FOREWORD

During and since World War II, there has been increasing interest in aspen (*Populus tremuloides*) in the Lake States, its availability and supply, properties and uses, and management. Aspen is a tree of primary importance in 20 million acres or 40 percent of the total forest area of the three Lake States - Michigan, Minnesota, and Wisconsin.

At an informal meeting at Madison, Wisconsin, in January, 1947, forestry representatives of several federal, state, and industrial groups in the Lake States agreed that it would be desirable to bring up to date what is known on aspen and make it available to anyone interested. The job of preparing this information in the form of reports was assigned to each of the groups listed below. The reports will be duplicated as rapidly as completed, and the entire project should be finished by the end of 1947. Each report will concern one aspect of the subject. Copies will be available from the Lake States Forest Experiment Station or from each contributor.

Report Number	Subject
1	Aspen Properties and Uses
2	Aspen Availability and Supply
3	Logging Methods and Peeling of Aspen
4	Milling of Aspen into Lumber
5	Seasoning of Aspen
6	Aspen Lumber Grades and Characteristics
7	Mechanical Properties of Aspen
8	Machining and Related Properties of Aspen
9	Aspen Lumber for Building Purposes
10	Aspen for Containers
11	Aspen for Core Stock
12	Small Dimension and Other Industrial Uses of Aspen
13	Aspen for Veneer
14	Aspen for Pulp and Paper
15	Aspen for Cabin Logs
16	Aspen for Excelsior
17	Aspen Defiberization and Refining of Product
18	Chemical Utilization of Aspen
19	Preservative Treatment of Aspen
20	Marketing of Aspen
21	Possibilities of Managing Aspen

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REPORT NO. 21

POSSIBILITIES OF MANAGING ASPEN IN THE LAKE STATES1/

By
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INTRODUCTION

The management of aspen or popple (Populus tremuloides) has received little attention in the past, largely because of the former abundant supply of other and more valuable tree species in the Lake States. Because of a rapidly expanding market for all forest products during the past decade, particularly during the war, the attention and ingenuity of industry have turned toward the use of aspen. As a consequence, aspen has now become one of the important pulpwood species in the Lake States, and is used for many other products. That it will retain its place for some time to come seems quite certain in view of its large acreage, its aggressiveness, and new uses which are constantly being found. For this reason, there is need for information on the possibilities of managing aspen as a forest crop.

ACREAGE AND VOLUMES

The aspen type constitues nearly 40 percent of the total commercial forest area in the Lake States. According to the latest (1945) statistics, there are 19,858,000 acres of commercial aspen type in the region. Of this, 6 percent is in the sawlog-size class. Pole stands cover 18 percent. The remaining area is restocking and denuded land. (Details of availability and supply of aspen are found in Report No. 2 of this series.)

By comparing the 1945 volumes with those of 1936 (table 1), it is found that the quantity of aspen available for use has increased considerably during the last decade.

1/ Although the experimental data presented in this paper were collected in Minnesota, it is believed that many of the recommendations may be applied fairly generally to aspen areas in the Lake States.

2/ Maintained by the U. S. Department of Agriculture, Forest Service, in cooperation with the University of Minnesota, University Farm, St. Paul 1, Minnesota.

Table 1.- Volumes of standing aspen in the Lake States

Year	Total volume	Merchantable volumes	
		Pulpwood	Saw timber
	Millions of cubic feet	Thousands of cords	Millions of board feet
1936	3,135	10,371	4,127
1945	4,360	17,300	6,380
Increase in 10 years	39%	67%1/	55%1/

1/ The high increase is due partly to growth and partly to closer utilization practices taken into account in the later statistics.

DEMANDS

Aspen in the Lake States is used primarily for box lumber, pulpwood, excelsior, and match stock,3/ and to a lesser extent for construction lumber, interior finish, flooring, furniture manufacture, veneer, and novelties. Through the defiberizing method of producing coarse-fiber aspen, it shows promise for additional uses.

Despite its wide variety of uses, the best available information (6) indicates that of a total annual growth of 408 million board feet, only 40 percent is being used at present. Of the total annual cubic volume growth, the annual drain is only 25 percent. Thus the demand, especially for small or low-grade products, is still considerably below the actual growth.

CHARACTERISTICS OF ASPEN

THE SPECIES

Aspen as referred to in this paper includes primarily the quaking aspen (Populus tremuloides). The big-tooth aspen (Populus grandidentata) is frequently found in the same stand, and the properties of both species are so closely related that for commercial purposes they are seldom separated. Their characteristics and requirements are sufficiently similar to permit like treatment in management. The quaking aspen is by far the more common. It is distinquished from the big-tooth aspen primarily by its lighter bark and smaller leaves.

3/ See Report No. 1, "Aspen Properties and Uses," and other reports in this series for detailed uses of aspen.

SOIL REQUIREMENTS OF ASPEN

Although aspen is found on a wide variety of soils, it reaches its best development on soils that are porous, loamy, humic, and rich in minerals, especially calcium. It prefers moist but well-drained soils, and develops poorly on dry, sandy soils and on stiff, poorly aerated clay soils. On poorly drained soils decay sets in early.

Despite the fact that aspen springs up on all kinds of soils, it is one of the most sensitive species in regard to site requirements. On sites well-adapted to aspen, it develops into a good tree; on sites poorly adapted, it is short and scrubby and decays at an early age. A large portion of the present aspen acreage, therefore, will yield commercial products only under considerably improved utilization practices. The bigtooth aspen is probably less exacting in its soil requirements, and is often found growing fairly well on the poorer sites.

Of the 19.9 million acres of commercial aspen type in the Lake States, it is estimated by the Forest Survey that 15 percent is on good sites, 54 percent on medium sites, and the remaining 31 percent on poor sites. Only the good sites may be expected to yield high-quality sawlogs and veneer. The medium sites will yield box bolts and small, low-grade sawlog materials but the main product on these sites will be pulpwood.

A certain percentage of the poor sites will yield some pulpwood, but a great portion of these areas is so-called "off-site" which does not yield merchantable products under present utilization standards. Thus, in the management of aspen, correct site determination is extremely important.

A site index table (11) as revised by S. R. Gevorkiantz is shown in table 2. This indicates that aspen varies widely in its rate of height growth on different sites, and serves as a guide for management.

Table 2.- Heights1/ of aspen on various sites, at ages 20 to 80 years

Age	Site				
	Excellent	Good	Medium	Poor	"Off-Site"
Years			Feet		
20	46	40	34	29	23
30	59	51	44	37	29
40	71	62	53	44	35
50	80	70	60	50	40
60	87	76	66	55	--
70	93	82	70	59	--
80	98	86	74	--	--

1/ Average for dominant trees in well-stocked, even-aged stands.

Although it is found as a temporary understory in certain forest stands, aspen is one of the most intolerant forest species in the Lake States. In order to attain its optimum development, the upper half of the crown must have full sunlight. Side shade, on the other hand, is beneficial in that it helps to develop straight, limb-free trees, and probably to a large extent prevents cankering. The latter seems to be the case especially when the understory is balsam fir or spruce.

Aspen growing in competition with overtopping trees becomes stunted, defective, and poorly formed; however, during its youth it responds readily to release.

GROWTH RATE

Aspen is known for its rapid growth. Under good conditions it will average 2 to 3 feet in height growth each year during the first 20 years of its life. On moderately productive sites it attains minimum pulpwood sizes in 25 years. Stands with less than full density may produce pulpwood even earlier.

Under the very best growing conditions, aspen will reach an age of 100 years, a height of 100 feet, and a diameter of 22 inches, but as a rule its maximum age on good sites is about 80 years. However, due to presence of decay and an increasing mortality during the later years, the rotation for management purposes should ordinarily not exceed 60 years. In pure stands on good sites, the best trees will at the latter age have reached a height of about 80 feet and a diameter of 15 inches. On average sites, the rotation must of necessity be less (about 50 - 55 years), at which time dominant trees reach a height of about 65 feet and a diameter of about 12 inches.

REPRODUCTIVE CAPACITY

Natural Seeding

Aspen is dioecious, i.e., male and female flowers are never produced by the same tree, but on separate trees.

Flowering usually takes place in May, and the seed ripens within 2 to 3 weeks after pollination. The seed germinates within a day or two when in contact with moist soil, but deteriorates rapidly if it falls on an unsuitable seedbed. Even under good storage conditions it will remain viable only a few weeks. Therefore, when planting stock is desired, the aspen seed must be sown immediately in well-pulverized seedbeds which must be kept moist and protected against excessive light and heat until the seedlings are well established (2). Aspen begins to bear seed when only 20 to 25 years old. This agrees with observations in the Northeast (21).

Despite the required combination of factors, such as good seedbed, good seed crop, and abundant moisture, many aspen stands have become established through natural seeding. Good seed years occur frequently, and some seed is produced nearly every year. The fine tufted seed is carried by the wind over great distances. Natural regeneration by seed often occurs when a fire exposes bare mineral soil during the spring of a good seed year.

Aspen most commonly reproduces by root suckering following cutting. According to Kittredge (11), root suckers may spring up over a radius of 30 feet or more following the removal of an aspen tree. The root suckers are produced by the dormant buds (2) on the horizontal roots near the surface. These dormant buds, which are present in great numbers, are activated by the sudden strong light following removal of the mother stands. The suckers are usually produced during June. Under full sunlight they will attain a height of 3 to 4 feet by late fall. Both sexes of aspen produce root suckers.

ORIGIN OF ASPEN STANDS

PURE STANDS

Aspen is an extremely aggressive forest type. Johnson, Kittredge, and Schmitz (10) explain that aspen probably occurred in the original forest only in groups or as scattered individuals. As cutting and fires removed these older stands, numerous aspen suckers came up and formed groups. Subsequent fires killed these groups, and more aspen suckers came up from the established roots. Each new fire caused more suckering, and the aspen type spread rapidly. Shirley (16), however, besides recognizing the importance of suckers, also emphasizes the part played by seeding in the origin of aspen forests. No doubt a combination of seeding and subsequent spread by suckering following fire account for the presence of many even-aged stands of aspen.

MIXED STANDS

The best aspen is found on virgin forest soil, most frequently in mixture with hardwoods or white pine. Under such conditions it is not uncommon to find perfectly sound 80-year-old aspen 20 inches in diameter. In addition to aspen, a certain amount of reproduction of other and more tolerant species generally is present. Where such reproduction escaped damage from logging and fire, it became an understory or component of the more aggressive aspen suckers (10). The most common associate species of commercial importance are white pine, black spruce, white spruce, balsam fir, and hardwoods such as basswood, red maple, sugar maple, red oak, bur oak, white birch, and yellow birch. These mixtures indicate the best aspen sites. When white birch alone is the associate of aspen it generally signifies at least one past fire.

FACTORS AFFECTING MERCHANTABILITY

NATURAL ENEMIES

The aggressiveness and fast growth of aspen is to a great extent offset by losses from natural causes. The more important of these are discussed briefly.

Fires

Although fire has been the most powerful force in establishing present aspen stands, it should not be considered beneficial in their management. On the contrary, Stoeckeler (17-18) shows that the degree of soil deterioration caused by repeated fires is reflected in the quality of the subsequent stands. One fire, especially a light one, may not reduce the

the establishment of pure aspen stands, rob the soils of organic matter and lower the quality of aspen even on the best sites.

Often a light ground fire in an aspen stand may not kill the trees or cause visible injury, but later the damage shows up in the form of decay.

The best quality aspen invariably is found on favorable soils in mixtures with other hardwoods which have escaped fire.

Wildlife

Aspen is a favored food for a number of wildlife species. It is the most important food for beaver. Utilization of aspen by beaver is confined to stream courses or other habitats favored by the animal. Deer feed freely on aspen. In areas of heavy deer concentration, they may cause considerable damage to young reproduction. Rabbits clip off young shoots and often girdle small saplings. Bark wounds caused by rabbits may start fungous infections.

Insects

An insect causing serious damage to aspen is the forest tent caterpillar (Malacosoma disstria). This has been studied extensively by Hodson (9). Contrary to its common name, this caterpillar does not spin a tent. The larvae feed on the leaves of aspen and birch. Ordinarily the damage is insignificant, but outbreaks during the early summer of successive years may cause the epidemic to spread over large areas. Fortunately there is but one brood a year. A single defoliation generally does not cause any damage beyond a reduction in the current season's growth, and new foliage is formed by midsummer. However, when defoliation is repeated the following year, it may result in considerable mortality, especially in the older age classes. Termination of outbreaks according to Hodson (9) may be caused by parasites and by weather conditions such as late spring frosts. The last large outbreak in Minnesota took place during the period 1935 to 1938. The area covered by this infestation was very large, and before the cycle ended very few untouched aspen stands remained in the northern part of the state. The mortality was especially heavy on the poor sites and in old stands where repeated defoliation had taken place. The larvae of this insect are very susceptible to DDT.

Another insect enemy of aspen is the popple borer (Saperda calcarata). It causes worm holes in standing trees and thus reduces the quality of the product. It also causes much damage by weakening the trees, subjecting them to breakage. The popple borer is a primary insect. It will attack vigorous trees, and is not confined to poor sites. There is a tendency for adult insects to attack trees adjacent to those where they were reared, according to information furnished by A. C. Hodson. These so-called "brood-trees" may be attacked repeatedly, causing stand openings. In partial cuttings of aspen, brood-trees should be cut in order to reduce future damage.

Aspen is also susceptible to various bark-injuring insects. Wounds caused by these pests often lead to canker infections. An important secondary insect is the bronze birch borer (Agrilus anxius) which tunnels under the bark of trees weakened by other causes.

Carpenter ants (Componotus herculeanus), which use the tunnels of the popple borer in the base of small trees, also cause considerable damage in young stands.

Diseases

Of the various diseases of aspen, one of the most common is the hypoxylon canker (Hypoxylon pruinatum). It causes very heavy losses, especially in younger aspen stands.

Hypoxylon canker is described by Lorenz and Christenson (12) as "probably one of the most important diseases throughout the range of the tree." Gruenhagen (8), in studies in Wisconsin, found 24 percent of all popple infected. Bier (5) reports that this canker is caused by a wound parasite, and that "bark punctures resulting from insect attack commonly serve as centers of infection." Gruenhagen indicates that spores are wind-borne. Bier points out that attacks are not confined to young trees, but rather to the young bark of all trees. Thrifty trees are as susceptible to the disease as suppressed trees. Gruenhagen found the canker most prevalent on poor sites and less infection on large trees. Baxter (3) apparently supports the latter view, and suggests maintenance of vigorous growth throughout the life of the stand as a control measure. Local observations in Minnesota seem to indicate that the canker is found most frequently on poor and medium sites, and on sites deteriorated by fires. The disease is much less common on good sites, especially when aspen is growing in hardwood mixtures. The latter is indication in itself that the site has not been deteriorated by fire. It has been observed also in Minnesota that aspen growing in mixture with balsam fir and spruce is relatively free from canker.

Another canker on aspen is Cytospora chrysosperma. It attacks young stems and twigs, which are thereby killed by girdling. There is some evidence that the Cytospora canker is a very weak parasite and not a primary invader of living trees.

Of the diseases which affect the utilization of aspen, wood rots are by far the most important. Rots are caused by the false tinder fungus (Fomes igniarius) and the butt rot fungus (Fomes applanatus). Of these, F. igniarius is the more serious, inasmuch as it may cause decay throughout the entire length of the tree. The spores of this fungus enter through wounds and bruises which expose the wood. Meinecke (13) estimates that one-third of the infections are caused by fire, one-third through bruises and cankers, and the rest through knots, roots, and minor wounds.

Three stages of rot are recognized; namely, (a) incipient, which causes slight discoloration of the wood; (b) intermediate, which causes brown discoloration without affecting seriously the hardness of the wood but makes it unsuitable for certain uses; and (c) the final stage, which causes punk and soft wood and is a serious defect. Ordinarily in the incipient stage there is no outward sign of disease. During the intermediate stage, small, round knobs appear on the trunk. When rot reaches its final stage, fruiting bodies, or so-called "conks" generally appear on the tree. Presence of conks indicates a high cull, and trees so affected generally are left standing by experienced cutters.

MERCHANTABILITY OF ASPEN AS AFFECTED BY NATURAL ENEMIES

Fire, wildlife, and insects, with the exception of wood borers, generally do not directly affect the merchantability of aspen. Indirectly, however, their effect may be great in that they provide an entrance for wood-destroying fungi.

wood rot is the greatest single cause for cull in aspen. The intermediate stage of decay is recognized as a defect, but the wood is usable for various purposes such as box lumber, low-grade construction lumber, pulpwood, etc. The final stage of rot includes all stages of spongy wood, irrespective of color. This stage of decay is a serious defect and is culled by all industries using aspen lumber. Inasmuch as advanced rot generally affects only the core of a log, some decay is allowed in material sold for veneer and match stock, the amount depending upon the diameter of the bolt. A certain amount of final stage rot was permitted in pulpwood during the war, primarily in bolts of larger diameters.

On the basis of several logging studies conducted by the Lake States Forest Experiment Station, primarily within the Chippewa National Forest in Minnesota, it appears that site, stand age, and individual tree vigor as determined by visual appearance all affect the amount of decay in aspen stands. Satisfactory information on the interrelation of age and site is not yet available. However, Anderson (1) in his yield studies of aspen in Wisconsin found that the cull percent was highest on the poorer sites. Table 3, which is based on detailed scale records of several thousand trees on good sites and on estimated cull percent in unmanaged stands for lower sites is useful as a temporary guide for estimating the merchantable volumes in aspen stands in Minnesota. These trends in decay agree fairly well with those given by Schmitz and Jackson (15), but the individual values are somewhat at variance.

Table 3.- Usable sawlog volumes at various ages (percent) 1/

Site class	Age of stands								
	40	45	50	55	60	65	70	75	80
	Percent of gross volume merchantable								
Good 2/	90	87	85	82	76	68	57	47	25
Medium 3/	83	79	73	62	50	38	11	--	--
Poor 3/	75	54	33	14	--	--	--	--	--

1/ Volumes are by the Scribner rule for trees 7 inches d.b.h. and larger to a minimum top diameter of 6 inches inside bark and a minimum log length of 8 feet.

2/ Based on scale records in logging studies in northern Minnesota.

3/ Based on estimated cull percent in unmanaged stands.

That individual tree vigor within the aspen stands is closely related to cull as well as to growth was clearly demonstrated in a cutting study in a 50-year-old stand on the Pike Bay Experimental Forest in northern Minnesota. A 1-acre uncut plot, for which previous measurements were available, was chosen for the study. All the trees within the plot were remeasured prior to clear-cutting, and classified on the basis of their vigor, relation to surrounding trees, dominance, and crown density (7). Coincident with logging, the gross and net volumes were recorded for each tree. The results of this study are briefly summarized in table 4.

Table 4.- Cull percent and growth in relation to tree vigor

Tree vigor class	Average cull percent	Average last 5 years d.b.h. growth			
		Dominant	Co-dominant	Intermediate	Suppressed
		Inches			
1	5	0.75	----	----	----
2	17	0.55	0.36	----	----
3	20	0.50	0.29	----	----
4	35	0.46	0.30	----	----
5	50	----	0.25	0.21	0.10

The study shows clearly that the trees with the lowest vigor are the most defective and the slowest growing. These facts throw considerable light on the question of the most desirable cutting policy for aspen. Since the cull percent is much heavier in the smaller, weaker trees, the conclusion is that any partial cutting attempted should be "from below," at least in stands of this age class. A diameter-limit cutting which removes the larger trees will leave as growing stock the more defective portion of the stand.

YIELDS OF ASPEN IN UNMANAGED STANDS AS AFFECTED BY SITES

The yield of aspen is rather low compared with that of most other commercial forest species. Earlier estimates of volume yields were too high, chiefly because proper weight was not given to: (a) the exceptionally high natural mortality rate of the species; (b) the high cull percentage, especially in older stands; and (c) the natural slowdown in growth with age. Aspen needs much growing space. The high mortality rate, due to crowding and disease, is nature's method of providing this room. Anderson (1), as a result of yield studies by the Forest Survey in the Lake States, came to the conclusion that "the actual volumes in natural aspen stands in the Lake States fall so far behind normal yield tables that the usefullness of the latter is questionable." This is no doubt true for some of the earlier tables.

Table 5, however, which corrects some of the earlier errors, indicates yields that may reasonably be expected at various ages on good, medium, and poor sites in well-stocked unmanaged stands.

Table 5.- Yield of aspen by age and site classes.
Gross volumes per acre

Age Class	Site classes: Good	Medium	Poor	Good	Medium	Poor
	Standard cords1/			Board feet - Scribner2/		
20	8	..	..	.....	.....	.....
25	19	7	..	.....	.....	.....
30	29	16	5	1,300	300	.....
35	36	24	13	4,000	1,400	.....
40	42	30	17	7,000	3,000	1,100
45	46	32	18	8,500	5,000	2,400
50	47	33	16	9,000	6,000	3,000
55	46	30	13	9,100	6,000	2,900
60	43	26	10	9,000	5,800	2,500
65	37	20	6	8,400	5,200	1,800
70	29	14	4	7,400	4,500	1,400
75	21	9	..	6,000	3,200	700
80	12	4	..	4,200	1,500	.....

1/ Cords: Gross volume in standard cords of peeled wood in trees 4 inches d.b.h. and larger, to a minimum diameter of 3 inches inside bark.

2/ Board foot volumes are gross volumes by the Scribner rule of trees 7 inches in d.b.h. and larger, to a minimum diameter of 6 inches inside bark.

This table, prepared by S. R. Gevorkiantz for the use of the Forest Survey, checks very closely with observations from a number of logging studies and permanent sample plots on the Chippewa National Forest. It assumes a normal trend of mortality with advancing age, but does not take into consideration the sharply increased proportion of cull found in stands of advanced age. (See table 3.)

MANAGEMENT OF ASPEN

PAST CUTTING PRACTICES AND THEIR RESULTS

Because of various factors such as low stumpage prices and utilization practices, high reproductive capacity, etc., very few aspen stands in Minnesota have been given any sort of management in the past. Generally the merchantable volume was clear-cut at an advanced age, leaving undersized and cull trees. Attempts at management have consisted primarily of cutting to certain "diameter limits." In such cases, wind, sleet, and decay almost invariably have taken so heavy a toll in the residual stands that subsequent cuttings were impractical. Clear-cuttings and diameter-

limit cuttings, which were essentially merchantable clear-cuttings, have, however, in most cases resulted in satisfactory restocking of the areas. In many instances, past cuttings have resulted in desirable tree mixtures.

The poor utilization practices of the past have had two serious effects upon the condition of aspen stands now available for management; namely, (a) suppression of promising young growth by defective and undersized trees left; and (b) invasion by brush species which rob the soil of its nutrients and water, and slow down the growth of the new stand. As a result, many stands that have followed cutting of aspen, even on the best sites, will produce lower-grade materials than the original stand.

OBJECTIVES OF MANAGEMENT

Although the uses for aspen have been tremendously expanded during the past decade, we are currently consuming only one-fourth of the annual cubic volume growth of this species in the Lake States.

Considering the vast areas of aspen, and the amount of low-grade material which goes to waste every year, the primary purpose of management should be to improve the quality of the growing stock and wood products. Management for quality automatically will also result in greater quantity.

As seen from the previous chapters, aspen on the poorer sites is particularly susceptible to diseases. It grows slowly and produces less on these sites, and has relatively short life span. Management efforts, therefore, would be more wisely expended on the good sites.

EXTENSIVE MANAGEMENT

On large holdings, many of which at present lack even the crudest management, much can be gained by practicing extensive management.

Aspen stands on any large forest property consist of many different age classes as a result of past fires. The acreage in each class may vary a great deal and thus present an irregular pattern for management. The desirability of working toward an equal distribution of age classes is obvious. Once attained, an orderly marketing plan can be carried out and there will be less loss through mortality and defect.

The first step for the forest manager should be to classify the areas by site classes, segregating the sites into approximate age classes, and from this information decide upon a cutting policy. Following this initial step a more intensive management plan may be adopted during the next rotation.

The Chippewa National Forest provides a good illustration of how extensive management of aspen might be applied. In 1930, there were 4 more or less distinct age classes present; namely, ages 60, 40, 20, and 5. Cutting was progressing in the 60-year class which was already highly mature. The complete liquidation of this age class, however, was not

accomplished until 1940. In the meantime, the 40-year class had reached maturity and clear-cutting on the poorer sites was started. Removal of this low-site material has been possible due to large wartime demands, but complete disposal of this age class will not be accomplished until 1950 or 1955. By that time the next age class, which represents by far the greatest acreage, will be 40 to 45 years old and the forest would be faced with the disposal of tremendous quantities of material at one time. Foreseeing difficulties in having a large acreage mature at one time, the forest initiated a policy of clear-cutting of the medium sites in this age class (which is not yet fully mature) during the war, while the market would absorb smaller products. In the meantime, the cutting of the better sites in the older age class is being prolonged so as to maintain average quality products during the first few years of cutting the 40-year class. The liquidation of this age class should be completed by 1965 to 1970 at 55 to 60 years of age. In the meantime, the next age class will be 40 to 45 years old, and the reproduction resulting from clear cutting of the original 60-year class will be just behind.

A balanced cutting program of this sort is hardly more difficult than indiscriminate clear cutting. It will, however, pay generously in the form of more and better products, and pave the road to more intensive management.

INTENSIVE MANAGEMENT

At present it may seem impractical for owners of large holdings to apply intensive management to their aspen stands under the existing standards of utilization. However, owners of smaller tracts should be interested in forestry methods which will result in the greatest possible returns per acre. Whether or not the aspen market improves soon, the large owners will, in time, have to adopt better management practices if the quality of aspen is to be improved.

Thinnings

Aspen responds exceptionally well to thinning, especially during early life. Following fire or clear-cutting, aspen suckers often become established in such great numbers that the trees tend to stagnate before natural thinning becomes effective. Subsequently the stands suffer loss of vigor and become more susceptible to cankers and other diseases.

To what extent noncommercial thinnings will actually "pay" in the form of increased total volume yields is not certain. Considering the tremendous acreages and volumes of inferior aspen, perhaps we should not be too concerned about increased quantities. It is felt, however, that better-quality aspen could and should be grown on good sites.

Observations in young, thinned stands on the Pike Bay Experimental Forest indicate that they are relatively free from canker or other visible diseases 10 years after thinning. There also are indications that the rotation age, and thus the cull percent, may be reduced considerably

through thinning. In a normal rotation, larger, sounder, and more valuable materials will be the final result of early management. Thus, non-commercial thinnings may be justified for the sake of thriftiness alone.

Table 6 shows how quickly young aspen responds to thinning. At the time of thinning in 1936, the stems were very spindly and dominance was not clearly expressed. The stand is of sucker origin. The site index is 75 feet at 50 years.

The 5x5 foot spacing evidently was too light. The 10 x 11 foot thinning was too severe to obtain optimum 10-year increment. However, individual stems on this plot are growing rapidly and in time the stand will be fully stocked with large trees. The other three spacings appear promising. From the 10-year measurements, it was evident that the three closer spacings needed another thinning to maintain growth rate. However, in order to maintain the contrast between plots, a commercial cut of the same intensity was applied to all of the thinned plots. This cut, which removed four and one-half cords of pulpwood per acre, left the stands in excellent condition for future growth. At present, the original 8 x 9 foot spacing looks the most promising.

Table 6.-Results of thinning young aspen 1/

Spacing of trees left in thinning	After thinning - age 13					Ten years later - age 23				
	No. trees	Ave. d.b.h.	Basal area	Cubic feet	Merch. cords	No. trees	Ave. d.b.H.	Basal area	Cubic feet	Merch. cords
Check	3,633	1.6	53.9	610	...	1,333	3.0	66.7	1,257	7.37 3/
5x5' 2/	1,717	1.8	30.3	372	...	1,383	3.2	77.8	1,479	10.50
6x6' 2/	1,217	1.8	21.4	258	...	1,075	3.6	77.9	1,559	12.81
7x7' 2/	975	1.9	18.9	242	...	933	3.9	78.1	1,659	15.87
8x9' 2/	545	2.2	14.3	190	...	512	4.9	66.9	1,320	17.49
10x11' 2/	396	2.1	9.6	128	...	359	4.8	44.9	887	11.38

1/ The plots were 0.6 acre each. The above figures are per acre.

2/ Approximate

3/ Merchantable pulpwood to 3-inch top inside bark.

Various other thinnings in young aspen stands show the same trend in development. In one stand, from which 5.8 cords of pulpwood were removed at age 30, measurements showed that 6.8 cords had grown back during the next 5 years. Inasmuch as the thinning had been made primarily from below, this rapid growth had been produced by the best individuals in the stand. During the same period, the uncut plot grew only 3.3 cords.

Another stand, which was thinned to a wide spacing at age 20 had at age 35 twice as much board-foot volume per acre as the unthinned plot, although some of the trees were inclined to be limby. This volume, too, was produced by a considerably smaller number of trees. It is evident in this experiment that the rotation in the thinned plots will be shortened by at least 10 years and that the trees then will be larger than in the uncut plot at normal rotation age.

Thinnings in Minnesota did not result in much sunscald as was reported to be the case in Canadian experiments (4).

Intermediate Cuttings

After a stand grows out of the cordwood class but before reaching the time for final harvest, there is a period of 15 or 20 years when it should be possible to make partial cuttings. These probably should be mainly aimed at improving the stand, but some valuable products such as box bolts and small sawlogs will result. In order to obtain information on what kind of a cut to make, a series of cutting plots on the Pike Bay Experimental Forest was established in 1935.

The plots were situated on a good site having a site index of 80 feet at 50 years. The 43-year-old stand was well stocked with 334 trees, and a basal area of 110 square feet per acre. Diameter-limit cuttings of 8, 9, and 10 inches were used. In addition, one plot was clear-cut and one left uncut. Remeasurements 6 years later revealed that the 10-inch diameter limit cutting had produced considerably more total volume than any of the other cutting plots and slightly more than the check plot. In the 8-inch and 9-inch cuttings, the growing stock had been reduced too much while the check plot was too dense. Heavy cuttings, such as to an 8-inch or 9-inch diameter limit, have the further disadvantage that they open the stands sufficiently to encourage suckering, which is not desired before the final harvest, and stimulate brush invasion. When there is insufficient light, such as is the case following partial cuttings, the suckers do not develop properly and most of them are crushed later when the residual stand is cut. Indications are that suckers, which result from this final cut of the residual, somewhat weaker and more decadent trees may be less vigorous than those developed from the larger and healthier trees.

In the experiment just cited, a light diameter-limit cutting worked out fairly well, but it should be remembered that any cutting which leaves the smaller and less thrifty trees tends to increase cull percent of the residual stand. This was brought out previously in table 4. If, however,

for economic reasons, such as to eliminate marking costs, it is decided to use diameter-limit cuttings, it is essential first to determine the volume by diameter classes. This information serves as a guide in fixing the allowable cut as well as the diameter limit. In order to maintain the residual stand in a satisfactory growing condition, cuttings from above should not exceed 40 percent of the merchantable sawlog volume and about 15 percent of the merchantable trees.

For best silvicultural treatment of undisturbed stands on good sites, the intermediate cuttings should be made from "below." Small merchantable trees, which later will develop a high cull percent, should be removed. In addition, a few of the larger trees may be cut to improve distribution of the growing stock.

It may be impractical to mark all the trees to be removed. In this case it is necessary to mark only the larger trees which are to be cut because of poor form, defect, or poor distribution. In addition to marked trees, all stems below a certain diameter may then be cut for pulpwood or small logs without marking.

Rotation and Cutting Cycles

The greatest obstacle to management of aspen is heart rot, which increases rapidly with age.

From several cutting studies conducted on and in the vicinity of the Chippewa National Forest, it was found that even on good site the maximum gross volume in unmanaged stands was produced between ages 55 and 60. The greatest net volume, however, was produced between ages 50 and 55. Table 3 shows the increasing cull percent with age and table 5 indicates a reduction in gross volume.

In some cases it may be desirable to sacrifice volume in order to obtain larger diameters, such as for veneer. However, when it is considered that nearly half the volume may be lost during the additional period it takes to grow the larger products, these must bring a stumpage price of approximately 3 times the normal rate in order to compensate for the loss of volume and time.

A rotation of about 55 or 60 years, therefore, seems best for unmanaged aspen on good sites in Minnesota. Early thinnings in order to favor best-quality trees, however, will undoubtedly produce desired sizes at an earlier age. Under the most intensive management practices, commercial thinnings should be started at age 25 to 30. When the stand is mature, it should have had 3 to 4 such thinnings or improvement cuttings, which will then leave a fully stocked stand of 200 to 250 of the straightest, soundest, and most vigorous trees for the final cut. The final harvest should be a complete clear-cutting.

REGENERATION OF ASPEN

Regeneration of aspen by natural seeding, as previously pointed out, takes place only under certain conditions, such as following severe fires which remove competition and expose mineral soil. In actual forest management, however, no certain means have as yet been found to obtain aspen stands by natural seeding. Although planting is used in other countries (2), this method of regeneration is still too expensive here, considering the ease with which fully stocked stands can be obtained through root-suckering.

Following clear-cutting, aspen suckers generally appear in sufficient numbers to form fully stocked stands. The first prerequisite for satisfactory aspen suckering is an abundance of sunlight. It is imperative, therefore, that a thorough job be done in removing the old stand. Unmanaged stands always contain a number of cull trees which cutters are inclined to leave. Leaving such trees standing not only decreases the number of root-suckers, but the shade of these trees seriously hampers the growth and development of the reproduction and causes an even higher degree of defect in the next rotation. In any clear-cutting job, therefore, all aspen should be cut down whether merchantable or not.

Aspen Root-suckers as Future Stands

There is some question as to whether second-growth stands resulting from suckers will make as good trees as the mother stand. The alarmingly high mortality in young sucker stands and the wood discoloration found in a great number of stems raises a question as to whether rot in the mother tree is transferred through the roots to the suckers. Possibly rot is transferred from diseased roots to suckers but not from a decaying stump. That deterioration of the stump allows rot to travel through the roots to the suckers is very questionable inasmuch as the rots which cause deterioration of dead wood do not attack living tissues. Furthermore, as the suckers become established, they form their own root system and no longer depend on the mother root for their food. Schmitz and Jackson (15) found no evidence to prove that suckers are infected by the parent stump through the roots.

In most merchantable stands, a certain number of trees are vigorous and free of rot. It is expected that these, at least, will produce rot-free suckers.

In an attempt to find out the incidence of decay in suckers, two stands of sucker origin, 10 and 23 years old, were examined to determine presence of stem discoloration which may be an indication of rot. A strip was cut at random through each of the stands, and each tree was classified as to dominance and degree of discoloration. In the 10-year-old stand it was found that of a total of 4,800 stems per acre, the wood of 2,210 trees was unaffected by any stain whatever. Of this number, 875 were dominant trees. In the 23-year-old stand there were 3,100 stems per acre. Of these, 1,015 were free of discoloration and 385 were in the dominant class.

To what extent discoloration is a true indication of rot is not known. It is clear, however, that trees without discoloration are free from rot. There are more than enough of these to assure a fully stocked stand.

Suckering as Affected by Season of Cutting

The general opinion that clear-cutting of aspen results in abundant regeneration through suckering is based on the fact that most aspen logging has been carried on during the fall and winter months. Good reproduction generally occurs following such operations, especially when the stands are not overmature and when a good job of clear-cutting has been done.

The heavy wartime demands for lumber and the increased production of aspen pulpwood during the past decade has, however, resulted in a considerable trend toward summer logging. Local observations and examinations in northern Minnesota show that aspen regeneration is to a large extent unsatisfactory on areas logged in summer, even where properly clear-cut. In many cases, heavy brush cover is taking over the site. These observations on the failure of summer-cut aspen to sprout vigorously agree with results of an experiment in Wisconsin reported by Stoeckeler (19).

There may be several reasons for these failures. It is possible that the aspen roots during the active growing season are depleted of their stored food and thus lack some of their ability to produce vigorous sprouts. A more tangible reason is that suckers produced the same summer become established so late in the season that most of them are winter killed. The natural season for suckering to start after a winter logging job is about mid-June. After summer logging, however, most suckering takes place the following year. In the meantime, the brush species which were present at the time of logging have had time to recuperate and constitute serious competition for the nearly established aspen suckers.

As a result of these observations, it is recommended that the final cut of aspen on good sites be made between October and April, so far as practicable. Summer cutting should be concentrated on such sites where reproduction of aspen is not desired.

Increasing Suckering

Where aspen for various reasons fails to reproduce following the final cut, the forest manager must help nature. Since full sunlight is needed, the final cut should remove all of the overstory, including cull aspen and other species of inferior quality. If reproduction fails to become established due to other causes, such as summer logging or dense brush cover, more drastic measures must be taken.

The present stands became established as a result of fires. Fire, however, as a tool in human hands, thus far has not been used to obtain aspen reproduction. Furthermore, Stoeckeler (20) shows that past fires have definitely deteriorated the sites. In a search for a practical and

inexpensive solution to this problem, a cutover area on the Pike Bay Experimental Forest was cross-disked with an Athens type disk plow. The area chosen had been summer-logged three years previously. It was extremely brushy and had a scattered overstory of cull trees left. A survey prior to disking showed 61 percent stocking with 750 aspen sucker clumps per acre. When the area was re-examined in the fall following disking, it had a stocking of 91 percent of new aspen suckers, or 2,400 clumps per acre. The stocking inside a 50-foot radius of standing cull trees was 100 percent, with 5,300 sprout clumps per acre resulting from disking. In this case there evidently were sufficient living aspen roots (probably from standing cull trees and existing reproduction) in the ground to assure a well-stocked stand of aspen suckers. No doubt, elimination of some of the competing brush also helped. The root injury caused by disking probably stimulated suckering.

Disking two to three years following logging has the advantage that the slash has decomposed to an extent where it does not seriously hamper machine operation. Unquestionably, the aspen reproduction will be denser and more vigorous when disking is done earlier, and less time will be lost in growing the new crop.

RECOMMENDATIONS

GOOD SITES

During the early life of a pure aspen stand it often is difficult, even for the professional forester, to determine whether the stand is adaptable for quality production.

1. Good sites especially are well-adapted to intensive management.

2. Clay loam or silt loam soils, which originally supported good-quality hardwoods or white pine, make good aspen sites if they have not been too severely burned. Some former spruce-fir lands with good drainage are also good aspen sites.

3. Young aspen stands on good sites generally are characterized by straight, thrifty appearing, canker-free stems with greenish bark.

It is too early to predict how much effect thinnings and intermediate cuttings will have in increasing the quality and quantity of the future volume of aspen stands. The foregoing observations and demonstrations seem to indicate that such cultural treatments are profitable where markets exist for small products.

Where intensive practice is feasible, the following system of management is recommended for aspen on good sites:

1. Start management early. Keep the stand thrifty. Make a noncommercial thinning before age 20 to improve spacing. A spacing of about 8x8

feet appears desirable. Remove all poorly formed and diseased trees. Reduction of cull, better growth, and improved quality of the crop trees are the principal benefits of this initial cutting.

2. As the stand closes, pulpwood cuttings may be made at 5 to 10 year intervals. From 4 to 6 cords of bolts per acre should be removed each time. These harvests should remove the smallest and poorest trees, favoring 250 to 300 of the best stems per acre for crop trees.

3. By age 40 to 45, all inferior trees should have been removed and the number of crop trees reduced to 200 to 250 per acre which will be available for the final cut.

4. The stand should be clear-cut at age 50 to 55. On the very best sites, however, the final harvest may be delayed until age 60 without serious loss due to cull.

The best aspen is produced in mixed stands on good sites. Its quality and growth on these sites often is superior to its associates. When such proves to be the case, aspen should be encouraged in partial cuttings. This can be facilitated greatly by eliminating low-value or poor-quality hardwood species around stumps of freshly cut aspen. Full sunlight is thus provided for the aspen suckers.

Where balsam fir, spruce, or white pine occupies the understory, the mature aspen should be removed gradually. Otherwise these conifers, which grow well under a partial shade, may suffer shock due to sunscald or similar types of injury.

It also should be borne in mind that aspen ordinarily will remain sound longer and attain a more advanced age in mixed stands than in pure stands.

When mature aspen occurs in mixture with pole or small sawlog-size oaks, these should be left when the aspen is clear-cut. In most cases they will continue to grow until the end of the next aspen rotation. Where paper birch is mixed with aspen, it should be cut with the aspen at the end of the rotation. Sudden exposure of birch causes high mortality and induces attacks by the bronze birch borer, with the result that within a few years most or all of the birch is killed.

MEDIUM SITES

These sites constitute a wider variety of soils than good sites. Most common are those which formerly supported poorer grade white pine or hardwoods and mixtures of white and red pine. They also include former good sites which have been severely or repeatedly burned.

Medium sites generally are characterized by somewhat poorer forms of the young aspen stems. The bark of the young stems generally is whiter on medium sites and some canker may be found early in life.

Management of aspen on medium sites should be primarily for pulpwood and box bolts. The merchantable life span on such sites is only 10 to 15 years

(between ages 30 to 45). Aspen on such sites should be clear-cut and reproduced during this period. It is better to start cutting a little too early in such stands than too late. The following steps can be recommended:

1. A noncommercial thinning to improve the growing space before age 20 will greatly improve the quality. A spacing of about 7 x 7 feet seems feasible. Wider spacings will have a tendency to spread canker through sunscald.

2. Make a commercial pulpwood cut 7 to 10 years following the first thinning, favoring about 300 of the best trees per acre. Follow this with a second pulpwood cut 7 to 10 years later, leaving 200 to 250 stems per acre of the largest, thriftiest, canker-free trees.

3. Clear-cut the stand at age 40 to 45 for box bolts and pulpwood. Watch the stand closely, and clear-cut sooner if canker becomes prevalent. If through judicious cutting the stand is still growing well and the trees are sound and canker-free, the rotation age may be extended to 50 years in order to obtain larger sizes.

It is assumed that through soil build-up and fire protection, some of the medium sites will produce better aspen during the next rotation.

The medium sites generally are better suited for other species than aspen. In partial cuttings, therefore, such species as white pine, red pine, spruce, and oak should be favored so as to induce stronger mixtures and gradual conversion to better species.

POOR SITES

These include all sites which formerly supported pure red pine or red and white pine mixtures severely burned. Poor sites generally are characterized by deformed aspen stems, a whiteish gray bark, and a high mortality rate, primarily due to canker.

Most aspen on such sites does not even reach pulpwood size under the present utilization standards. In cases where it does, the merchantable life span is very short, generally only 5 to 10 years. Clear-cutting is recommended as soon as the stand can be commercially cut. Schantz-Hansen (14) states that on the Cloquet Forest aspen deteriorates rapidly from age 25, and that it is wise, therefore, to harvest the stands while they have a commercial value. He shows that growing and harvesting of aspen on poor sites can be profitable in the vicinity of a wood-conversion plant which uses small-size pulpwood. For most poor aspen sites, however, Shirley (16) suggests converting to conifers by planting.

SUMMARY

1. Aspen management has received very little attention in the past. With the dwindling supply of other species and increasing demands for wood products, more attention is being focused on aspen and its management possibilities.

2. Aspen is the most extensive forest type in the Lake States where it constitues approximately 40 percent of the commercial forest area. Its commercial volume was greater in 1946 than 10 years previously, due partly to growth and partly to closer utilization standards. Despite its wide variety of uses and increased utilization, less than half of the annual growth is consumed.

3. Although aspen is found on a wide variety of soils, it is very sensitive in regard to site requirement. On sites well adapted to aspen, it develops into a good tree; on sites poorly adapted, it is scrubby and decays at an early age. It is estimated by the Forest Survey that only 15 percent of the aspen acreage is on good sites; medium sites constitute 54 percent; and poor sites 31 percent.

4. Aspen grows rapidly, but this is to a great extent offset by its high rate of mortality. Former estimates of volume yield were too high. Aspen has many enemies. The most serious are cankers and woodrots. The latter are the primary cause for cull, which increases with age.

5. Past cutting practices included clear-cutting and diameter-limit cuttings. Both methods have been poorly applied and resulted in inferior second-growth stands. Diameter cuttings may have a place in management if they are properly applied so as to leave sufficient growing stock.

6. Aspen on good sites lends itself to intensive management. It responds exceptionally well to thinnings and early improvement cuts. Experiments show that aspen should be cut from below in order to develop high quality material, and prevent mortality and cull.

7. Considering that less than half of the annual growth of aspen is consumed at present, efforts should be concentrated on the development of quality rather than quantity. The best aspen grows on the good sites. Intensive management, therefore, should be confined to such sites at least for the present.

8. Aspen stands reproduce after cutting primarily through root suckers, which must have full sunlight in order to develop properly. Unmanaged aspen stands nearly always contain a large number of cull trees, which are generally left by the cutters. The shade of such trees seriously hampers reproduction establishment and growth, and it is essential that they be felled at the time of clear-cutting.

9. Regeneration of aspen by suckering is less certain to succeed following summer logging than winter logging. In Minnesota this is primarily due to brush competition.

10. Aspen suckering can be stimulated by disking, especially if cull trees have been left standing. Disking reduces brush competition and permits light and heat to reach the soil surface. Once well established, aspen suckers will quickly outgrow the brush.

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