NORTH AMERICAN ASPEN: ITS GROWTH AND MANAGEMENT

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NORTH AMERICAN ASPEN:

ITS GROWTH AND MANAGEMENT

By

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INTRODUCTION

In rebuttal to a prediction by Chief Forester F. A. Silcox that Bend, Oregon, would be a ghost town in ten years due to overcutting, P. Hosmer made this statement in 1939:

> What we're going to do is first, start a crusade urging the mill companies to speed up production as fast as they can, and cut out all the pine by 1946. That'll get all the ground cleared off and make it easy to put our plan into effect; second, we're going to take one lousy looking little shoot off a poplar tree and plant it right in the middle of the cut over area. We probably won't even take the trouble to plant it - we'll just drop it out there. It'll grow all right.

Mr. Hosmer's mock naivete probably has elicited a bitter chuckle from many an eastern forester since then, as he viewed the results of this proposal come true in his own back yard. Northern black cottonwood was probably the species referred to, but the capabilities described are equally as applicable, if not more so, to the common aspens, which have shown astonishing aggressiveness in occupying millions of acres of forest land logged off in the lumberman's path.

The vast areas of low-value or worthless aspen lands in North America have presented a tremendous economic problem to those people dependent upon them, and the question of restoring their productivity has become ever more urgent to the Nation, as supplies of high-quality timber shrink and lumber needs expand. With the advent of World War II interest in the availability and supply, properties and uses, and management of aspen took a sudden rise due to the greatly increased lumber requirements for the war effort. Since then many new uses have been discovered for this erstwhile despised species and, faced with the realization that conversion would not be possible for many years to come, foresters have been studying cultural practices for increasing the quality and quantity of aspen yields.

Since a considerable amount of literature has accumulated during the last forty years on many widely varying aspects of this species' growth and management it seemed that gathering all of this material together and presenting it, in substance, in a single publication would be of some value to workers actively engaged in solving the problem of increasing the utilization of aspen. This thesis is intended to serve that purpose.

To the best of the author's knowledge the bibliography, which is the basis of this work, contains virtually all existing, published, technical literature on the growth and management of North American aspen. In addition, a few unpublished papers which came to the author's attention and some publications on European aspen which are prominently mentioned by investigators here have been included. Nearly all of the published literature was personally reviewed by the author in preparation for the thesis.

No attempt has been made to present information in great detail for obvious reasons, but a large proportion of the listed publications are cited in the body of the text to facilitate easy and quick reference on specific topics. Aspen utilization has been briefly discussed, although this is not strictly within the confines of the subject, because of its direct bearing on management. On the other hand, conversion of aspen lands is not covered , even though all references on this subject specifically concerning aspen itself are listed, because it requires separate treatment due to its scope and complexity.

The author, in conclusion, offers some suggestions for handling aspen lands to increase their contribution to the forest economy of the regions where they occur, but it is pointed out that his opinions do not reflect an intimate familiarity with the practical aspects of the situation from first-hand observation.

SILVICS AND ECOLOGY OF ASPEN

The Species and Ranges of Aspen

North American aspen properly refers only to two species of the genus Populus, Populus tremuloides Michx. and Populus grandidentata Michx., which are similar in their silvical characteristics, and which, where associated, are considered one species for management purposes. Their designated common names are quaking aspen and bigtooth aspen respectively, but they are also known locally by a variety of modifications of the names aspen and poplar, such as quaking asp, American popple, and large-toothed poplar. The closest relative of the American aspens is European aspen, Populus tremula Linnaeus., a species whose growth habits closely resemble those of our own aspens. Foresters in this country have frequently drawn on the European experience with this species to supplement data accumulated through research on North American aspen.

Quaking aspen, which has a much wider range than bigtooth aspen, being, in fact, the most widely distributed tree in North America, and which makes up the bulk of the aspen volume as well, is a somewhat variable species. Botanically, three varieties, which are probably climatic races (USDA, Forest Service, 1948), are recognized (Sudworth, 1928), although the literature generally distinguishes only a western form, Populus tremuloides aurea Tidestrom, from the eastern form, Populus tremuloides Michx. Sudworth (1934) said that silviculturally both of these forms may be considered one species, and most dendrology books include the range of the former with that of Populus tremuloides Michx., while noting that a western variety exists. The evidence of the literature shows, however, that there are some definite differences in the silvical characteristics of the eastern and western forms which will be indicated later. Baker (1921) separated _Populus tremuloides aurea_ into two altitudinal races, but these have not been officially recognized. In this thesis, "aspen" should be understood to refer to both species and all of their varieties or races, unless otherwise specified.

The range of quaking aspen extends from southern Labrador to the southern shores of Hudson's Bay and northwesterly to the mouth of the Mackenzie River and the valley of the Yukon River, Alaska, through the northern states to the mountains of Pennsylvania, northwestern Missouri and northwestern Nebraska, and through all of the mountain regions of the west, often ascending to elevations of ten thousand feet above sea level, to the sierras of central California, northern Arizona, and New Mexico, the high mountain ranges of Chihuahua and to Mount San Pedro Martin in Lower California (Sargent, 1933).

Populus grandidentata Michx. occurs from Nova Scotia through New Brunswick, southern Quebec and Ontario to northern Minnesota, southward through the northern states to northern Delaware, southern Indiana, and Illinois, northeastern and central Iowa, and along the Allegheny Mountains to North Carolina and westward to central Kentucky and Tennessee (Sargent, 1933).

Sites

While not characteristic of the most extreme sites from the standpoint of soil conditions or climate, aspen apparently occurs on a wider variety of sites than any other North American tree. In contrast, however, it is very sensitive to site quality; its growth, form, vigor, and maturity are largely governed by the site on which it occurs.

Soils. Baker (1925) stated that aspen grows in practically every variety of soil in the climatic belt to which it is suited from loamy sands in parts of the western yellow-pine type to heavy clays characteristic of parts of central Utah, although stand development varies considerably with soil differences. Kittredge (1938) reported that sampling of aspen communities in northern Minnesota and Wisconsin found it occurring on fifty-four different soil types, and expressed the opinion that it probably occurs on as many more types which did not happen to be represented by any of the plots. Roe (1935) claimed that aspen occurs on all soil types, in the Lake States, although Kittredge (1938) said it is rarely found, if at all, on dry sandy outwash formations, and less favorable peat deposits. Alberta aspen occurs over a wide range of edaphic conditions, including dry knolls, moist river flats, and such soils as loam, clay and sandy (Moss, 1932). During investigations in the Lake States, with a grouping of soils according to surface geological formation, aspen was found on all except the coarser sands of glacial outwash and the shallowest soils of the rock outcrops (Kittredge and Gevorkiantz, 1929). The only soil limitation discovered was in the deep, medium or coarse sandy soils, which are least retentive of moisture and low in their content of nitrogen, lime, and other nutrients. These sandy soils are characterized by less than ten per cent of silt and clay, less than 0.03 per cent of nitrogen, less than 0.2 per cent of lime and a hygroscopic coefficient of about two per cent or less. Organic matter was as low as one per cent, and acidity varied from extremely acid with a pH as low as 4.3, to slightly acid or neutral.

Despite aspens adaptability to a wide range of soil conditions, its growth and development are very sensitive to soil quality. On good soils, except near the limits of its range, aspen is a relatively tall, well-formed, and thrifty tree, while poor soils cause it to be short, of scrubby form, and to decay at an early age.

For its best growth, quaking aspen requires a deep, fertile, moist but well-drained, loam soil. Particularly, it prefers moist situations with adequate drainage. In Utah, however, aspen will grow on average sites where there are no water supplies except from rainfall and where the annual precipitation is as low as 17 inches, of which only a little more than five inches falls in the growing season (Baker, 1925). This may indicate that the western variety is somewhat more drought resistant. Stoeckeler (1948) found that texture, which affects the aeration and moisture relations of the surface soil, showed a good relation to site class and growth rate optimum for quaking aspen being about 50 per cent of silt-plus-clay. Permanent water tables at three to seven feet below the surface of light sandy soils added about 15 feet to the site-index. Studies in Connecticut (Lunt and Baltz, 1944) showed that aspen excelled in basal area on moister sites. On relatively sterile sandy soils in

Wisconsin, height growth of quaking aspen was significantly greater on sites having a higher water table and content of organic matter (Wilde and Pronin, 1950).

Bigtooth aspen seems to be less exacting, at least in respect to moisture requirements. Robinove and Horton (1929) observed that in the region about Douglas Lake, Michigan, Populus tremuloides was the dominant tree in the lowlands containing a lot of organic matter, with very few Populus grandidentata. The reverse was true on the sandy uplands. Gates (1930) reported this same situation from ecological studies of the aspen association in Michigan. Stoeckeler (1948) found bigtooth aspen on plots ranging from 6 to 42 per cent of silt-plus-clay, but not on heavier soils. Quaking aspen, however, was found on soils ranging from 12 to 81 per cent of silt-plus-clay. These facts, and its occurrence on the knolls and drier sites, led Stoeckeler to believe that bigtooth aspen requires the better-drained, better-aerated soils.

That fertility, as well as suitable moisture relations, is necessary for good growth was shown by Wilde and Paul (1948), who found that in spite of an accessible ground water table, growth, specific gravity, and alpha cellulose content all were lower on impoverished soils in Wisconsin, than on soils of reasonably high fertility. A high site index soil in Wisconsin (site index 82) had abundant lime, phosphorous, potash, and magnesium in the B_2 horizon and in the true parent material (horizon C_2) (Stoeckeler, 1948). The average annual growth on this site was 55 cubic feet per acre, contrasted with 11 cubic feet on the poorest site examined. Abundant lime was characteristic of excellent aspen soils and evidently contributes to greater longevity and soundness.

Conversely, Wilde, Buran, and Galloway (1937) found that the fertilizing value of Aspen-Birch duff developed on heavy, morainic or outwash soils had a decidedly lower fertilizing value than the litter of hardwood-hemlock types developed on better soils.

Stoeckeler (1948) considered fertility less important for bigtooth aspen. In Wisconsin, bigtooth aspen, on similar sites, had a lower site index than quaking aspen, which Wilde and Paul (1948) interpreted to mean that the former is thus more exacting. However, bigtooth aspen is normally a somewhat smaller, shorter-lived tree.

It should be pointed out that information about the effect of soils, or single soil factors on the growth of aspen, is still very limited. Moreover, specific studies of this phase of the aspen problem have been undertaken only in the Lake States where aspen grows largely on podzolic soils of glacial origin, developed under relatively uniform climate.

Climate. In spite of the great extent of aspen's range, in latitude as well as longitude, the sites on which it is capable of forming continuous stands, are characterized by a cool, fairly moist climate, with long winters and short growing seasons.

The upper and northern limits of elevation and latitude, respectively, of aspens occurrence are probably controlled by insufficient length of growing season, low growing season temperatures, or both. The northern limit approximates the July isotherm of 13 degrees Centigrade (Halliday, 1943), while in the American rockies the upper limit has an average annual temperature of less than two degrees Centigrade (Baker, 1925). In Alaska it grows up to elevations in protected gulches of from 2,000 to 3,500 feet. At these limits aspen is low, shrubby, and exists mostly in protected situations and sites with a southern aspect.

The lower and southern limits of aspens range indicate that they are determined by insufficient water supply during the growing season. Over most of its northern territory aspen receives 30 to 40 inches of rainfall annually, and thus even along its southern limit in the Lake States and the northeastern part of the United States, it comes down to, or close to, sea level. In the drier, western part of the United States, however, the aspen zone is elevated as the range extends southward. Where rainfall is low aspen forms stands only on sites which have exceptional soil moisture, and here they are poorly developed and become decadent at an early age (Baker, 1925). Aspen does extend out into the plains regions, but only along water courses where the water table is always accessible to part of its root system.

Site classification. Aspen quality, yields, and rotations are so dependent upon site quality that site classification is absolutely necessary for intelligent management. The most accurate evaluation of site is, of course, provided by the growth of aspen itself. Site index, the height of the dominant stand at an arbitrarily chosen age, is the usual criterion accepted. Evidence that this is a better criterion of habitat productivity than is volume growth has been presented by Kittredge (1938). Baker (1925) recognized five site qualities in the Central Rocky Mountain region and described them as to soil, topography, and elevation. His site indices are about twenty feet lower for each class at a given age than are indices of corresponding classes prepared for the Lake States

(Kittredge and Gevorkiantz, 1929). Weigle and Frothingham (1911) decided on a division into three site quality classes but did not describe the sites for future reference.

Stands under about twenty years of age are too young for site index to be accurately determined by direct measurement, however, (Stoeckeler, 1948) and thus the method has only limited utility. In order to establish some other basis for predicting the site index of young aspen stands, which make up a large percentage of the aspen type in the accessible regions, a number of investigators have attempted to discover correlations between various site characteristics and site quality. Ground vegetation species, or plant indicators, have been classified by some as a scale of site quality because of their general confinement to a particular site or sites (Kittredge, 1938; Sisam, 1935; Lake States Forest Experiment Station, 1935; and Stoeckeler, 1948). A table of plant indicators has been compiled for the Lake States according to climax associations, telling with which of these associations each is found, and rating it according to its constancy (Rudolf, 1950). This will be of great assistance in planning conversion of aspen lands to other species. Original cover types, revealed from records or evidence on the land itself, such as relicts or adjacent types are another guide (Kittredge and Gevorkiantz, 1929; Gates, 1930; Lake States Forest Experiment Station, 1935; and Stoeckeler, 1948).

Soil quality is the most logical indirect measure of site quality since it comprises a large proportion of the complex of factors contributing to "site", but forest soils are still an embryonic science, and information on aspen soils in particular is very fragmentary. However, two valuable studies have been made by Kittredge (1938) and Stoeckeler (1948). Kittredge made habitat classifications according to soil texture, surface geological formation, a combination of texture and surface formation, and soil type and profile groups. This is a series which comprises successively larger proportions of the total number of edaphic factors which influence the floristic composition and growth of plant communities. Correlations between mean site index of aspen and the soil classifications become successively closer as larger proportions of the growth factors were represented. Soil profile groups had a correlation coefficient of 0.778. Stoeckeler concluded from his study that soil class, as judged by texture of the A and B horizons and pH of the subsoil, and severity of fires (which markedly reduce soil productivity) are the best bases for judgment. He set up five soil classes which cover in a general way the range of site index classes for aspen as defined by Kittredge and Gevorkiantz (1929).

Tolerance

Aspens extreme intolerance is well-known. There is no disagreement that aspen is practically, if not the most, intolerant tree in North America (Weigle and Frothingham, 1911; Baker, 1925; Cheyney, 1942; and Toumey and Korstian, 1947). Baker reserved judgment in the case of lumber pine, Pinus flexiles James, but regardless, aspen is less tolerant than its associates everywhere. It cannot reproduce itself under its own shade, for this intolerance is true from the seedling or sucker stage to old age. In a series of diameter limit cuttings in a 43 year old stand of aspen, the height growth of the resulting suckers was found to bear a direct relation to the degree of cutting (Zehngraff, 1947). Weigle and Frothingham (1911) believed that root sprouts or suckers are more intolerant than seedlings, although there is still no conclusive proof of this.

Fortunately, aspen stands quickly differentiate into crown classes, dominance being expressed by the more vigorous individuals, and stagnation rarely occurs. Young aspen stands are usually very dense, but competition on the average site reduces the number of trees from 2,300 at twenty years to 295 at seventy years (Kittredge and Gevorkiantz, 1929). On the other hand, the degree of dominance expressed in aspen stands seems to vary with site quality, for yield tables show a considerably larger number of trees per acre, at equal stand heights, on poorer sites.

Aspens intolerance means that it can be maintained as a pure type for more than one or two rotations only by protecting it against competition. This fact, together with its singular reproductive features, almost entirely determine the silvicultural methods used in aspen management.

Regeneration

Reproduction from seed. Aspens begin to bear seed when comparatively young. Thrifty trees may begin to bear when only twenty years old, (Weigle and Frothingham, 1911) and aspen continues to bear seed throughout its lifetime, with good crops coming every four to five years and light crops during most of the intervening years (U.S.D.A., Forest Service, 1948).

Optimum years for seed production are between the ages of 50 and 70. Aspen is dioecious, as are all other willows and poplars. The flowers are borne about ten days before leafing in April and May, the exact time depending upon region, site, and the beginning of the growing season, and they mature from May through June. It was found that there is practically no difference in the characteristics of the seeds of *Populus tremuloides* and *Populus grandidentata* (Faust, 1936).

In the north and east sections of its range, aspen produces its almost minute, tufted seed in great abundance. At the height of dispersal, masses of the white "cotton" may accumulate to depths of several inches in depressions. Seed is distributed in effective quantities for long distances (Kittredge and Gevorkiantz, 1929) by air and water, and germination takes place within a day or two if suitable seedbeds are present. Viability of fertile seed is high, averaging 99 per cent for *Populus grandidentata* (U.S.D.A., Forest Service, 1948). Estimates of the length of time over which seeds remain viable under natural conditions generally agree on about two weeks to a month varying with local environmental conditions (Weigle and Frothingham, 1911; Kittredge and Gevorkiantz, 1929; Moss, 1938; Johnson, 1946; and U.S.D.A. Forest Service, 1948). From observations and repeated tests, it is evident that seeds of both species of aspen will germinate under a varied range of environmental conditions as long as sufficient moisture is provided. Germination will even continue unhampered when the seeds are totally submerged in water and can occur after several weeks of freezing (Faust, 1936). Faust said that when there is sufficient rainfall, there are usually thousands of seedlings germinating on the old leaves or moist soil under or near the mature trees.

All of this would seem to indicate prolific reproduction of aspen from seed while in actuality reproduction from seed plays a very minor role in the establishment and maintenance of aspen stands. Seedlings are usually only of importance in filling in occasional openings in other forest types, although large areas, particularly fresh burns or recently logged areas where the mineral soil is extensively exposed, are sometimes invaded primarily by seedling reproduction. Trees of seedling origin are quite rare in the Rocky Mountains of the United States, where the western variety of aspen, Populus tremuloides aurea, grows. Baker (1925) made a search for seedlings in this region during the years 1913 through 1916, but could find none. Only two instances of the occurrence of seedlings of western aspen have been reported since that time (Ellison, 1943; Larson, 1944). Baker advanced two reasons for the rarity of seedlings: (1) Poor seed crops. The number of trees producing pistillate flowers is small, and these bear only occasionally. Only about five per cent at most of these succeed in producing and dispersing normal seed. Staminate trees are more numerous than the pistillate trees, but even these fail to cover any considerable percentage of the total aspen covered area, and are usually a great distance from the flowering pistillate trees. In addition many of the staminate catkins drop off before reaching maturity, and a large portion of the remaining pollen crop is abortive. (2) At the time of seed dispersal in the west, the surface soil is dry and showers are infrequent, so that germination except in local wet places is extremely unlikely in the short period of viability the seeds are known to have.

Weigle and Frothingham (1911) estimated that not more than half of the trees, referring to the eastern variety of aspen, are seed producers and contended that a large proportion of the seed are abortive. Nevertheless, the production of viable seed appears to be adequate when conditions are propitious for seedling growth. Therefore, the scarcity of seedling reproduction of eastern aspen is probably mainly due to infrequent occurrence of favorable germinating conditions and high mortality after germination. Bare soil is the first requisite for seedling establishment. Weigle and Frothingham (1911) stated that unless the seeds fall on mineral soil — on recently burned over or cleared land or on other aspen spots not covered with vegetation or undecomposed leaf litter — their chances for growth are very small. In a cut-over hardwood area in northern Michigan which was reclothed by aspen, the young trees were confined mostly to areas where the mineral soil was exposed by acts of logging, such as skid rows, yarding sites, etc. (Buttrick, 1921).

A moist seedbed is a second requirement, if the seedlings are to have any chance of survival. Kittredge and Gevorkiantz (1929) observed that seedlings start abundantly only in the occasional year in which good rains occur and the ground is thoroughly moist during the brief period while the seeds are falling and retain their vitality. Moss (1938) found evidence that establishment of aspen seedlings under natural conditions occurs only when the surface layer of soil is continuously moist during at least the first week of their growth.

Even when these conditions are met, seedlings may be killed by fungi or later by heat or drought (U.S.D.A., Forest Service, 1948). If the seedlings do become established, there is a strong possibility of later overtopping by brush or weeds (Zehngraff, 1949), since seedlings do not have as rapid growth as suckers.

As a result of exposure to all these hazards, only a very small percentage of aspen seedlings ever gets beyond a few inches in height.

Although seedling reproduction of aspen is of little consequence to the forest manager at present, there are some indications that it may have some significance in the future. As noted above, Weigle and Frothingham (1911) believed that seedlings are less intolerant than sprouts. They also stated that, "trees which sprout repeatedly, . . . tend to 'run out' after a few generations, and it becomes necessary to infuse 'new blood' by introducing seedlings". There has been conjecture about both the European and American aspens as to whether trees of sprout origin are less vigorous, shorter-lived, and susceptible to infection through the parent root system. This will be discussed later. Barth (1942) contended that seedling European aspen have better form, thinner branches, and better height growth, and are less susceptible to rot than trees of sucker origin. On the other hand, Shirley (1941) asserted that there is no evidence to indicate that stands of sprout origin are any less vigorous than those of seedling origin, and indeed it is true that no concrete proof of seedling superiority in any respect has ever been presented.

<u>Aspen's root system</u>. The root system of aspen is of particular importance because of its dependence upon root suckers for reproduction. A distinguishing feature of the aspen root system is the fact that the many root suckers make it very difficult to distinguish individual root systems except in the case of small seedlings (Day, 1944). Original parent trees usually must be traced by age and size relations of the roots.

Day (1944) and Baker (1925) both described aspens root system as shallow and widespread with few or no taproots. Day found that sinkers or vertical roots may descend to considerable depth under some conditions, one having reached a depth of seven and one-half feet. These sinkers generally descend in old root channels and their course and depth seem to depend largely upon the location of the former roots.

Baker discovered the ultimate feeding roots in all levels down to two or three feet, though most frequently from six inches to two feet; while Day observed practically the entire lateral root system to be confined to the top foot of soil. In many cases nearly all of the lateral roots were found in the top six inches of soil. Baker observed that sprouts appear where the roots rise close to the surface (four inches or less, according to Day), especially where two very shallow roots cross and the upper is brought very near the top of the soil. He believed that certain small roots are devoted primarily to reproduction, since they run for long distances in the shallower soil layers without much change or furcation and with practically no feeding rootlets. Suckers arise from the root collar of the parent trees and on the stumps, as well as from the roots, but these comprise less than ten per cent of the total

(Baker, 1925). Both investigators found a thickening of the root at its junction with the sucker. This was confined to or most pronounced on the side away from the parent tree, which Day interpreted as an indication of translocation of food material produced in the leaves toward the growing tip of the root rather than toward the parent tree.

Reproduction by suckers. The importance of sucker reproduction cannot be stressed too much for it is their extremely prolific and rapid production which accounts for the tremendous acreage and economic significance of the aspen type in North America today. Aspens suckering ability begins at a very early age. Seedlings only two years old may produce suckers, at which time the lateral roots are four to six feet long (Day, 1944). This sprouting ability remains sufficiently unimpaired at the maximum ages reached by aspen to insure well-stocked stands. Proof of this is supplied by an experiment conducted in Utah, in which acre plots of 70, 90, and 110 year-old aspen stands were clear cut (Baker, 1925). The 100 year-old plot, which had borne about one thousand trees, produced more than 50,000 suckers under somewhat less favorable conditions than the other two plots, which both yielded over 100,000 trees from about the same original stocking. Kittredge and Gevorkiantz (1929) confirmed this ability, citing the case of a 95 year-old uncut stand in the Lake States (this is comparable to a much older stand on the Rocky Mountains), which had 2,300 suckers of recent origin to the acre. Both authorities found the age of maximum production to be 70 years. Since rotations of aspen under management should never exceed

70, or at the maximum 80 years, age should have no significance under normal conditions in obtaining adequate reproduction. Neither, apparently, is the health of the parent tree involved, for Weigle and Frothingham (1911) said that badly decayed aspens are also capable of producing sprouts profusely. According to Reim (1935), occurrence of sprouts of European aspen is little affected by site differences.

A number of other factors can materially affect the production of root suckers, however, most important of which are degree of cutting, season of cutting, fire, and artificial stimulation by disking. Sprouting occurs continually in aspen stands, but owing to intolerance, the sprouts rarely live longer than a few years. In young stands sprouts are rare, but as the stand breaks up with over maturity, they become numerous, forming an understory, if light is sufficient (Baker, 1925). Kittredge (1929) said that the relation of the number of suckers to the density of the parent stand is less well-marked (meaning less consistent) than the relation to age, but that the number of suckers decreases and rarely exceeds 600 to the acre in stands that have more than 250 to the acre. Actually, the production of suckers in natural stands is usually sufficient to maintain adequate stocking, but the forest manager requires fully stocked even-aged stands. A study in the Lake States, on the possibility of converting aspen lands to conifers, revealed that clear-cutting produced only a few more than an uncut plot. Zehngraff (1947 and 1949) reported that reproduction is not always adequate if cull trees are left. In addition, the defective and undersized trees, which are often left in cutting, and brush which thrives better in partial shade than aspen, will suppress the young aspen growth and produce low yield, poor quality stands.

If logging or fire occurs during the growing season, particularly the latter part, suckering is much less prolific than during the dormant season (Weigle and Frothingham, 1911; Baker, 1925; Zehngraff, 1946; Stoeckeler, 1947; Zehngraff, 1949). According to Baker sprouting was merely delayed for one or two years and ultimate stocking was equal to areas cut during the dormant season. Season of cutting did not appear to affect height growth, after the third year following cutting. In contrast, Stoeckeler obtained directly opposite results. Zehngraff (1946) found that on areas logged during the spring, suckers are not produced until midsummer, and that some of them are winter killed as a consequence of not being thoroughly hardened-off by fall. Summer logged areas may not produce suckers until mid-summer of the following year, by which time brush provides severe competition.

Fire has long been recognized as the biggest single factor in the tremendous spread of the aspen type. Shirley (1921) expressed the opinion that stimulation of the growth of aspen suckers produced by light burning is due to increased heat absorption of the blackened soil surface. The soil, as a result, warms up earlier and remains warmer during the early part of the growing season, and he speculated that the increased soil temperature would stimulate chemical activity in old roots, thus making stored food more rapidly available for suckers. The advantage in numbers and growth of the suckers disappeared after the first year when the surface was covered with leaves of first year suckers. Of course, fire first makes this possible by thinning or removing the overhead stand on forested land, and Weigle and Frothingham (1911) said that fires severe enough to kill full-grown trees may not destroy the sprout-producing capacity of the roots.

Recently, disking has been shown to be a cheap and effective treatment for increasing stocking of poorly stocked aspen lands (Zillgitt, 1951). Increased stocking in one instance was due largely to natural seeding, when the disking coincided with a bumper seed crop and abundant rainfall in the first-year growing season.

Weigle and Frothingham (1911) said that experiments with European aspen, which they felt were applicable to the American species, showed that suckers are not produced from roots covered with more than six inches of clay and sod, although they will develop abundantly if the soil above the roots is loose and only two inches thick. This illustrates the necessity of good soil aeration.

Nursery and field practice. Zasada reported in 1950 that regeneration by planting and seeding was still untried in this country, and, insofar as the author knows, it has not been experimented with for other than shade and ornamental plantings. If it should be found feasible to utilize artificial methods of regeneration in the future, early attempts will have to be based largely on practices used with the related American poplars, a summary of which is available in the Forest Service's recently published "Woody Plant Seed Manual" (U.S.D.A., Forest Service, 1948), and on the very excellent work done with European aspen. Some of the references on the latter are Yanchevsky (1904), Anonymous (1923), Reim (1935), Barth (1942), and Grey (1949).

Certain basic requirements for successful cultivation of all species of poplar seedlings are evident. Seed should be of local origin, and preferably collected from healthy well-formed trees producing a high percentage of large well-filled seed. Collection should be made as soon as the pappus is visible and the seed immediately dried by spreading out in a thin layer, if possible in a cool, dry room to avoid exposure to strong wind and sunlight. Prompt sowing after drying is necessary for high germination, and cleaned seed or ripe catkins (inserted in the seed bed) afford greater success than seed containing down.

Seed beds must have light, fresh, fertile soil, and the surface layer, particularly, should be fine-textured. Strip sowing facilitates weeding and reduces competition. Seed may be firmed into the soil, but covering is to be avoided. Seed beds must be kept constantly moist, but not saturated, for about two weeks after germination. Watering should be frequent and light, using a fine spray to prevent disturbance of the seed bed. Protection from sun, rain and wind with some covering is necessary at least until the first leaves appear, after which it should be gradually reduced. Covering must be in such a manner as to insure adequate ventilation, however. Immediate steps should be taken to protect the seedlings from disease or insects at the first sign of their appearance. Planting stock should be at least two years old, advisedly transplants, for forest plantations.

A few basic studies have been carried out on the problem of optimum storage and germinating conditions for seed of American aspen. Faust obtained greatest longevity of stored seed when they were dried for three to eight days, immediately upon collection, in a room at about 24 to 25 degrees Centigrade, and stored at a constant low temperature of about 5 degrees Centigrade. She observed that seeds germinate whenever there is sufficient moisture (even when submerged) between 0 and 35 degrees Centigrade; sturdiest seedlings germinated at 5 to 29 degrees Centigrade. Moss (1938) and Johnson (1946) both found the relative humidity at which seed is stored to be of paramount importance in longevity. Moss recommended 10, and Johnson 20, per cent. Moss, in addition, experimented with various storage temperatures and concluded that -5 degrees Centigrade was optimum; seeds stored at this temperature showed "remarkable prolongation of life." Johnson did not specify any storage temperature, but seeds of Populus tremuloides and Populus grandidentata retained viability for 455 and 555 days, respectively, at the recommended relative humidity of 20 per cent.

Attempts at propagation of aspen by cuttings have generally achieved such a low degree of success that its feasibility on a commercial scale has never been credited. Snow (1938), however, succeeded in obtaining rootings of dormant cuttings to an extent of sixty-five per cent when they were taken at the proper time, and given optimum chemical treatment. Cuttings taken in January and early February were almost all negative, while best results were obtained on those taken in the latter part of March just as the leaf buds were beginning to swell. Chemical treatment was with indole-butyric acid; the most effective range of treatment was within 5 to 20 grams of acid for a period of 22 to 51 hours.

Aspen and Succession

Origin of aspen stands. Originally, aspen was a relatively unimportant, secondary species, throughout almost its entire range. The only region in which the aspen type (defined by the Forest Service in 1913 as: "A stand containing 60 per cent or more of aspen, often nearly pure, but also with various conifers in mixture.") formed extensive stands was at the transition to grassland in the Middle West, a band of *Populus tremuloides* some fifty miles wide (Moss, 1932). In the forest formations through which it grows, the boreal forest of Canada, Alaska, and the northern parts of the Lake States and New England; the Rocky Mountain forest complex; and the northern section of the deciduous forest formation in the southern parts of New England and the Lake States, aspen occurred as scattered trees throughout the old-growth forest, with the exception of small patches where lightning or Indians had started fires. The creation of the enormous acreages of aspen which now exist in much of these regions paralled the development of the logging industry and the following land settlement.

These were only indirect, or secondary, factors, however. Fire has been called "the great introducing agent of aspens" (Weigle and Frothingham, 1911), and correctly so. Logging, and abandoned farm land certainly offered opportunity for aspen to take over a great deal of land, but they did not have the sweeping and lasting effects which the fires that inevitably followed did.

A very clear and concise account of the story was given by Kittredge and Gevorkiantz (1929) for the Lake States, where the largest acreages of aspen exist. Cutting in the Lake States was at first only in the valuable white pine type. As white pine became more scarce and other species later became more valuable, the poorer stands of white pine, mixtures of white and Norway pine, and of white pine and hardwood-hemlock were successively cut over, many of them several times in repeated cullings.

In the process, most of the aspen stems were broken off, and suckers sprang up. The hazardous conditions of the slash-covered lands and the lack of public regard for fire protection resulted in frequent widespread fires, with aspen the beneficiary. Much of the cut-over land burned several times in the ten or twenty years following cutting. Each fire cleared the ground of shade-giving vegetation, exposed the mineral soil, and facilitated sprouting by killing the tree trunks without killing the roots, except in the case of severe ground fires. And so, with each fire aspen sprouts became more abundant, and the aspen type more extensive.

In the old-growth stands, white pine, spruce, or balsam fir seedlings were usually on the ground as advance growth. Occasional areas and patches of land escaped the fires and this advance growth became an understory in the sucker stands of aspen which quickly overtopped it, by virtue of their rapid growth. Some small, or defective trees of the original type were left in the early logging, providing a seed source, but most of these trees were later destroyed by wind storms and fires. On the whole, therefore, mixed stands of aspen and conifers are not common or extensive.

Baker (1925) described a process similar to this in the Rocky Mountain region, with the exception that he believes progressive drying of the climate has hindered the reproduction of the conifers and made them grow in open stands, thus helping to prevent the exclusion of aspen by suppression, which at the same time is not subjected to the critical period of germination and the seedling stage of life.

Associates. As is true with most pioneer species, the factors which establish the aspen type tend to exclude most other species of trees, since they are characteristic of associations nearer the climax unless they are themselves pioneer species. Thus there are few species of trees which are typical associates of the aspen type, which technically should probably be termed a consociation. Paper birch is the most common of the few typical associates (Kittredge and Gevorkiantz, 1929). In the East, gray birch may occur in place of paper birch (Cheyney, 1942). Weigle and Frothingham (1911) said that the most common companions of aspen in restocking burned over lands in the Northeast are paper birch and pin or "fire cherry."

The trees which actually are associated with aspen on a particular site will depend upon a variety of factors, operating singly or in combination, among which are the quality of the site, former cover, degree of logging, number of fires, length of time ensuing major disturbances, seeding habits of the various species, and proximity of other types. According to Kittredge and Gevorkiantz (1929) the other species associated with aspen in the Lake States in order of their abundance are balsam fir, white pine, white spruce, black spruce, sugar maple, red maple, Norway pine, jack pine, elm, red oak, bur oak, black ash, green ash, yellow birch, basswood, jack oak, pin cherry, ironwood, and tamarack. Of these only balsam fir, pine, spruce, and sugar maple are sufficiently numerous to have any importance. Baker (1925) listed Douglas fir, white fir, and lodgepole pine as the most common associates in the West. Alpine fir, Engelmann spruce, and the conifers which seldom form stands, such as limber pine and bristle-cone pine, are less frequent associates.

There is quite a number of shrubs, grasses and herbs which are able to thrive in the aspen understory, particularly in the lighter stands, but these would be much too numerous to mention if all the sites which aspen exempts throughout its range were to be embraced.

Succession on aspen lands. It is generally agreed now that the aspen type is, without exception, a purely temporary one. In a few areas where special conditions give it an essentailly subclimax status, a few authorities were formerly prompted to call aspen the permanent or climax type. Weigle and Frothingham (1911) believed that certain stands toward the northern limit of aspen's range and at high altitudes in the West were, because of their apparently static nature, permanent. They stated unqualifiedly that small stands about springs or other moist spots were undoubtedly in many cases permanent, and asserted further that in parts of Alaska and northern Canada could often maintain itself almost indefinitely among the more "shade-intolerant" species of the far North. Fetherolf (1917) contended that a strip or belt of aspen existed in the Rocky Mountains where no native conifer could replace it, because there was, according to him, no conifer in the district with exactly the same requirements and qualities as aspen.

Sampson (1916) and Baker (1918) flatly refuted claims of aspen permanence in the Rocky Mountains. Sampson reported that investigations in Utah to determine its stability indicated that the aspen type was a temporary one, slowly but surely replaced by conifers. He noted, as evidence, aspen's inability to shade out conifers in its understory. Baker asserted that aspen's apparent permanence in certain areas was just a case of lack of seed trees, and also cited the fact that conifers generally seemed to do well when planted under aspen. He admitted, however, that the seeding in of large areas by conifers was a slow process. Pearson (1914) reported that Douglas-fir, white fir and Engelmann spruce thrived in the shade of aspen, eventually overtopping it.

Kittredge and Gevorkiantz (1929) found that lack of seed sources and scarcity of young coniferous growth in aspen stands resulted in prolonging the aspen association in the Lake States. Only fifteen per cent of the area of the aspen type was found to be actually in the process of converting naturally to conifers. Of one and one-third million acres of good spruce fir-lands which have been replaced by aspen in the Lake States, Bowman (1944) estimated that only about one-third of a million would likely be eventually dispossessed by spruce and fir growing in the understory. Shirley (1941) pointed out that there is a number of factors involved in the scarcity of seed supply. Not only are seed trees few, but they are poorly distributed, and this obstacle is emphasized by the small radius of seed distribution of most species. In addition, seed production of most Lake States conifers is characteristically irregular. Finally, a large portion of the seed crop is regularly consumed by birds and rodents. Shirley concluded that irrespective of other conditions, inadequacy of seed supply is destined to prevent natural return of conifers to aspen lands for many decades.

There is one region where aspen is actually extending its range without the aid of fire or logging. This is in the grassland formation in Alberta, around the northern and western borders of which there is a heavy concentration of aspen and balsam poplar in open, park-like stands, merging into the boreal forests on the north and Rocky Mountain forest complex on the west. Moss said that the explanation for the advance of the aspen association is the elimination of fire, the fire apparently favoring the grasses in this case. Brink and Forstad (1949) indicated that they did not consider this sufficient explanation, and speculated as to whether there might be some significance to the coincidence of the beginning of this advance and accelerated retreat of the glacier, during which time the timberline has moved northward.

Moss claimed that there is evidence that white spruce is the chief constituent of the climax vegetation over a considerable part of the region now dominated by aspen and poplar. Yet he claimed that there is also evidence that aspen is the climax tree of the drier and generally more southern parts of the region, which seems rather inconsistent, since there appears to be no logical place in this region to locate the boundary between permanence and non-permanence of aspen. Halliday and Brown (1943) attributed the heavy concentration of aspen around the grassland partly to a function of adaptability to climate and lack of competition, but felt that it might also bear a relation to the repopulation centers southwest of the Great Lakes; extension of abundance northward might be connected with the apparent immaturity, post-glacially, of much of the cover there.

Eventually, then, aspen lands will revert to the climax type -- if disturbing influences, such as fire, logging, and grazing, are eliminated. For practical reasons, however, this can never be completely achieved. Fires, though much less numerous and rarely as widespread as formerly, will always be more frequent than they were in the virgin forest; logging will continue, and the ability of the forest manager to influence stand composition must be reckoned with. Certain species, such as white pine and hemlock in the Lake States, have been so drastically reduced in numbers that they can hardly regain their former standing. Burning and erosion have radically changed the site quality of much land, thereby indefinitely delaying the return to climax vegetation. Seed trees of the original cover type may have been eliminated from an area so that other types will take over the land from aspen first, and, in any case, the change to a climax association may require intermediate steps regardless.

Gates (1930) made a study of the aspen association in Michigan. He compiled a list of important invaders and their frequency according to site, estimating how long replacement would take on each site. Fires are still so frequent on aspen lands that they largely control succession. Gates found that the frequency, severity of fires, the character of the stand in which they occur, and the type of site on which they occur all are important to the progress and direction of succession.

Success in conversion of aspen lands to other types either by planting or cutting methods is so difficult to achieve, owing to aspen's aggressiveness, that it is of utmost importance for the forest manager to be thoroughly familiar with the potential natural succession on his lands and to encourage or plant the species best adapted.

Enemies of Aspen and Control Measures

Too little is known about the numerous, in fact almost legion, enemies of aspen to state unequivocally that a particular one is the most "important." In the first place it is impossible to evaluate separately all of the effects of a particular enemy upon the growth and yield of aspen. Fire, for instance, annually destroys large areas of aspen stands, but is this loss as great as the reduction in growth and yield from debilitated soils and the higher incidence of disease in fire-scarred stands? How much do leaf diseases and insects reduce growth in standing aspen? Is the volume loss due to mortality caused by canker diseases greater than the cull produced in standing trees from wood rots? If boring insects were eliminated from aspen stands, would the amount of disease be materially reduced?

There are no definite answers to any of these questions at present, and if there were the problem of defining the term "important" would still be an obstacle. For example it would have to be decided whether all aspen stands at large should be included in estimates or whether they should be confined to aspen under management, and also whether losses to the recreational and protective values of aspen cover should be assessed.

Actually, the question is a purely academic one, for the high cost and low effectiveness of direct control measures make it ridiculous to contemplate any but the most limited kind of protection for unmanaged stands. As for managed stands, it is necessary only to know the approximate importance of the various destructive agents and what practical control measures can be applied. For these questions there are some answers, although a great deal remains to be learned.

Diseases

There are no disease or insect epidemics which threaten aspen's existence, to the chagrin of many foresters, and local epidemics are sporadic, and generally unpredictable. Of greatest concern to the forest manager is the host of endemic diseases and insects which attack these short-lived, highly susceptible species.

Aspen stands become decadent so early, even on the best sites, that the pathological rotation is generally the one which must be adopted in management. Stand decadence is, in most cases, due primarily to decay. Meinecke (1929) stated that the risk of infection, as well as the probability that infection will develop into decay, is a function of time. He found that the pathological felling age (point of annual increment decline) on a site between classes I and II (see Baker, 1925) in Utah was between eighty and ninety years. In contrast, however, studies in Minnesota (Schmitz, 1927) revealed that, on average sites, average annual growth reaches its peak at about fifty years. Allowing for the lag in culmination of average annual growth behind annual increment, and for the fact that the site studied in Utah was somewhat above average, this still points up a difference of about twenty years in pathological rotations.

Baker (1925) observed that growth is more rapid in New England than in the Rocky Mountains, but that, on the other hand, decay takes place earlier, so that the maximum and average sizes are about the same in the two regions and the stands are very similar. Whether the greater longevity of stands in the West is a reflection of a greater resistance to disease inherent in Populus tremuloides aurea, or of some other factor such as lesser risk of infection in the generally much drier climate of the West, is not known.

The period of grace, for which cutting may be delayed beyond the pathological rotation age without serious loss is relatively short. Stoeckeler (1948) estimated about fifteen to twenty years on the best sites and only about ten on the poorer sites. Because of uncertain markets, and the poor state of organization of most managed aspen lands, this constitutes a major cause of loss of volume and of potential income throughout the range of aspen. Weigle and Frothingham (1911) cited a case of loss in a Maine stand described as having been "excellent." Cutting was delayed for twenty years in this stand and they attributed an estimated thirty-six per cent loss to the delay.

As indicated above, it has been definitely established that the age at which stand decadence begins is directly related to site quality. In the Rocky Mountains, stands may be rendered worthless before they have reached an age of forty years, whereas aspen will usually live to an age of 120 years on good sites with little external appearance of deterioration (Baker, 1925). Yield studies of aspen in Wisconsin revealed that cull per cent is higher on poor sites (Anderson, 1936). Poor site stands in Minnesota may begin to deteriorate rapidly at twenty-five years of age (Schantz-Hansen, 1945), while maximum net volume on good sites in Minnesota is produced between ages fifty and fifty-five (Zehngraff, 1947). Stoeckeler (1948) found a direct correlation between pathological rotation ages and soil classes.

Some evidence has also been presented that the incidence of cull in individual trees within aspen stands is related to tree vigor. The trees on an acre plot in Minnesota were classified according to a recently recommended system based on vigor, relation to surrounding trees, dominance, and crown density (Gevorkiantz, S.R. et al, 1943). The plot was then clear-cut and the gross and net volumes recorded, and the figures seemed to demonstrate clearly that trees with the lowest vigor are the most defective and slowest growing (Zehngraff, 1947). Other authorities had previously expressed the opinion that some specific diseases of aspen are related to tree vigor, but this is the first general claim supported by statistics.

As mentioned before, the number of diseases and insects attacking aspen is very large. Seymour (1929), for example, listed 133 diseases as having been reported on _Populus tremuloides_ and 48 on _Populus grandidentata_. The number of those which have real economic importance, however, is relatively limited and many have only one listed occurrence in the literature, although they may be more common than this would ordinarily indicate. To mention and attempt to discuss all of these would be both impractical and pointless, and the following discussion is confined to those species which seem to be fairly common or most severe.

Wood rots. Zehngraff (1947) declared that wood rot is the greatest single cause for cull in aspen. Meinecke (1929) estimated that an allowance of twenty-one per cent must be made for cull in the West, of which more than eighteen per cent is due to rot. Schmitz (1927) estimated that on average sites in Minnesota total rot increases from approximately fifteen to thirty-one per cent from 30 to 70 years. And an estimate of nineteen per cent decay in all standing aspen was made by Baxter (1943).

Three diseases, Fomes igniarius (L.) Gill (including the variety Fomes igniarius nigricans), Fomes applanatus (Pers.) Wallr., and Armillaria mellea (Vahl.) Quel., cause most of the decay in aspen, and of these Fomes igniarius, or white heart rot, is by far the most important, according to all authorities. It is found throughout the range of aspen, and while the canker diseases may be more important in many areas because of the mortality they cause, Fomes igniarius is apparently always responsible for the greater portion of decay in standing aspen. As early as 1909, Schrenk and Spaulding reported that Fomes igniarius had been found at such extreme points as Maine, western Canada, Oregon, southern New Mexico and Colorado, and there have been many accounts of its prevalence and severity since then.

As the common name indicates, Fomes igniarius attacks the heartwood. Trees must usually be old enough to have formed heartwood before infection is possible, although occasionally the disease will attack "false heartwood" formed under an open wound (Spaulding, 1937). Ordinarily, decay is confined to the heartwood and the older, changing sapwood, but it may sometimes reach and kill the cambium (Hartley and Hahn, 1920). Rot is most often centered in the main part of the trunk rather than in the butt or top, but is not necessarily confined to any particular portion of the bole (Boyce, 1948). On the other hand, Horton and Hendee (1934) found that it invariably extended farther down than it ran up. Although the disease itself rarely is lethal to aspen, the trunk inevitably becomes broken off by wind when decay is sufficiently advanced.

Three stages of decay are recognized: incipient, intermediate, and advanced (Schmitz, 1927). Incipient decay is apparently never culled by wood-using industries, and whether a deduction is made for intermediate decay depends upon the use to be made of the wood. For those uses such as excelsior, box lumber, low grade construction lumber, and pulpwood this stage of decay is not serious and therefore generally not culled (Zehngraff, 1947). For a few purposes even wood in the final stage of decay is not rejected, but, obviously, trees cut for lumber or dimension stock must not show evidence of decay past the incipient stage, since beyond this point the wood becomes brittle and loses strength. In the past, the tendency has been to overcull for lack of exact information about the actual effect of specific stages of decay on utilization for various purposes, but research is correcting this.

Another factor has often been involved in excessive allowance for cull, this being the scaler's ignorance of the extent of the decay in stumpage indicated by external signs. Studies have been made which have partially obviated this difficulty. Horton and Hendee (1934), and

Riley and Bier (1936) investigated the relation of the fruiting bodies of the fungus (or sporophores) to the progress of decay. Both concluded that they were useful in estimating the maximum per cent of cull, and the latter asserted that log-makers could quickly learn to estimate cull from them with considerable accuracy. Horton and Hendee stated that fruiting bodies, if present, give a complete indication of the amount of defect in a tree or log by their number, size, and distribution. Brown (1934), however, contended that while the maximum height of fruiting bodies is correlated with rot percentage, their number is not. He found that another measure, rot diameter which may be determined with an increment borer, is as simple and accurate as any. Hirt and Hopp (1942) rendered the age of fruiting bodies useful by discovering that one tube layer is formed on them each year, except when their growth is restricted by surrounding callus or other adverse factors.

Fomes igniarius, as well as the other decays, requires some wound before infection takes place. The chance of infection depends upon the surface exposed by wounds and the time of exposure, which involves the character of the wound, and the age and vigor of the tree (Schrenk and Spaulding, 1909; and Meinecke, 1929). Meinecke found that infections are most common on wounds like fire scars and bruises from falling trees having large surfaces, or those forming spore traps, like ingrown stubs and broken tops with a rough surface of splintered wood. That boring insects are influential in producing avenues for infection has also been pointed out (Schmitz, 1927; Regnier, 1932; and Bier, 1940). Grazing or browsing animals, where plentiful, often provide ideal conditions for the spread of fungus diseases by barking trees (Packard, 1942), and heavy grazing causes root injury which can admit disease. Schrenk and Spaulding (1909) decided that climate, character of the surrounding forest (except as it does or does not contain the host), and character of the soil have little or nothing to do with the virulence of Fomes igniarius.

Verrall (1937) said that there seem to be three forms of Fomes igniarius, one of which is specific to aspen, and thus there is the possibility that the presence of sporophores on other species may not be a serious source of inoculum to aspen.

Fomes applanatus (Pers.) Wallr. and Armillaria mellea (Vahl.) Quel. respectively cause white butt rot and shoestring root rot of aspen. Both are of wide distribution in North America and next to Fomes igniarius these seem to be the most prevalent rots in aspen, but the literature presents no reliable estimate as to which is responsible for the greater amount of decay, nor even what approximate percentage of decay they are responsible for. Schmitz (1927) said that Fomes igniarius is so prevalent as to usually mask or conceal rot caused by Armillaria mellea and Fomes applanatus. They are definitely less important than Fomes igniarius, however, and it is probably safe to estimate that they rarely cause more than four or five per cent of the decay in aspen stands, and generally less than that.

Both are commonly present in aspen stands as saprophytes and gain entrance into living aspen through wounds at the base of the tree or on the roots, caused most frequently by fires and grazing. Armillaria mellea may be present in the roots of healthy trees (Boyce, 1948), but is virulent only on trees of poor vigor resulting from unfavorable environmental conditions, such as drought or poor soil (Baxter, 1943 and Boyce, 1948). Rotting of the wood, both heartwood and sapwood, of the roots and root collar are caused and the death of the tree follows.

Fomes applanatus is usually present mostly on dead timber, but when afforded an opportunity for entry into live trees through wounds it will decay the heartwood in the butts, seldom extending more than two feet up in the bole (Horton and Hendee, 1934), but sometimes for twelve to fifteen feet or more (Boyce, 1948). Occasionally it will attack the sapwood and kill the trees when decay has progressed far enough.

Young aspen stands which are primarily of root sucker origin often contain a high percentage of defective and diseased stems, posing the question of whether rot is transmitted through the roots from the parent trees. Schmitz (1927) could find no evidence that suckers are infected by the parent stump through the roots. He reported studies by Ecklund and Wennmark (1925) on the same problem with *Populus tremula*, however, which led them to believe that *Armillaria mellea* is transmitted through the roots after a certain number of years. Zehngraff (1946) presented evidence that whatever the reason for the high percentage of diseased suckers enough sound stems are left to produce well-stocked mature stands.

<u>Cankers</u>. There are only two widespread canker diseases which cause serious damage to aspen stands. These are *Hypoxylon pruinatum* (Klotsche) Cke. and *Cytospora chrysosperma* (Pers.) Tr.

Hypoxylon pruinatum is widely distributed from Alberta east to Nova Scotia, and south to Minnesota and Massachusetts (Boyce, 1948). Hartley and Hahn (1920) described a canker disease in Colorado which is probably *Hypoxylon pruinatum*. Although first reported in New York (Povah, 1924) and Maine (Schreiner, 1925), its greatest prevalence is in the Lake States, and it has been called unquestionably the most serious disease of that region (Christensen, Anderson, and Hodson, 1951). Infection in Wisconsin was found to range from 0 to 53 per cent, with an average of 24 per cent (Gruenhagen, 1945). Data from different parts of aspen's principal commercial range in the eastern United States and Canada indicated that about twenty per cent of the trees were either infected at the time of investigation, or had been killed by Hypoxylon canker previously (Christensen, Anderson, and Hodson, 1951).

Artificial inoculations and field observations have definitely demonstrated the disease to be a wound parasite (Bier, 1940), but inoculation experiments also suggest that infection takes place through cuts with difficulty (Gruenhagen, 1945). Infection occurs easily through bruised and killed tissue and is commonly associated with insect punctures, wind breakage, and branch nodes (Bier, 1940). The disease does not appear to grow very deeply into the wood, but is confined mostly to the bark and cambium. If infected below the crown the trees are girdled and killed, or the trunk may become so weakened that it is broken off. Small trees may be killed in two or three years, those up to four inches in diameter in 5 to 7 years, and larger trees in 10 to 15 years (Christensen, et al., 1951). Bier (1940) found cankers on trees of all ages up to sixty-five years. Trunk cankers were located in the upper part of the bole in older trees, and since cankers were never found attacking the thick corky bark in the basal region of older trees Bier concluded that susceptibility is not dependent on the age of the trees, but on the age of the bark. He also asserted that incidence of Hypoxylon canker is not related to individual tree vigor; that trees of all crown classes are equally liable to infection.

Other observations have in some cases contradicted Bier's findings, however. Several studies have indicated that smaller and younger trees are more susceptible, although definite proof is still lacking (Povah, 1924; Schreiner, 1925; Lorenz and Christensen, 1937; Gruenhagen, 1945; and Christensen et al., 1951). Also, there is some evidence that vigor does affect susceptibility to some degree. Lorenz and Christensen (1937) found fewer dominant trees infected than those in lower crown classes. The question of vigor versus incidence of Hypoxylon is really unsettled and will require further research.

Zehngraff (1949) said Hypoxylon appears to increase with stand density. Investigators in Wisconsin (Gruenhagen, 1945 and Wilde,

1948) and in Minnesota (Zehngraff, 1947) encountered less disease on good sites than on poor and medium sites.

Cytospora chrysosperma, which is the imperfect or conidial stage of Valsa sordida Nit., is, like Hypoxylon pruinatum, a wound parasite, and most frequently enters through dead twigs and small branches which die naturally from shading. Cytospora is much less virulent, though, becoming parasitic and killing trees by girdling, only if the hosts' vigor is definitely reduced by drought, poor site, frost, or fire. Long (1918) reported that aspen growing at the lower limits of its range is often attacked and the smaller trees killed outright. In New York vigorously growing trees inoculated with Valsa sordida either healed the wound or a small canker formed and was healed over. Trees on poor sites died, but some were transplanted to a site favoring vigorous growth and these apparently recovered and grew vigorously (Schreiner, 1931a).

It is prevalent throughout the range of aspen in the United States, but important only in the western part of the United States, and the New England area (including New York), (Long, 1918; Hubert, 1920; Brown, 1922; Povah, 1924; and Schreiner, 1931b). Even here it approximates the damage done in the Lake States by Hypoxylon canker only under abnormal conditions. Meinecke (1929) described a canker, which he believed to be Cytospora chrysosperma, as the most important bark disease of aspen in Utah, yet estimated that it was responsible for a cull percentage of only about 2.25. In contrast, Brown (1922) called Cytospora canker the most serious disease of poplars (including aspen) in Arizona and characterized it as "very destructive," and in New York stands weakened by fire had over sixty-eight per cent infection, with thirty per cent mortality (Povah, 1924). The disease is a relatively minor one in the Lake States (Christensen, 1940), though quite common as a saprophyte.

One or more species of Nectria causes a canker disease of aspen. Nectria attacks hardwoods generally, and is particularly abundant in the Lake States and in the northeastern section of aspen's range. Factors affecting the severity of Nectria are apparently little understood, but seem to involve both variations in susceptibility of the tree and environmental conditions. Very slowly developing target-type cankers are formed which rarely girdle the tree and are primarily important because they deform the bole causing trees to be culled, or result in breakage. The fungus enters through unprotected wounds and small injuries.

There are few specific references to the disease as occurring on aspen. Lorenz and Christensen (1937) rate the disease as only "occasional" in the Lake and Central States. A recent report from the Lake States Forest Experiment Station (Christensen, et al., 1951) said Nectria cankers "seldom are common on aspen and when they do occur rarely kill the tree or expose the wood to invasion by decay fungi..." and "... do not seem at present to be of much practical importance.." Meinecke (1929) found the disease in Utah, and losses in a representative stand amounted to a little over four per cent, due approximately equally to direct losses and to losses to decay entering the dead wood exposed by cankers.

A canker disease called Neofabraea populi Thompson has been reported from Ontario (Thompson, 1939). Trees three to six years old and not over 1.5 inches in diameter are affected. Cankers are located near the base of the stem and occasionally kill the trees.

Leaf diseases. Leaf diseases are not important enough to be considered a factor affecting the management of aspen. Individual leaf diseases periodically become epidemic locally but few cause more than a temporary slowdown of growth. It has been suggested in one instance that the aggregate effect of leaf diseases cause early deterioration of poplar stands on burned-over areas and abandoned farm lands in the East, but no evidence of this was produced (Cornell Station Report, 1934).

Napicladium tremulae (Frank) Sacc. causes twig blight of aspen, a drying out and death of young shoots and leaves during the summer. McCallum (1920) first reported its presence in North America in 1920 and found it common in Quebec and Ontario. Lorenz and Christensen (1937) found it associated with the dying of the leaves and leaders of young aspen reproduction throughout the Lake States. Christensen et al (1951) said it occurs from Maine to Minnesota, and that it is of wide distribution in aspen suckers, but doubted that young sucker stands are excessively damaged by it. Marssonia populi (Lib.) Sacc. is an anthracnose of poplars which kills small lateral twigs of aspen and the portion of the main stem where these twigs join it (Halsted, 1897), and may ruin trees in the advanced stage. It is widespread, but most prevalent in the southern Rocky Mountain region (Boyce, 1948).

Sclerotinia Whetzellii Seaver and Sclerotinia bifrons Seaver and Shope cause ink spot disease of aspen leaves which are common in the East and West, respectively (Seaver, 1945). The disease produces black sclerotia on the leaves during the summer which drop out, leaving holes in the leaves; severely infected leaves die, and sometimes small trees are killed. Ink spot disease is present in endemic form throughout most of the United States and Canada, affecting only quaking aspen. Hartley and Hahn (1920) considered Sclerotinia bifrons to be the most important leaf disease in the Pike's peak region of Colorado, but only one severe outbreak of the disease over a large area has occurred, that being in Quebec, neighboring provinces, and adjacent parts of the United States (Pomerleau, 1940). Pomerleau reported that phenological observations indicate the fungus prefers fairly cold climates and requires a rarely occurring combination of climatic factors to become epidemic. Septoria musiva Pk. and Septoria populicola cause necrotic lesions on the leaves of various poplars throughout the United States and Canada (Thompson, 1941). Inoculations prove aspen's susceptibility, but no serious damage resulting from these diseases has been recorded.

A leaf rust, *Melampsora albertensis* Arth., is common on aspen in the West, but of minor importance (Jackson, 1917; Hartley and Hahn, 1920; and Meinecke, 1929). Douglas-fir is the alternate host of this rust. A powdery mildew, *Uncinula salicis* (Fr.) Wint., is common on aspen in the Southwest (Meinecke, 1929), but of no consequence.

Insects

As a group, insects probably cause greater loss indirectly, by reducing tree vigor and growth rate, and by carrying disease and providing avenues of infection, than as a result of direct physical injury. Periodically, some of aspen's insect enemies become epidemic, and temporarily over localized areas cause damage exceeding that resulting from disease or other enemies. Generally speaking, however, insects are not responsible for extensive cull or high mortality.

Two insects have proved to be primary destructive agents of aspen. One of these, and probably the most important, is the forest tent caterpillar, *Malacosoma disstria* Hbn., which is a defoliator. Records show that outbreaks of this insect have been occurring at more or less regular intervals of ten years for at least one hundred fifty years (Baird, 1917). They occur simultaneously in a number of widely scattered areas throughout the United States and Canada, and, to judge from the most recent epidemics, may be increasing in duration and extent in response to the tremendous expansion of the aspen type, the preferred food of the forest tent caterpillar (Christensen et al., 1951).

The most serious depradations during the last two outbreaks, as far as is known, have been inflicted in the Lake States. Several surveys following the first of these found from twenty to eighty per cent of the trees dead, the degree of damage depending upon the site, number of complete defoliations, and age of the trees. The last outbreak is currently in progress, having begun in 1949 at the eastern end of the Upper Peninsula of Michigan, and appears to be at least as severe as the previous one. Epidemics are terminated naturally after several years by a number of environmental factors, among which spring fronts, high summer temperature, parasites, disease, and starvation are known to be operative. (Hodson, 1941). Between outbreaks populations are very low.

The other important insect of aspen is the common poplar borer, Saperda calcarata Say. This wood borer mines in the bark, sapwood, and heartwood, excavating galleries which may exceed a foot in length. Trees attacked severely by the poplar, and there is a tendency for the insects to concentrate on those previously attacked, producing so-called "brood trees" (Hofer, 1920), are greatly reduced in quality and may be weakened to the point of subsequent breakage. Study of affected trees showed that one of the reasons for the rapid deterioration of many attacked trees is heart rot which rapidly penetrates the opening made by the insect; other insects too are commonly associated with poplar borer injury (Hofer, 1920). Poplar borer is very widespread (Chrystal, 1919), but is not given to extreme population gradations as is the forest tent caterpillar, being an ever-present source of injury in aspen stands.

Hofer (1920) contended that the poplar borer attacks only trees from two inches up, larger ones often close to the limbs and the smaller ones from the base up, but later investigations have found the borer attacking trees as small as one inch in diameter (Christensen et al., 1951). In Saskatchewan Peterson (1948) found evidence that density of stands has a direct influence on the pattern of borer infestations, the latter being concentrated around the margins of stands and only penetrating into them where the trees are scattered. A survey in Minnesota during 1947 revealed a strong predilection of the borer for stands on poor sites (Christensen et al., 1951). Infertility, climate, excessive sap flow, parasites, disease, woodpeckers, and unsuitable or insufficient food all contribute to keeping the poplar borer in check (Peterson, 1948).

A number of other leaf-feeding and wood boring insects may attack aspen, most of which cause serious damage only occasionally or locally if at all. <u>Agrilus liragus</u> is a borer commonly found on weakened and dying aspen. The flat-headed wood borer, <u>Poecilonata cyanipes</u> Say, often deposits its egg masses in the scars of the aspen borer and in axe marks and bruises, and extends its damage to the heartwood. <u>Plectrodera scalator</u> Fabr., the cottonwood borer, has been observed attacking younger aspen in the Lake States. It is always found near the ground line and the larval mines extend some distance below the ground into the roots. <u>Saperda concolor</u>

Lec., poplar-gall saperda, and *Saperda moesta* Lec., poplar-twig borer breed in the branches of aspen causing galls with ultimate death of the branch. A carpenter moth, *Prionoxystus rodiniae* Peck, is prevalent on aspen in certain areas of the Lake States, and a different species in the Southwest is found in trees infested by the poplar borer. The larvae of the carpenter moth burrow in the wood of the trunk. A round-headed borer, *Xylotrechus oblileratus* Lec., has been described as a chief predator of aspen in the Southwest. The flat-headed larvae of one or more species of the genus Dicerca are common secondary invaders of dying and dead aspen. *Cryptorhynchus lapathi* L., poplar and willow borer, occasionally attacks isolated trees killing small branches and twigs. Carpenter ants, *Campanotus herculeanus* L., frequently take over old larval galleries and extend the damage.

A variety of beetles are common defoliators of aspen trees. Among these are the leaf beetles, *Chrysomela scripta* Fabr. and *Chrysomela tremulae* Fabr.; the American poplar beetle, *Phytodecta americana* Kby.; and the curculionid beetles, *Tricolepis inornata* Horn, in the Southwest. Occasional outbreaks of the large aspen tortrix, *Archips conflictana* Walker, in Canada and the Lake States, and the early aspen-leaf curler, *Proteopteryx oregona* Wlshm., in Canada have defoliated considerable areas of aspen. The white marked tussock moth, *Hemerocampa leucostigma* S. and A., and the gypsy moth, *Porthetria dispar* L., sometimes attack aspen, although it is not a preferred host. Isolated aspen trees are sometimes stripped by the poplar sawfly, *Trichiocampus viminalis*.

Animals

Aspen has an important place in the diet of many animals throughout its range, from both choice and necessity. Except for the beaver, few of these animals kill older trees directly, and beaver damage is limited. Where animals feeding on aspen become concentrated, however, aspen reproduction is seriously limited and sometimes virtually eliminated, at least temporarily. A secondary but important influence is the increased susceptibility of stands to insect and disease attack caused by injuries and retardation of growth.

Grazing and large browsing animals cause the greatest destruction. Tallies of reproduction killed or injured in Utah (Sampson, 1919) by sheep averaged approximately 32 and 65 per cent respectively for lightly and heavily grazed plots. Corresponding destruction by cattle grazing was slightly less than half that from sheep, but, on the other hand, cattle browse higher on the stems so that seedlings must be four to five years old before they are exempt from serious damage, in contrast to about three years for sheep. Pearson (1914) blamed grazing for keeping down suckers for many years in sections of Arizona and New Mexico. Curtis (1948) reported that no aspen reproduction of any consequence occurs where sheep and cattle graze in Utah. Bark injury is heavy in the winter elk range of the West (Packard, 1942).

Aspen is not a preferred food species for deer. Hill (1946) reported that deer in the Black Hills eat little or no aspen except during April through June, and Swift (1946) listed it as a poor second choice or even starvation winter food. In spite of this, in areas where populations become too heavy for the normal food supply, as is currently the case in the Lake States, there is heavy usage of aspen twigs and sprouts for winter forage. A recent survey in Wisconsin showed that 40 to 50 per cent of the aspen in the northern and central portions of that state had been damaged. Aspen can withstand a single heavy winter browse, however, and come back with a heavy crop of sprouts the following year. Contrariwise, moose exhibit a high preference for aspen as a winter browse (Aldous and Krefting, 1946), but rarely attain a high enough population concentration to cause extensive damage. When populations do become high, as on Isle Royale, Michigan, they bark and often kill standing trees (Krefting and Lee, 1948).

Aspen is the favorite food species of beaver, and is used also for building dams and lodges. Beaver will forage as far as four hundred feet or more from the shores of rivers and streams, and will cut trees up to eleven inches in diameter, although their preference is for those about two inches in diameter (Bradt, 1947). The bark of most trees up to three inches in diameter is completely utilized for food, but beavers cut many larger trees which are wasted because they lodge in other trees, are too unwieldy, or are not considered palatable. One study measured a waste of sixty-four per cent (Aldous, 1938). An acre of aspen will support an average colony of five beavers for from 1 to 2.5 years, depending on the character of the stand and other factors (Bradt, 1947). When the available food supply at their home site is exhausted, the beavers migrate to a new location.

The snowshoe hare feeds on aspen sprouts and will sometimes girdle small trees. A survey reported by Christensen et al. (1951) revealed that five to ten per cent of the aspen reproduction in northern Wisconsin had been browsed by hares. Bird (1930) alleged that in the parkland region of Alberta aspen would advance much more quickly onto the prairie if it were not for the rabbits. Other animals known to feed on aspen to some extent include red squirrels, black bears, porcupines, goats, gophers, bighorn sheep, mule deer, and field mice.

Aspen is one of the staple foods of ruffed grouse the year around. Leaf buds, catkins, flower buds, and leaves are all eaten during various seasons. Feeding is most intensive during the spring, and buds are the most important part eaten (Edminster, 1947). Two species of sapsuckers seriously scar trees by drilling.

Fire

While fire is a great aid to the establishment of aspen stands it should not be inferred that burning after aspen is established is beneficial. To the contrary, fire is very destructive to standing aspen. These thin-barked species are easily killed by fire, and all fires, whether light or heavy, invariably reduce growth, cause fire scars which admit disease, and deteriorate the site.

If fires are too frequent, particularly when they are annual, aspen is likely to be destroyed completely, and a meadow of grasses develops (Gates, 1930). Pearson (1914) expressed the opinion that repeated fires had undoubtedly in some instances entirely exterminated aspens in Southwestern areas, despite its great capacity for propagation by root suckers. Numerous investigators have further attested to the connection between fire injury and decay. Meinecke (1929) rated fire wounds as the most important factor in the spreading of disease in aspen. Stoeckeler (1948) investigated especially the relation between fire and lowering of site quality, which may amount to a reduction of seventeen feet in site index from a single fire of moderate severity. Found contributing to this deterioration were consumption of the litter, F, and H layers of the soil, thus destroying much of the vast network of fine feeding rootlets in the lower portions of the organic layer; loss of nitrogen for tree growth; and decreased infiltration and water holding capacity.

Rigid fire protection is therefore an absolute necessity in management, and it is to be expected that with it aspen sites should gradually rejuvenate themselves.

Climatic factors

Aspen is well adapted to climate within its range, but severe weather sometimes causes considerable damage. Windstorms occasionally cause breakage and some windfall over extensive areas, especially of trees weakened by decay. Aspen is one of the more susceptible trees to glaze injury (Baxter, 1943) and hail bruises admit infection.

Drought very definitely lowers the vigor and growth rate of trees, predisposing them to insect and disease injury. Aspen is relatively susceptible to sunscald of the boles from direct sunlight, particularly after excessive thinning of stands (Bickerstaff, 1946, and Zehngraff, 1949). High temperatures are extremely lethal to aspen seedlings. Frost, on the other hand, retards or kills many aspen sprouts (Baker, 1925), taking a high toll of those originating after fire or logging during the growing season, or not appearing until the third year after removal of the crown canopy.

Protective Measures

The prevailing low value of aspen timber, because of poor quality and limited demand, militates against elaborate and costly control measures. The cost of most artificial or direct control measures for diseases and insects is almost completely prohibitive. Utilization standards are relatively low for most products into which aspen is converted, and indirect methods of control are usually the most effective for keeping loss at a reasonable level efficiently.

The forest service declared recently that, "in the long run, healthy, growing forests, well-suited to the site and able to resist attack, will be the best defense against most insects and diseases, and more attention should be given to testing and applying the indirect methods of control." (U.S.D.A., Forest Service, 1947). Indirect control refers to the modification of forest conditions, through silvicultural and forest management practices, designed to make them less favorable for insect and disease outbreaks.

Direct controls are justifiable only for the prevention of fire and animal damage. Fire is probably still responsible for the greatest amount of destruction to aspen. Furthermore, it is the major introducing agent of disease and seriously reduces growth and vigor, thereby increasing the degree of loss from both diseases and insects. Consequently, fire protection is the most important, single control measure to be applied to aspen stands, and is, in fact, the only active protective measure in force over most of the aspen acreage today. The first step taken in putting any aspen land under organized management should be increased fire protection, if only to reduce the risk of carrying stands to maturity.

The problem of controlling animal damage is an important one in the West where a good part of the aspen type is used as range-land for domestic cattle and sheep. Grazing on these lands should, be strictly regulated, and is on the national forests. Sampson (1919) recommended that sheep be completely excluded for three years following cutting to guarantee establishment of full stands, though light cattle grazing is permissible. In stands being managed primarily for timber production, anywhere, grazing should be strictly prohibited. It has been suggested that regulated grazing may help growth of young stands by reducing competition, but the benefits, which are subject to doubt, hardly seem to warrant the cost of supervision and the risk of introducing excessive decay.

In regions where browsing animals are too numerous game control laws should be revised to reduce their populations in the states concerned. Small animals, such as rabbits and rodents, may sometimes need to be trapped or poisoned on areas of young growth which are particularly subject to injury.

When extensive management is practised, maximum net volume production is best assured by selection of the proper rotation age according to site quality, since the rate of decay rapidly increases with age. Removal of the overhead canopy in logging must be as complete as possible, for leaving standing cull trees, or trees below the merchantable diameter limit as in "diameter-limit" cutting, invariably suppresses young growth and favors invasion of the site by brush species which compete for water and nutrients. Trees which cannot be felled should be girdled or poisoned.

Intensive management practices must be concentrated on the better sites. It has been demonstrated that on such sites aspen responds well to thinnings (Zehngraff, 1947). The most important effect of thinnings is a shortening of the rotation by as much as five or ten years if properly applied, allowing the stand to be removed before extensive decay can set in. By proper thinning procedures growth can be concentrated on selected, vigorous, healthy, well-formed crop trees, thus maintaining maximum resistance to insect and disease injury. Since stump sprouts and root collar sprouts are poor risks these should be discriminated against, while seedlings should be favored when they are distinguishable. Thinnings can and do partially serve the functions of salvage and sanitation cuttings by removing trees which have succumbed to insect or disease attack, or appear to be poor risks.

It is important for reproduction cuttings to be made during the dormant season to ensure prompt sprouting and full stocking. Needless to say, care should be taken to avoid injury to standing trees in all logging and road-building operations.

Growth and Yield

By the nature of their usual origin because of the species' extreme intolerance most aspen stands are naturally very even-aged. Aspen reproduction in thrifty stands is rare, although fires may open up stands sufficiently to admit new growth, giving them a two-aged form. As the stands decline and break up after maturity, the new growth may be relatively uneven-aged for several years, but tends toward even-aged form later on.

Under optimum conditions for reproduction, which is most commonly of sucker origin, extremely dense aspen stands originate. Tallies of sprouts on completely clearcut sites in Utah totaled as high as 40,000 per acre (Baker, 1925). Clearcuttings during the dormant season in Minnesota produced from 6,100 to 22,850 stems per acre within one to three years following cutting. (Zehngraff, 1946a). Initial stocking varies widely, of course, with changes in the factors controlling reproduction. For example, in contrast to the 40,000 sprouts per acre produced on clearcut areas in Utah, mentioned above, only 2,734 sprouts to the acre were produced when a residual stand admitting only 0.5 to 0.6 full sunlight was left. Natural mortality is very high in young stands, due to intense competition for light, water, and nutrients, and at twenty years of age in the Lake States only about 1700 stems to the acre remain on the best sites and about 2000 on poor sites. These numbers are reduced to approximately 330 and 420, respectively, at the age of sixty years (Anderson, 1936). Zehngraff (1947a) recommended that the number of trees be cut to between 200 and 250 per acre on good sites by age forty to forty-five for maximum growth in managed stands. The small number of stems remaining in mature aspen stands points up the fact that the most serious result of improper cutting practices is not reduced reproduction *per se*, but rather the pernicious effects which they have on ensuing reproduction.

Incomplete cutting, and cutting during the growing season particularly, delay reproduction and cause sprouts to be less vigorous and slower growing. The poorly stocked young stands are easily invaded by brush and weeds which further inhibit growth, and are more susceptible to both animate and inanimate injurious agencies. Surviving trees have poor form and quality and stand decadence is hastened. Weigle and Frothingham (1911) found that a sufficient number of thrifty, dominant sprouts for a pure stand of aspen remained nine years after cutting only when the density of the crown cover was no greater than 0.1. Thus the yields in poorly managed stands are invariably lower, and the risk of carrying them to a given age is increased.

Data on the rate of growth of stands less than twenty years of age is limited, but averages approximately 2 to 3 feet in height per year, not being as dependent on site differences as is mature growth (Weigle and Frothingham, 1911; Kittredge and Gevorkiantz, 1929; Tunstell, 1945). This does not apply to stands in the Rocky Mountains, for here young sprouts average only slightly over one foot in height increment per year even on the best sites (Baker, 1925). These growth rates, combined with the prompt inception of root sucker growth after fire or logging, enable aspen to easily overtop any competitors, and not until the growth rate has slackened with the approach of maturity, at the earliest, can other species overtake and replace aspen. Gates (1930) found that replacement requires a longer period of time on sandy pine soils than on the better hardwood soils, and that fires as often as once in twelve years favor aspen at the expense of the pines. Baker (1925) reported that of the conifers associated with aspen in the Rocky Mountains only Alpine fir is capable of equalling the growth of aspen during the average life of a stand. The height growth of seedlings is not as rapid as that of sprouts for about the first twenty years, but when seedlings become successfully established in large numbers on bare areas they completely dominate the site as do stands of sprout origin. Weigle and Frothingham (1911) assumed that aspen seedlings are longer-lived than sprouts in conformance with the general rule for seedling and sprout growth, but no experimental evidence is available to confirm this. Seedlings which happen to start within stands composed primarily of root suckers, however, usually lose out in the struggle for dominance.

Height growth falls off markedly on good sites in the Lake States after 50 years, but diameter growth declines little up to ages of 70 and 80 years. Because of sustained diameter increment unmanaged stands on good sites continue to add volume until losses due to natural mortality balance stand growth between 55 and 60 years (Lake States Forest Experiment Station, 1948a). Deductions for decay set the age of maximum net merchantable volume at between 50 and 55 years.

The dominant trees in unmanaged stands do not generally exceed 10 inches d.b.h. and seventy-five feet in height at the age of maximum yield (Anderson, 1936; Zehngraff, 1927a). While individual trees may reach diameters of 12 to 16 inches d.b.h. and heights of 80 to 90 feet if left to grow until seventy to eighty-years old, stands are heavily deteriorated by that time, and at ninety years exist only as scattered cull trees.
Development of poor site stands is strikingly inferior to that of stands on good sites. Height growth is most seriously affected, diameter growth somewhat less. Stoeckeler (1948) calculated that maximum net merchantable volume in cubic feet was reached at 45 years or less on low quality soils. On the poorest sites, termed "off

sites," aspen has a scrubby form, and yields practically no merchantable material under normal utilization standards, although Schantz-Hansen (1945) showed that stands situated very close to wood-conversion plants using small-size pulpwood can yield a profit. Poor site stands generally become decadent before they reach the age of fifty years, at which enough trees would otherwise attain the size necessary for appreciable pulpwood yields. Cordwood for fuel, excelsior, etc. is usually the only product, and it may have to be harvested before stands are 35 years old.

Populus grandidentata is reported to reach optimum growth at an earlier age and size than Populus tremuloides, which would indicate shorter rotations in areas where stands are predominantly composed of this species, notably in part of Minnesota (Robinove and Horton, 1929).

Except for the Rocky Mountains, aspen yield tables have been constructed only for the Lake States, but they very probably are all applicable, within the limits of accuracy they possess, to southern Canada and northeastern United States as well. Kittredge and Gevorkiantz published the first set of yield tables for well stocked Lake States stands in 1929. Tables were prepared for yields in total cubic feet, board feet by both Scribner Decimal C and International log rules, and cordwood. Yields were classified according to five 10 foot site index classes from 40 to 80. In a publication by Johnson, Kittredge and Schmitz (1930) the tables for volumes in board feet and cordwood were partially reproduced (see Tables 1, 2, and 3 in Appendix). The yields for site indices 40 and 80 were dropped from the tables and the site index classes 50, 60, and 70 were simply labelled poor, medium, and good. These changes in form were probably partly for the reason that the large majority of sites in the Lake States fall into one of the three classes retained, and partly in realization of the fact that on a practical scale five classes were both unnecessary and difficult to distinguish. Identification of these site classes was later simplified by relating them to original cover which can usually be ascertained easily (Lake States Forest Experiment Station, 1935d). The highest quality class is described as aspen of fresh or moist soils originally occupied by hardwoods or white spruce, pure or in mixture with white pine or balsam fir. Medium site aspen is on fresh soils originally occupied by Norway pine and white pine with some hardwoods of inferior quality. Poor sites consist of dry sands capable of supporting jack pine and inferior Norway pine, sometimes interspersed with an undergrowth and mixture of scrub oak.

The tables show possible yields of 37 peeled cords or 6,600 board feet per acre (by the more conservative Scribner Decimal C log rule) on poor sites, whereas forest surveys made shortly after their preparation found that typical volumes even on medium sites were only 3000 to 5000 board feet per acre (Anderson, 1936).

Actual volumes in natural aspen stands fell so consistently and so far behind the normal yield tables that Anderson concluded that "the usefulness of the latter is brought into question." Reasons advanced for the great discrepancies were: (1) existence of fewer merchantable trees per acre in the typical aspen stand than shown in the normal yield tables (particularly if cull trees are omitted), (2) lower average volume per tree in forest stand than in a well-stocked stand because of poorer form, (3) volume of average forest tree is less on account of crooks, rot, and other defects, and (4) more exacting standards of utilization current at the time of the survey with respect to top diameter and minimum size of merchantable trees. Zehngraff(1947a) attributed the over-estimates to failure to accredit proper weight 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.

The largest source of error is undoubtedly the high proportion of aspen lands which are under-stocked. Recent figures from the forest survey in the Lake States revealed that of the nearly twenty million acres of aspen type, almost five million acres, or a quarter of the total, are poorly stocked or denuded (Cunningham, et al., 1946). Early survey data disclosed that whereas normal aspen stands at sixty years of age are supposed to have from 330 trees per acre on hardwood land to 422 trees per acre on pine land, the actual numbers of sound trees in average stands were only 215 and 110, respectively (Anderson, 1936). Not only were there fewer merchantable trees, but the open-grown trees were shorter and of poorer form, and consequently contained less merchantable volume. According to the yield tables a 14" tree from a well-stocked stand contains about 170 board feet, yet trees of the same diameter in under-stocked stands contained only about 110 board feet.

Survey figures on merchantable volume were in general agreement with those of Schmitz and Jackson (1927), although showing considerable variation with site and product. A later study of heart rot in Canada in which the figures for all sites were grouped together found an extraordinarily high rate of decay amounting to 50 per cent defective or cull volume between 70 and 80 years of age. Although these figures are not applicable to the Lake States, and are not specific enough for general application in any case, they serve to emphasize the important role of decay in determining yields in unmanaged stands.

A yield table constructed from early forest survey data, Anderson (1936), (see Table 4 in Appendix) gives empirical yields in both gross and net volumes under the forest survey standards of utilization in force at that time. The site classification adopted corresponds fairly closely to the system used by Johnson, Kittredge, and Schmitz (1930). The sites were defined by the natural cover type and heights were omitted, apparently because of the reduced correlation between site productivity and site index in under-stocked stands. Yields are revised downward drastically from those given in the previous tables, but, strangely, follow the same trend of continued merchantable volume increase with age even during overmaturity. It seems extremely doubtful whether the figures for at least the 70- and 80-year age classes can be considered valid.

The most recent yield table for the Lake States, published by Zehngraff (1947a) (see Table 5 in Appendix), agrees with the recognized form of volume-over-age curves, showing maximum yields at between 50 and 55 years. The yield figures represent the gross volume which may be expected in well-stocked, unmanaged stands. Sufficiently detailed information on the relation of cull to age on various sites in well-stocked stands was not available for close estimation of theoretical net merchantable yields. Stoeckeler (1943) has constructed a set of yield curves, however, for five soil classes corresponding to the site-index classes of Kittredge and Gevorkiantz (1929), which show empirical merchantable yields in cubic feet and cordwood from investigations in Minnesota and Wisconsin.

Baker (1925) composed an empirical yield table for aspen in the Central Rocky Mountain region which sets forth gross yields in cordwood and board feet. It is meaningless to compare yields on a given site in this region with yields on sites of coordinate quality in the Lake States because the growth rate of aspen in the former region is much lower on all sites considered collectively. Obviously, therefore, productivity is correspondingly higher in the Lake States. On the other hand, if the stricter standards of utilization adopted in the preparation of Baker's table are taken into consideration it appears that final yields may equal those of the Lake States. This is because the rate of volume increment does not fall off until ages of 80-90 years due to greater stand longevity (Meinecke, 1929), by which time individual trees are approximately as large as those in mature stands of the Lake States.

Accurate prediction of yields under management is impossible at present, but it seems certain that some increase can be achieved simply from the increased stocking which proper management can effect. In addition, experimental evidence gives high promise of increased yields, improved quality, and shortened rotations under intensive management on good sites

MANAGEMENT OF ASPEN LANDS

Aspen Supply and Utilization

Acreages and volumes. The entire stand of aspen saw timber in the United States has been estimated very roughly at 2,300,000,000 board feet, in addition to which there are probably about 40,000,000 cords of wood suitable for fuelwood and pulpwood (Betts, 1944). In the region of Canada made up of the provinces of Nova Scotia, New Brunswick, Quebec, Ontario, and Manitoba, the volume of poplar (including aspen and balsam poplar) was estimated at approximately 2,661,000,000 board feet and 53,357,000 cords (Craig, 1937).

The stands of commercial aspen saw timber in the United States are located principally in the Lake States and the Northeast, particularly in the former region. The combined stand of aspen, cottonwood and balsam poplar of saw timber size in the eastern part of the United States was placed at approximately 80,000,000,000 board feet in 1938 (U.S. Senate, 1941). In the Central Rocky Mountain Region (Colorado, Idaho, Nevada, New Mexico, Utah, and Wyoming) Baker (1925) estimated the stand of aspen at 12,658,000 cords on 4,000,000 acres. A survey made in the Pacific Northwest during 1930, by the Pacific Northwest Forest Experiment Station as a part of the forest survey of the United States, showed less than 5,000,000 board feet of saw timber and about 30,000 cords of pulpwood in Washington and Oregon.

As yet, detailed statistics on the areas by site class, volumes by size class, growth, etc. have been published only for the Lake States. Here, up to date information obtained from the 1934-36 survey, re-evaluated in 1945, has recently been compiled and published (Cunningham et al., 1945; Chase, 1947; Horn, 1948; and U.S.D.A., Forest Service, 1950).

The aspen type (Lands on which "aspen and paper birch, either singly or together, make up more than 50 per cent of the stand" were arbitrarily classified as aspen type. "Aspen," in the survey, included <u>Populus balsomifera</u> L., and <u>Populus detloides</u> Marsh. as well as the true aspens; <u>Populus tremuloides</u> was estimated to make up about 80 to 90 per cent of the volume.) occupies 19,858,000 acres or 39 per cent of the commercial forest area in the Lake States. This is slightly more than twice the area of the next largest type, the northern hardwoods. Of the total aspen acreage, over half is to be found on sites of medium quality (site index 60-70), with one-third on poor sites (site index 59 or less) and one-sixth in the good site classification (site index 68 or greater). Approximately 24 per cent of the aspen type falls in the merchantable pole and saw timber size classes, nearly 2/3 being in the pole timber class. About 52 per cent is considered as satisfactorily restocking to seedlings and saplings, while an area a little greater than that bearing merchantable timber is so poorly stocked as to be practically deforested.

As of 1945, aspen constituted 13 per cent of the saw timber volume (Volume measurements included all <u>Populus</u> species, but not paper birch) of all tree species in the Lake States. This equals approximately 6 1/3 billion board feet (by International ¼-inch rule), of which 70 per cent occurred in saw timber size stands, the balance being scattered through pole size and unmerchantable stands. The actual, usable saw timber volume, however, after discounting for inaccessibility, rot, and loss resulting from overmaturity was almost 20 per cent smaller. In contrast to the relatively low aspen saw timber supply, the total volume of aspen pulpwood was nearly as great as the collective total of all other common pulping species combined, amounting to 17,300,000 cords of standard pulpwood exclusive of saw log material. In addition, if standards were lowered to permit the pulping of all aspen sticks over 4 inches d.i.b. with less than 50 per cent defect, the utilizable volume would be increased by more than 25 million cords.

Although the total volume of aspen in the Lake States is very large, it is not all available for cutting at any given time. It was estimated that only about one-half of the saw timber size material and three-fourths of the total cordwood volume (including standard and sub-standard pulpwood and pulpwood in saw log material) is in stands with sufficient volume per acre to permit economic logging operations.

On the other hand, growth between 1935 and 1944 was far in excess of drain due to cutting and all natural losses, and the margin is expected to increase even more in the future. Growth for the ten year period 1934-44 was four times greater in cubic feet and $2\frac{1}{2}$ times greater in board feet than drain. Ingrowth of aspen into the merchantable classes will be comparatively slow until 1965 when, with continued and improved fire protection, the vast areas of restocking aspen lands will "come of age." It was estimated that total cut for the region could, without overcutting, be increased almost three times, and the saw timber cut about twice, before 1960, and increased thereafter. Estimated allowable annual cuts of saw timber for the period 1945-1959 and of pulpwood for the period 1946-1965 are 300 million board feet (International $\frac{1}{4}$ inch rule) and 2,040,000 cords respectively.

Obstacles to Utilization

Aspen was used only in small quantities until the large demand for lumber during the war literally forced its use, principally in the Lake States. Limited demand has been primarily due to the small size lumber yielded. On many sites aspen never attains saw log size, and previous to the war trade prejudice and supplies of larger, higher quality timber species limited cutting of aspen. Combined with low stand density and high cull percentage, small size still restricts most aspen logging to operation on a small, narrow margin scale (Garland, 1947 and Zasada and Kleunder, 1949). With the long established logging and sawmilling methods set up to handle larger species, like the northern hardwoods, costs are high for the small-sized aspen logs obtainable and are increased by the uncertain availability of operable supplies of merchantable timber in many areas, due to irregularity of aspen stands and the mixed pattern of ownership.

The increased utilization of aspen during the war has led to studies aimed at finding more economical and efficient harvesting methods. Mechanical equipment, such as power saws, mobile pulpwood harvesters, loading machines, and mechanical barkers and peelers, has been developed, but most of it is still in the experimental stage (Schantz-Hansen, 1948). Some of these machines have demonstrated their efficiency, but the expense of powered equipment requires a large operation in valuable timber, which indicates that its use will generally be precluded for medium and low quality aspen stands. Of particular interest to growers of pulpwood stands are methods of artificial peeling, because they can lead to a wider market and higher prices while allowing cutting during the dormant season. Various systems of bucking, skidding, and bunching and of manpower disposition are also being tried, with the object of reducing the number of man hours of work required to get aspen timber from the stump to the plant. Woods operation of chipping machines, now being studied, would help to accomplish this while leading to closer utilization.

Most aspen is cut into a variety of rough products. In the past a great deal of the timber has been improperly or wastefully cut and often not seasoned. Furthermore, a large proportion of aspen lumber is manufactured by small, portable sawmills, and much of it is poorly sawn and ungraded, producing low quality lumber at high cost. Zasada and Kleunder (1949) have advocated wider use of the "center split horizontal band re-sawmill" for the advantages of accurate sawing, large volume production, high recovery (large overrun), and low cost of operation.

Lack of information as to location and quantity of supplies of aspen for specific products, and ignorance of the properties of the wood, have shared responsibility with high costs of production and poor utilization practices for creating buyer prejudice against aspen. Garland (1947) pointed out that forest survey figures are not detailed enough to be useful as criteria for utilization recommendations and asserted that a series of type maps showing species composition, age of stand, condition of stand, and site classification by areas as small as forty acres is needed. Owners and managers of aspen stands can help to solve their own marketing problems by advertising the timber they have to sell. In order to do this successfully, the forest owner must have made a reasonably accurate survey of his timber holdings. Furthermore, the owner should be familiar with the specifications for all of the products for which a possible market is available. He must then decide what kind of operation will most completely utilize the timber he has for disposal, with greatest financial return. Finally, prospective timber buyers have to be contacted and informed of the amount and kind of timber for sale. Zasada (1949) recommended that they be supplied the following information: (1) The amount of timber in board feet or cords, and the exact area involved. (2) The kind of timber, its quality and size. (3) The location of the timber, distance from town, railroad siding, and wood-using plant. (4) Means of access to the timber - highways, woods roads, and trails which pass through or near the timber tract.

Aspen's poor substitution for many products of the original, dominant timber species, in regions where it is now widespread, created a general prejudice against the wood which has only gradually dispelled with more complete knowledge of its true characteristics. Like any other species, the wood of aspen has certain definite use limitations. On the other hand, it has distinctive properties which make it particularly well-suited to some uses (Zasada, 1947). In spite of the many retarding factors, the market for aspen has expanded considerably during recent years, particularly in the Lake States, because of its relative availability and some degree of conformance with the requirements for a growing list of products.

Aspen wood is light colored, light weight, uniform in texture, straight grained, and free from staining or odorous materials. It is fairly easy to work and finish, has a low tendency to split in nailing, forms strong joints when glued, holds paint reasonably well, and can be seasoned satisfactorily by air-drying and kiln-drying. These properties are advantageous for use of the wood as boxes and crating, pulpwood, excelsior, core stock, veneer for matches and food containers, toys and novelties, and limited small construction use where decay resistance and great strength are not necessary. The first three of these products now represent a large proportion of the total aspen drain, and the pulpwood market holds particular promise for increased demand in the future.

Aspen's low strength and decay resistance, poor nail holding power, numerous knots, lack of attractive grain, and low density, combined with the fact that only a limited amount of wide, clear lumber can be obtained from the small logs, make it less desirable than many other species for products such as construction lumber, commercial veneer, railroad ties, mine props, fuelwood, fence posts, high-grade furniture, and chemical wood. Nevertheless, aspen satisfies the requirements for several of these products well enough to be used in considerable quantities because of its greater availability. Lesser amounts of aspen are used for a great variety of other things, and a complete list of all products for which aspen is used, to some extent, would probably total in the hundreds.

Aspen's competitive rating in the lumber market can probably be raised, but it will require better handling from growth on the stump to final manufacture. Research must continue to try to find new uses for small material which will lower the utilization limit, forest managers should aim for greater yields of larger-sized, higher quality logs, improved logging systems are needed to enable lumbermen to more fully utilize the timber in stands and leave the land in better condition for future growth, and processing and marketing standards must be raised to command higher prices.

Aspen Silviculture

The application of correct silvicultural techniques to aspen stands is essential for high productivity. Neglectful cutting practices are conducive neither to thrifty aspen growth nor to replacement of the type with a healthy stand of other desirable species. The result of careless cutting is almost invariably a stand of defective, slow-growing aspen mixed with other inferior species and invaded by brush.

Assuming favorable marketing conditions and other economic factors such as tax rates, the question of profit in the management of aspen as a permanent, pure crop depends upon site quality. Accordingly, its determination is the first preliminary to organized management of aspen lands. Stoeckeler (1943) has prepared a table indicating the recommended choice of treatment for aspen lands based on the two simple criteria of soil texture and fire history. Regardless of the owner's decision, however, successful management depends upon planned cuts according to clearly defined requirements.

Aspen silviculture need require only a minimum of technical skill to apply and can be varied in intensity in order to adjust management costs with potential yields from merely a properly applied reproduction cut at maturity to the inclusion of frequent, light thinnings begun early in the stand's life. At present intensive management is possible only on the best sites, but great improvements can be made in the condition of most aspen stands with extensive management methods.

Reproduction Cuttings. It has already been made manifest that aspen's silvical characteristics adapt it to a clearcutting system, and that because of the species' avidity for light this literally means "clear" cutting. Also explained, in the section on reproduction, was the effect which season-of-cutting has on aspen's sprouting ability, and the stimulating effect of disking the soil following removal of the mature stand. This knowledge can insure immediate and complete regeneration of aspen stands if strictly applied.

Conversely, it helps to illustrate the most effective methods of eliminating aspen to make way for other species. If economic conditions or poor stand quality make conversion desirable there are several effective methods of holding back or destroying aspen sprouts. Basically, all involve cutting, girdling, or poisoning. Girdling has the advantages of economy if the stand is too poor for commercial cutting, reduced sprouting, and gradual release of advance growth, but is not adapted to sapling-size stands. Poisoning is effective in young stands (Day, 1947; Egler, 1949; and Wible, 1949) and preferable to cutting from the standpoint of reduced sprouting, but may be a hazard to wildlife and management.

When the stand is to be held until maturity an excessively heavy thinning about ten years before the final removal of the overstory will stimulate the production of root suckers which will be suppressed by the remaining trees and inhibit development of later sprout growth. Girdling a year before the final cut discourages sprout production and cutting back sprouts a year after their inception on a clearcut area weakens them and aids outstripping by other species, but several such liberation cuts are usually necessary (Rudolf, 1950).

Slash disposal can be dispensed with in aspen stands. Slash does not interfere significantly with sprout production or growth, and its low flammability and rapid decomposition classify it as a minor fire hazard (Boyce, 1948; Westveld, 1949). Decomposition is complete within four or five years.

Limiting the length of rotation is the most important silvicultural tool that the forest owner has for controlling the amount of defect in a stand. Studies in the Lake States have demonstrated that rotations should not exceed 55 years on good sites, 45 years on medium sites, and the minimum period necessary to produce a commercial crop on poor sites (Zehngraff, 1947a). Some owners may wish to grow larger, more valuable trees by sacrificing volume, but Zehngraff estimated that the larger products must bring a stumpage price approximately three times higher than usual in order to compensate for the loss in volume and time. The larger class of products should therefore be grown only on the very best sites which, with intensive management, will produce them in a normal rotation or slightly longer without involving serious risk.

It is obvious that heavy volume losses can be avoided only by cutting aspen stands promptly at maturity. The first step in management must therefore be to classify the aspen lands according to site and age classes than an orderly cutting plan may be adopted. Harvesting completely and at the proper time will usually be fully sufficient to restore and maintain the productivity of aspen lands at a reasonably high level.

<u>Intermediate Cuttings</u>. For even higher yields of larger, sounder, and more valuable materials thinnings must be resorted to. As early as 1911 Weigle and Frothingham observed the desirability of thinnings, but only within the last twenty-five years has serious experimentation been carried on to measure their effects and discover how best to apply them. The results of studies conducted on the Pike Bay Experimental Forest in Minnesota have generally indicated that "aspen responds exceptionally well to thinning, especially during early life." (Zehngraff, 1947a). Evidence is not complete enough to predict how much thinnings can increase the quality and yields of aspen stands but presently promises at least reduced defect and larger possible sizes, which alone appear to justify non-commercial thinnings on good sites.

An unfavorable report on the effects of thinning was made after trials on the Petawawa Forest Experiment Station in Canada (Bickerstaff, 1946). A basic difference existed between the type of thinnings made in this study, however, and those which have been applied on Lake States sample plots. Commercial thinnings were applied to four young aspen stands of varying age, site, and density and remeasured ten years later. In order to make them pay for themselves and on the premise that only one thinning would be economically feasible during the rotation, the thinnings were very heavy, removing 70-80% of the original stand in each case. This necessarily removed the larger, more vigorous trees, leaving a drastically reduced growing stock of smaller trees from the lower crown classes. The significant feature of the remeasurement data is that, although the per acre yield and increment and yield of the thinned plots was about the same as for the unthinned plots and sunscald damage and other injuries were high on the former, the volume increment per tree was much higher on the thinned plots.

Success with thinnings on the Pike Bay Experimental Forest has demonstrated that such cuttings should be made from below, with no attempt to make early operations pay for themselves. Trees removed were selected with a tree classification based on vigor, soundness, form, and utility to serve as a guide (Zevorkiantz, S. R. et al, 1943). Tree vigor, as expressed by such external characteristics as (1) position in the stand and relation to surrounding trees and (2) crown density, is the most important basis for the classification. Trees of low vigor are the most defective and slowest growing, thus arguing that thinning from above defeats its own purpose which is to concentrate growth on the most promising individuals in the stand. The trees removed in thinnings should be those which are losing out in the struggle for dominance, defective trees, and trees which have wounds or other avenues of disease entry which make them poor risks. In addition, other low-value or poor quality hardwoods which interfere with the growth of the best aspen should be removed on good sites where the latter is often superior to its associates. Although promoting more rapid growth, thinnings of this sort also serve partially as improvement and salvage cuttings in older stands.

In 1936 a series of thinning plots was established in a 13-year old stand of good-site aspen and remeasured in 1945 at the age of 23 (Zehngraff, 1946d). According to the results young aspen responds to thinning almost in direct relation to increased spacings up to 8 feet by 9 feet. Spacings of 7 by 7 feet and 8 feet by 9 feet offer the best possibilities for management. If the plots thinned to these spacings in the experiment had been clearcut for pulpwood in 1945 added growth already would have paid for the thinning costs.

Recent experimental, non-commercial thinnings in 11-and 20-year-old stands indicated that thinning costs are much lower at 10 than at 20 years (Lake States Forest Experiment Station, 1952a). Notwithstanding the fact that in the older stand only dominant and codominant trees that were interfering with selected crop trees were removed while all but 600 to 900 of the best trees per acre were left in the younger stand, the earlier thinning was more economical because of greater time required, even after projection of the prevailing wage rates at 5 per cent.

After aspen stands reach pulpwood size it appears that partial cuttings of moderate severity can be made to advantage from above, or at least without serious detrimental after-effects (Zehngraff, 1947a). Diameter limit cuttings of 8, 9, and 10 inches were tried in a 43-year-old stand on a good site on the Pike Bay Experimental Forest in 1935. Remeasurements six years after cutting 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 a check plot. A 9-inch diameter-limit cutting was studied on an optimum site for aspen in Arizona. A residual stand of 854 cubic feet/acre in trees four to eight inches in diameter was left, and remeasurements five years later found that growth exceeded by one and one-half to two times that of comparable stands of ponderosa pine.

However, the objections cited above to this form of cutting still apply if the residual stand is too small or defective.

Zehngraff cautioned that cuttings from above should not exceed 40 per cent of the merchantable sawlog volume and about 15 per cent of the merchantable trees. Economic conditions permitting such intermediate cuttings should also be made from below, utilizing small merchantable trees and some larger trees of poor form, quality, or risk.

THE ASPEN PROBLEM AND COURSES OF ACTION

The aspen problem is a part of the much larger land use problem left in the wake of the wave of destructive exploitation which, in less than a century and a half, enveloped most of the great timberland regions of the United States. With the end in sight for the last of the high-grade, virgin timber, this country is left with vast areas of unproductive or partially productive lands still languishing from the effects of the economic blight which followed exhaustion of the original timber supplies. For the most part, these lands are fitted only for the production of timber crops and, in large measure, the people must look to a regrowth of the lumbering industry for a brighter economic future.

Revival of the forest lands has been particularly slow in the Northeast and the Lake States despite a high concentration of wood-using industries, and it is in these regions that the aspen type reached its greatest expansion. As an interim protective influence which lessened the deterioration of denuded lands, aspen performed a valuable service, but, with contemplation of accelerated forestry programs for restoring the forest lands to full productivity, aspen areas present a particularly difficult problem. So great is the area of the aspen type that in spite of an expanding market for the species the demand will apparently never equal the supply; definitely not in the foreseeable future. Meanwhile, aspen has not outgrown its unofficial classification as an inferior species and discrimination against it continues. Though able to out-produce other species in total cubic volume, it will never be able to compete in satisfying the Nation's great future requirements for high-grade saw timber, needed both for peace and as a reserve supply in case of war. Nor are the revenues derived from aspen, on medium and low quality sites. certainly, comparable with the potential returns from other species.

In their present state, a large majority of the aspen-bearing lands afford little or no income for their owners, and, in fact, represent a real economic loss to the population at large by their idleness. The huge areas of land preempted by the aspen type could be growing much more valuable timber crops and halting the decline of the lumbering industry in these regions, but instead are generally only a financial burden to local and state governments which must supply them with governmental services regardless of their productivity.

Increased production from aspen lands is clearly vital to the forest economy of the Lake States and the Northeast, and is highly desirable in other regions where aspen has even less value. A number of serious difficulties have, however, hindered progress toward that end, most of which have arisen from the very fact that these lands are of low value. The great quantities of aspen in comparison with the limited market and low value, the poor quality and low stocking of the large majority of stands, costly and inefficient logging methods, and low yields of merchantable size material have discouraged ownership of aspen lands, with the result that a majority of them has now become public owned through tax forfeiture or purchase. These same factors, plus lack of experience and technical information, have been prohibitive to planned management for sustained yield.

Those aspen lands which are publicly owned are largely of the lower site and age classes, and these are divided amongst several levels of government. Private companies generally own better aspen lands, but lack sufficient consolidated acreage and a proper distribution of age classes for effective management, and most small woodlot owners are indifferent about management of their stands. Thus, "management" to date has consisted almost exclusively of necessary fire protection, with the exception of experimental work carried on by the federal government. The natural consequence has been continued improper cutting, resulting in even greater areas of defective and under-stocked stands.

It is obvious then that the magnitude and complexity of the aspen problem will necessitate maximum cooperation and coordination of effort between private forestry and the public agencies concerned with land use for an effective solution. The required long range nature of whatever formal measures were adopted and the large government ownership of aspen lands further indicate that the public would have to supply the initial impetus and carry the major part of the burden of execution for any program decided upon. For obvious reasons, the initiators and directors of such plans would have to be the states, specifically the state forestry agencies. However, the assistance of all government departments supervising land resources would be indispensable.

Three alternative courses of action for developing aspen lands are apparent: (1) planned management for aspen, (2) conversion to more valuable species in the near future, or (3) temporary management for aspen with conversion to other species after one or more rotations. The decision in the case of a particular stand requires consideration of a number of factors, including site quality, age, density of stocking, amount of defect, character and density of the understory, ownership status and condition of surrounding forest lands, and marketing possibilities.

Generally speaking, the primary consideration must be site quality. In view of the tremendous area of aspen, and its site sensitivity, aspen management not only logically should but must be concentrated largely on the most productive sites, or those having a site index of sixty-five or higher. Medium and low quality sites are usually characterized by light soils originally occupied by conifers and best adapted for conifer growth. On the other hand, medium sites already being successfully managed for aspen would of course retain their status, at least temporarily, and some of the better medium sites should be managed for aspen where marketing conditions are particularly favorable for small-sized material or in cases of need to expedite management over a wider area.

Planting on the best aspen sites, meaning usually those sites originally occupied by high-quality northern hardwoods, should be very limited. Establishment of conifers on these sites is undesirable if favored hardwood species can be grown, and the risk involved in planting hardwoods is too great to justify such a venture while much greater areas of aspen land await planting of conifers. Given time, most aspen stands on these sites will revert naturally to more tolerant hardwoods and the indicated method of handling, if conversion is the objective, is extensive management with cuttings favoring gradual ascendancy of these species.

As a result of the recent, great and continuing strides made in the fields of utilization and silvicultural research, profitable sustained-yield management now seems feasible for millions of acres of aspen land. Zehngraff (1949) has defined the objective of aspen management as "quality production," pointing out that because of the great waste in aspen every year, due to poor quality, this would be tantamount to greater quantity production as well. Improved quality is the best remedy for many of the utilization ills still plaguing aspen and if these could be minimized the obstacles to aspen management would be no greater than for other species. In fact, aspen's natural attributes adapt it to an inexpensive and simplified form of management. It grows in remarkably regular and even-aged stands under normal conditions, allows a short rotation, has little tendency to stagnate seriously yet responds well to thinning with added growth on good sites, and is surely and promptly reproduced if certain precautions are observed.

Intensive management practices are not now practicable on a large scale, but must be limited to small holdings and the better organized lands of a few private companies. The immediate goal must be to organize the lands of individual owners for more intensive future practices by segregating stands into separate site and age classes, and to adopt a cutting policy which will improve stocking and establish an equal distribution of age classes while utilizing the existing mature timber as completely as possible. In this connection it is essential that fire protection be maintained, and even increased in some areas, and that logging practices be improved to prevent the spread of aspen to new areas and the further deterioration of those sites on which it is already present.

The states and federal government and the larger industries are progressing gradually toward continuous long-range management on their forest holdings, but, notwithstanding technical assistance available through the extension service and state forestry agencies, small owners have lagged far behind in applying organized management to their stands. The small owner stands in need of an expanded and more detailed program of assistance, particularly from the standpoint of marketing.

New Jersey has made commendable progress in this direction through a cooperative plan involving several public agencies and private enterprise. The step most instrumental in its success has been the employment of private timber agents to arrange and supervise marketing of timber crops, which has strengthened the owner's bargaining position and resulted in improved harvesting practices, thus leaving stands in better condition for future growth.

Eventual conversion to coniferous species seems to be the best choice for treatment of the majority of medium and low quality aspen stands, and is the course favored by most professional foresters as well as private owners. Conifers are capable of providing much greater returns on these sites, and there is a present compelling need for softwood timber in the Lake States and the Northeast. Shirley (1941) estimated that the total differential between the values created by products now grown on all aspen and brush lands in the Lake States and the yields which probably could have been obtained from these lands, had they restocked with the original timber types, amounts to about $16,000,000.

Stands in which there is already stocking of other desirable species, whether coniferous or hardwood, in the understory should naturally be managed in such a manner as to preserve this advance growth and insure natural conversion as soon as is reasonably possible. Cutting of mature aspen should give priority to release of valuable species from suppression, and unmerchantable stands should be girdled wherever practical. Unfortunately the area of aspen land upon which there is adequate reproduction of conifers for well-stocked stands is very limited because of the severe conditions to which most sites have been subjected. The proportion of aspen lands bearing an appreciable stocking of conifers in the Lake States was estimated at between 10 and 20 per cent, with balsam fir, a low value species itself, comprising more than half of the total (Kittredge and Gevorkiantz, 1929). Furthermore, field observations demonstrate that conversion of aspen lands in this region by natural succession must be expected to require at least a hundred years under the most favorable conditions (Rudolf, 1950), and in the Rocky Mountains one hundred fifty to two hundred fifty years (Baker, 1925).

The situation in the Lake States and the Northeast is too urgent for natural transformation to be considered a satisfactory solution. In summarizing the experience and findings of Lake States foresters and weighing the probably costs and returns of converting aspen lands, Shirley (1941) called for a public planting program. Calculations indicate that the costs of planting aspen lands, though high, could be met by the returns in the form of timber growth during the first rotation. Profits, if any, would not be sufficient to motivate large-scale private planting projects but the potential, added social and economic benefits to be derived seem to fully justify the expense of a public program.

Actually, what is needed is a single program designed to resolve the aspen problem in its entirety. In many states, government and private enterprise are, and have been for some time, attacking the problem in as many ways as possible, but their efforts have only been partially coordinated and on too limited a scale to make appreciable headway. The administrative, technical, and economic difficulties involved in formulating and executing a definitive program for rejuvenation of the aspen lands are such that no single authority could undertake the task alone. Moreover, if maximum returns and efficiency were to be achieved action could not be unilateral, for the interests of regions and communities as well as individual owners must be served, particularly since the public would have to underwrite a large share of the program.

No immediate large-scale action could be taken for several years after a program were decided upon in principle for time would be required to supplement the background of information and experience already acquired in handling aspen lands and to serve as a trial period for testing and improving procedures. Realization of the final goal would take a great many more years, and foresters should take action now if many of the potential benefits are not to be lost.

CONCLUSIONS

1. Aspen is very exacting in its requirements for good growth. Low site quality markedly effects the species' susceptibility to decay, form, and rate of growth. Knowledge of site quality is, therefore, extremely important to intelligent handling of aspen lands.

2. There is a sound demand for good aspen in operable quantities. Furthermore, it appears that the demand can be expected to increase in the future, and value with it. Proper management can do much to enhance the value of the species by increasing the supply of high-quality material.

3. Only vigorous growth can hold damage from aspen's many natural enemies to a minimum, and consequently management for aspen on a permanent basis should be concentrated largely on good sites where the healthiest stands naturally occur and where response to management is most pronounced.

4. Limiting rotation age is the most important measure applicable to individual stands for obtaining maximum yields of rot-free material, and therefore age, as well as site-quality, determination is essential for instituting management of aspen.

5. Full stocking and optimum growth of succeeding generations of aspen can be assured only by complete removal of the overstory during the final cut, either by cutting alone or some combination of cutting, girdling, and poisoning. Adequate regeneration

is also less certain following cutting during the growing season than during the dormant season.

6. The effects of fire, even though light, may be disastrous to plans for management. Fires directly damage and kill the thin-barked aspens and increase the liability to disease and insect attack by reducing vigor and providing points of entry, and, finally, lower site-quality semi-permanently. An efficient fire protection system should be an integral part of all management plans.

7. Aspen is very adaptable to intensive silviculture on good sites. The dominant and most vigorous individuals in a stand are quick to take advantage of increased growing space provided by thinnings. Experiments to date have indicated that thinnings are best applied early, frequently, and lightly, and should be from below.

8. On medium and poor sites aspen loses its advantage of high volume production for a given period. Conifers are clearly superior from the standpoints of both volume and value returns and should supplant aspen as soon as is practicable. The condition of most aspen lands is such that natural succession to more valuable species will not occur naturally for an inordinately long period of time, and the economic welfare of many forest industries demands an expanded program of forest planting.

RECOMMENDATIONS

The experience in cooperative organization and information being gained from various research projects and the National forest survey are providing a useful springboard from which many states could launch more ambitious programs of forest improvement than was ever before possible, if and when public support could be mustered. The exact knowledge of present condition and potential capabilities of the forest lands now becoming available provides the basis for the kind of well-founded, comprehensive plans which make large-scale action possible.

As forest survey work is being completed the states should take the initiative in directing detailed analysis of all public lands to determine the best possible method of handling them for the long-range benefit of the public at minimum cost. The objective is, of course, to increase and stabilize the flow of forest products so that forest industries, communities, and individuals who depend on them will be assured of a steady and substantial income. Successful planning of this task will require the assistance of all groups concerned with the problem.

Plans for the public lands should be designed partly to complement and assist the plans of private owners for the mutual benefit of both. This implies the necessity for consultation between public and private landowners to promote integration of future management plans, insofar as possible. State forestry agencies should serve as a depository for and clearing house for the exchange of information and plans.

Conversion of a large percentage of the publicly owned aspen lands will doubtlessly be desirable and an accelerated program of planting should be high on the agenda for public action. Planting should be on a firm basis of anticipated coverage of the costs within one rotation. This would eliminate many of the poor sites, at least temporarily, and relegate them to other uses than the production of timber crops such as recreational and wildlife areas. One consideration in locating areas for planting should be the possibility of hastening natural conversion of lands on which planting is not presently possible.

Better management of aspen lands not slated for immediate or eventual conversion can be achieved only by continued research and education combined with gradual improvement of the physical and economic conditions created by our former careless treatment of the forest lands. A clear and thorough analysis of the objectives and the required measures for the Lake States, which has universal application, was presented in the report of the forest resources for that region(U.S.D.A., Forest Service, 1950). The measures which are particularly important for stimulating management of the aspen lands are those needed to stabilize ownership and promote sustained yields, including consolidation of holdings for better administration, integration of management plans, removal of legislative obstacles to good management, and employment of all available aids.

Two other measures which the author suggests for study are a larger program of assistance to the small woodland owner and cooperative management arrangements for the public lands between the government and private enterprise. A large proportion of the forest land, much of it capable of producing good timber, is in the hands of small private owners, largely farmers, who are doing little to increase its productivity although such holdings are ideally suited to intensive management. Technical assistance has been supplied, but the owners need additional aid in marketing their crops to advantage and enforcing proper cutting regulations to leave the lands in good condition.

Many forest industries need to acquire additional areas of land to balance age and site-class distributions for instituting sustained-yield management. These companies often could not afford to buy this land outright and sustain the additional costs which might be necessary to plant or improve the condition of growing stock on them, but neither is the public able to apply more than the barest essentials of management to much of its land. Leasing arrangements which would defer the costs of purchase until profits were forthcoming from the land or by which the public would retain ownership and share income from the land until under well organized management would seem to promise benefit for both parties.

APPENDIX

TABLE I

Yield of Second-Growth Aspen, Trees Seven Inches and Over,

Scribner Decimal C Log Rule

Kind of Site	Age	Trees per Acre 7 inches and more	Average height	Average Diameter, breast high	Basal area per acre	Volume per acre*
	Years	No.	Feet	Inches	Sq. feet	Board ft.
Good....	30	35	69	7.3	10	500
	40	167	70	7.6	52	3,400
	50	297	72	8.1	103	9,600
	60	290	77	9.3	135	17,300
	70	235	82	10.9	150	23,600
	80	180	86	12.6	154	27,400
Medium..	40	68	65	7.5	21	1,000
	50	213	66	7.7	69	4,300
	60	300	68	8.3	112	10,300
	70	268	71	9.5	132	16,400
	80	229	74	10.6	140	19,700
Poor....	50	68	58	7.4	20	1,000
	60	174	59	7.6	55	3,200
	70	240	60	8.0	84	6.600

*Stump height, 1 foot; top diameter inside bark, 6 inches. Bark is not included in volume.

TABLE II

Yield of Second-Growth Aspen, Trees Six Inches and Over, International Log Rule*

Kind of Site	Age	Trees per Acre 6 inches and over	Average height	Average diameter, breast high	Basal area per acre	Volume per acre**
	Years	No.	Feet	Inches	Sq. feet	Board ft.
Good....	30	170	63	6.0	33	3,800
	40	319	66	6.7	80	9,200
	50	403	70	7.6	124	16,700
	60	320	76	9.0	143	23,700
	70	235	82	10.9	151	30,100
	80	130	86	12.6	155	34,800
Medium..	30	80	59	6.1	14	1,400
	40	215	60	6.3	45	5,000
	50	358	62	6.9	96	10,700
	60	378	66	7.9	127	16,500
	70	290	70	9.3	138	21,300
	80	234	74	10.6	143	24,800
Poor....	40	74	53	6.1	13	1,400
	50	200	54	6.4	42	4,500
	60	306	55	7.0	81	8,200
	70	327	59	7.6	102	11,500

* Based on a 1/8-inch kerf.
**Stump height, 1 foot; top diameter inside bark, 5 inches. Bark is not included in volume.

TABLE III

Cordwood Yield for Well-Stocked Aspen in Trees Four Inches and Over in Diameter, Breast High

Kind of Site	Age	Average total height of dominant trees	Average diameter breast high	Basal area per acre	Peeled volume per acre*
	Years	Feet	Inches	Sq. feet	Cords**
Good....	20	40	2.9	83	5
	30	51	4.2	102	25
	40	62	5.4	120	43
	50	70	7.0	133	55
	60	76	9.0	144	63
	70	82	10.9	151	67
	80	86	12.6	155	69
Medium..	30	44	3.5	94	12
	40	53	4.5	110	30
	50	60	5.9	122	44
	60	66	7.6	133	51
	70	70	9.3	139	55
	80	74	10.6	143	57
Poor....	40	44	3.5	88	11
	50	50	4.6	98	26
	60	55	5.8	105	33
	70	59	7.1	109	37

* Stump height, 1 foot; top diameter inside bark, 3 inches.

**Standard cord, 4 by 4 by 8 feet. Close piling. Volumes in cords were obtained by applying the factors used for conversion of merchantable volumes in cubic feet to cords to corresponding average diameters at breast height. As a check, the same results were obtained from curved distributions of stems of different sizes per acre for a given age. These latter curves were also used for obtaining volumes in cords for stands with average diameter less than 4 inches.

TABLE IV

Aspen Normal Yield Table Adjusted to Forest Survey Standard of Utilization

Age Years	No. Trees Per Acre[3]	Basal Area Sq. Ft.	Ave. DBH	Gross Vol.[1] Bd. Ft. Scrib.	Gross Vol.[1] Total Cords	Net Volume[2] Bd. Ft. Scrib.	Net Volume[2] Total Cords	Pulpwood Cords
				Best Hardwood Land				
20	1,703	90	3.1	------	3.5	------	2.7	1.6
30	1,054	107	4.3	50	17.3	28	10.8	6.9
40	757	126	5.5	970	36.3	414	20.6	11.8
50	495	137	7.1	3,730	52.1	1,720	31.7	16.2
60	330	145	9.0	12,910	61.1	5,690	43.4	12.1
70	235	152	10.9	21,730	66.5	10,150	50.3	5.2
80	130	156	12.6	25,750	63.5	12,230	52.0	2.4
				Spruce Balsam Land				
20	1,889	90	3.0	------	2.8	------	2.7	0.2
30	1,211	103	3.9	------	12.5	------	9.2	1.5
40	866	123	5.1	325	30.2	106	20.0	4.9
50	570	134	6.6	2,795	46.9	937	30.9	11.3
60	376	142	8.3	9,020	55.7	3,130	37.7	15.1
70	265	146	10.1	16,642	59.4	6,271	39.9	8.7
80	206	152	11.6	21,275	61.5	7,420	40.5	5.1
				Pine Land				
20	2,062	90	2.8	------	2.1	------	2.3	0.3
30	1,363	101	3.7	------	9.9	------	7.8	1.6
40	972	114	4.6	165	22.2	84	16.2	4.4
50	643	125	6.0	1,295	38.2	565	26.6	9.2
60	422	135	7.7	5,515	49.7	1,973	31.2	11.5

1. Gross Volume includes all living trees
   (a) Board Feet Scribner - Trees 9.0" and over to 6" top
   (b) Total Cords - Trees 5.0" and over to 3" top
2. Net Volume includes only the usable portions of merchantable trees.
   (a) Board Feet Scribner to variable top-minimum 6"
   (b) Cords - to 4" top inside bark
   (c) Pulpwood - includes portions of trees suitable for pulpwood to 5" top which have not been utilized for sawlog.
3. Trees 1" and over

TABLE V

Yield Table of Aspen by Age and Site Classes

Age Classes	Site Classes Standard Cords Good	Med.	Poor	Board Foot Scribner Good	Med.	Poor
20	8	-	-	-	-	-
25	19	7	-	-	-	-
30	29	16	5	1300	300	-
35	36	24	13	4000	1400	-
40	42	30	17	7000	3000	1000
45	46	32	18	8500	5000	2400
50	47	33	16	9000	6000	3000
55	46	30	13	9100	6000	2900
60	43	26	10	9000	5800	2500
65	37	20	6	8400	5200	1800
70	29	14	4	7400	4500	1400
75	21	9	-	6000	3200	700
80	12	4	-	4200	1500	-

These volumes are based on the following heights of dominant trees at 50 years:

Good Site - 72 ft.
Med. Site - 64 ft.
Poor Site - 55 ft.

Cordwood volume is the gross volume in standard cords of peeled wood in 4" D.B.H. and larger to a minimum top diameter of 3" inside bark.

Board foot volumes are gross volumes by the scribner rule of trees 7"D.B.H. and larger, the minimum top diameter being 6" inside bark.

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