acre to 0. Competition from understory shrubs (Stoeckeler and Macon 1956), bracken fern (Maini and Horton 1966b) and the overstory reduces height growth and survival of suckers (Zehngraff 1947, Farmer 1963). First year dry weight increment of trembling aspen suckers may decerase by a factor of three with increasing basal area density of the residual overstory.[1]

Evidence on the effect of age on the ability of clearcut aspen to sucker is conflicting. Suckering increased up to age 70 in one Minnesota study (Kittredge and Gevorkiantz 1929) although in another study age had no effect (Sandberg and Schneider 1953). Suckers reached maximum numbers for bigtooth aspen at age 40, and for trembling aspen at age 35 in the lower peninsula of Michigan (Graham *et al.* 1963). In Canada, suckering was similar in root cutting from aspen 20 to 150 years of age (Maini 1968). Wisconsin stands averaged 1,852, 2,011, and 2,807 suckers per acre when cut at age 30, 40, and 5 respectively (Stoeckeler and Macon 1956).

Very young aspen stands may regenerate well whe clearcut. In northern Minnesota, trembling aspe stands 2, 4, and 8 years of age averaged 30,00 35,000, and 41,000 suckers per acre respectively t first year after clearcutting.[2]

Aspen suckering in Wisconsin stands increased a site index increased (Stoeckeler and Macon 1956 but in Minnesota stands, site quality did not affe suckering (Sandberg and Schneider 1953). Sour conclusions are difficult to make since better site usually yield a higher stocking of aspen, an importa variable in sucker production. Also height growth c genetically superior clones on poor site may exce that of inferior clones on a better site (Zahner an Crawford 1963). Thus genetic variability may a count for apparent differences in site quality as we as sucker production.

SILVICULTURAL PRACTICES FAVORING SUCKERING

The only factor the forest manager can manipula to regenerate harvested aspen stands is the degree overstory and understory competition remaining. T other factors affecting sucker regeneration — aspe stocking, stand age, clonal variability, and site — a fixed for a given mature stand. But the forest ma ager can take steps to ensure the next stand is we stocked with aspen. The basic requirement is to co trol competition from the remaining vegetation usi one or more of the following techniques.

Full-Tree or Tree-Length Harvesting

Tree-length harvesting systems probably offer th greatest potential for properly regenerating aspe stands, and could eliminate the need for any furth treatment to encourage suckering. Nearly all of th overstory and understory shrubs were eliminated one study when fellers and skidders were told not favor residual trees or advanced regeneration durin their mechanized harvesting operation (Zasada an Tappeiner 1969). Excellent sucker regeneration w achieved and the new stand should be virtually 1 percent stocked with aspen at maturity.

[1] *Unpublished information by the author.*

[2] *Ibid.*

Felling or Girdling Residuals

siduals may be felled or girdled but this can be st expensive method of site clearing, and costs in mixed stands with many unmerchantable Saskatchewan and Manitoba now require ete clearcuts in aspen (Jarvis 1968) and many al Forests require all trees over 2 inches d.b.h. felled.

Chemical Control of Residuals

idual residual trees other than aspen and than 3 or 4 inches d.b.h. may be killed by cut- treatments. Dilute herbicides can be applied to ood by a tree injector.[3] The incisions should d one-fourth to one-half inch into the sapwood se to the base of the tree as practical (Arend Roe 1961). Tests with new chemicals containing ram (4-amino-3,5,6-trichloropicolinic acid) have good results on species that generally have been ant to herbicides (Brinkman 1970). Tree injec- treatments cannot be used on aspen because the icals may be transported through the connect- oot system and thus prevent suckering (Quaite).

xperimental aerial applications of 3 pounds acid valent per acre of 2,4-D or 2,4-D/2,4,5-T mixture arly August generally have been successful in cing residual overstories (Perala 1971). Paper and red oak were readily killed but red maple basswood were highly resistant. Aspen suckers dy established were killed to the ground line but unaffected parent roots produced an abundance ckers the following year. Chemical treatments to ve competition should be made within the first growing seasons after logging to avoid partial kill der suckers which can lead to possible stem dis- ons.

Ground Scarification

arification improves sucker initiation and sur- by reducing the understory, litter, and duff, and sing the forest floor to solar radiation. Undis- rd litter may foster a high cutworm population h can in some cases eliminate the succulent emerging suckers (Graham *et al.* 1963). Leveling the understory also gives aspen suckers an excellent chance of overtopping the slower growing shrub regeneration. Sufficient scarification can usually be achieved in harvesting if skidding covers much of the cutting area. Scarification may be poor after winter logging in deep snow.

If harvesting fails to scarify an area sufficiently, other means such as shearing can be used, but only at great expense. Sheared aspen sites invariably result in dense aspen suckering. Discing also has initially increased sucker stocking (Zehngraff 1946b, Zillgitt 1951), but several field reports of poor survival and height growth suggest that this method should not be recommended.

Prescribed Burning

Many studies show that burning increases the number of suckers (Shirley 1931, 1932; Horton and Hopkins 1965; Buckman and Blankenship 1965; Maini and Horton 1966b; Tucker and Jarvis 1967). Perala[4] found that dormant season burning increased aspen suckers from a preburn number of 17,000 stems to 24,000 per acre. More important, the fire killed 75 percent of the standing residual hardwoods and cull aspen and reduced their basal area from 30 to 7 square feet per acre.

Several important conditions are necessary for successful prescribed burns in aspen: uniform distribution of fuels for complete burn coverage; suitable burning conditions; and well-cured fuels. Aspen slash may require up to one year curing before it will sustain a fire hot enough to kill standing residuals.

The recommended weather conditions and minimum burning indexes (Nelson 1964) for a successful prescribed burn in aspen are:

Air temperature	> 65° F.
Relative humidity	< 35 percent
Buildup index	> 30
Timber spread index	> 25
Wind	6-12 m.p.h.
Number of days with less than 0.1 inch rain	> 5

See page 103.

[4] *Unpublished manuscript by the author.*

Burning in the autumn is preferred over spring burning because of greater availability of standing fine fuels to carry the fire.

Season of Harvest

If prescribed burning or mechanized harvesting is not carried out, then the season of aspen harvest may affect sucker production. Although evidence is conflicting, it is probably desirable to harvest aspen during the dormant season especially in areas where brush or bracken fern would compete with regeneration if it were harvested during the growing season (Stoeckeler and Macon 1956, Graham *et al.* 1963).

Zehngraff (1946a) reported less suckering in spring- and summer-logged northern Minnesota aspen stands. Suckers produced later in the season were short and succulent, susceptible to frost, and less able to compete with brush. In Wisconsin, sucker numbers following late summer harvesting were about three-fourths of that following dormant season harvesting (Stoeckeler and Macon 1956). However, studies in Michigan and Minnesota showed that season of logging had little effect on the number of suckers present after two growing seasons (Sandberg and Schneider 1953, Graham *et al.* 1963).

Stoeckeler (1947) felt reduction in suckering may be linked with low levels of carbohydrate reserves in the roots during active leaf development in the spring and early summer. Tew (1970) found carbohydrate reserves varied with the season. However, the length of the period of sucker production rather than the number of suckers produced varied with the carbohydrate reserves. The variability in reports on aspen suckering according to season of harvest is probably tied closely to other variables such as genetic variation and the amount of understory and overstory competition left after logging.

HOW MANY SUCKERS ARE ENOUGH?

Past studies suggest 6,000 suckers per acre are needed for a minimum initial stocking (Graham *et al.* 1963). Stoeckeler and Macon (1956) show that 6,000 per acre would result in 90 percent milacre stocking and 9,000 per acre virtually assures 100 percent stocking. But uniform distribution is as important as density for obtaining good aspen regeneration. Sorenson (1968) concluded that an initial 1,000 well-spaced suckers per acre would yield as gre volume in crop trees at age 15 as a stand havin initial density of 10,000 stems per acre.

Under conditions of complete overstory rem and good scarification, more than the minimum 6 suckers are usually obtained to fully utilize the and obtain maximum production of wood or f High density aspen stands undergo less attack hypoxylon cankers (Anderson and Anderson 19 and are less susceptible to damage by poplar borers (Myers 1967). However, in Michigan, d stands of over 35 thousand suckers per acre so times suffer excessive mortality, leaving too scatte a stand for best development (Graham *et al.* 196 Initial high sucker densities obtained in Minne (up to 60,000 per acre) are reduced rapidly in n bers through natural mortality yet total producti remains higher than in less dense stands.[5]

SUMMARY OF TREATMENTS FOR SUCCESSFUL REGENERATION

Complete removal of overstory and scarificat to minimize understory competition are necessary aspen suckering. Full-tree or tree-length harvest systems when properly administered can meet th requirements without further treatment. Where sho wood systems are used, all unmerchantable tr should be removed. Residuals can be felled or che ically treated following a timber sale if only a f remain. If many are left it will be more economi to burn, especially if the residuals are conifers or a herbicide resistant. Prescribed burning is also reco mended to reduce understory competition. If the ov story consists of species with low resistance to her cides, aerial spraying may be a suitable alternati Mechanical treatments, such as shearing, are reco mended only as a last resort due to their expense minimum initial stocking of 6,000 suckers per acre needed for good regeneration.

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Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key — out of the reach of children and animals — and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts: wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Department of Agriculture, consult your county agricultural agent or State Extension specialist to be sure the intended use is still registered.

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U.S. DEPARTMENT OF AGRICULTURE

SIMULATION OF GROWTH:

A New Approach to Yield Forecasting

I. E. Bella, *Research Scientist*
Northern Forest Research Centre, Edmonton, Alberta, Canada

ABSTRACT. — For increased efficiency in timber growing, the forest manager needs to be able to forecast the outcome of alternative silvicultural strategies and select the optimum one for any given set of management objectives. There are many potential stand condition and treatment combinations. A general and flexible approach is outlined for yield forecasting that could eventually provide the needed answers. This "stand model" simulates periodic height and d.b.h. increment of every tree on a sample plot, from starting age to harvest, and calculates stand characteristics simply by summing tree data for a unit area. Some potential uses of the model in aspen management are given and development work in progress is outlined.

The usual way of forecasting growth and yield of forest stands is from yield tables or functions. Smoothed trends of yield for a given species — expressed in terms of age, site index and possibly basal area density and average d.b.h. — are based on stand data from sample plot measurements. Schlaegel's (1971) yield tables for aspen is one example.

These methods of forecasting forest yield have been widely accepted and used by forest managers. Current rapid advances in utilization and increasing demand for wood fibre will require intensification of forestry practices as well as improvements in management planning and analysis. For the latter, it will be necessary to forecast yield for a number of alternative stand conditions and treatments and to select the optimum combination for a set of management objectives.

Yield tables are not suited for this purpose because their use in prediction is limited to stand conditions similar to those of the original sample. A more general approach is needed to predict yield. Its main objective should be to make long-term forecasts for treatment comparisons rather than just to provide short-term predictions for specific, undisturbed stands.

NEEDED: A FLEXIBLE METHOD, A SIMULATION MODEL

Although further improvements are possible in the yield table method of forecasting, one cannot overcome the main limitation of the method: its use is restricted to the specific conditions of the data base, beyond which extrapolations are fraught with danger. This limitation of yield tables arises from their reliance solely on stand parameters. The use of stand averages in this way tends to conceal causal relations that might provide the basis for major improvements in forecasting methods. Processes of stand growth and development should be studied and evaluated on an individual tree basis, because that is the seat of such processes; whereas stand growth and yield may simply be looked at as the sum of individual tree performances on a unit area.

Although much tree growth information has been collected in the past, there was no technique to synthesize the data into models that would provide meaningful estimates of stand growth and yield.

The advent of large, high-speed computers made

the development of these simulation models possible. The computer has three main functions: (1) it provides a structural frame-work — in form of a stored program— for the forest system, including the descriptions of all the important interactions that affect tree growth and mortality; (2) it stores relevant information on *every* tree (e.g., height, diameter, spatial coordinates); and (3) it evaluates (computes) in quantitative terms the effects of all the requisite interactions.

To build a stand growth model, one begins with the identification of the most important components of tree growth. These components in the aspen model are:

Soil and climate (expressed by height growth of dominants).

Species characteristics (tolerance, growth habits, clonal characteristics).

Age.

Intertree competition (stocking, stand density, and structure).

Next, all the components require quantitative description. Because of the complexity of the forest system, and our limited knowledge of it, simplifications are usually necessary to describe the relationships. The more important of these simplifications are called assumptions. They should be stated clearly in a model and their limitations recognized. Increasing the number of assumptions usually weakens the model.

These components then have to be reassembled (i.e., interfaced) and translated into a suitable computer language. Flow charts are useful to help visualize interrelations (fig. 1). A stand model can be developed to practically any degree of refinement, depending on the degree of complexity of the stand and the availability of basic data, time, and money. In the aspen model, for example, clonal structure of the stand may be included directly by assigning a clone identification number to each tree. In this model, however, clonal effects are considered only in terms of tree-growth differences.

A STAND GROWTH MODEL

Simulation of aspen stand growth in this model is based on height-growth trends of dominant trees. Using height increment in this way is particularly suitable for simulating aspen growth, because aspen is an intolerant species that readily expresses dominance even in dense stands. Results available from a number of aspen growth (reviewed by Bella)[1] show that height growth of the largest trees is quite stable and is not affected by competition. Thus height growth of these trees in a stand can be predicted accurately. The height-growth regression necessary for simulation can usually be derived from site index curves.

The same kind of relation seems to hold for diameter growth of the largest trees in vigorous young aspen stands, at least up to 15 years of age (Sorensen 1968). These relations have to be defined in stand growth simulations as they indicate limits of competition effects on tree growth.

The model generates potential height increment for each individual tree during a simulation run. These increment values include, in addition to the mean trend value for a given clone and period, a certain amount of random variation. Potential height increment is reduced according to each tree's competitive position, or index. Evaluating this index of competition is the most crucial part of the model. Background work for this is presented by Bella (1971).

Potential diameter increment is estimated from potential height increment using an appropriate regression derived from open-growing aspen tree data. This potential increment is reduced according to the tree's competitive status using a numerically derived relationship.

One of the most difficult problems in forecasting growth and yield of forest stands is the meaningful prediction of mortality. Mortality both from suppression and from other causes, can be handled readily in the model. Basic data for model building can be obtained from permanent sample plot records that include a frequency distribution of dead trees by size and final increment classes at different ages. Criterion of death in the model is defined so that simulated results of mortality distributions of dead trees conform to what is found in actual stands. In the aspen model, suppression mortality is assumed to be directly

[1] *Bella, Imre E. Simulation of growth, yield and management of aspen. Univ. Br. Col., Fac. For., Unpublished Ph.D. Dissert. 190 p. 1970.*

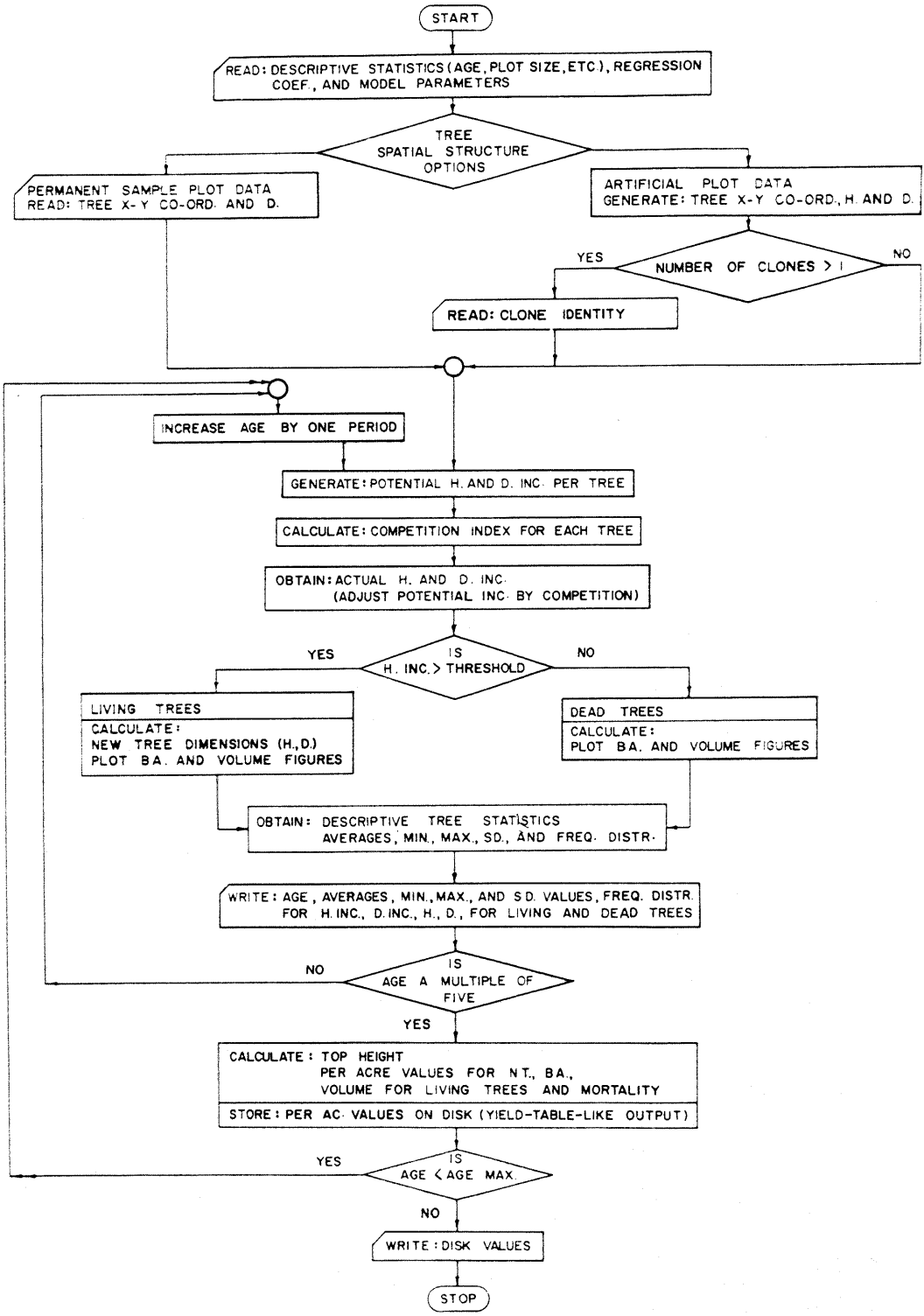

Figure 1. — *General flow diagram of the aspen stand growth model (where B.A. = Basal Area; D. = Diameter; FREQ. DISTRI. = Frequency Distribution; H. = Height; INC. = Increment; NT. = Number of Trees; SD. = Standard Deviation). Notations and symbols are similar to those used in FORTRAN programming.*

related to the trees' competitive status and inversely to current increment — including a certain amount of random variation. Simply, trees most likely to die are the ones with high competition index and slow growth.

It was relatively easy to work out in the aspen model how to simulate tree growth at the two extremes of the competition spectrum; i.e., for the largest dominants and for the small, suppressed trees. The difficult part was the simulation of tree growth between the extremes. Some of the relationships between tree growth and competition were derived numerically. That is, algebraic expressions were developed by trial and error to conform to current knowledge of competition effects.

TESTING THE MODEL

Each component is analyzed and tested during model building, using experimental data as much as possible. Standard statistical techniques, however, are not suitable to validate the complete model because of its "loose" nature due to the interfacing, presence of random components, and the incorporation of different assumptions through model coefficients. One of the better ways of validation is to compare actual yield from a permanent sample plot with simulated yield of the hypothetical stand. Initial stand conditions would have to be identical. Appropriate yield table statistics also provide some useful comparisons.

Although yield tables are usually tested for conditions in which they are to be used, a similar test of the model would neither be practical nor necessary. Because a simulation model is realistic, it may be considered sufficient to validate it with only certain benchmark values.

The aspen model has been tried for simulating the growth of aspen only in undisturbed, natural stands of average, or below average density. For greater ease of calibration, the trees in the hypothetical stand were assumed to belong to the same clone. After the various model coefficients were refined, simulated stand statistics (table 1) showed good similarity with comparable permanent sample plot data or with appropriate yield table values (fig. 2).

Table 1. — *Summaries for growth simulation of aspen stand for above-average site class in Saskatchewan (in English units per acre, and in metric units per hectare)*

Age in years	Top height	Trees: Living: Total	Trees: Living: Over 4 in.	Trees: Dead	Average d.b.h.: Total	Average d.b.h.: Over 4 in.	Basal area: Total	Basal area: Over 4 in.	Volume yield: Total	Volume yield: Over 4 in.	Volume dead trees	Gross volume yield
	Ft.	No.	No.	No.	In.	In.	Sq.ft.	Sq.ft.	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.
14	28.4	4,090	0	0	1.6	--	60	0	577	0	0	577
19	34.3	3,420	20	670	2.2	3.8	88	2	1,037	13	43	1,080
24	39.8	2,930	150	490	2.7	4.1	115	14	1,593	147	80	1,715
29	44.7	2,490	520	440	3.2	4.2	135	49	2,111	557	132	2,365
34	49.2	2,010	850	480	3.6	4.3	144	87	2,502	1,106	255	3,011
39	53.2	1,690	1,080	320	4.1	4.5	154	121	2,914	1,734	245	3,668
44	56.8	1,340	1,060	350	4.6	4.8	151	136	3,099	2,186	381	4,234
49	60.0	1,040	950	300	5.0	5.2	144	139	3,159	2,480	434	4,729
	Meters	No.	No.	No.	Cm.	Cm.	Sq.m.	Sq.m.	Cu.m.	Cu.m.	Cu.m.	Cu.m.
14	8.6	10,107	--	0	4.1	--	13.8	--	40.37	--	.00	40.37
19	10.4	8,451	--	1,656	5.6	--	20.2	--	72.56	--	3.01	75.57
24	12.1	7,240	--	1,211	6.8	--	26.4	--	111.47	--	5.60	120.00
29	13.6	6,153	--	1,087	8.1	--	31.0	--	147.71	--	9.24	165.48
34	15.0	4,967	--	1,186	9.1	--	33.0	--	175.07	--	17.84	210.69
39	16.2	4,176	--	791	10.4	--	35.4	--	203.90	--	17.14	256.66
44	17.3	3,311	--	865	11.7	--	34.7	--	216.84	--	26.66	296.26
49	18.3	2,570	--	741	12.7	--	33.0	--	221.04	--	30.37	330.90

POSSIBLE USES OF THE MODEL IN MANAGEMENT

A most obvious operational use of this model is that of a very general and flexible yield table. Detailed size data are available on every tree during a simulation run, thus stand table information can readily be printed. Stem volume estimates can be provided in any desired standard, and to specified limits of merchantability. Similar estimates may be obtained for tree weight. Most of the tree volume and weight equations are already available from earlier studies, and new ones can easily be derived.

While earlier methods of growth and yield predictions are not suited to extrapolation, an important use of this model would be to forecast yield for stand conditions on which no historical data exists. For example, stand development and yield after logging probably will differ in aspen sucker stands from yields in stands originating after wildfires. Most of the aspen growth data now available are from stands of the latter kind, although the manager also needs to forecast yield for cutover areas.

The effect of various density control treatments, their timing and intensity, on subsequent growth and yield may be evaluated by simulation. The feasibility of new treatment techniques could be studied and answers provided without having to wait decades for experiments to mature. A problem that deserves attention is the evaluation of the effect of mechanical strip thinning on growth and yield in young aspen stands. Recent operational trials in young pine stands in Manitoba showed this kind of thinning to be an effective (in terms of growth response and lack of serious damage due to treatment) and inexpensive method of density control.

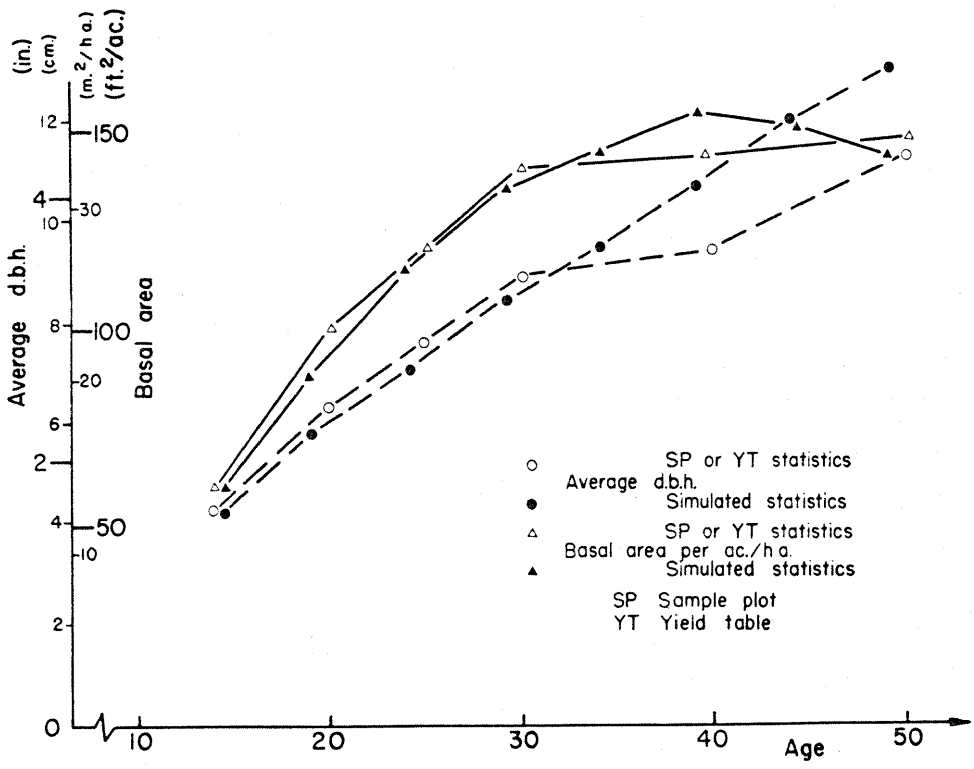

Figure 2. — *Average diameter and basal area per acre trends from a permanent sample plot (up to age 30 years) and from yield tables (over 30 years, Site Index 75, MacLeod, W. K. Yield and volume tables for aspen in central and northern Alberta. Univ. Brit. Col., Fac. For., Unpublished M.F. thesis, 66 p. 1952), and similar trends from aspen stand growth simulation for above average sites in Saskatchewan.*

If selection thinning is contemplated in aspen stands, the model may be used to evaluate the increase in yield by favoring trees in a fast-growing clone and cutting trees from poorer ones. Information on differences in tree growth from clonal effects could be taken from various clone studies, or the range in tree growth estimated from even limited data. Using the model, this tree growth information could then be translated into stand growth and yield statistics. Similar use could be made of tree growth information from tree breeding studies.

As demands for wood fibre increase, forest fertilization becomes a more practical method of increasing yield. Information will be needed on growth responses over a range of site and stand density conditions to carry out effective fertilization programs. Some basic information on tree growth and stand growth responses from pilot fertilizer trials will be required to establish some reference points or benchmarks. Then yield predictions for a range of treatments could be made with the model.

The model would also help to evaluate the relative importance of certain components and factors affecting tree and stand growth. This is done by manipulating parameters and coefficients in the model and observing the effect of these changes on growth and yield through simulation. This "sensitivity analysis" provides useful information for planning silvicultural treatments, because it enables the manager to concentrate his effort on responsive factors. For instance, if tree growth was found to be highly dependent on competitive status and relative tree size but not very dependent on spatial distribution of the trees, then thinning should concentrate on favoring the most vigorous trees, without much concern about creating some irregularity in stem distribution.

WORK IN PROGRESS

Although simulation runs with the aspen model showed promise, they also indicated the need for further refinement and testing before the approach could be put to full practical use as a management tool. In the interim, the model should facilitate improvement in understanding tree and stand growth relations. For example, experimental simulation runs with the aspen model showed that in dense, fully stocked stands, artificial lowering of the diameter increment of the largest trees gave rise to higher stand volume yield — a rather unexpected situation. Apparently, greater uniformity in tree sizes and the lack of less efficient "wolf" trees, resulted in a reduction of competition effects among medium size trees and an increase in their growth.

Current work is being concentrated on further testing and refining the intertree competition submodel. The effect of age and site on tree growth-competition relations has to be studied at different stand densities. Long-term permanent sample plot data with tree maps — from establishment to maturity— are needed for aspen and also for other species. In this way, effects that are species-dependent can be evaluated, a prerequisite for a better understanding of intertree competition and for its generalized description. These studies form the basis for expanding the scope of these models, perhaps to include the simulation of growth of mixed stands.

Research is needed to find out how crowding and competition in very young stands affect tree growth in later years. There is some evidence to suggest that the growth of the biggest trees (both in height and d.b.h.) in young, vigorous stands is not affected by competition (Sorensen 1968). We need to know, over a practical range of stand density levels, to what age and under what site conditions this relation may apply. We need to know how smaller trees in the stand are affected, and about their future development. Most studies show, in stands over 15-20 years of age, that if aspen grows under dense stand conditions over a prolonged period of time, the trees lose their ability to take full advantage of a sudden increase in available growing space.

This kind of information is necessary to strengthen the aspen model.

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GROWTH AND YIELD OF MANAGED STANDS

Bryce E. Schlaegel, *Associate Mensurationist*
Northern Conifers Laboratory, North Central Forest Experiment Station
Grand Rapids, Minnesota

ABSTRACT. -- Merchantable aspen production can be increased by thinning between the ages of 10 and 30 years. Early cleaning is recommended to remove competing hardwoods. Generally, thinning should leave: 750 to 900 trees per acre at 10 to 15 years of age; 200 to 400 trees per acre at age 20 years; or about 275 trees per acre at 30 years. Thinning past age 30 is not recommended. Cordwood yields of managed stands are shown by site, age, and stand density.

[illegible] stands managed for timber production will [illegible]tially pure and they may need one or more [illegible]. Management objectives may vary depend[illegible] the size of trees to be grown. Specific questions [illegible] manager might ask are: Should aspen stands [illegible]ned? If so, when and how should they be [illegible]? To what density should they be thinned? [illegible]swer these questions, a careful examination [illegible] made of the site quality and stand age, com[illegible], vigor, and stocking.

SITE

[illegible]index is an accepted measure of aspen site [illegible]ity and is estimated from the age-height re[illegible]p (Schlaegel 1971). Present site index curves [illegible] are anamorphic, which assumes that, re[illegible] of site, every stand will follow the same [illegible]rowth pattern. It has been shown for other [illegible] that the shape of height-growth curves differ [illegible] to site; i.e., they are polymorphic (Stage [illegible] 1971). This also appears to be true for [illegible] polymorphic curves have not yet been [illegible].

[illegible]ctors that influence aspen site index are [illegible]lope percent, slope position, silt-clay ratio, [illegible] water table, pH, and rock content.

[illegible]her factors may also influence aspen height [illegible]. Aspen has high genetic variability. Past fire [illegible] may affect site quality (Stoeckeler 1948) and could change the growth pattern. Insect attacks and ice storms may reduce height growth for several years. Past cutting practices can also affect the development of the present stand; commercial clearcuts may have left poor quality trees.

STAND COMPOSITION OBJECTIVES

A large portion of our present aspen stands are a mixture of several species. These species are in competition for water and soil nutrients. One objective of aspen management is to obtain pure aspen stands, which have lower regeneration costs. If, at the time of the final cut, the stand has a large volume of unmerchantable species, an investment must be made to remove them so a dense sucker stand will result. Any unwanted hardwood reproduction can be removed early in the rotation or when thinning the aspen. If undesirable species are removed early, regeneration costs will be minimized at final harvest.

A pilot study established in north-central Minnesota tested such a thinning in a 10-year-old aspen stand. All undesirable hardwoods were removed and the stand was thinned to about 750 stems per acre. The results were compared with those from a combined cleaning and liberation cutting in which the undesirable hardwoods were removed and the aspen was left unthinned, and from a control area where no cutting was done. When the study was installed the aspen averaged 2,800 stems per acre, and other hardwoods 148 stems per acre. The other hardwoods were

in two age classes: sprouts and seedlings 10 years old, and older trees ranging from 20 to 40 feet tall that had been unmerchantable when the previous stand was cut.

After 19 years the control area had considerably less aspen volume and basal area than either the thinned area or the cleaned area (table 1). The cleaned area had the highest basal area and volume. The volume of merchantable trees (3.6 inches d.b.h. and larger) was similar on the two treated areas. However, the average merchantable volume per tree was 32 percent greater on the area that was thinned. Thinning also produced approximately twice as many trees 8 inches d.b.h. and larger, which are potential veneer trees.

This illustrates the importance of hardwood removal early in the rotation. Both cleaning and thinning increased merchantable volume of aspen by about 30 percent at age 29, and thinning concentrated the volume growth on selected aspen trees.

THINNING EFFECTS

Thinning aspen stands stimulates tree growth, increases the total yield of merchantable material, and increases the net value of the products harvested during the rotation. In general, aspen stands of a given age on a given site will produce the same volume for a fairly wide range of stand densities. Thus, thinning merely puts the growth on fewer selected trees.

At what age and to what density should the thinning be done? Fifteen years after weeding treatments in a 1-year-old sucker stand in Minnesota that left densities ranging from 260 to 1,500 stems per acre, the average diameters of the 200 and 400 largest trees were similar (Sorensen 1968). After 20 years, largest volume and highest quality trees were on the unthinned control. Natural pruning was less effective on the low density plots, resulting in extreme branchiness and poor bole quality. Thus, reducing the stand density at 1 year of age does not seem advisable.

Although reducing stand density in the first year of the rotation is not recommended, thinning may be desirable early in the rotation. It should be delayed until the trees are large enough so that potential crop trees can be selected with a high degree of confidence. A thinning study in a 20-year-old stand tested square spacing treatments of 10, 15, and 20 feet, and an unthinned control. At age 50 years, 30 years after thinning, the 10-foot spacing and the control area were essentially equal in total volume (table 2). However, all thinned treatments had more trees 10 inches d.b.h. and larger than the control, with the 15-foot spacing having the most.

Because thinning costs money, a more practical approach may be to postpone the first thinning until it will yield some merchantable volume. One successful procedure is to make a moderate crown thinning at age 30 leaving about 275 crop trees per acre. In Minnesota, such a thinning yielded nearly 15 cords per acre. After 32 years, cordwood and saw-log

Table 1. — *Stand density and volume 19 years after removal of undesirable hardwoods and precommercial thinning in 10-year-old aspen*

Item	Aspen thinning and hardwood removal	Hardwood removal only	No cutting
Basal area (sq. ft./acre)			
All aspen	90	104	76
Aspen≥7.6 in d.b.h.	36	18	20
Number of trees/acre			
All aspen	419	676	438
Aspen≥7.6 in d.b.h.	95	47	53
Volume/acre			
Cubic feet 1/	2,240	2,600	1,820
Cords 2/	25.9	27.8	19.9
Cords 3/	8.5	4.3	4.7

1/ Total inside bark cubic-foot volume of all aspen 3.6 inches d.b.h. and larger.

2/ Inside bark volume to a 3-inch top of all aspen 3.6 inches d.b.h. and larger.

3/ Inside bark volume to a 3-inch top of all aspen 7.6 inches d.b.h. and larger.

volumes were similar in the thinned stand and in the control; but actual volume growth was 32 percent more and total cordwood production was 16 percent higher in the thinned stand. Such thinnings must leave enough trees so that the crowns close within a fairly short time, reducing the invasion of brush and other tree species in the understory.

Table 2. — *Stand density and volume 30 years after thinning in 20-year-old aspen*

Item	Spacing (feet)			
	10 by 10	15 by 15	20 by 20	Control
Basal area (sq. ft./acre)				
All aspen	99	79	59	100
Aspen≥9.6 in. d.b.h.	47	65	54	35
Number of trees per acre				
All aspen	238	134	80	266
Aspen≥9.6 in. d.b.h.	77	91	68	56
Volume per acre				
Cubic feet1/	2,880	2,225	1,660	2,940
Cords2/	26.6	20.8	15.4	26.5
Cords3/	17.4	22.8	19.1	14.7

1/ Total inside bark volume of all aspen 0.6 inches d.b.h. and larger.
2/ Inside bark volume of all aspen 3.6 inches d.b.h. and larger to a 3-inch top.
3/ Inside bark volume of all aspen 9.6 inches d.b.h. and larger to a 5-inch top.

Thinning in stands nearing rotation age is not recommended. A thinning in a 37-year-old stand did not increase either total volume production or the number of veneer-sized trees after 10 years (Schlaegel and Ringold 1971).

Merchantable volume production will be greatest under intensive management, which means precommercial thinning and cleaning followed by several intermediate cuts. This was demonstrated in a series of treatments established in a young aspen stand in Minnesota. After initially thinning at age 13 to densities of 400 to 1,700 stems per acre, intermediate cuts were made at ages 23, 28, and 33 years. Stocking densities between 550 and 975 trees per acre resulted in 51 percent more total net aspen production — standing merchantable volume plus thinning volumes — than the control at 48 years of age. Only 48 veneer trees 10 inches d.b.h. and larger per acre were found on the control, compared with 132 veneer trees per acre on the intensively thinned plots, an increase of 175 percent.

Thus merchantable aspen production can be increased by early stand cleaning and liberation cutting, precommercial thinning, commercial thinning at age 30 years, and combinations of precommercial thinning with intermediate cutting. Recommendations for a precommercial thinning, age 10 to 15 years, would be to leave from 750 to 900 trees per acre and remove all undesirable hardwoods. Thinning at age 20 should leave from 200 to 400 trees per acre, depending on the final product desired; 200 trees per acre will produce more veneer volume while 400 trees per acre will produce more pulpwood volume. At age 30 years, a crown thinning to about 275 trees per acre results in more pulpwood and veneer production than no treatment.

GROWTH AND YIELD

The evaluation of thinning must be based on expected growth responses and how they will affect the final yield. Recently data from several studies were analyzed and growth and yield tables were prepared for thinned aspen stands (Schlaegel 1971).

Total cubic-foot yield (Y) can be estimated from stand basal area (B) and average stand height (H):

(1) $Y = 0.41898\ (BH)$

Merchantable cubic-foot stand volumes to a 3-inch top (V3) and a 5-inch top (V5) can be estimated from total cubic-foot yield (Y) and average stand diameter (D):

(2) $V3 = Y\ [0.9858 - 5.4737\ (0.4876)^{D}]$

(3) $V5 = Y\ [0.9804 - 12.3277\ (0.57)^{D}]$

They can then be converted to merchantable cords per acre (table 3). However, to estimate future yields, the future values of the stand basal area, average stand height, and average stand diameter must be predicted.

Net periodic annual basal-area growth (BAG) is essentially constant for a broad range of sites and has relatively little change with basal area densities, but decreases rather rapidly with increasing age (table 4). Basal-area growth can be estimated from the table and added to the present basal area to obtain an estimate of future basal area.[1]

Estimates of future stand height can be obtained from a set of site-index curves. Using the estimates of future stand basal area and height, future total stand volume can be estimated from Equation 1.

[1] *Additional information on projecting stand basal area is given in Schlaegel (1971).*

Table 3. — *Aspen yield by site, age, and stand density*

Age (years)	Ht. (feet)	Merchantable cords (to 3-inch and 5-inch top diameter) per acre when basal area density is-- 40		60		80		100		120		140	
		3-in.	5-in.	3-in.	5-in.	3-in.	5-in.	3-in.	5-in.	3-in.	5-in.	3-in.	5-in.
SITE INDEX 90													
20	58	9	0	12	0	13	0	11	0				
30	74	15	10	21	12	27	10	31	4	33	0	29	0
40	83	17	15	26	22	34	26	41	28	47	25	52	15
50	90	19	18	28	26	38	34	46	41	54	44	62	43
60	94	20	19	30	29	39	38	49	47	59	54	68	59
SITE INDEX 80													
20	52	8	0	11	0	11	0	10	0				
30	66	13	9	19	11	24	9	28	4	29	0	25	0
40	74	15	14	23	19	30	23	37	25	42	22	46	13
50	80	17	16	25	23	33	31	41	36	48	39	55	38
60	84	18	17	26	26	35	34	44	41	52	48	61	52
SITE INDEX 70													
20	46	7	0	10	0	10	0	8	0				
30	57	11	8	17	10	21	8	24	3	25	0	22	0
40	65	13	12	20	17	26	20	32	21	37	19	41	12
50	70	15	14	22	21	29	27	36	32	42	34	48	33
60	73	15	15	23	23	31	30	38	36	46	42	53	46

Table 4. — *Net periodic annual basal area growth by age and stand density*

Total stand age (years)	Basal area (in square feet per acre) 20	40	60	80	100	120	140
20	2.39	3.40	3.89	4.03	3.92	3.62	3.14
25	1.92	2.72	3.11	3.23	3.04	2.89	2.51
30	1.60	2.27	2.59	2.69	2.62	2.41	2.09
35	1.37	1.94	2.22	2.30	2.24	2.07	1.79
40	1.20	1.70	1.94	2.02	1.96	1.81	1.57
45	1.06	1.51	1.73	1.79	1.74	1.61	1.40
50	.96	1.36	1.56	1.61	1.57	1.45	1.26
55	.87	1.24	1.41	1.47	1.43	1.32	1.14

Average stand diameter growth was linear for aspen between the ages of 10 and 60 years and averaged 0.184 inches per year after the initial thinning. Therefore, future stand diameter (DBH_f) at age A_f can be estimated from Equation 4 by using the initial stand age (A_i) and diameter (DBH_i):

$$(4)\quad DBH_f = 0.1841\ (A_f - A_i) + DBH_i.$$

Future merchantable yields can then be computed with Equations 2 and 3.

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THE BASIC HABITAT RESOURCE FOR RUFFED GROUSE[1]

Gordon W. Gullion, *Research Associate*
Dept. of Entomology, Fisheries and Wildlife, University of Minnesota
and
Franklin J. Svoboda, *Junior Scientist*
Dept. of Entomology, Fisheries and Wildlife, University of Minnesota

ABSTRACT. — There is a close correlation between the distribution of the aspens and of ruffed grouse. (*Bonasa umbellus*) both on a continent-wide and local basis. As an aspen stand regenerates from destruction by fire or removal by cutting and progresses towards maturity, it is continuously providing some of the needs of grouse at some stage of their annual life cycle. Aspen leaves and staminate flower buds constitute the most important year-long food resource. As the aspen regeneration thins from high density sucker growth through the sapling stage to the pole stage and finally mature timber, best quality cover is provided for ruffed grouse broods, wintering and breeding grouse, and finally nesting hens. But to sustain highest density grouse populations these age classes must all be available to each wintering and breeding grouse within a normal foraging range of about 10 acres.

GENERAL RUFFED GROUSE - ASPEN RELATIONSHIPS

At least 100 years ago Parker Gillmore made an observation that has since been overlooked by too many generations of wildlife and forest managers: "In the undergrowth which springs up in that portion of the country [Maine] where timber has been destroyed by fire, I ever found them [ruffed grouse] very abundant, it being almost impossible to wander half a mile through such openings without flushing a covey" (Jasper p. 121 *in* Studer 1888). Judging by the forest composition now in recently burned Maine forests, it seems probable that most of the "undergrowth" seen by Gillmore consisted of aspen regeneration.

Also, it is probably no accident that the North American distribution of the aspens fairly closely delimits the native distribution of the ruffed grouse as well (fig. 1) (Bailey *et al.* 1955). There are some places where aspen is common in North America where these grouse do not occur; and there are ruffed grouse populations in the southern Appalachians, some parts of the Midwest, and on the Pacific coast where aspen is absent. Recent successful introductions into the Beaver group of islands in Lake Michigan (Moran and Palmer 1963), the Ruby Mountains in northeastern Nevada (Hoskins 1968), and into Newfoundland (Inder 1967) suggest that isolated aspen forests lack these grouse simply because the birds have failed to disperse into them. On the other hand, it is only in the warmer climates where grouse encounter less severe wintering conditions that they persist in the absence of aspen; and though sometimes locally common in these peripheral habitats, ruffed grouse seldom approach the widespread abundance common in the more northern regions where aspen is, or was, a dominant component of the forest.

Minnesota Studies

From a 15-year study of ruffed grouse — forestry relationships on and in the vicinity of the Cloquet Forestry Center in east-central Minnesota, it has become apparent that at some time during the regeneration and growth of an aspen stand, these trees

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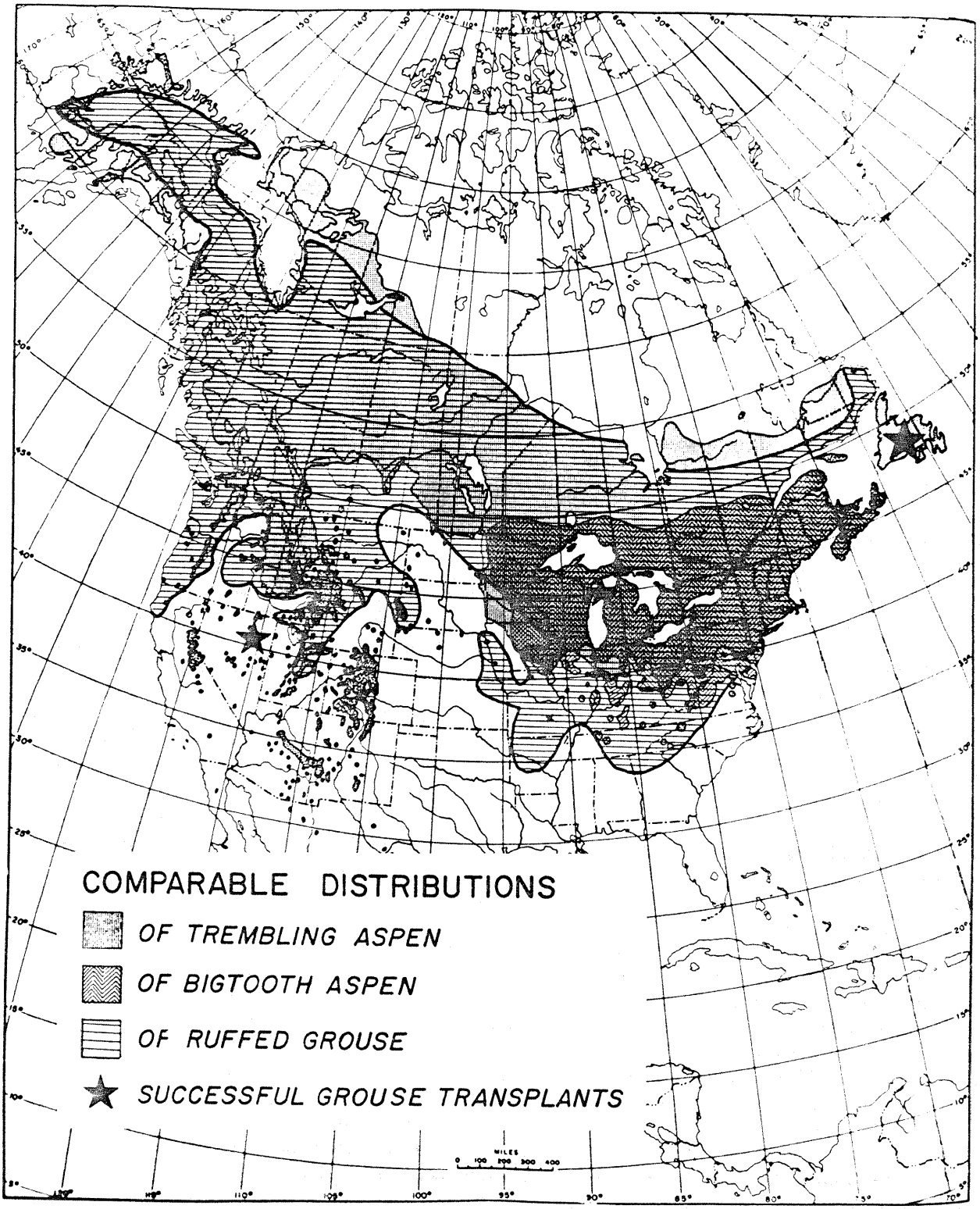

Figure 1. — *Distribution of the North American aspens and ruffed grouse. The distribution of the aspens from Fowells (1965); the distribution of ruffed grouse based on Aldrich (1963); base map from Fowells (1965).*

meet every need of the ruffed grouse at some stage of the bird's life history. If the habitat available to grouse contains a mosaic of aspen age classes within the restricted foraging range of ruffed grouse, aspen alone can meet all the habitat needs of resident grouse throughout the year, from brood cover for chicks through essential food resources and winter and spring breeding cover for the grown birds to nesting cover for the hens. No other species of shrub or tree in North American forests appears to fill the needs of ruffed grouse so adequately.

Fortunately, the aspens are not only "the most widely distributed tree species in North America" (Fowells 1965) but are economically important as well (Schneider 1970). It is hardly surprising therefore that the ruffed grouse has a larger North American range than that of any other resident game bird (Edminster 1954).

The Function of Aspen as a Resource for Grouse

To understand how the aspens function as a basic habitat resource of ruffed grouse we first need to consider briefly the basic habitat needs of these birds. Food, cover, and water are the three basic needs of living animals. A lack of free water for drinking probably seldom limits a browsing species such as grouse. But insufficient food and cover may be limiting even in extensive forested areas.

Food — A Factor Limiting Grouse Occurrence

Although wildlife biologists generally have long discounted food shortages as a threat to ruffed grouse populations in hardwood forests, our studies at Cloquet have shown that statements such as "When its preferred foods are used up . . . it can always turn to tree buds, the supply of which is virtually inexhaustible . . . " (Edminster 1954) are probably erroneous. The food resource for ruffed grouse is probably much less catholic than formerly believed.

During a series of winter "feeding runs" extending through the period when snow covered the ground during the winters from 1965 to 1970 we found that ruffed grouse fed on the flower buds of the male aspens six times as much (in relation to availability) as upon all other hardwood species combined. In 1967-68 this preference reached 13 to 1 (Svoboda and Gullion, unpublished data).

Furthermore, examination of several thousand ruffed grouse droppings collected at Cloquet from 1964 through 1969 provided the basis for the statement by Vanderschaegen (1970), "The most important food plants for ruffed grouse in the Cloquet area are aspens. Aspen buds, catkins, or leaves were used at all seasons of the year. Aspen buds (both vegetative and male flower) are the number one winter food, male buds and catkins the number one spring food, and buds and leaves the second most important fall food." Vanderschaegen found that even during summer the leaves were a most important source of food, constituting more than 53 percent of the identifiable material examined and outranking five-fold the second most important — the seeds of sedges (*Carex* spp.).

Beaked hazel *(Corylus cornuta)* ranked second overall, but under some conditions can be *most important* as a winter food resource. Catkins of the birches *(Betula papyrifera: B. lutea)* never ranked better than a poor third, and ironwood *(Ostrya virginiana)*, often considered important elsewhere (Stollberg and Hine 1952) is rare in the Cloquet Forest.

The arrangement of flower buds and physical characteristics of the aspen twig are probably important to ruffed grouse. The twig is rigid and usually enters the fall season with 6 to 8 easily detached flower buds near the tip (fig. 2). This combination allows grouse to take their evening meal quickly and quietly before they dive into a snow burrow for the night.

We have observed ruffed grouse taking flower buds at a rate exceeding 45 per minute. Birds feeding in aspen seldom spend more than 15 to 20 minutes collecting the 90 to 100 grams of buds that constitute a meal. This compares to a 150-pound human consuming about 27 pounds of food in 15 to 20 minutes.

Grouse cannot feed as rapidly or effortlessly on any of the other arboreal foods available to them. Rapid feeding has two distinct advantages for grouse: (1) it minimizes their accessibility to predators (an evening feeding period beginning about sundown coincides with the early foraging flights of horned and other owls) and (2) short feeding periods reduce the expenditure of energy needed to keep warm during

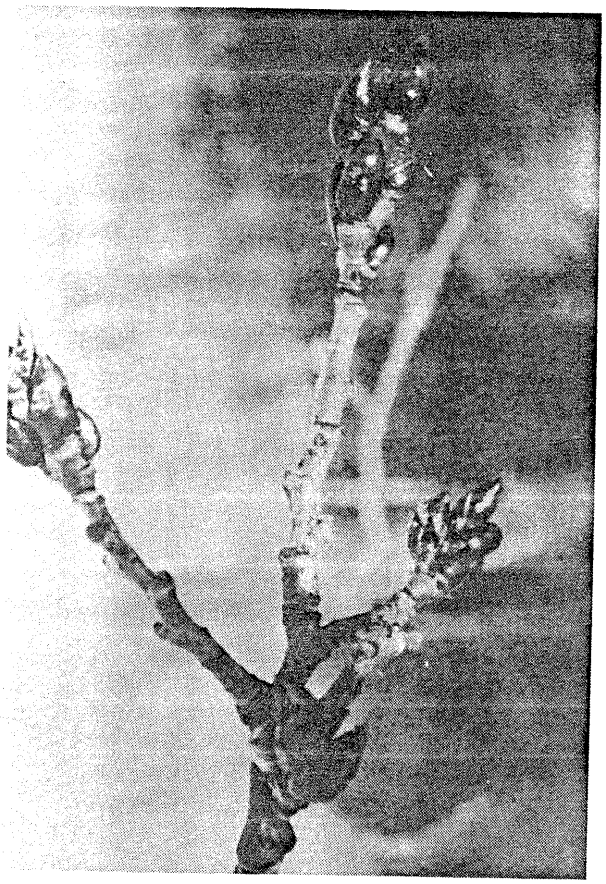

Figure 2. — *A terminal twig of trembling aspen showing three typical clusters of staminate flower buds and the apical vegetative buds.*

cold winter evenings. During the colder part of winter ruffed grouse are in snow burrows almost continually, perhaps as much as 23 hours a day, except for their brief emergence to feed hastily upon a readily available food such as the aspen flower buds.

When snow is deep and crusted ruffed grouse may spend much more time feeding on the hazel catkins they can reach from the snow surface — but when conditions favorable for this type of feeding persist winter losses of grouse also increase.

Huff (1970) has shown the male flower buds of aspens to be one of the richest sources of nutrients available to these birds through the winter when snow lies on the ground.

Observations over the past 6 years show that ruffed grouse prefer certain clones of aspen for feeding. Huff's analyses (1970) have shown the flower buds from preferred clones of trembling aspen to be about 30 percent richer in protein (14.2 vs. 10.9 percent dry weight) than flower buds taken from male aspen clones where we have seen no feeding use by ruffed grouse for the past 13 years.

Contrary to the belief that ruffed grouse are forced into arboreal feeding by snow covering their ground-level resources, we have found that heavy and sometimes exclusive use of staminate flower buds of the aspens begins many weeks before snow covers the ground.

Our earliest record of use of aspen buds is of a 13-week-old male ruffed grouse feeding in aspen on September 30, 1964 (Godfrey 1967).

In spring at least the male ruffed grouse continue to use the developing staminate catkins of aspen almost to the exclusion of other food until the aments have shed their pollen, dried, and begun falling from the twigs in early May. Only then do the grouse commence using the evergreen, frost-resistant herbs (e.g., *Cornus canadensis, Coptis groenlandica, Gaultheria procumbens, Fragaria* spp., *Linnea borealis*) that have been available to them at ground level since the snow melt — which may have been complete as much as 3 to 5 weeks prior to aspen catkin maturation at Cloquet.

In addition to our observations of grouse feeding preferences over a 6-year period, the analysis of droppings collected from 1964 to 1969, and the analyses of nutritional values from 1968 to date, we have further evidence of the dependence of grouse upon the aspen for food. All the previously perennially occupied breeding activity centers from which aspen was cut were abandoned by grouse even though their drumming logs were not disturbed and both hazel and birch remained in virtually their precutting abundance. At least 11 of these centers have gone "full-cycle" and now are being reoccupied by grouse 7 to 13 years after cutting.

On the Cloquet Forestry Center there are large pine stands from which all or most of the aspen has been removed through timber stand improvement. These stands are devoid of breeding ruffed grouse, even though adjacent tracts where aspen remains uncut among the pine canopy had breeding grouse densities as high as one bird per 6 acres in 1971 (this

compared with one breeding grouse per 3 acres in best quality aspen stands).

On the Bob Lake portion of the Cloquet study area there are two tracts of northern hardwood forest from which aspen was selectively cut in about 1960, leaving a forest of maple, oak, paper birch, basswood, ironwood, and some other hardwoods intact. Both of these tracts have been devoid of breeding ruffed grouse since we began studying them in 1965: one is 218 acres in extent, the other 95 acres. On adjacent areas where soil and topography are the same but aspen remains in the forest canopy, we had a breeding ruffed grouse density exceeding one bird per 6 acres in 1971.

We believe it is also significant that more than 98 percent of the persistently used drumming logs on both our Cloquet study area (including 247 logs occupied in 1971) and on 2,800 acres of the Mille Lacs Wildlife Area (94 occupied logs in 1971) are within sight of mature *male* trembling or bigtooth aspen.

Aspen Meets the Spectrum of Cover Needs of Ruffed Grouse

Aspen in various age classes best provides the quality of cover needed by ruffed grouse at various stages of their annual life cycle. But first we need to reconsider what constitutes secure cover for ruffed grouse. Some types of cover, long considered to be essential to grouse, provide better hunting cover for the major grouse predators and so are actually detrimental to the maintenance of high density ruffed grouse populations (Gullion and Marshall 1968).

Analysis of the longevity of 446 drumming male grouse over a 11-year period has shown that the longest lived grouse occupy sites where the stems of sapling aspen, hazel, mountain maple, alder, or other hardwood species provide a dense stand of small diameter (under 6 inches) stems. This we call "vertical cover" and believe that this quality of cover is not only most effective in protecting the birds from surprise attack by raptors (hawks and owl) overhead but also allows the bird to maintain effective surveillance for mammalian predators on the ground for a radius of 50 to 60 feet at all times.

The less secure cover, which we call "horizontal cover," provides effective hunting or ambush cover for the animals that commonly prey upon ruffed grouse. Brush piles, slashing, windfalls, and the boughs of conifers both close to the ground and in the forest canopy all provide such cover for grouse predators.

Several brush species substitute structurally for aspen stems as adequate vertical cover for ruffed grouse. But none of these can be managed as easily, provide a year-long food resource, or have the economic value of the aspens. Furthermore, none of the other northern hardwoods regenerates as root suckers after being cut in the same manner as aspen, producing a fairly uniform, dense stand over a large piece of ground. Nor do any other hardwoods provide an adequate food resource for these grouse as the trees mature.

Specifically, the young regenerating sucker growth of aspen can provide in its first year high quality brood habitat for grouse by the time the chicks hatch in mid-June, following winter clearcutting or early spring burning. As the regeneration grows it continues to provide a high quality brood habitat for perhaps as long as a decade following the initial removal of the stand by logging or fire, especially if it is growing on a low, moist site.

At about 10 years of age in northern Minnesota, the aspen growth has gone through its first natural thinning and developed into a sapling stand 25 to 35 feet high that has a density of less than 8 thousand stems per acre. Then it provides a good quality cover for wintering and breeding ruffed grouse. In both 1970 and 1971 our average grouse spring density was a breeding bird per 4 acres in the 8- to 12-year old aspen regeneration at Cloquet.

Natural thinning continues as the aspen stand grows toward pole-size, and the value of the stand to ruffed grouse increases as space between stems increases and the canopy grows higher overhead. The 13- to 25-year old aspen stands on the Cloquet area supported a breeding grouse per 3 acres in both 1970 and 1971.

But when the stand density thins below roughly 2,000 stems per acre, at about 25 years of age at Cloquet, long-occupied coverts rather abruptly become devoid of breeding ruffed grouse. However, it is at about this age that the aspen flower-buds commence being used as a winter-long food resource; and the

more open, park-like aspen stand appears to be the most secure nesting cover for ruffed grouse hens. Most hens select nesting sites where they can fly directly from the nest into the crowns of male aspen to feed upon the new-grown leaves (Barrett 1970, Kupa 1966, Schladweiler 1968).

Earliest Snow-cover Is Available In Aspen Stands

Depth of winter snow is an environmental factor of critical importance to ruffed grouse in northern Minnesota (Gullion 1970). Ruffed grouse survive the winter best when they can bury themselves in 8 or more inches of soft, powdery snow.

In northern Minnesota snow reaches satisfactory depths earliest in aspen and hardwood stands. During some winters snow depths under closed canopy conifer stands may never reach adequate depths, and the grouse depend all winter upon the snow accumulation in the hardwoods for adequate roosting snow.

Grouse, Aspen, and Forest Management

Combining what we know about ruffed grouse needs and behavior and the silvicultural requirements of the aspens (Graham *et al.* 1963), it appears that there are three important considerations in managing northern forests where ruffed grouse for recreational hunting is an important goal:

1. Aspen must be maintained in the forest composition;
2. Forest stands containing aspen must be clearcut when logged to preserve aspen clonal stock and to encourage high-density sucker regeneration; and
3. Cuttings must be small enough and spaced both in distance and years so that at least three age classes of aspen (preferably four) are available to grouse on each of the 10-acre breeding activity centers that appear to represent about the highest density grouse population (a bird per 5 acres) we can expect under most conditions.

This management of both aspen as a wood resource and ruffed grouse as a wildlife resource can best be achieved by clearcutting aspen on a 40- to 50-year rotation, cutting no more than 10 acres out of any 40 acres at one time, and spacing the logging at about 10-year intervals.

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MANAGEMENT FOR DEER

John D. Byelich, *Wildlife Biologist*
Jack L. Cook, *Wildlife Research Biologist*
Ralph I. Blouch, *Wildlife Research Biologist*
Department of Natural Resources
Lansing, Michigan

ABSTRACT. — Deer in the Lake States are declining. Early stages of second growth forest following the logging era favored deer. Aging and successional changes toward more tolerant types are causing range deterioration. Aspen is the major deer-producing forest type. Commercial harvest of aspen improves deer range, but not enough is taking place to reverse the downward trend of deer or to save the type from conversion. Additional efforts to cut or otherwise treat aspen stands specifically for deer have been of token size. Michigan has earmarked a deer license increase for range improvement and is now embarked on a large scale habitat management program aimed principally at aspen types.

DEER AND ASPEN IN THE LAKE STATES

The history of the white-tailed deer is so involved with that of the aspen, aspen-birch, and spruce-fir forest types of the Lake States area that any discourse regarding the deer's fate must include the story of recent changes in these forest types and a projection of their future.

The original great forests of the Lake States were for the most part logged off by 1920 (Dahlberg and Guettinger 1956, Swift 1946). In the wake of early logging deer populations peaked at various times between 1850 and 1900. This was a response to the improvement in deer range that immediately followed the vast clearcutting. Herds were again reduced to a new and possibly all-time low between 1890 and 1910 as a result of the habitat destruction caused by widespread forest fires and uncontrolled hunting of deer for market. From 1910 through 1950 deer populations again increased as the cutover and burned-over land of Minnesota, Wisconsin, and Michigan was reclothed with aspen, birch, oak, jack pine, northern hardwood reproduction, and shrubs. Greatly improved forest fire protection along with more restrictive game laws enabled deer to fully occupy this new habitat.

These large deer herds were for the most part underharvested from 1930 through 1950 (Jenkins and Bartlett 1959, Dahlberg and Guettinger 1956, Erickson *et al.* 1961). Light deer harvests, the bucks-only laws, and some closed seasons caused serious overbrowsing in winter range by the 1930's. Since 1930, maturing of the aspen stands, chronic overbrowsing, and conversion to conifers through natural plant succession have greatly reduced the carrying capacity of the Lake States deer range.

The deer-producing cornucopia of second growth trees and shrubs has emptied and at the present time game managers and administrators face a confused public, which in general displays a naivete toward any biological or ecological explanation of the deer-food problem or any prescription for maintaining a reasonable deer herd. The current situation is similar to that described by Dahlberg and Guettinger (1956) during the early decades of deer problems in Wisconsin. For many reasons people who decide what happens in the Lake States believed in regulating the harvest of deer rather than the total management of the resource, which would have included improvement of the range.

After 20 years of harvesting as many deer as politically acceptable liberal deer seasons would permit, the Lake States deer herd is probably headed toward a population low that will not provide a reasonable or adequate hunting-recreation opportunity. In Michigan, hunter numbers have increased since 1964, while

the kill has decreased from the 1964 bag of 141,000 to 60,000 in 1971. In Minnesota the decline in the deer take began in 1966. The harvest dropped from 103,000 in 1968 to 67,000 in 1969. There was a closed season in 1971. Wisconsin dropped from a peak harvest in 1967 of 128,000 deer down to 72,000 in 1970. It is becoming increasingly apparent that antlerless deer harvests cannot be continuously substituted for deer range renovation if even a reasonable fraction of the deer populations that existed between 1930 and 1960 is to be produced and sustained.

The high population of deer in the Lake States in the past was a result of severe forest disturbance over a long period of time. The composition of forest cover that emerged set the stage for a tremendous increase in deer numbers. The heyday of deer production that resulted from the new composition of cover is now beginning to bottom out. However, the basic forest composition that was so productive of deer food and cover in the past still occurs in approximately the same proportions and locations as it did in the more productive years. But now, in the early 1970's, it is important to recognize that this cover composition is changing fast. The natural process of plant succession is adversely affecting the deer habitat at a rapid rate in the Lake States forests and it appears that the greatest change will occur in the next 10 years. The species involved are basically the following: aspen, paper birch, scrub oak, jack pine, and the herbaceous plants and shrub communities that form their understory as a result of adequate light. The openings so essential to deer are also more abundant in these intolerant types.

Aspen and aspen-birch are the types that seem most likely to provide adequate deer food — browse from shrubs and young trees associated with the types and from the young aspen (Rutske 1969, Grange 1949). Aspen leaves are a preferred summer food in Wisconsin (McCaffery 1970). McCaffery and Creed (1969) found more deer in the aspen type than in all others during the summer months. Minnesota game men found that aspen stands under 30 years old are preferred deer range. In Michigan, the Phoenix Project studies have shown the close relationship of aspen communities and deer, and they emphasize the impact that proper management of this forest type can have on deer populations (Westell 1954, 1955, and 1960; Graham *et al.* 1963).

The most important deer-producing areas in Michigan are predominantly aspen areas. Department of Natural Resources mail surveys of deer hunters for the years 1961-1965 reveal that 360 townships produced 75 percent of the deer taken each year. These areas, totaling 13,000 square miles, comprise only 39 percent of the region's total northern forest type. In these townships aspen is the most frequently occurring forest type. The ownership pattern within them is 25 percent State, 11 percent Federal, and 64 percent private. A further look at statistics from 12 counties that include about half of the above townships shows that a highly significant correlation ($P < 0.01$) exists between the average buck kill per county and the acreage of the aspen type in the county (fig. 1).

This close correlation could mean simply that deer in these counties are closely related to forested land in general, and that the aspen acreage merely reflects the overall forest influnce. To test this hypothesis we computed a regression of deer kill on acreage of total commercial forest land and found no significant correlation (fig. 2). We conclude, therefore, that aspen is the strongly influencing factor.

This evidence convinces us that aspen forests are the major deer producers in our area, and it clearly points out where the emphasis of our range management efforts should be applied.

There are about 51 million acres of commercial forest land area in Minnesota, Michigan, and Wisconsin. Eighteen million acres (35 percent) are occupied by the aspen-birch forest type group.[1] Minnesota has 5.5 million acres of aspen type alone, Wisconsin 3.5 million acres, and Michigan 4.5 million acres, a total of 13.5 million acres or about one-quarter of the total commercial forest land area in the Lake States. About half of the aspen type is publicly owned. The Lake States have an overabundance (from a deer standpoint) of aspen in the 30-to-60-year age class. Aspen is growing faster than it is being cut. If this

[1] *Lundgren, Allen L. Economics of aspen management. A paper presented at joint meeting of Great Lakes Deer Group and The Ruffed Grouse Workshop, Quadna Mt. Lodge, Hill City, Minn., Sept. 22, 1970.*

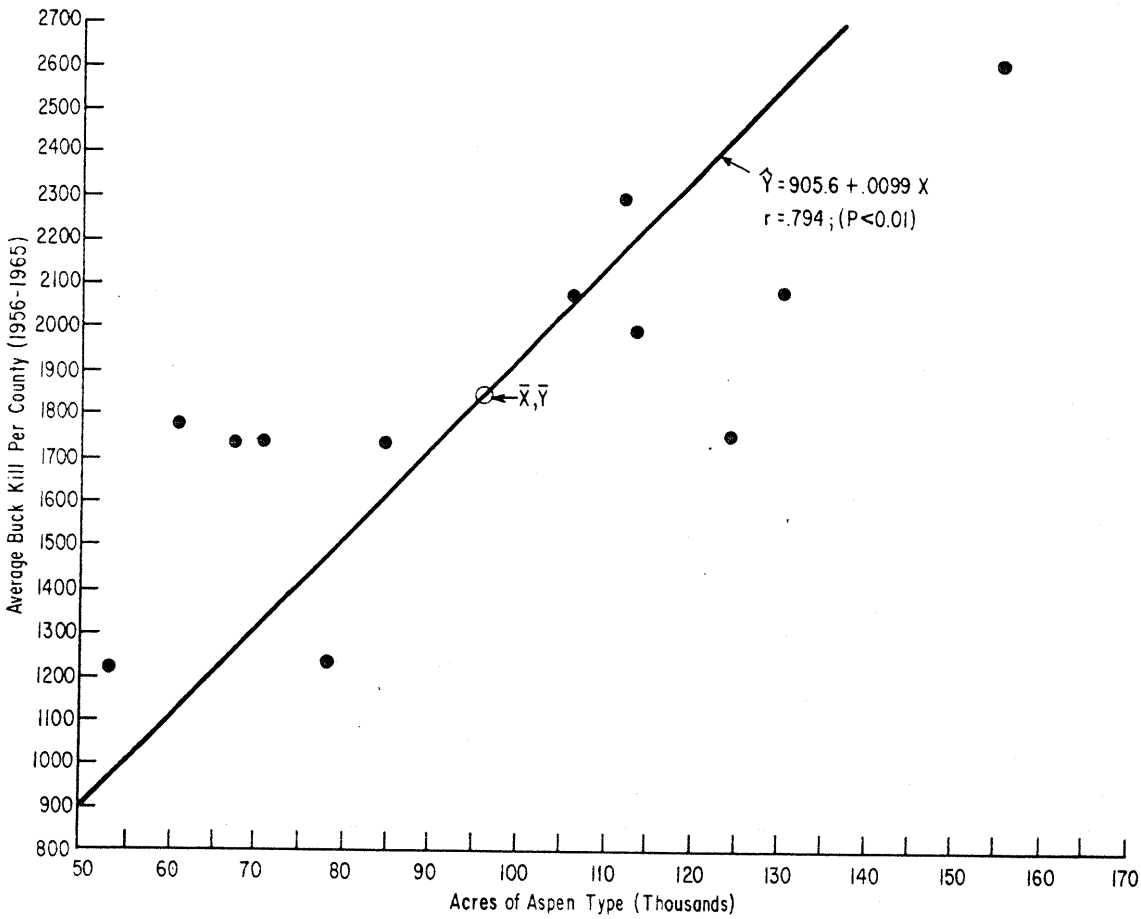

Figure 1. — *A regression and correlation of average estimated buck kill per county from mail survey reports (1956-1965) with acreage of aspen type for 12 Lower Michigan counties.*

older aspen is not cut it will convert to more stable, more tolerant, forest types such as northern hardwoods, spruce-fir, or pine.

Lundgren[1] estimates that we are at present cutting 200,000 acres per year of the aspen type out of a possible 300,000 acres per year, based on a 40-year rotation. In theory then, a 300,000-acre cut could be maintained indefinitely. Much additional aspen occurs in other types of the aspen-birch group. Because one-third of the Lake States forest land is in the aspen-birch group, we can assume that a similar proportion of the region's forest is potential good deer range. Other forest types, of course, contribute to the carrying capacity of the range, but to a lesser degree.

Some foresters in Michigan point out that older, less well-stocked stands of aspen are changing to other forest types through natural succession. Absence of fires after 1935 and limited acreage of clearcutting of mature aspen have resulted in fewer aspen stands being originated than before. During the rapid increase of maturing aspen between 1955 and 1970, supply was ahead of demand and caused some concern about an aspen surplus. Estimates of allowable cuts continued to increase, reflecting accumulation of volumes in mature aspen stands (many of which were poor quality), small stands in other forest types, and overstories in swamp conifers economically unattractive to loggers. Aspen cutting has not kept up with the incidence of early fires, and regenerated stands

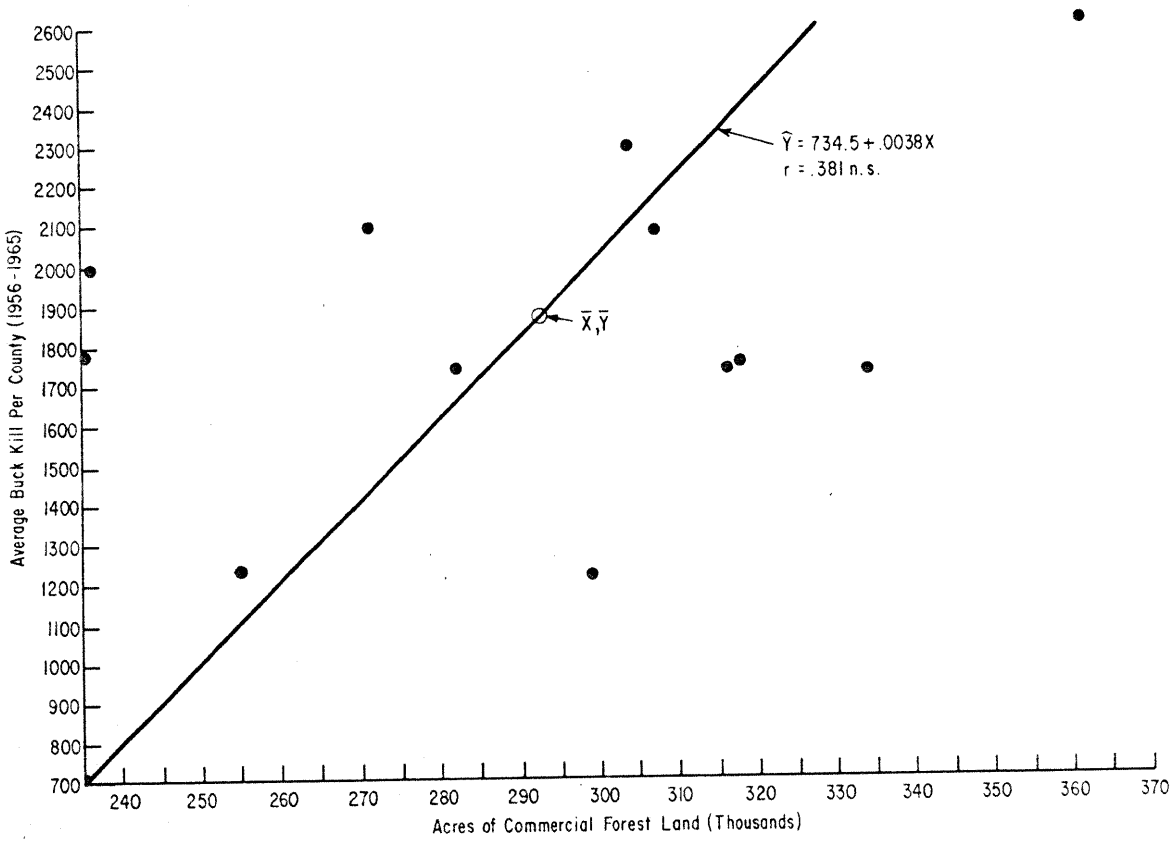

Figure 2. — *A regression and correlation of average estimated buck kill per county from mail survey reports (1936-1965) with total commercial forest land for 12 Lower Michigan counties.*

have not equaled the original post-fire volunteer acreage. Foresters now predict that there will be a shortage of good quality aspen by 1980, that supply will not keep up with demand, which should remain relatively high, and that other species will be substituted for aspen as a source of pulpwood.

MANAGEMENT OF ASPEN FOR DEER IN THE PAST

Continuous cutting or otherwise removing overstory are the major biological manipulations needed to maintain and renew potentially productive deer range. In addition to yearly commercial wood harvests, State game agencies in Wisconsin, Minnesota, and Michigan have been making forest cuttings specifically to improve deer range.

In Minnesota during 1969 and 1970, 12,000 acres, primarily in the aspen-birch type, were cut, burned, or otherwise improved. Access roads were constructed to improved areas. A similar effort will be made in 1972 and 1973. A Wisconsin deer range maintenance program started in 1969 when about 22,000 acres in the aspen-birch type were cut. Cuttings were designed to maintain the aspen type. Since 1958, Michigan has cut 48 square miles of poor-quality aspen, aspen-birch, and mixed aspen-hardwood with tree-cutter bulldozers, and 21 square miles of aspen-birch and lowland species by handcutting crews to improve deer range (Cook 1969). These cuttings were near deer yards and were designed to provide deer food by producing sprout growth of aspen and associated species. Totaling 44,000 acres, they were a small effort when compared to the 10 million acres of aspen-birch,

rest type in Michigan, es have been cut over States combined the er the last 3 years

game agencies in the habitat renovation program has so far failed. Such efforts to be would have to involve large areas of the and aspen-birch forest types in the three States. It would be as unrealistic to suggest that the entire forest be changed to create ideal habitat as it would be to declare that the problem is so vast that it is hopeless. During the next few decades an increasing proportion of our forests will undergo some type of alteration due to man's capacity to manipulate resources for profit and other motives. The overall plan for future forest management should be designed to include the production of wildlife as well as wood. Such a plan should accelerate recycling of forest succession at a rate in excess of that realized only from commercial harvest of forest products.

Jordan (1970) believes that a new approach to deer-habitat management is needed and advocates the development of systems of deer-food management as a method of solving deer food problems. He states, "Deer habitat managment is the planned manipulation and control of vegetation to satisfy food and shelter requirements of deer." The purpose of herd management is to provide a reasonable, stable, and acceptable yield of deer for hunting. Ultimately, the solution of the deer-timber problem must come from better herd management and from development of systems of habitat management that apply habitat practices to specific units of deer range, in an ordered sequence, over a continuous period of time, and that produce predictable effects on deer herds.

Deer range research is not popular with many administrators and politicians because it is costly, is not easily understood, is often a long-term operation, and it deals primarily with vegetation rather than with the animals themselves. One of the most significant drawbacks is that deer are a renewable resource, used directly by an unorganized public (hunting and viewing). They are not a resource extracted by private individuals or groups for profit, or one with a fixed price tag that lends itself to exploitation through established business channels with the attendant political direction from organized business groups.

Big game license fees are too low in the Lake States (Heuser 1971). They are earmarked for habitat improvement only with extreme difficulty. While $5.00 deer licenses cover a full season, Heuser points out that it is not difficult to obtain a daily $8.00 ski lift fee, or a $5.00 a day golf green fee, or a $4.00 a day camping fee. Funds could be raised from hunters for adequate research of and for range management if they knew the money would be used for these purposes and would, as a result, improve their hunting. In his Lake States deer problem summary Heuser (1971) emphasizes the competing interest facing big game managers who are under pressure from many groups such as farmers, hunters, resort owners, politicians, nature groups, and public agencies.

MICHIGAN'S NEW DEER HABITAT MANAGEMENT PLAN

The Michigan Legislature in 1971 increased the cost of deer licenses and stipulated that $1.50 of each license should be used for the maintenance and improvement of deer habitat. This money will now permit, for the first time, the application of a large-scale program of management for deer habitat. The Legislature appropriated $616,000 for this work in the 1971-1972 fiscal year. An action plan has been developed and is currently being implemented. Its goals and prescriptions for treatment are summarized below:

The goals of wildlife habitat management for the primary deer producing townships in Michigan are to preserve, maintain, improve, and expand the deer range to the extent that it will: (1) Stop the downward trend of deer numbers, and (2) Increase the herd to approximately 25 to 30 deer per square mile.

To accomplish these goals, the primary concern will be to preserve and maintain suitable wildlife habitat that is being lost to regrowth, aging, and conversion. Specifically, management will be concerned with the preservation of the aspen type, forest openings, upland brush, oak, and jack pine in the State Forests. The major emphasis of the plan will be to favor the preservation, improvement, and expansion of the aspen type. Every effort will be made to adhere to the following guidelines for deer habitat improvement:

(1) Maintain a desirable proportion of *aspen* *ype:* not less than 35 percent of upland area.

(2) Preserve, improve, and expand *forest openings.* im for not less than 15 percent of upland area.

(3) Manage for the most desirable proportion of *referred forest types* (aspen, openings, upland brush, ak, jack pine) that are most valuable to deer and ther wildlife. These preferred types should cover not ess than 60 percent of the upland forest area.

(4) Attain, within the next 10 years, an equitable listribution of different size classes of each forest type n each wildlife management unit. Plan for 25 percent of upland area to be in the 1- to 10-year age class.

(5) The lowland coniferous cover and its immedi- ite upland edge are the most valuable areas for food and cover during the winter months. Manage the upland edge of the lowland cover for long-range food producing areas by maintaining about 25 percent of the lowland perimeter in forest regrowth and open- ngs. In selecting sites for improvement, favor the most protected areas, with the lowest gradient, on the south and east sides. These sites support the widest ecotones with the greatest variety and area of plants.

Commercial cutting will be used as much as pos- sible. Where treatment is required beyond the capa- bility of commercial harvest and subsidized sales, tractor tree cutters, hand-cutting, and prescribed burning will be used as best fits the need.

The scale of this program is large. If goals are reasonably well accomplished, over 400,000 acres of deer range, largely aspen land and openings, will have to be treated within the next 10 years. We feel this should have a significant effect in turning back the tide of successional range degeneration and restoring deer numbers to levels of past decades for the fullest use and enjoyment of the public.

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EFFECTS OF THINNING ON GROWTH AND YIELD

John W. Hubbard, *Management and Research Forester*
Boise Cascade Corporation, Big Falls, Minnesota

ABSTRACT. — Comparative studies of noncommercial and commercial thinnings covering an 18-year period (on the Boise Cascade Corporation Experimental Forest near Loman, Minnesota) demonstrate how quaking aspen diameter growth was increased by thinning thus shortening the rotation.

A 12-year-old noncommercial thinning in an aspen sucker stand and a commercial thinning in a 32-year-old merchantable stand demonstrate how cultural treatment can shorten the rotation age and increase the production of veneer or saw logs in aspen stands.

NONCOMMERCIAL THINNING

To illustrate what can be accomplished by a noncommercial thinning let's examine such a thinning in quaking aspen sucker stand on our experimental forest. A well-stocked aspen stand (site index 85 to 90) was clearcut during the fall and winter of 1953-54. Seven growing seasons later, six 1/10-acre plots — which were as similar as possible in average tree diameter, stocking, and site — were established in the spring of 1960 in the aspen sucker stand that resulted from the clearcut. The area outside each 1/10-acre plot was expanded to ½ acre to serve as a buffer zone and given equal treatment.

Three of these permanent plots were designated as reserve or control plots and three were thinned before the growing season in the spring of 1960 reducing the stem count from 3,750 to 695, giving an 8 by 8 foot spacing and saving the best dominant and codominant trees.

Two of the thinned plots were axe thinned. The work required 9.5 man hours per acre. The other was thinned with 2,4,5-T herbicide. Although this thinning was successful, the herbicide was translocated through the root system to the residual trees, inhibiting growth for a number of years. Therefore, data from this plot were not used.

All trees were remeasured at d.b.h. to 100th inch each fall following the growing season.

Annual average d.b.h. growth in the thinned plots fluctuated from 0.04 to 0.38 inch and the unthinned or control plots from 0.05 to 0.20 inch. The low point in growth was reached during the 1971 growing season when most of the trees were completely defoliated by the tent caterpillar *(Malacosoma disstria)*.

The average diameter growth on the axe-thinned plots has exceeded that on the control plots since thinning by 1.39 inches and presently has a volume in trees 5 inches d.b.h. and larger of 10.50 cords compared to 1.20 cords on the unthinned plots.

Let us assume that d.b.h. growth will continue at the same average rate as it has in the 12 years since thinning. Projecting the average growth of each individual tree on the thinned plots will give an average diameter of 6.3 inches in 6 years at age 25. A commercial clearcut could be made at that time yielding approximately 37 cords per acre. It would take the control plots considerably longer to approximate the same average diameter and cordage. We have thus significantly reduced the commercial rotation with the noncommercial thinning.

Although one study (Noreen 1968) questions the possibility of a net monetary return from precommercial thinning and another (Sorenson 1968) indicates poor diameter growth for crop trees in a thinned stand, it would seem from our study that more comprehensive research in noncommercial thinning is warranted if we want to reduce rotation or increase diameter.

COMMERCIAL THINNING

In 1954 a commercial thinning experiment was established in two separate units known as Unit I and Unit II at different locations on our experimental forest. The stands on these units covered a total of 12.1 acres, were very similar, and had a site index of 85 to 90. The average age in Unit I was 31 years and the average age in Unit II was 34 years. Each unit was divided into three equal strips, one designated for clearcutting, one for partial cutting, and one for reserve as a control. Two 1/10th-acre permanent plots were established within each strip to measure results. All 12 plots were measured prior to treatment in the spring of 1954. The clear and partial cuts were made in the spring in Unit I and in the fall in Unit II.

The clearcuts removed an average of 50.3 cords and 124.57 square feet of basal area per acre and the partial cut removed about half the 593 stems and 27.86 cords from the total of 57.76 cords of volume (table 1).

The original plan in the partial cut areas was to thin from below to an approximate 13 by 13 foot spacing and 65 to 70 square feet of basal area. But it was found that a salvage of diseased or defective trees just about took care of the thinning with a basal area cut of 60.92 square feet and a final reserve of 69.99 square feet. Because the salvage of defective trees did not always leave uniform spacing, a few openings larger than desired resulted. Unfortunately, some trees on the north side of these openings suffered sunscald.

The final clearcut was made in Unit II after the growing season in 1970 at 50 years of age; the scaled, cut volumes exceeded the plot volumes.

Results

By 1970 aggregate volume in the partial-cut areas exceeded volume in the control by 17 cords, a net gain of 8.70 cords since 1954. The d.b.h. of the average tree in the partial-cut areas exceeded the average tree in the control by 1.73 inches. Net diameter growth in the partial cut exceeded that in the control by 1.45 inches.

Veneer Potential Compared

In order to determine the veneer potential of the partial-cut areas compared to the control strips, veneer bolts on all plots were tabulated by size in 1969 (table 2). Bolts were then converted to finished veneer values (including residues) as reported by Noreen and Hughes (1968). It is evident that the partial cutting has had a marked influence on the size and value of veneer bolts.

Table 1. — *Plot data for aspen cutting study — average of two units*

	Per acre data 1/			Average	Age
	Trees	Volume	Basal area	d.b.h.	
	Number	Cords	Square feet	Inches	Years
Clearcut strip (Fall 1954)	525	50.32	124.57	6.56	32.5
Partial-cut strip:					
Before cutting (1954) 2/	592	57.76	141.39	6.77	32.0
Cutting	288	27.86	60.92	6.25	--
After cutting (1954)	252	29.52	69.99	7.43	32.5
Fall 1970	190	52.84	125.17	10.99	49.0
Cumulative yield		80.70			
Mean annual growth (49 years)		1.65		.23	
Reserve strip (control)					
At time of cutting	542	49.03	119.49	6.49	32.5
Fall 1970	318	63.65	148.66	9.26	49.0
Mean annual growth (49 years)		1.30		.19	

1/ All volumes computed by formula on an individual tree basis.
2/ The total of the trees and basal areas cut plus those remaining is not equal to those previous to cutting because of natural mortality and logging damage between initial measurement and measurement after cut.

Table 2. — *Veneer production for an uncut aspen stand compared to a partial-cut stand after 15½ growing seasons*

Top diameter (inches, inside bark)	Conversion return per bolt	Control		Partial cut	
		Bolts	Total value	Bolts	Total value
	Dollars	Number	Dollars	Number	Dollars
8	0.94	45	42.30	34	31.96
9	1.42	42	59.64	32	45.44
10	2.04	14	28.56	22	44.88
11	2.89	6	17.34	19	54.91
12	4.03	-	-	7	28.21
13	5.40	-	-	4	21.60
Total value on plots			147.84		227.00
Veneer value per acre			369.60		567.50
Total pulpwood value (at $1.00/cd., 1954 and $1.25/cd., 1969)			79.56		92.19

Clearcut Strips

The first growing season following the 1954 clearcutting the sucker counts showed an average of 15,950 stems per acre. This had been reduced by natural mortality to 1,825 stems in 1971.

In the fall of 1971 the average dominant tree had a d.b.h. of 3.21 inches and an average height of 36 feet so these stands are already well on the way toward the next crop and have a 17½ year average jump on the reserve and partially cut areas. Only time will tell whether an early clearcut is economically more advantageous for pulpwood production than a partial cut at the same age. This should prove a fertile field for studies by economists.

COMBINING THE NONCOMMERCIAL THINNING WITH THE COMMERCIAL THINNING

If we are aiming for a saw-log or veneer market, what potential is theoretically possible if we combine a noncommercial thinning with a commercial thinning or partial cutting? We realize the many mensurational, biological, and climatic pitfalls involved in making straight growth projections based on the past average growth of individual trees especially when a year of practically no growth, due to the tent caterpillar, is injected into the averages.

Fully aware of the limitations involved, we made an adjusted projection based on the average past growth of individual trees in our sucker thinning and the growth information from our aspen commercial cutting experiment (1954-1970). Potential mortality trees (six of the largest trees on one plot, alive but infected with hypoxylon stem canker) in the present sucker stand were eliminated and growth projected by tree to age 32, with some adjustment for additional mortality based on this and other noncommercial thinning studies.

I then made a theoretical commercial partial cut reserving crop trees selected in the field on the two axe-thinned plots and simulating the partial cut in our 1954 aspen cutting study. In all, 385 trees with a volume of 36.15 cords were removed, reducing the stand to 74.28 square feet of basal area per acre (table 3).

The final projection based on growth of individual trees in our 1954-1970 partial-cut study was made to age 50 (table 4). The same experimental forest local volume table was used for all volume calculations.

This shows that our cultural measures have accomplished three things: increased the average stand d.b.h. by 4.53 inches, greatly increased the number of

Table 3. — *Results of theoretical management of an aspen sucker stand originally thinned at age 7 years and partially cut at age 32 years*

	Per acre data[1/]			Average d.b.h.	Age
	Trees	Volume	Basal area		
	Number	Cords	Square feet	Inches	Years
ACTUAL STAND					
Spring 1960 (following thinning)	695	--	9.63	1.60	7
Fall 1971	675	10.50	86.61	4.84	19
PROJECTED STAND					
Projected to age 32 (Fall 1984)	550	57.75	198.81	8.13	32
Simulated cut, age 32 (Fall 1984)	385	36.15	124.53	7.70	32
Reserve, age 32 (Fall 1984)	165	21.60	74.28	9.08	32
Projected to age 50 (Fall 2002)	148	52.93	158.87	14.03	50
Cumulative yield (Fall 2002)	--	89.08	--	--	--

1/ All volumes computed with an experimental forest local volume table.

Table 4. — *Stand table comparing a 50-year-old untreated stand with a theoretically managed stand on similar site (site index 85-90)*

D.b.h. class[1/] (inches)	Control stand			Managed stand		
	Total trees	Basal area per acre	Volume[2/] per acre	Total trees	Basal area per acre	Volume[2/] per acre
	Number	Square feet	Cords	Number	Square feet	Cords
5	10	1.430	0.20	0	--	--
6	43	8.280	2.13	0	--	--
7	28	7.560	2.30	0	--	--
8	35	12.460	3.65	0	--	--
9	43	19.280	5.63	0	--	--
10	43	23.650	7.35	8	4.610	1.36
11	43	28.440	10.45	3	2.230	.66
12	38	28.910	9.38	13	10.620	3.25
13	10	9.470	2.95	29	26.038	8.99
14	5	5.200	1.80	52	57.293	18.87
15	--	--	--	27	34.479	11.52
16	3	3.540	2.40	9	12.314	4.32
17	--	--	--	4	6.164	2.16
18	--	--	--	3	5.126	1.80
Total	301	148.220	48.24	148	158.874	52.93
Average basal area		.492			1.073	
Average d.b.h.		9.50			14.03	

1/ Trees 5 inches and larger.
2/ All volumes computed with a local volume table believed to be conservative.

stems in the larger diameters, and increased the total cumulative yield by more than 40 cords (theoretical thinning at 32 years, 36.15 cords, plus final projected volume of 52.93 cords). While there may be some question concerning such a large comparative increase in cumulative cordage, there is little question that significant increases in diameter can be accomplished by such management practices.

CONCLUSION

These comparative noncommercial and commercial thinnings and those carried on by others (Day in Upper Michigan, Steneker and Jarvis in Manitoba, and Zasada on the Chippewa National Forest in Minnesota) have shown that, *under the right conditions,* aspen has excellent management potential, especially if the aim is to supply a saw-log or veneer market. Because of its suckering ability, there are no planting or release costs and the larger average diameters should reduce logging costs. Thus for stands close to the mill more intensive culture is within the realm of economic feasibility. Government agencies with a subsidized labor force, should carefully consider more intensive management of aspen because the day of aspen surpluses, especially of saw-log or veneer size and quality, is rapidly drawing to a close.

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MECHANIZED HARVESTING SYSTEMS CAN AID MANAGEMENT

Z. A. Zasada, *Research Associate*
Cloquet Forestry Center, University of Minnesota
Cloquet, Minnesota

ABSTRACT. — Mechanized timber harvesting systems in the Lake States show promise for increasing labor productivity and improving utilization of the resource. These systems can be used in the aspen type for sustained timber and wildlife production with little impact on soils and scenic values.

Mechanization has changed aspen timber harvest-ıg in the Lake States during the last 10 years. The ·stems now under development have good potential ɔr increasing efficiency of timber harvesting; the roducts may be removed as short logs, tree-length ıaterial, full trees, or chips. These new systems offer ·veral advantages, including higher labor productiv-y, less manual work, and improved utilizatiion of the mber resource. At present they are used most suc-ɜssfully in clearcutting even-aged stands.

Because of public concern about the environment, :ceptable mechanical harvesting systems on public nds must meet certain multiple-use requirements. he Cloquet Forestry Center has studied the effect of echanized harvesting on the aspen forest. The re-lts of this research indicate that properly directed echanized harvesting can aid in the management the aspen type for sustained timber and wildlife ·oduction with little impact on soils and scenic ılues.

AREA AND CONDITIONS OF ASPEN TYPE TO BE HARVESTED

About 65,000 acres of aspen type have been har-sted annually in northern Minnesota during the ıst 5 years. This is about 1½ percent of the type medium and better sites. The harvested stands are ually more than 40 years old with trees in the 6-15-inch diameter range. Aspen occurs in five gen-ıl condition classes as follows: (1) pure aspen, (2) ɔen-birch mixture, (3) aspen-conifer mixture, (4) ɔen-northern hardwood mixture, and (5) under-·cked stands with brush.

Because of increasing use of aspen, it is expected that at least three-fourths of a million acres of this type will be logged in the next 10 years. The mer-chantable stands available for harvesting will be sim-ilar to those now being cut. The 1962 forest survey showed that 35 percent of the type was in the 40+ age class, and an additional 48 percent was in the 20 to 39 age class. How these stands are harvested will determine the quality of the next aspen timber crop as well as the potential for wildlife habitat.

MANAGEMENT OBJECTIVES

A good distribution of age classes and full stocking of pure aspen stands on medium and good sites must be provided to meet the demands for aspen forest products and the requirements for wildlife habitat. Aspects of aspen silviculture that must be considered at harvest time to meet this objective include site quality, reproduction, habitat improvement, soil pro-tection, stand development and protection, and length of rotation.

Recognition of site quality would make it possible to determine which areas are not suitable for either commercial wood production or habitat development. Stands on poor and medium sites would be harvested when they reach pulpwood size. On good sites, stands would not be harvested prematurely — they would be grown to produce the high-value products such as veneer and large saw logs of which they are capable. This approach will result in less loss through mortality and overmaturity, limit natural stand conversion, and provide more good wildlife habitat areas.

A complete clearcut is necessary for good aspen reproduction. It also reduces invasion by tolerant species that produce little usable volume and eventually allow complete conversion of the stand. Scenic values and wildlife needs may require limiting the size and dispersal of areas to be clearcut.

DEVELOPMENT OF STANDS SUITABLE FOR MACHINE HARVESTING

Pure stands of aspen have many characteristics that favor profitable mechanized harvesting; they are even-aged, contain a high volume per acre, and most important, the trees fall within a limited diameter range. In addition, most aspen forests occur on sites that permit year-round harvesting.

Stands of sucker origin following clearcutting can be better stocked and possess equal or better vigor than the original stand. Rapid growth and natural thinning are characteristic of such stands; trees will attain a height of 4 to 6 feet and number more than 7,500 stems per acre the first year. At age 10, the trees will be 25 feet tall and number 3,000 stems per acre. By age 20, further natural thinning will reduce the number of stems to about 1,700 per acre, and the trees will be 40 feet tall. The young stands show no tendency to stagnate because of heavy stocking. Individual tree dominance is pronounced. Good stand growth is maintained even without thinnings.

Because of uniform spacing and a common starting time, pure, well-stocked aspen stands contain a large number of trees fairly close to the same diameter. For example, at age 11 about 90 percent of the stand will be in the 1- to 2-inch size class; at age 20 about 80 percent will be in the 2- to 4-inch class; and at age 55 about 90 percent will be in the merchantable size class of 6 to 10 inches.

Recent proposals have been made for growing and harvesting tree crops using a very short rotation. A "Sycamore Silage" approach has been proposed by Herrick and Brown in the South. In Wisconsin, Einspahr and Benson suggest a similar approach for aspen. The limited range in diameters at given ages indicates that short rotations may be possible in aspen provided the stands are kept free of competition.

Aspen stands reach maturity when they are from 40 to 60 years old, earlier on poor than on good sites. Thereafter they open up as a result of decay or damage from ice and wind. Mature and overmature stands are invaded by brush and more tolerant hardwoods that usually reduce the quality of the next stand. Because aspen is a forest type that deteriorates rapidly after reaching maturity, harvesting at rotation age is necessary.

HARVESTING SYSTEMS IN USE

Three harvesting systems are used in the aspen type in northern Minnesota. The *shortwood system* is the conventional, most widely used method of logging, with felling, limbing, and bucking done at the stump and logs skidded or forwarded to haul roads. Although machines have been developed for full mechanization of this system, most small operators fell the trees with chain saws. Skidding is done with one of several types of forwarders equipped with power loaders.

In the *tree-length system,* trees are felled and limbed at the stump. Tree-length logs are skidded to a landing, where they are processed into logs or moved directly to the mill. This system is gaining in use due to the success of the rubber-tired skidder, which makes high-speed, long-distance skidding possible. The number of skidders used in northern Minnesota has increased from about 100 machines in 1965 to more than 1,000 during the 1970-71 logging season. The trend of mills toward equipping their yards to accept and handle tree-length wood will promote further expansion of this system.

The *full-tree system* has been used to a limited extent in harvesting aspen. With this system the only work done at the stump is to fell the tree. The full tree is skidded to the landing for limbing and processing into logs. Machines such a feller-buncher and tree processors also are available to fully mechanize the operation. As practiced by most operators, the system is partially mechanized with felling done manually.

These systems offer to the forest land manager three alternatives of removing the forest crop: (1) as logs, leaving cull logs, branches and tops in the forest; (2) as tree-length logs (or polewood), leaving only branches and tops in the forest; and (3) as full trees, leaving no residue in the forest.

EFFECT OF HARVESTING ON THE FOREST

The condition of the area following logging determines the treatments necessary to establish desirable forest reproduction, reduce soil erosion, and provide acceptable wildlife habitat and esthetic conditions. Residual conditions resulting from the three harvesting systems — slash cover, impact on soils, disturbance of the shrub understory, and damage to residual trees — were examined on commercial logging operations. The utilization of aspen was complete by current market standards. All merchantable aspen trees 6 inches in diameter and larger were cut for pulpwood. Because of variations in market contracts among operators, merchantable trees of other species were not taken on all the study areas. No special requirements were imposed on operators. Thus, the condition of these cutover areas probably are typical.

Damage to Residual Stand

Where aspen is managed for continuous timber production, the harvest cutting should remove the total stand — merchantable trees, nonmerchantable trees, and even advanced reproduction. Previous studies and observations show that the completeness of the clearcut varies with stand conditions and the degree of utilization of aspen and associated species. The harvesting sytem used and degree of mechanization involved also have a great impact on the condition of the site after logging.

A comparison of the three harvesting systems using manual felling and machine skidding shows that the tree-length and full-tree systems eliminate more of the residual trees than the shortwood system. A strip-cutting pattern with shortwood logs bunched on or along a skidroad confines the skidding activity to a limited area, whereas moving full trees or tree-length logs distributes skidding effects randomly over the area.

Fully mechanized operations result in a more complete clearcut than partially mechanized operations. Where machine felling was used, 90 percent of the nonmerchantable trees 1 inch in diameter and larger were eliminated to facilitate harvesting of the merchantable trees. In manual felling, only 65 percent were eliminated; although some were knocked down in the skidding operation, the cutters found it more efficient to walk around the nonmerchantable trees. The three fully mechanized harvesting systems were equally effective in eliminating the residual nonmerchantable trees.

Although fully mechanized operations do the best job of residual stand removal, during the next 10 years the partially mechanized tree-length system probably will be more widely used to move tree-length aspen timber from stump to landing. This system eliminates 50 percent or more of the residual stand and advance reproduction, but still does not accomplish the full stand removal needed in aspen management. A survey of 1,700 acres of aspen type in Hubbard County harvested by this method showed good reproduction — 7,000+ stems per acre 3 years after logging. However, the survey also showed that 26 percent of the poor-site plots and 41 percent of the good-site plots were stocked with tolerant hardwoods 1 inch in diameter and larger.

The effect of leaving this residual stand free to grow was shown by a study in the Pike Bay Experimental Forest in Cass County, Minnesota. A well-stocked stand of aspen that was established after clearcutting was thinned at age 13, and the invading tolerant hardwoods were removed. An untreated check area was left for comparison. Thirty-five years later, at age 48, all the volume in the treated area was in aspen. In contrast, only 71 percent of the volume in the untreated check area was in aspen; the rest was in hardwoods that were generally inferior in value and quality.

It is suggested that pilot plant trials be conducted now to determine the feasibility of requiring the removal of this residual material as part of the harvesting operation.

Ground and Understory Disturbance

The use of heavy machines in the forest has raised concern about their effect on soils and understory vegetation. The degree of disturbance observed in these logging operations was described by the following classes:

None. — No disturbance to soil or shrubs.

Light. — Wheel tracks of machine visible, no mineral soil exposed, litter layer packed. Brush layer broken down or bent. Machine usually traveled on

area only once in skidding full trees or tree-length logs.

Medium. — Wheels or logs broke through litter layer, mineral soil exposed, compacted. Shrubs broken down or uprooted. Machine may have traveled on same trail several times. Wheels did not break into root mat.

Heavy. — Same as medium, except area used several times as a main skidding trail for long skidding distances, often resulting in deep ruts and severing of roots to a depth of 4 inches or more. This situation can develop with only few trips when the soil is wet.

The greatest disturbance resulted from use of the full-tree system and summer logging (table 1). Machine activity increased the soil bulk density in the heavy and medium disturbance classes; this occurred on 35 and 45 percent of the tree-length and full-tree areas respectively, and 25 percent of the shortwood area. Medium and heavy disturbance occurred about 35 percent less often on winter-logged areas than on summer-logged areas.

Table 1. — *Understory and ground disturbance by harvesting system, in percent of area disturbed*

Harvesting system	Disturbance class			
	None	Light	Medium	Heavy
Shortwood	51	26	15	8
Tree length	34	28	29	9
Full tree	24	30	35	11

Aspen reproduction became established immediately after logging except where heavy disturbance occurred. Fall- and winter-logged areas were stocked the following summer. Spring- and summer-logged areas were stocked by fall. Only scattered trees and grasses became established on the heavily disturbed areas.

These measurements indicate that heavy disturbance of an area may limit regeneration and accelerate erosion on steep slopes. No such adverse effects have actually been observed, however, possibly because this disturbance class makes up less than 10 percent of the area and occurs in scattered small patches.

Aspen silviculture and wildlife habitat improvement guides recommend heavy disturbance of the shrub understory stands during the logging operation for successful aspen regeneration and browse production. The largest amount of shrub uprooting and density reduction results from use of the full-tree system followed in order by the tree-length and the shortwood system. However, if an effort was made to distribute the skidding activity over more area, equal amounts of brush disturbance could result from all three harvesting systems.

Slash Cover

About a third of the area harvested by the shortwood and tree-length systems was covered with slash from limbing and topping trees; however, the slash patterns were different. On the shortwood area the slash was arranged in continuous rows parallel to the cutting strip; on the tree-length area it occurred in randomly scattered piles. Where full-tree logging was used, slash covered less than 10 percent of the area and was concentrated so it could be safely disposed of by burning or chipping.

Slash from clearcutting aspen does not prevent establishment of a fully stocked stand of reproduction by suckering. In fact, the three harvesting systems are equally acceptable for stand establishment. Other multiple-use benefits such as scenic values and wildlife habitat improvement, and the need for prescribed burning or hazard removal should be considered when making a choice of aspen harvesting systems.

COST COMPARISON

Few data are available for comparing the costs of aspen harvesting systems. The limited information gathered in our studies shows that the costs for full mechanization are higher than for partial mechanization at current machine and labor rates. However, production rates per hour are much higher with full mechanization.

One study compared production rates and determined silvicultural impacts of four mechanized harvesting methods that might be used by a small operator. The study stand was 50 years old and had a volume of 18 cords per acre with eight trees per cord. Harvesting cost per tree (stump to landing) varied from 34 cents with manual felling and limbing with tree-length skidding to 40 cents with machine felling and bunching with full-tree skidding and manual limbing. The highest production rate — 31 trees per hour — and the best residual stand conditions for

aspen land management were achieved with full mechanization. The area was free of slash, shrub disturbance was heavy, and few residual trees remained.

The additional cost that will result from including silvicultural treatments in the harvesting operation needs further study. Available information indicates that for stands under 55 years of age, including this requirement will have little impact on production cost. Most of the residual trees are small and at least half are destroyed when removing the merchantable crop.

Size of Area

A limitation on size of clearcut is recommended by game biologists and landscape planners to meet the requirements of wildlife habitat and forest esthetics. There is no information on the size of current cutting areas but there are several indications that most are fairly small:

1. About 50 percent of the timber cut annually is produced by small operators, many who log only part time.

2. The large number of sale permits issued by public forestry agencies indicates that cutting is done on small areas. In 1967 and 1968 these agencies issued 626 and 617 permits in Itasca County, and 469 and 446 in Beltrami County.

3. Large timber producers who have fully mechanized operations will log areas with volumes of 500 to 1,000 cords. Such volumes can be harvested from well-stocked stands on 20 to 40 acres.

4. The scattered landownership pattern and variable land conditions of soils, swamps, and topography lessen the chances for large cutting units.

It is possible that most individual timber sales now meet the area recommendations of game biologists — 20- to 40-acre cutting units. Large clearcut areas often result, however, where a number of small sales are located next to each other. Better coordination of harvesting among large forest landowners may permit meeting the multiple-use needs of aspen land management.

The potential impact of mechanized harvesting on long-range aspen management should be recognized in future planning. Even the small operator can become a large producer because a two-man crew can harvest more than 100 cords per week. As mechanized harvesting becomes the common practice, careful planning will be necessary to meet both the objectives of efficient year-round timber production and aspen land management.

SUMMARY

1. In the next decade up to three-fourths of a million acres of aspen stands age 40 years and older will be harvested in northern Minnesota. How this area is logged will influence both the future management costs and the quality and yield of timber and wildlife. Silvicultural requirements for aspen based on research and experience are available to guide the harvesting program.

2. Mechanization has changed harvesting methods in aspen. It has provided ways of removing the forest crop that will result in residual forest conditions favorable to aspen land management.

3. As currently applied, mechanized harvesting has little adverse impact on forest soils or watershed conditions.

4. Mechanized harvesting has the potential of removing nonmerchantable trees and disturbing the shrub understories (requirements for stand establishment and growth and for wildlife habitat improvement) as part of the logging operation.

5. Pilot-plant tests are needed to determine the costs and stand conditions under which silvicultural, wildlife habitat, and esthetic requirements can be included in the logging operation. Similar tests are needed to determine methods of adapting size of clearcut to meet both land management needs and timber production requirements.

6. Good aspen silviculture can provide the stand structure and conditions necessary for efficient use of mechanized harvesting, as shown in the following tabulation:

Conditions best for machine performance	*Silvicultural conditions for aspen management*
Clearcutting.	Complete clearcut best for regeneration and stand development.

Harvesting one product and one species.	Pure stands grow best and produce highest yields.
Uniform size.	Rapid natural thinning maintains a limited diameter range through the rotation.
Large number of trees per acre and uniform stocking.	Pure aspen stands tend to be fully stocked.
Year-round logging chance.	Aspen grows on upland sites suitable for year-round logging.

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MANAGEMENT AND THE FOREST INDUSTRY

Richard W. Schneider, *Assistant Woodlands Manager*
Blandin Paper Company, Grand Rapids, Minnesota

ABSTRACT. — The forest industry of the Lake States is vitally concerned with the future of the aspen forest. Use of this resource is increasing significantly. Industry has three major concerns regarding the utilization of aspen: (1) the resource supply data is old and out of phase with demand projections being made; (2) a number of problems must be resolved in timber management and harvest; and (3) a balanced plan of multiple-use management for the aspen cover type is needed.

SUPPLY AND DEMAND

To state that the forest industries located within he geographical boundaries covered by this sympoium are interested in the aspen resource would be gross understatement. Recent trends in the utilizaion of this resource and projected future consumption evels firmly establish industry's commitment to and lependence on the aspen species. A great deal has een written regarding the aspen supply and demand ituation for this symposium and will continue to be subject of primary importance to industry in the uture. Many statistics have been presented and anazed by those more qualified than this author. Thus, choose not to belabor this point, but merely wish bring forth a few figures to reaffirm our position.

During the period 1946 to 1970, pulpwood producon in the Lake States, including all species, increased om 2¼ million cords to over 4¼ million cords. uring this same period, the aspen harvest alone icreased from 713,000 cords to 1,967,000 cords. The spen volume percentage of all species harvested icreased from 32 percent in 1946 to 46 percent in 970.[1] The pulpwood production levels should serve an adequate guide as it appears from analysis of source consumption reports that pulpwood comrises roughly 75 percent of the market. This brief nalysis indicates that the growth in use of aspen has een significant.

[1] *Reports of pulpwood production published by e North Central (formerly Lake States) Forest xperiment Station from 1948 to 1971.*

How does industry view the future aspen supply-demand situation? This is probably one of the most frustrating problems continually facing the respective company woodlands departments. Market conditions may indicate the advisability of significant capital investment in plant and equipment for the production of aspen-based products. The question is then tossed to woodlands managers for an analysis of the long range resource supply situation. The traditional routine of examining allowable cuts, current harvest levels and estimating surpluses within the supply area of interest then begins. Unfortunately, a report finally goes back to management with estimated resource statistics carrying a plus or minus 50 percent factor for unknowns. I am encouraged by the papers presented at this session which indicate the possibility of more sophisticated methods that may be applied to this subject of resource availability and should eventually result in more accurate projections.

In the interim, however, we are faced with the current dilemma of dealing with estimates based on data containing many unanswered questions. Aspen inventory and allowable cut data is old and extremely difficult to utilize. It has, to date, been a poor base for the investment values which are dependent upon this information. Current estimated aspen surpluses look inviting to production people and the general public in their observations of the forest resource. However, I find an increasing number of resource analysts reducing their estimates by 20 percent to 50 percent based on unknowns apparent in the data. Again, I feel that the new forest surveys and revolutionary data processing techniques will greatly improve this situation in the future.

Realizing the hazards mentioned above, in September of 1970 I attempted to project future aspen consumpiton levels for the Lake States. A group of wildlife managers were interested in this same subject. The analysis at that time indicated that the forest industries of the Lake States would be rapidly closing the gap on present estimates of aspen surpluses by 1980. These observations were, of course, made from existing forest inventories and based on current levels of aspen management. At this point, almost 2 years later, aspen use is growing and the projection of nearly complete use of the aspen resource within the next decade seems within reason. It also seems reasonable to assume that aspen utilization will remain strong as long as it continues to be a significant component of our forest types.

A few brief comments regarding the reasons for industry's increased interest is the aspen resource are probably in order. Aspen was elevated from its "weed tree" status in recent years due to advanced technology in its utilization and its increasing availability over the past twenty years. Research resulting in improved harvesting, processing, pulping, and milling methods has proven that aspen contains chemical and physical properties desirable to the manufacture of quality forest products in this region. The occurrence of aspen in relatively uniform and pure stands makes it a desirable species from a logging cost viewpoint. Its favorable growth rate, short rotation, and ease of regeneration on a range of forest sites usually results in a favorable forest management analysis. The manipulation of the aspen type has proven to be of significant value to deer and grouse populations of the Lake States. Thus, the aspen resource is a versatile forest cover type which responds favorably to multiple-use forest management objectives as well as having a ranking position in the forest products raw material supply picture.

MANAGEMENT AND HARVEST

If we now agree that aspen is of major importance to the future of the Lake States forest economy, let us look briefly at some of its timber management problems as they relate to the consuming industry. I doubt that there are many involved with the symposium that would dispute the fact that aspen at rotation age must be harvested by clearcutting. Intensive research has proven that this practice is ecologically sound and must be used if the aspen type is to be maintained at its highest level of productivity. This proven silvicultural system is attractive to loggers because it makes mechanized harvesting economical and efficient. Yet, one of the greatest threats to the future potential of the aspen forest is by well-meaning but poorly informed concerned conservationists who would terminate this required even-aged management practice. It is evident that industry is probably most concerned about the long range effect of such a threat should it materialize due to its potential catastrophic setback to the aspen supply picture. Everyone interested in the future of the aspen forest resource should promote the merits of properly applied even-aged management and its long-range multiple-use benefits.

Several other problems concern industry in the management and harvest of the aspen type. Most of these occur in the contracts for sale of aspen timber by public agencies upon which the Lake States forest industry is highly dependent. I would not question the intent of the objectives outlined in sale contracts for improvement in the quality of the new aspen forest which will follow the harvest; however, the methods remain of concern. Stand improvement techniques carried out as part of the timber sale, such as residual stem removal, slash distribution and management, and access road construction, are in need of clarification insofar as the cost of logging is concerned. Contracts indicate that such requirements are allowed for in the determination of stumpage rates. It is apparent, however, that considerable additional work must be done to more accurately identify the costs involved to the logger. Also, it may be advisable to accomplish many of these items on a post sale treatment contract that is completely removed from the harvesting operation. Whichever system is used, the costs must be accurately identified.

In aspen management, industry is obligated to do an efficient job of harvesting and utilization. Over the last decade, important advances have been made. Increased demand for aspen has resulted in a much more complete job of utilization in the 1970's than was ever envisioned in the 1950's. The development of mechanized harvesting by loggers has resulted in a much better job of harvesting. There is still room for improvement and the outlook indicates that progress will continue at an accelerated rate with the construction of additional aspen-consuming facilities. The advent of the metro-harvesting system utilizing all trees to a 2-inch d.b.h. class is an example of recent developments.

The public land agencies also have an obligation to facilitate efficient harvesting. Some advances have been made, such as area estimate sales, acceptance of weight scaling, and consumer scale. However, the logger feels that more improvement can be made. Many requirements are added to the contract without any advance discussion with him and without any test or study to determine what impact these requirements will have upon the logging operation.

If we consider that proper harvesting of the crop is the most important forest land management practice in managing aspen, then the key man in aspen management is the logger. The success of the harvest and renewal of the stand is essentially in his hands. He must be considered a partner to the forest manager in accomplishing the management objectives for aspen or any other forest cover type. He should become a part of the decision-making process in developing contract conditions. A logger who understands the long range objectives of the harvesting plan through continuous field contact by management personnel will in the majority of cases respond favorably and go that extra step to comply. The logger of today is generally a cost-conscious businessman and vitally concerned with the continuous yield of the forest for his livelihood. He is an integral part of the management process and not a separate step to be considered as a necessary evil. A mutual understanding of problems will be a major step toward better silviculture and utilization of the aspen resource.

MANAGEMENT AND MULTIPLE USE

Industry is concerned with several multiple use benefits other than timber from the aspen forest. The current concern for more attention to wildlife, esthetics, watershed protection, soil disturbance and recreation values in the management and harvest of aspen is substantial and growing daily. Improvements and changes in procedures are, no doubt, needed in management practices. However, past aspen management plans need not be apologized for because they have been, for the most part, in line with economic conditions, markets, and most public needs. Current environmental interest has now brought forth a number of new concerns that must be considered in the plan of management. Most of these concerns focus on the harvesting operation and will result in additional logging costs of varying degrees.

Manipulation of the aspen type is showing increasing potential in the management of the Lake States' major game species, deer and grouse. Habitat improvement has been realized for many years from almost every aspen harvesting operation. Benefits such as increased browse, openings, stand edges, and variable stand age classes have been an indirect result of harvesting operations and of major value to wildlife populations. This has all been accomplished by logging at no additional cost to wildlife management. In turn there has been no special design in the timber sale for wildlife management and general logging costs have not been affected. Recent proposals indicate that aspen timber sales should be planned for specific objectives in wildlife management. Items such as size of harvest area, pattern of cutting, distribution of openings and edges, and residual cover areas are a few examples.

Research and management experience has indicated that these changes in harvesting patterns may be desirable and we will want to include some of these objectives in future sale designs to a practical degree. However, many of these changes will result in increased logging costs due to required changes in operating methods. This additional cost should not be borne by timber management budgets and loggers alone. Many others will benefit from these improved techniques and should share in the costs involved. Also, at this point in time the wildlife management guidelines have not been firmly established. Before they become contractual requirements, they should be evaluated as to impact on production costs and the logger should participate in these decisions.

The esthetics of aspen harvesting is of major current interest. Objections arise daily to the appearance of areas following harvest. I believe we would all basically agree that there is no visual appeal to an area immediately after logging. However, the appearance does not usually relate to the quality of aspen management. Esthetic improvement beyond standard slash disposal and orderly logging requirements are additional costs for benefits received other than economically sound forest management. Changes in logging requirements and resulting costs which include size limitations of cutting area, slash disposal requirements to reduce visual impact, landscaped cuttings, and reserve screens must be recognized for their esthetic value and not solely as a cost of timber management.

This same analysis would apply to other multiple-use values of the aspen forest. Many of the suggested changes directing more attention to values other than timber are meaningful and desirable. However, these additional management costs must be evaluated and assessed to the respective benefit desired. Timber management and logging cannot absorb these costs alone. The other amenities to be improved through aspen management must carry their share of the load.

As a final note regarding multiple use of the aspen type, I would like to make a special plea to all agencies concerned with research and management. It is easiest when pressure is mounting for attention to a particular facet of management, to pursue this item in the name of progress. We are in need of better balance in striving for improved multiple-use management. In a hit-and-run approach to a specific problem, we may often be tipping the scale farther rather than heading toward a desirable level. There is a real need for the forest manager to draw together the best techniques from all disciplines concerned in an attempt to develop a balanced plan of management for the aspen forest. Such a balanced management plan will be practical and will result in realistic cost-benefit ratios.

SUMMARY

In summary, the forest industry of the Lake States is dependent upon and consequently vitally concerned about our aspen forest. We strongly endorse the research and management studies devoted to aspen which are presented in this symposium. The studies related to the supply and economics of the species will assist industry by providing more reliable data for potential expansion estimates. Utilization studies will be of significance as the demand for more complete use of this resource continues to grow. Additional contributions through genetics, silviculture, ecology, and protection research will be of increasing value to the forest manager. Finally, research efforts in the related use fields will assist in keeping us on the right track insofar as balanced use of the forest is concerned.

I have referred to some problems that are of concern to the forest industry regarding the supply, demand, management, and harvest of the aspen forest. However, it is my firm belief that the exchange resulting from this symposium will contribute significantly toward realization of the full productive potential of this key Lake States' forest resource.

MANAGEMENT ON THE NATIONAL FORESTS OF THE LAKE STATES

John R. Castles, *Assistant Regional Forester*
and
LaMont G. Engle, *Branch Chief*
Eastern Region, USDA Forest Service
Milwaukee, Wisconsin

ABSTRACT. — Aspen is managed on the National Forests to meet multiple-use goals. Consideration is given to aspen timber commodity values, other timber species commodity values, wildlife habitat, esthetics, and environmental protection. We have three broad options in treatments; regenerate aspen, allow natural conversion to another type, or artificially reforest with conifers. The choice of treatment depends on multiple-use objectives and local ecological conditions.

If there is a Cinderella among our eastern tree species, aspen is very likely it. A few years ago aspen was a despised weed tree and aspen stands were converted to stands of other species as soon as practicable. Now aspen is important in meeting the management objectives of our National Forests. Aspen has been able to establish itself and to prosper under conditions adverse for tree growth. Meanwhile, new utilization techniques have made it one of the most important tree species in the Lake States.

EXTENT AND UTILIZATION

The aspen-birch type covers 1.7 million acres or 30 percent of the commercial forest land on the National Forests of the Lake States. Aspen volume, according to our most recent timber inventory estimates, totals 880 million cubic feet. This is about 21 percent of the total commercial timber volume on the Lake States National Forests.

The present annual allowable cut is 51,000 acres. The estimated volume of aspen that should be harvested annually in all timber types is about 41 million cubic feet or slightly less than 5 percent of the total growing stock volume. Aspen is relatively well utilized on all our forests except for the vast reserve of aspen on the Superior National Forest. If we consider only the other Lake States forests, we find the area of actual regeneration cut is about 80 percent of the allowable.

The portion of aspen in the total volume of all species cut has remained remarkably stable at about 38 percent for over 15 years. During this time the harvest volume of aspen has increased from 220,000 cords to 275,000 cords annually (includes a minor amount of paper birch).

Stumpage prices received recently for aspen vary from our minimum rates of 50 cents per cord up to $5.00 per cord. The higher rates are received on parts of the Nicolet National Forest.

MANAGEMENT OBJECTIVES

As you know, it is important to keep the Forest Service in tune with the changing world in which we live. Making sure that we are responsive and alert to the changing needs of a dynamic society requires a continuing evaluation of our management objectives and policies.

In order to meet this need, the Forest Service has developed a new framework to help guide our thinking and decision-making throughout the Service. This guide is entitled "Framework for the Future." It is the result of much thought and discussion and I commend it to your attention. The objectives and policy statements identify the general scope and character of the role the Forest Service should play in the society of today and tomorrow. I mention this because its direction and timeliness is part and parcel of this new era in aspen management.

Some broad new objectives that we must consider in managing our aspen are:

- To promote and achieve a pattern of natural resource uses that will best meet the needs of people now and in the future.

- To protect and improve the quality of air, water, soil, and natural beauty.

- To generate forestry-based job opportunities to accelerate rural community growth.

- To encourage the growth and development of forestry-based enterprises that readily respond to consumers' changing needs.

- To develop and make available a firm scientific base for the advancement of forestry.

In order to meet these broad objectives, we have changed our concepts of aspen management. No longer do we confine our thinking to wood production alone. We must fit aspen lands into the total resource and environmetal picture. We have considerations that change or modify strictly timber production options. Moreover, a choice of action is not based on simple rules and it cannot be made for any single stand of timber in isolation from the surrounding land and human developments.

Timber, Wildlife, Fire, and Environmental Objectives

Both the wildlife and timber commodity values of aspen are important factors in management. But, because these subjects are examined in great depth by others at this Symposium we will only mention them briefly here.

Certainly, we must continue to consider the national need for timber which clearly calls for the intensification of management for conifer sawtimber, including the conversion of aspen to conifers. And, we will consider local industry needs for a continuing aspen wood supply.

Aspen is extremely important for the maintenance of good wildlife habitat. The total area in aspen, the mixture of age classes, and the spatial relationship of aspen stands with stands of other species are all important habitat factors. So size of area harvested, shape of the area, and distribution of the harvest areas must be considered in managing aspen stands. Of equal importance for wildlife are decisions regarding conversion of the type to conifers or northern hardwoods.

Fire protection is also a consideration in aspen management. In large areas of pine, strips of hardwoods are desirable for fuel breaks and for fire fighting purposes. Aspen may be regenerated for this purpose even though the soil is more suitable for pine. Separating pine stands with aspen strips also dovetails with wildlife and esthetic needs for diversity in conifer areas.

Environmental protection, of course, is paramount. Therefore, soil, air, and water protection needs may influence management decisions for aspen stands.

Esthetic Objectives

The esthetic values of scenic areas, heavily used recreation areas, and travel corridors need to be protected. In these areas we are particularly concerned with the appearance of timber treatments. High contrasts in form, line, color, and texture, such as occur in a poorly designed aspen regeneration cut, have a negative visual impact. With skillful planning, the visual impact of cuts need not be shocking. Size, shape, distribution of cutting units, topography, vegetation, and viewing distance can all be used to minimize contrast and maximize continuity in the landscape.

The size of an aspen clearcut largely determines its visual impact. Normally, small cuttings are preferred; a number of them made at different times can provide a variety of age classes. But simply setting a single upper size limit on cuts is not the answer. Resource values, deviations from the surrounding or characteristic landscape, and the apparent size created by the viewing distance, must all be considered. The appearance of even large cuts can be improved by leaving trees standing near natural features such as boulders, rock outcrops, hills, ponds, and marshes; the apparent size of cuts can be reduced by restricting the viewing distance.

An aspen clearcut can be shaped to blend in with the characteristic landscape. Straight cutting lines, strips, or rectangular blocks should be avoided in

favor of free-form shapes that follow natural projections, indentations, and soil and topographic features, thus exposing smaller areas of clearcut to view. Irregularity and variety in clearcuts are not only esthetically pleasing but can also be ecologically sound for natural plant communities.

Proper timing and dispersal help improve the appearance of clearcuts. Sufficient time should elapse between successive cuts on nearby areas. But the same spacing and timing guidelines cannot be used in all cases. Topography, forest type, stand conditions, soils, and other factors must be weighed in each situation.

Along selected roadsides aspen stands should be managed to maintain appropriate species in good health and provide beauty and variety. Silvicultural treatments used may include planting, thinnings, removals to provide vistas, conversion to other vegetation types, and leaving clumps of birch or spruce to frame vistas. Aspen itself lends richness to the landscape because of its colorful spring and fall foliage and its light bark.

Logging residue and slash should be promptly removed from roadsides, which act, in effect, as display windows. Logging slash along roads or trails, even though it is soon decayed, leaves a lasting, unfavorable impression on the public.

TREATMENT OPTIONS

We consider aspen to be an extremely "pliable" type in that several management options are feasible depending on multiple-use objectives and the ecological conditions of the area under consideration. Aspen is found on a wide range of soil conditions and can be associated with virtually every other species that grows in the Lake States. There are generally three broad management options for aspen stands: (1) maintain the aspen type through regeneration cutting, (2) convert naturally to another timber type that is ecologically higher in the successional ladder through partial cutting or by no cutting, and (3) artificially reforest other species by planting or seeding.

Maintaining Aspen

We manage pure aspen stands under the even-aged system of silviculture. There is no provision for thinnings in immature stands. Our aspen is considered mature when it is pathologically mature or at 40 to 50 years of age, whichever comes sooner; and allowable cut is usually based on about a 45-year rotation. We depend primarily on reproduction from root suckers of the cut aspen stems. We also obtain some seedling reproduction where mineral soil is exposed. If more than 15 percent crown cover remains after commercial harvest we consider an investment in residual tree removal. An investment of this type is generally not justified on an economic return basis for stumpage alone. We justify treatment on the combined values for wildlife, timber, and esthetics.

Some portions of aspen stands may be retained beyond rotation age or regenerated before they are mature in order to increase the spread of age classes in local areas. The aim is to obtain a normal distribution of age classes that benefits wildlife, maintains an even flow of timber products, and improves the characteristic landscape.

Natural Conversion To Other Types

The soil and the species mix of the stand are the primary considerations in determining the course of action. Management simply assists natural ecological succession toward the climax type on suitable soils. For instance, northern hardwoods often occur as an understory in aspen stands. If stocking of desirable hardwood stems is adequate and the site is well suited to hardwoods, we generally will manage for the hardwoods. The economic justification is not always clear, but we normally favor working with the natural vegetation and this swings us toward favoring the development of the more stable northern hardwood succession. However, even here such a stand may be regenerated to aspen for wildlife purposes or for timber production. Often there is a good mixture of paper birch with the aspen. In some of these cases we should manage for the birch, particularly on the more productive sites or where esthetic benefits are involved. Another common mixture is aspen with a balsam fir-spruce understory. The easiest course in such instances is merely to cut the aspen and obtain a mixed stand of fir, spruce, and aspen.

Reforesting Aspen Stands With Conifers

The term "conversion" is commonly used when pine or spruce are planted on an aspen regeneration

area. However, "conversion" is loosely used and may not be strictly true because we are usually restocking the area with species that originally grew there and are gone because of repeated fires after the virgin timber was logged.

Much of the aspen is on well-drained sandy soils that formerly supported the pines. On these areas we consider reforesting with pine rather than regenerating another stand of aspen. Economic analyses will usually indicate a favorable return in reforesting with conifers. It is also desirable in light of long-term outlook for needed conifer sawtimber. However, more immediate needs for wildlife habitat often outweigh the timber consumption considerations in deciding to maintain aspen on pine lands. To a more limited degree, fire protection and water yield considerations favor aspen management on a portion of the pine lands.

The other site extreme is the area of poorly drained soils — often with rather poor aspen stands. Some of these sites can be readily planted with spruce. However, some areas are rocky or have dense vegetative cover and are costly planting chances so that it is difficult to decide what to do. We have tried different techniques but do not have ready answers. Again, some of these areas have high wildlife values.

RESULTS OF MANAGEMENT

What are the actual results of management decisions made on the National Forests? Currently about 25,000 acres of aspen are being given regeneration cuts annually. The area on which aspen is to be maintained is currently about 21,000 to 22,000 acres. On almost one-half of this area we are investing funds to complete the removal of residual stems. This compares with virtually no investments in aspen regeneration only 5 years ago. In the short run the proportion of treated stands will increase as we continually intensify management and work off the backlog of 3-, 4-, and 5-year-old cuts being treated. On some areas the commercial cut does a good job of regeneration and no investment in further treatment is justified. If utilization of smaller trees improves, the area that does not need treatment after the commercial cut will increase.

About 3,000 to 4,000 acres are being changed to other timber types annually. One-half of this is natural succession, primarily to hardwoods; the other half is artificial reforestation to red pine or spruce. On the other hand, harvesting in other timber types such as oak, jack pine, spruce-fir, and hardwoods is resulting in 2,000 to 3,000 acres of aspen type being created annually.

Inoperable, poorly stocked stands are also being reforested with conifers or are being treated to create new well-stocked aspen stands. We do not know the extent of natural succession of aspen to other types where there has been no treatment. Undoubtedly some of this is occurring but will only show up in our periodic timber inventories. All told we expect to see less reduction in the aspen type in the near future than has occurred in the past.

MANAGEMENT ON STATE, COUNTY, AND PRIVATE LAND IN WISCONSIN

M. E. Reinke, *Director, Bureau of Parks and Recreation*
Wisconsin Department of Natural Resources
Madison, Wisconsin

ABSTRACT. — Aspen is managed on State and county forest land in Wisconsin under a new system. Statistical forest plans failed to meet the need. Data are now collected (23 items) from every stand. Land management printouts identify by year the individual stands that require attention for timber, wildlife, and other uses. The system provides greater personnel efficiency, stand treatment at the proper time, flexibility for changes, and coordinated input of all other disciplines. On private land, the Timber Management Guides, rotation age as determined by site index, and the owner's objectives determine aspen management.

My presentation on the management of aspen in Wisconsin will discuss a total forest management planning system rather than individual stand planning. Almost all of my allotted time will be devoted to total management planning on public land. We feel we can make our greatest contribution in the area of total management. I shall conclude with brief comments regarding the management of aspen on private land in Wisconsin.

PUBLIC LAND MANAGEMENT

What I am about to present is a new approach to the management of any large forest holdings. It is the culmination of 18 years of work in Wisconsin by many foresters, game managers, researchers, and others. This is our first presentation on the subject. We have waited these long years until the system has become operational, field tested, and proven. It governs the management of 1.1 million acres of aspen on Department of Natural Resources and county forests in Wisconsin plus 2 million acres of other forest types.

In the 1930's, the vogue was type mapping. Since World War II, "Statistical Plans" and CFI became popular. Based upon 100 percent aerial photo interpretation, plots were allocated, data summarized, and summaries and allowable cuts were developed for each forest property.

Need For A New Concept Recognized

By 1954, Messrs. J. A. Beale and S. W. Welsh recognized the vast shortcomings of statistical plans. They ordered further investigation into a new concept.

Field foresters in public land management were asked, "What do you want from a management plan?" Supervisors and administrators were asked the same question. Objectives were then developed.

We traveled. Other States, Federal, and industrial owners were contacted. None of the management systems viewed met the objectives we had set. Most plans were based upon forest inventory systems rather than management oriented concepts.

Objectives of Wisconsin System

What did foresters, supervisors, and administration want? What was wrong with our statistical plans?

Field foresters wanted a plan that would answer these questions: (Does your plan?)

Where to harvest cut *each year*.

Where to make commercial intermediate cuts *by year*.

Where to make noncommercial cultural cuts and *when*.

Where are all the planting chances?

What stands should be considered for shearing for wildlife and *when*.

When markets do not absorb all the aspen, what stands are let go?

Where do we put public works or inmate crews when they become available?

The supervisory staff and administration wanted to know:

When research finds occur, can the plan for each forest be changed readily and rapidly?

When catastrophic losses occur, such as fire or insect mortality, can acreage control be corrected readily?

When a forester is transferred, can his replacement reach the same productive field efficiency within a few days on the job?

How many foresters are necessary on a given forest to meet the work load?

What is the necessary annual budget to do the cultural investment work?

Will a stand receive treatment at the proper time to assure maximum growth, income, and employment opportunity?

What can we expect in volume and revenue from each forest by year?

How can we manage the total forest to achieve maximum benefits to the public from timber, wildlife, and recreation?

New Management System Developed

A new system was developed and implemented to answer these questions. It consists of five components:

Forest type map.

Field reconnaissance.

ADP programming.

Management printout.

Multiple-management coordination.

Let us define each component.

Type Mapping

All forests are 100 percent cover type mapped and broken into compartments of approximately 700 acres each. Then individual stands in the compartment are numbered for identification purposes. We can now refer to compartment 47, stand 19 and readily identify the individual stand. Survey descriptions are too broad to use. Stands average 8 acres.

Field Reconnaissance

Each stand in the forest is examined. Some 23 separate pieces of information *for management purposes* are collected for each stand including type, acres, year of origin, total height, rings in last inch, site index, basal area, volume, management objective and prescription, logging chance and operability, recreational potential, soil type, projected year of harvest, year of treatment, and remarks.

About 300 thousand pieces of detailed information on a 100 thousand acre forest are then fed into the computer.

ADP Programming

Computer programs are developed to provide management data (not inventory) based upon the input of administrative decisions and latest research findings. An example will clarify.

The decisions regarding aspen were to:

Harvest at a rotation age as calculated from the site index of the stand.

Program no thinning cuts.

Program release of valuable understory.

Strive for equal age class distribution of aspen type on the forest within limits of 5 years plus or minus rotation age.

Enter a compartment twice during 15 years if necessary to prevent loss of growth or degeneration of the stand.

These are simple calculations — when done by data processing.

The Printout

The printout generated shows *by year* what individual aspen stands (and other types) should be sold that year.

This is the guideline to the forester. He may vary from it. It does not usurp the forester's professional judgment when he visits the stand 5, 10, or 15 years from now. He manages the forest; we supply the guidelines.

Multiple Management

Essentially only timber management has been discussed to this point. Now about the other facets of management such as game, fish, and recreation.

To assure land is managed in the public interest rather than in the interest of the discipline that administers the land, the game manager, fish manager, and other technicians plan their optimum management of the same land as if they "owned" it. Conflicts are then resolved at the lowest possible field level based upon the public need and benefit. Three examples will be helpful.

(A) A fish manager plans stream improvements on a trout stream plagued with beaver. He suggests immediate harvest of an immature aspen type that was scheduled for cutting in 1982 and a change in the management objective for the stand from natural regeneration of aspen to conversion by planting. The forestry objectives are changed to provide poor beaver habitat and more shade on the stream. The printout is altered to schedule by year a new cutting date, planting, and chemical treatment.

(B) Game management input is highly complex particularly for deer. Three separate printouts are provided the forester and game manager to assist in decision making:

1. Critical acreage determination. Wisconsin research has shown good deer habitat requires at least 25 percent aspen type within each 6,000-acre area. The printout identifies where "shortages" exist and where shearing or other treatment may be required to prevent loss of aspen to natural succession. In these areas, aspen shearing is programmed if more than 30 feet of residual basal area remain after the timber sale and if the regeneration objective is for aspen after a joint review.

2. Areas of poor site index. The poorest site index of about 15 percent of the total aspen acreage on each forest is identified. A printout schedules these stands by year for shearing or treatment on a 10-year cycle for natural food patches should the game manager so elect. Many of these stands are fully stocked but on poor sites.

3. Areas of poor operability. Aspen types of poor operability are identified on a printout for decision by the game manager as possible shearing sites.

(C) Recreation is a broad term. Esthetic management in relation to total acreage is most important.

Our public land is zoned for various uses such as established esthetic management zones. Variations in normal silvicultural cutting practices to achieve a higher degree of acceptability are presently being developed. It will require field investigation of each stand, prescribing what will be done specifically, and recording the data for a stratified printout showing by year what is to be done and where.

It has been our experience that objectives set by one forester for esthetic management will carry on into the future and not be destroyed when he transfers only if the work is programmed and scheduled by year.

Does the Wisconsin System Work?

Yes! The forester knows where to go to do his work. Field efficiency is improved. Stands receive treatment at the proper silvicultural time. When markets or personnel are inadequate, stands to cut and not to cut are identifiable.

With personnel transfers, a new forester can pick up the fieldwork within 2 days. When new research findings, administrative decisions, or catastrophic losses occur, all forest plans can be changed in 2 days. And, land management is maximized for wildlife, esthetics, and other products of the forest.

Does your management system provide these benefits?

PRIVATE LAND MANAGEMENT

A staff of 57 foresters in Wisconsin assist some 8,000 private landowners annually. The equivalent of 67 million board feet was marked or designated for cutting on private land in the past year. The volume of aspen involved is unknown.

Our recommendations for aspen are based upon:

1. USDA Forest Service, *Timber Management Guide* for aspen-white birch.

2. Harvest at a rotation age according to the site index of the stand. Site index curves showing the prescribed rotation ages are used by the foresters.

3. The landowner's objectives. The pure silvicultural approach is often altered by the objectives of the landowner. Successful service foresters are masters at determining the mortgage and interest rate on the farm, the need for a new tractor, or the interest of an absentee owner in wildlife or esthetics. The needs and desires of an owner are considered in making management recommendations.

MANAGEMENT IN ONTARIO

C. J. Heeney, *R. P. F., Silviculturist*
Division of Forests, Ministry of Natural Resources
Toronto, Ontario, Canada

ABSTRACT. — The management of native aspen in Ontario has progressed more slowly than that of other species. Now, however, some species which have been used traditionally by industry are slowly being supplemented, or replaced, by poplar. This increased use has emphasized the inadequacy of present inventory data for poplar species and the quality of reproduction after logging. The use of fast-growing hybrid poplars in selected areas is one of the more promising methods of meeting local shortages of native aspen.

In Ontario there is minimal management of aspen stands at the present time. This species is abundant, versatile, and productive, but in the exploitation stages of forestry pine, yellow birch, spruce, and maple have been preferred by industry. Only in recent years has aspen received any attention, and this has been sporadic, at best. An indication of increasing interest is the number of recent conferences on poplars:

1. Poplar Symposium, Harrison Hot Springs, British Columbia, 1967.

2. International Poplar Commission Meeting, Maple, Ontario, 1968.

3. Poplar Workshop, Maple, Ontario, 1970.

In government service, I have come to measure intent by expenditure. In Ontario, little has been spent to date on aspen research or management.

In the poplar working group, work has been primarily restricted to harvesting the present timber resource. For this reason, it is preferable to divide this paper into two sections:

1. Inventory and management of our present aspen resource.

2. Research developments and future management opportunities.

INVENTORY AND MANAGEMENT OF OUR PRESENT RESOURCE

The annual allowable cut of poplar in net merchantable cubic feet in Ontario is between 400 and 500 million cubic feet. The exact figure is of academic interest only. Flowers (1970) compares three sources of data for an allowable cut, ranging from a high of 738 million cubic feet to a low of 260 million cubic feet. Ontario ranks second among the Canadian provinces, close behind Alberta, in allowable cut of poplar (fig. 1, Fitzpatrick and Stewart 1968).

Poplar represents 49 per cent of the hardwood volume and 18 per cent of the volume of all species in Ontario. The major poplar area across the north contains 78 per cent of the total poplar volume in the province with almost 50 per cent centering in the Kapuskasing-Cochrane, Thunder Bay-Sioux Lookout forest districts (fig. 2).

Perhaps more important than the actual volumes and surpluses of aspen timber is its utilization. Natural stands have been mainly harvested, not managed. The species is relatively short-lived and subject to rapid decay. In the poplar, spruce-fir types, generally only the conifer is utilized; the poplar component is not harvested. This material is inevitably wasted under present economic and ecological conditions.

Many poplar stands, originating from the large fires that occurred after the turn of the century, are now

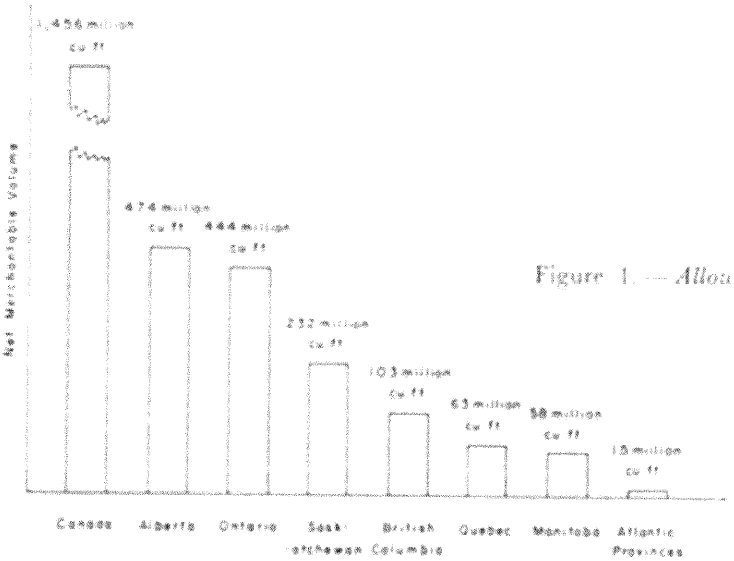


Figure 1. — *Allowable annual cut of poplar. Source: Provincial Forestry Departments.*

Figure 2. — *Map of poplar area. Major poplar area is crosshatched.*

nearing maturity. The resultant imbalance of age classes, together with the rapid decay of the species, makes projections of volume and allowable cut difficult and unreliable.

It is difficult to obtain up-to-date, accurate figures on poplar utilization for Ontario. I will use, for comparative purposes, the volume cut on Crown lands between 1956 and 1969, as reported by Flowers (1970).

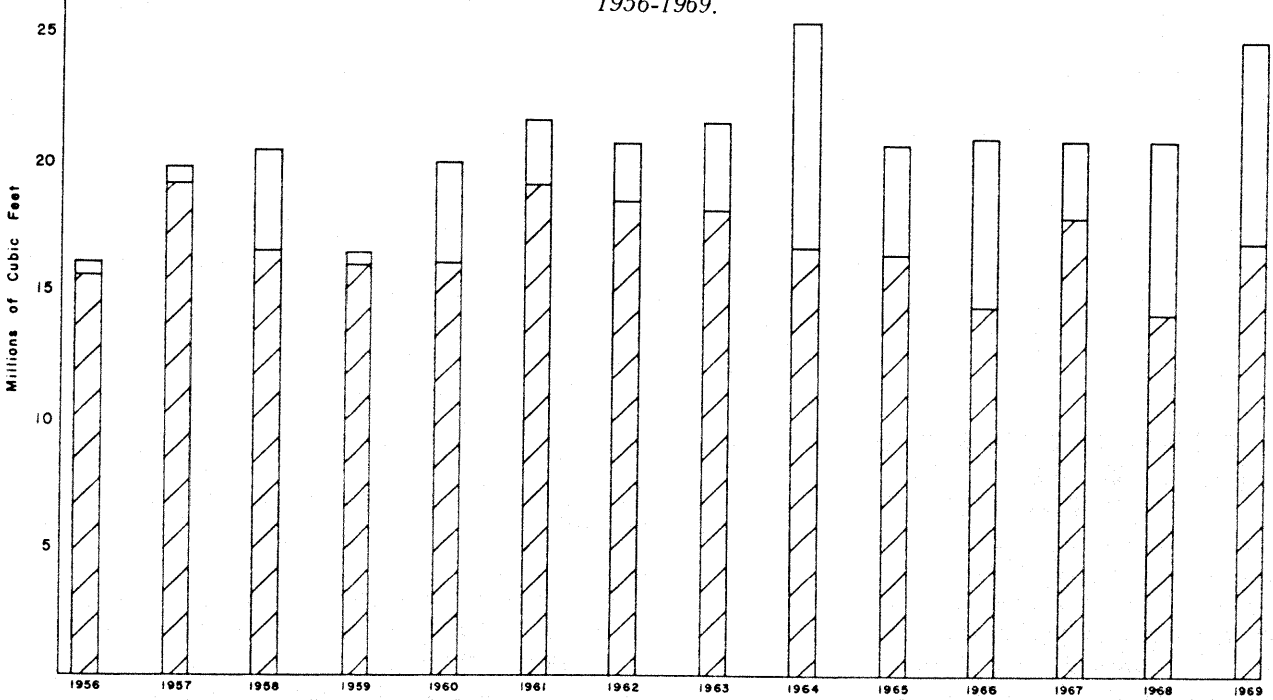
The total cut of poplar is remarkably stable. This because a sharp increase in the use of poplar for new products, such as particle board and veneer, has been offset by a decrease in poplar pulpwood consumption (fig. 3). This trend has been demonstrated to be Canadian-wide by Clayton (1968).

The present annual consumption of poplar in Ontario from Crown and patent land is between 35 and 40 million cubic feet. This is only 10 per cent of the annual allowable cut. When those volumes destroyed, or just not cut, from the operating areas are considered, the actual depletion figure is, in fact, much larger. Poplar is wasted in several ways: in some mixed stands, only the conifer is cut and the poplar left to deteriorate; in others, only selected quality and sizes of poplar are cut. The latter results in top logs and the smaller and more defective trees that were part of this original merchantable volume being left in the forest. The present annual depletion in northern Ontario was estimated at 100 to 150 million cubic feet by Flowers (1970). This is 2.5 to 3 times the amount utilized by industry.

Several new plants and mills are being planned. Their requirement for poplar is not significant in relation to the volumes available. Poplar pulpwood utilization in Ontario does not show any sign of increase at the present time. However, in Ontario present conifer depletion is 670 million net merchantable cubic feet per year and is expected to reach the allowable cut of 750 million net merchantable cubic feet by 1980. Thus, future industrial expansion will mean utilization of more hardwood. This should significantly increase the demand for poplar by the year 2000.

For a species that comprises such a large percentage of the annual allowable cut in this province, poplar has received relatively little attention by research and management. This lack of interest can be attributed to poor markets, surplus allowable cut, and priorities that have directed staff and budget re-

Figure 3. — *Total poplar cut from crown lands; pulpwood volume (crosshatched). 1956-1969.*



sources toward other species. It is difficult to manage stands for which there is no market or, at best, an imperfect market.

Several investigators in Ontario and elsewhere have studied the regeneration of aspen following logging or burning. The results of these investigations to date are inconclusive, to say the least. It is generally agreed that most aspen regeneration occurs by root suckers rather than seed. Soil temperatures and light are important factors. Horton and Maini (1964) report that maximum suckering would result from clear-cutting followed by scarifying, or from a moderate intensity fire. They further report that "there is little chance of vigorous suckers becoming infected with rot from the parent stump." However, this opinion is not supported by pathological investigations of sucker-origin aspen stands.

The quality of aspen suckers resulting from a commercial logging operation leaves much to be desired. Smith (1970) reports that 100 per cent of the trees in the 15- to 20-year age class contained stain or rot. Work by Basham in 1960 gave similar results without identifying the origin, or the extent, of decay.

There is ample evidence to show that a quality problem exists in young aspen stands that originate as suckers after normal logging operations. To assist in improving regeneration quality accurate identification of sites best suited to poplar is required. A research scientist at Thunder Bay is working on this at present as part of a study on coppice regeneration of aspen. We believe that the ability to identify the site and the site requirements of the species will improve and facilitate management of both native and hybrid poplars. Investigations will continue in these areas. In addition, the hybrid poplar program carried out under the direction of Dr. Zufa, a Research Scientist, with the Department, shows considerable promise.

RESEARCH DEVELOPMENTS AND FUTURE MANAGEMENT OPPORTUNITIES

Total timber resources in Ontario, especially poplar, exceed the present market demand. Nevertheless, there are regional deficiencies, especially in southeastern Ontario, where large pulp mills have been operating for some time, and at other locations close to large wood-using industries. An increasing number of wood-using industries are searching for ways to meet future raw material requirements at an acceptable cost. The use of rapidly growing species on short rotations close to the mill and grown under conditions that permit mechanized harvesting, appears to be a most promising approach to the problem.

Poplars are well suited for short rotation, high yield plantations.[1] They hybridize freely, and are among the fastest growing trees found in the Ontario-Lake States area. Their young growth is especially rapid. They can be propagated either by seed or vegetative reproduction, grow on a wide variety of soils and climatic conditions, and respond well to good site preparation, soil cultivation, and fertilization.

Test plantations of hybrid aspen on good poplar sites have fast growth and high yields (tables 1, 2, and 3). These plantations were established on good aspen sites prepared by ploughing. If cultivation was carried out, it was done in the year of planting. In some plantations, the young trees were repeatedly browsed.

A comparison of growth of the hybrid aspen to that of native aspen would be of great interest. Unfortunately, such a comparison cannot be made because there is no available information on the growth of native aspen in plantations. However, in order to gain some perspective, the yield of hybrid aspen was compared to the yield of native aspen, as shown in the yield tables for Ontario (Plonski 1960). These tables refer to the yield of unmanaged aspen stands and do not indicate the growth that could be obtained in managed stands. Despite these limitations, it is apparent that the yield of hybrid aspen exceeds that of native aspen on Site Class I. Average diameters at breast height (d.b.h.) in the 9- to 15-year-old plantations are similar to those attained in natural stands at 35 to 50 years of age. The average heights of trees in the 9- to 15-year-old plantations correspond to the heights of 30-year-old trees in natural stands. The mean annual increment (MAI) of the unmanaged natural stands reaches a maximum of

[1] *Zufa, L. The potential of short rotation poplar plantations in Ontario. Paper presented to Int. Poplar Comm. 14th Sess., Bucharest, Romania, Sept. 27-Oct. 2, 1971. Res. Branch, Ontario Dep. Lands & For.*

Table 1. — *The yield of hybrid aspen in plantations, examples of good growth, from*

Hybrid	Location	Spacing	Age	Height	D.b.h.	Total volume per acre	Annual increment per acre
		Feet	Years	Feet	Inches	Cubic feet	Cubic feet
P. grandidentata x alba	Gore Bay Manitoulin Island	8	12	57	6.5	3,048	254.0
P. alba x grandidentata	Basin Depot Algonquin Park	9	15	50	8.0	2,683	178.8
P. canescens	Basin Depot Algonquin Park	9	15	53	8.1	3,488	232.5
P. canescens	Basin Depot Algonquin Park	9	15	51	7.6	3,074	205.0
P. tremuloides x tremula	Elmvale Simcoe County	10	11	54	5.9	1,422	129.2

1/ The hybrid aspens were developed and the plantations established by the Tree Breeding Unit, Research Branch, Ontario Department of Lands and Forests, under the guidance of Dr. C. Heimburger.

Table 2. — *The growth and yield of hybrid poplar in Wainfleet (Ontario) plantation at 9 years of age, 8 by 8 feet spacing; total area 1.4 acres, with 14 varieties, in 2 replications; examples of good growing varieties; figures in brackets represent selected measurement at 10 years of age, 1971*

Poplar type	D.b.h.	Height	Volume 1/ per acre	Mean annual increment per acre
	Inches	Feet	Cubic feet	Cubic feet
P. x euramericana cl. "I-45/51"	5.2 (5.6)	48	2,065 (2,509)	229 (251)
P. x euramericana cl. "I-65A"	5.8 (6.3)	49	2,287 (3,063)	254 (306)
P. x euramericana cl. "I-214"	4.9 (5.3)	47	1,822 (2,185)	202 (219)
P. x euramericana cl. "Regenerata"	5.2 (5.5)	39	1,700 (2,023)	189 (202)
P. alba x davidiana pop. 363	5.5 (6.0)	51	2,721 (3,262	292 (326)

1/ Volume above 1.97 inches, based on the volume table for P. x euramericana cv. "Robusta" and P. canescens, by Sopp (1962), and calculated on the basis of the average tree of the variety times the number of trees per acre.

109 cubic feet per acre at 55 years of age, while in plantations MAI's between 103 and 326 cubic feet per acre were attained between 7 and 10 years of age (table 2).

The growth of hybrid cottonwoods in plantations in southern Ontario is shown in tables 2 and 3. The planting sites were prepared by ploughing and were cultivated in the year of planting. No other treatment was given the plantations. The soil was heavy clay (Wainfleet) and swampy (Grand Bend). Such soils are not the best for Euramerican poplars. Both plantations were established with rooted cuttings at 8-foot spacing. At 10 years of age the trees were already overcrowded and the growth reduced because of the lack of space. Notwithstanding these negative effects, the average annual diameter growth was between 0.50 and 0.69 inches d.b.h. and the average

Table 3. — *The growth and yield of hybrid poplar in Grand Bend, Ontario, plantation at 7 years of age, 8 by 8 feet spacing; total area 1.8 acres, with 7 varieties, in 3 replications; examples of good growing varieties; figures in brackets represent selected measurements at 10 years of age, 1971*

Poplar type	D.b.h.	Height	Volume[1/] per acre	Mean annual increment per acre
	Inches	Feet	Cubic feet	Cubic feet
P. x euramericana cv. "I-214"	4.8 (5.7)	40	1,371 (2,211)	196 (221)
P. x euramericana cv. "Eugenii"	4.0 (5.3)	35	866 (1,796)	124 (180)
P. x euramericana cv. "Marilandica"	3.6 (4.8)	31	601 (1,292)	86 (129)
P. canescens x (alba x grandidentata) pop. 355	3.6 (4.8)		721 (1,642)	103 (164)

1/ Volume above 1.97 inches based on the volume tables for P. x euramericana cv. "Robusta" and P. canescens, by Sopp (1962) and calculated on the basis of the average tree of the variety times the number of trees per acre.

annual height growth between 4.4 and 5.7 feet. At 10 years of age, the mean annual increments (MAI) of the best clones were 221 cubic feet per acre (table 3) and 306 cubic feet per acre (table 2).

In two other test plantations, established with rooted cuttings without stems on fresh sandy loams in the spring of 1969, the best Euramerican poplar clones reached an average height of 12 feet and measured 1.5 inches d.b.h. at the end of the second growing season. This growth can be considered satisfactory as it corresponds to the growth of rooted cuttings under optimal nursery conditions.

Five trees of Euramerican poplar clone I-214 were planted in a row at 20-foot spacing on a good micro site at the Maple Arboretum in the spring of 1959. At the age of 12 years, these trees measured 14.8 inches d.b.h. and 59 feet in height. The average annual growth was 1.23 inches d.b.h. and 4.9 feet in height. This diameter growth is similar to the figures published for the same clone and age on medium quality sites in Lombardy, Italy (Prevosto 1969).

These observations on the performance of Euramerican poplars in southern Ontario indicate that on good sites and under intensive management, optimal growth and high yields can be achieved. Preliminary calculations indicate an acceptable economic return on investment over a period of two rotations. Stumpage values of $2 to $3.00 per cord were obtained after compounding establishment and tending costs at 4 per cent over the length of the rotation.

No valid comparison can be made between the growth of Euramerican poplars and the growth of native eastern cottonwood because of the lack of adequate information. However, the available data on the growth of eastern cottonwood indicate that selected clones of this species will perform similarly to the Euramerican poplars. According to Larsson (1970), the annual diameter growth of the best trees in a plantation of eastern cottonwood seedlings in southern Ontario. averaged 0.87 inches d.b.h. between 6 and 9 years of age.

Thus high yields can be predicted for short-rotation plantations of poplars in Ontario. The concept of poplar timber production in short rotations therefore justifies further and larger scale experimenting at least in southern Ontario. In the north, work will probably continue with native aspens at least until completely frost-hardy hybrids have been found.

Present plans are to establish annually 200 to 300 acres of plantations for timber production in the Lake Huron, Lake Simcoe, Kemptville, and Pembroke Forest Districts (fig. 2). These plantations will consist

of hybrid aspen, Euramerican poplar, and eastern cottonwood and be designed, by spacing and type of planting stock, for pulpwood, saw log or veneer production as determined by local industrial requirements. The rotations will range from 8 to 25 years and spacing from 9 by 9 feet for pulpwood to 20 by 20 feet for veneer.

In addition, planting research will continue to select better clones and to increase the range of successful plantations. At present, we are interested in improving the performance on dryer sites and producing young wood with a greater specific gravity.

It is expected that through the careful selection of planting stock and planting areas, and the knowledge of management practices this program will make a significant contribution to poplar management in Ontario.

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