USDA Forest Service
Research Paper RM-124
June 1974

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

SILVICULTURE OF PONDEROSA PINE IN THE BLACK HILLS: The Status of Our Knowledge

ABSTRACT

This Paper, intended as a guide for professional foresters, describes major silvicultural conditions likely to be encountered in the Black Hills, reasonable treatment options, and probable results and implications of these treatments. It also describes silvical characteristics and behavior of Black Hills ponderosa pine, and a variety of proven silvicultural tools.

Oxford: 181$174:187. **Keywords:** Timber management, silviculture systems, Black Hills ecology, *Pinus ponderosa.*

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SILVICULTURE OF PONDEROSA PINE IN THE BLACK HILLS: The Status of Our Knowledge

by

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For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

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Charles E. Boldt and James L. Van Deusen

INTRODUCTION

BLACK HILLS FORESTS: A MODEL OF SUSTAINED YIELD

The ponderosa pine (*Pinus ponderosa*) of the Black Hills cannot be expected to match the high levels of wood production attained by forests in areas which are favored by more abundant precipitation, deeper and richer soils, and longer growing seasons. But, while the rigors of the Black Hills environment do impose fairly stringent limitations on forest growth and yield potentials, the fact remains that the area is intrinsically well suited to timber crop culture. This basic premise is neither speculative nor theoretical—its validity has been demonstrated by actual forest responses to nearly a century of consumptive use.

During this period, virtually all of the area's unreserved and operable forest acres have been cut over at least once; many acres have received multiple partial cuts. Large tracts which were logged free of regulatory restraints—prior to establishment of the Forest Reserve in 1897—were commercially clearcut and practically stripped of all trees large enough to yield a mine timber or a railroad tie.

Persistent harvesting, coupled with the destructive impacts of wildfire, insects, diseases, and wind, have nearly eliminated the original old-growth sawtimber stands on upwards of one-half of the commercial forest acres in the Black Hills, and left only light stands of scattered old-growth remnants on the bulk of the remaining acreage.

Despite these massive withdrawals, however, growing stock capital has not been depleted. On the contrary, it has increased steadily in recent decades to unprecedented levels. Total annual increment of merchantable wood, forestwide, has also increased until it is now roughly equal to the average annual cut during the 21 years of unhampered forest exploitation which preceded establishment of the Reserve (USDA-USDI 1967). It is equally remarkable, after all this harvest activity, that only about 1 percent of the commercial forest acres in the Black Hills are currently classed as inadequately stocked for timber production.

The important implication of these facts seems clear: the old-growth pine forest of the Black Hills has been converted—with uncommon success and completeness—to a well-stocked and manageable second-growth forest. Furthermore, the conversion has been accomplished with no large or prolonged falldown in forest productivity. These facts provide convincing evidence of the feasibility of successful timber crop culture in Black Hills ponderosa pine, on a sustained basis. All that is needed is sufficient managerial skill and silvicultural know-how.

PURPOSE OF PAPER

This Paper is an attempt to bring together in a single reference most of what is known about silviculture of ponderosa pine in the Black Hills. The Paper is intended specifically as a field guide for professional foresters who are responsible for prescribing and supervising the application of silvicultural treatments in the woods. It attempts to describe (1) all of the major silvicultural conditions, or problem situations, that the field practitioner is likely to encounter, (2) the treatment options that reasonably may be exercised in each particular situation, and (3) the probable results and practical implications of the various options—insofar as they are predictable—to help the silviculturist choose the option which will come closest to satisfying established management goals. The Paper also contains relevant background information on silvical characteristics and behavior of ponderosa pine in the Black Hills environment, along with an assortment of working tools that have proven helpful in doing a variety of silvicultural jobs.

Much has been learned about the culture of ponderosa pine crops in the Black Hills since Case Number 1 marked the beginning of forest husbandry in the area in 1898.[2] The existing fund of information has been generated by both experience and research. Inevitably, some of what has been learned has never been adequately documented, and that which has been recorded is scattered through a variety of information sources—published and unpublished, old and new. Consequently, a concerted effort and considerable digging is required to piece together a reasonably complete composite picture of the state of silvicultural knowledge and know-how in the Black Hills. Unfortunately, most of the foresters who are actually guiding the practice of silviculture have neither the time nor the resources to tackle this fairly formidable exercise in information retrieval. This Paper has been written for them.

[2]Case Number 1 was a landmark in American forestry in that it was the first exercise of the provisions of the Organic Act of 1897, the first sale of Federally-owned timber, and the first instance of regulated timber harvest on the newly created Forest Reserves (Jackson 1951).

SILVICS

HABITAT

The Black Hills and Bear Lodge Mountains were formed by a regional uplift of the earth's surface millions of years ago. About two-thirds of this elliptically shaped, maturely dissected, domal structure lies in South Dakota; the other third, including all of the Bear Lodge Mountains, is in Wyoming (fig. 1).

Because of similarities in geologic makeup and responses to erosion, both the Black Hills and Bear Lodge Mountains have developed the same four visible and distinctive gross geomorphologic features: (1) a "hogback ridge" of mesozoic sandstone, limestone, and shale, more or less continuous and encircling the whole area; (2) a "red valley," least developed on the east side, and made up of less resistant sedimentary formations, containing some gypsum and iron deposits (which give the soil its characteristic color); (3) a limestone plateau composed of remnants of a once-continuous cap of deep

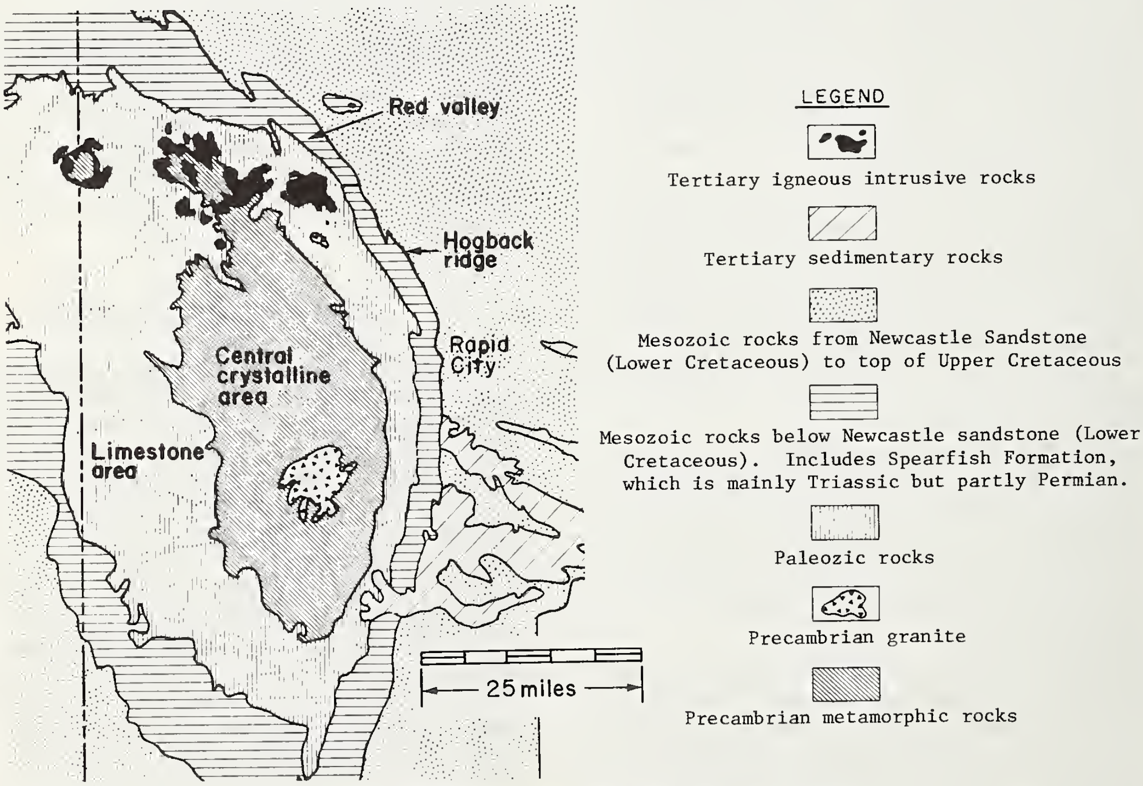

Figure 1.—Generalized geologic map of the Black Hills.

sedimentary layers of paleozoic age; and (4) a central core of crystalline rocks consisting of intruded, igneous material and surrounding metasediments. The first three of these four geologic features encircle the crystalline core in concentric bands of varying width (fig. 2), each with its own distinctive geomorphic characteristics. The entire system is elevated 1,000 to 4,000 ft above the surrounding plains.

The central, crystalline area is characterized by rough to rounded hills and divides with elevations which generally range from 4,300 to 6,000 ft. Two of the highest peaks in this area, Harney and Terry, both exposed igneous intrusions, rise to 7,242 and 7,077 ft, respectively.

On the eastern side of the Black Hills, the limestone plateau forms a narrow ridge occasionally flattening out to narrow uplands with elevations of 3,600 to 4,400 ft. However, the plateau is much more extensive on the west than on the east side because of generally lower west-side dips. Here, the deep sedimentary

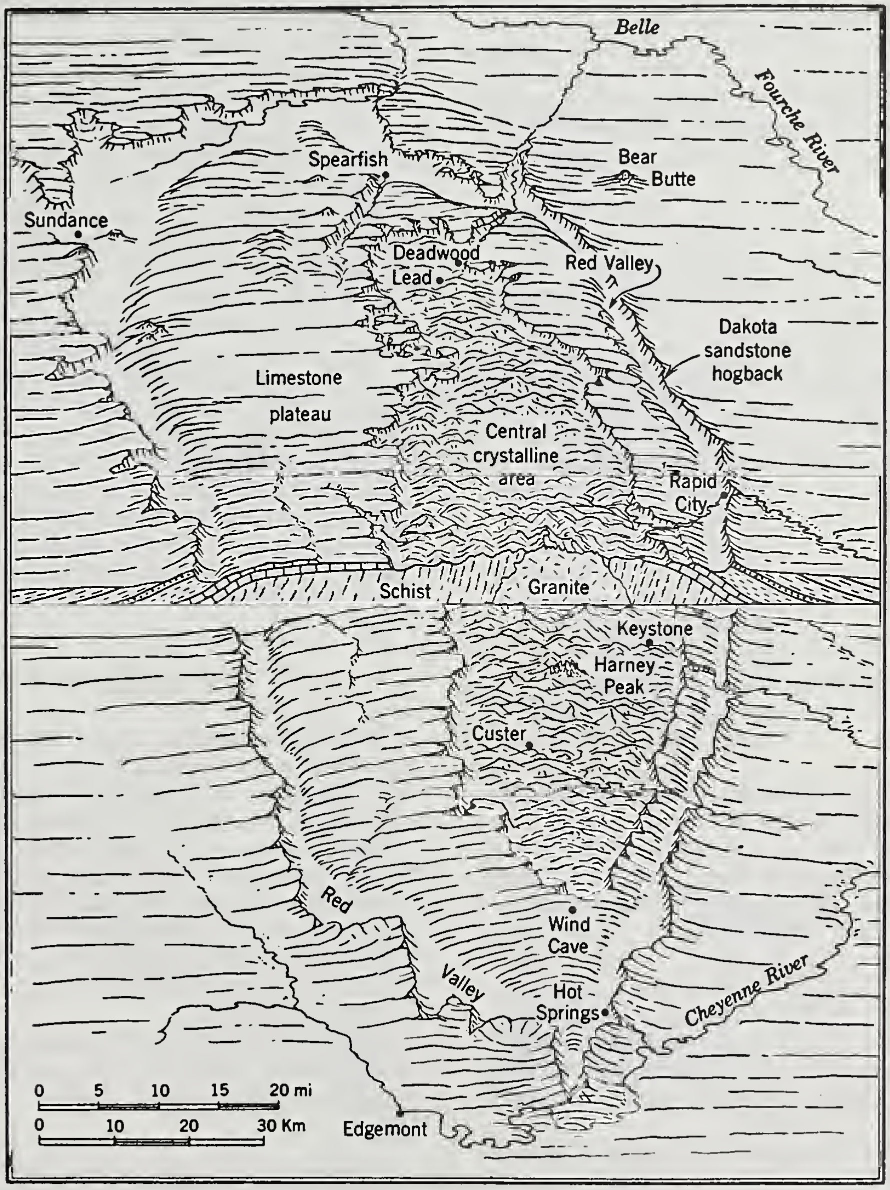

Figure 2.—Diagram of Black Hills showing the main topographic regions on this broad domal structure. (From Strahler, Physical Geography, 3d ed., copyrighted 1969 by John Wiley & Sons, Inc., N.Y. Reproduced by permission.)

formations form wide, rather level divides separated by narrow, steep valleys. Elevations range from 4,500 to slightly over 7,000 ft.

Of the four major landform features, the central crystalline area and the limestone plateau are the main timber-producing areas. In addition, the really important discharges occur in watersheds of the same areas. Limitations imposed by precipitation, soils, areal extent, and mounting competition by other land uses in the red valley and hogback sectors restrict the potentials of these areas for successful forest culture for wood production.

Soils in the Black Hills have not been surveyed, but their general profile characteristics approximate those of the Gray Wooded Soils Group. Radeke and Westin (1963), who examined about 30 profiles during their investigation, described the wooded soils of the Black Hills as having the following general profile characteristics:

01	F layer, 1-2 inches thick	Forest litter, partially decomposed.
02	H layer, 1-2 inches thick	Decomposed forest litter.
A2	Horizon, 3-15 inches thick	Gray loam or silt loam; weak platy structure; very friable moist.
A2 and B2t	Horizon, 2-9 inches thick	A transition zone of variable depth and thickness. Brown loam to silty clay loam; moderate fine blocky structure; blocks often coated with gray dust; friable moist.
B2t	Horizon, 5-26 inches thick	Brown clay loam to clay; moderate to strong blocky structure; very firm moist.

These morphological characteristics generally agree with those found by Myers and Van Deusen (1960) in the more than 100 profiles they examined throughout the Black Hills and Bear Lodge Mountains. Soil depths, measured to the top of the C horizon, ranged from 2 to 57 inches, with an average of 24 inches.

The climate of the Black Hills and Bear Lodge Mountains is modified from that of the surrounding plains by the prominence of the uplift itself, which gives rise to an orographic rainfall belt. Precipitation is increased, while temperature extremes are reduced.

Average annual precipitation ranges from 17 inches in the southern Hills to a small zone of more than 28 inches near Lead in the northern Black Hills. Annual precipitation in the Bear Lodge Mountains averages 18 to 24 inches (fig. 3). Sixty to seventy percent of the annual precipitation falls from April to September. May and June are normally the wettest months; January and February are usually the driest (Orr 1959).

Length of growing season in the region averages about 100 days. Average monthly air temperatures vary from about 68° F in July to 22° F in December, while average annual air temperatures range from 41° to 45° F.

Though pure stands of ponderosa pine are usual, white spruce (*Picea glauca* var. *densata*) occupies about 2 percent of the commercial forest acres and accounts for about 4 percent of the total timber volume. Spruce often grows in nearly pure stands, along stream channels, lower slopes, and north-facing slopes of the northern Black Hills. Oddly, spruce is not found in the Bear Lodge Mountains.

Lodgepole pine (*Pinus contorta*) is also apparently native to the Black Hills, but is found as isolated trees, or in a more or less pure stand of 125 acres north of Rochford. Only isolated trees of lodgepole pine have been found in the Bear Lodge Mountains.

Several other tree species are native to the area, growing in association with ponderosa pine. They represent the montane forests to the west as well as northern and eastern boreal forests. Most abundant are quaking aspen (*Populus tremuloides*), paper or white birch (*Betula papyrifera*), bur oak (*Quercus macrocarpa*), and Rocky Mountain juniper (*Juniperus scopulorum*). A single, small stand of limber pine (*Pinus flexilis*) in the Harney Peak area has been described by Thilenius (1970).

SPECIES BEHAVIOR

Ponderosa pine is a dependable seed producer in this region. Seed crops are normally good to excellent, by local standards, every 2 to 5 years; the longtime average interval between good crops is 3 years.[3] This characteristic, coupled with favorable spring and summer moisture conditions, makes natural reproduction readily and abundantly available. Ordinarily, it is only where a suitable seed source is absent that one must resort to seeding or planting to restock deforested sites.

Extremely high stand densities are common in naturally regenerated stands (fig. 4). Dense seedling stands often contain more than one

[3] *In some years, perhaps, cones and seed will be produced in abundance throughout the area. More typically, though, crops will show considerable local variation in any given year. Widespread crop failures are probably more common than widespread bumper crops.*

tree per ft^2. Unfortunately, natural thinning normally proceeds very slowly, so that initially crowded stands are apt to remain overstocked for long periods, perhaps their full lifespan. For example, a plot stand adjacent to the one shown in figure 4 contained 15,000 trees per acre at age 12. At age 63, it still contained 6,600 trees per acre, with an average d.b.h. of

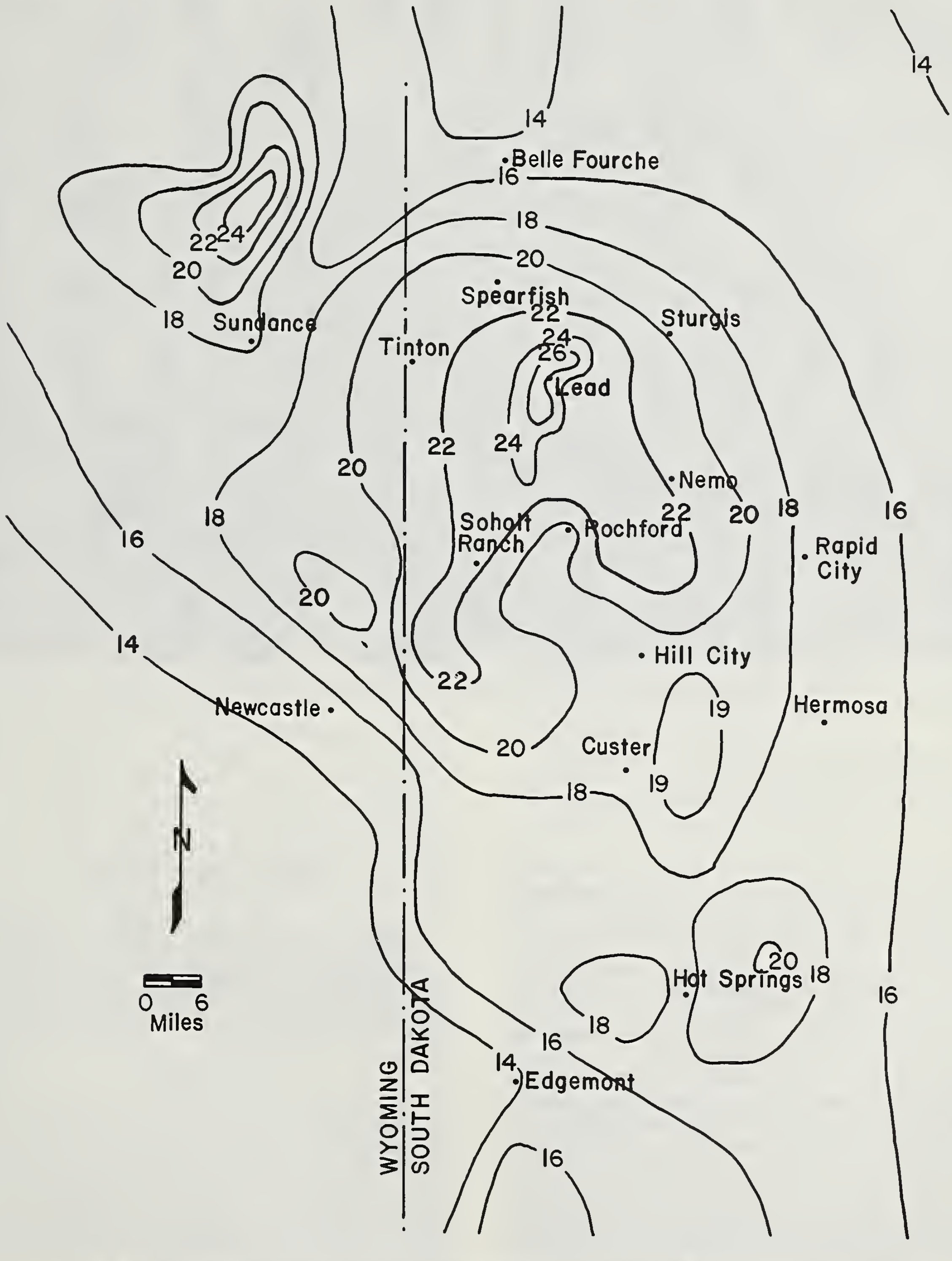

Figure 3.—Isohyetal map of average annual precipitation in the Black Hills area (Orr 1959).

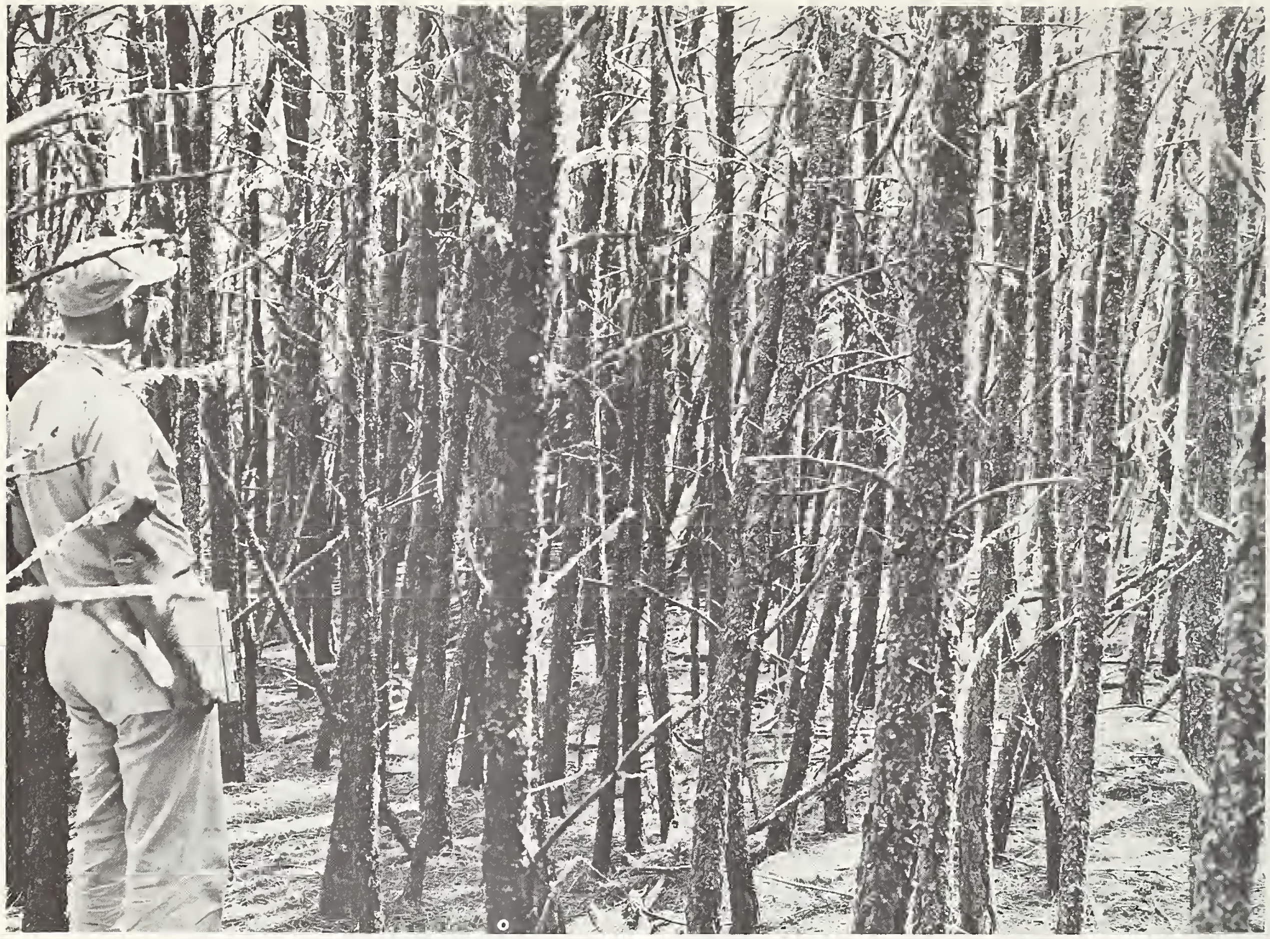

Figure 4.—Stagnant sapling stand: 63 years old; 5,800 trees per acre; average d.b.h., 2.5 inches.

only 2.4 inches (Myers and Van Deusen 1960a).

Though stands may become and remain so dense that they stagnate, release by thinning can produce striking growth responses at most any age.

There is ample evidence that good silviculture can enhance productivity of Black Hills pine sites and stands. However, one must keep in mind that species behavior is strongly influenced by certain environmental factors which impose upper limits on the productivity potentials of Black Hills forest land: (1) a relatively short growing season; (2) limited precipitation; (3) frequent high temperatures, persistent winds, and low humidity during the growing season, all increasing evapotranspiration; and (4) a generally shallow soil mantle with limited capacity for moisture storage.

DAMAGING AGENTS

There are a variety of agents that kill or deform ponderosa pine trees and stands in the Black Hills. Some pose a continual threat, while the impact of others tends to be greatest at some particular stage of tree or stand development.

INSECTS

Only one native insect has demonstrated a capacity for devastating Black Hills pine forests—the mountain pine beetle (*Dendroctonus ponderosae* Hopk.). At epidemic levels, this pest has killed entire stands of pine, greatly influencing the distribution of age classes throughout the area.

Three other insects are of varying but lesser importance throughout the Hills: the pine engraver (*Ips pini* Say); red turpentine beetle (*Dendroctonus valens* LeConte); and pine tip moths (*Rhyacionia* spp.).

Mountain Pine Beetle

General Description

The mountain pine beetle, formerly known in this area as the Black Hills beetle, has been a serious economic pest as long as records have been kept of its activity. An extremely serious outbreak swept through the area between 1895 and 1910, killing trees that contained an estimated 1 to 2 billion fbm (board feet) of lumber. More recently, the northern Hills has been the scene of two serious buildups. In 1963, severe and widespread losses were averted by concentrated efforts of Federal, State, and contract insect control crews. Another outbreak is currently underway. During these increases to destructive levels, annual pine mortality may exceed 50,000 trees.

McCambridge and Trostle (1972) and Cole and Shepherd (1967) present complete yet concise descriptions of the life history and damage caused by the mountain pine beetle. Attacks are usually manifested by reddish- to yellowish-brown "pitch tubes" on the bole from ground to midcrown (fig. 5). Sometimes a copious flow of resin from the tree will prevent successful attack by the beetle. These unsuccessful attacks are called "pitchouts."

The only early external sign of a successful attack is sawdust in the bark crevices or on the ground at the base of the tree. A few weeks after attack, bluestaining fungi, carried into the trees by the beetles, discolor the sapwood. This is a second, and certain indication that the tree has been successfully attacked and killed. The fungi appear to be essential to successful attacks and brood establishment.

Foliage discoloration, known as "fading," provides later evidence of infestation. Chlorophyll loss can start within 3 to 4 weeks after attack, but it usually is not noticeable until the following spring. The needles eventually become a deep reddish brown and all drop off within 2 or 3 years after attack.

The mountain pine beetle has a single annual generation. Adults begin emerging in July, though the early emergence is sporadic and irregular. Emergence gradually increases through late July and early August, and usually reaches a peak for 5 to 10 days about the middle of August, unless interrupted by low temperatures. Females attack live trees shortly after emergence and construct egg galleries in the phloem. The beetle develops beneath the bark; it is outside the tree only during the emergence and attack period.

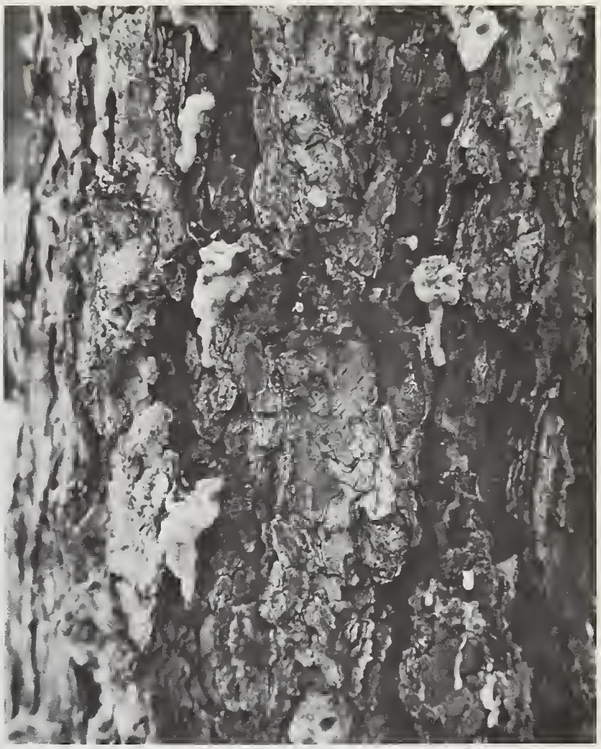

Figure 5.—Pitch tubes on ponderosa pine resulting from attack by mountain pine beetle.

Infestations can balloon at alarming rates. A Forest Service survey during a major buildup in 1963 showed that one infested tree was producing enough beetles to kill six more trees.

Control

Various direct-control methods have been attempted, including chemicals such as an emulsion of ethylene dibromide (EDB) or a 1.5 percent lindane-diesel oil solution. Spraying can begin as soon as spring weather permits, but should be discontinued when about half the population has reached the adult stage. Treatment may be resumed when the flight is over and continued as long as winter travel to the trees is practical. Cacodylic acid (dimethylarsenic acid), an herbicide, has shown promise of control in several recent trials. When introduced into the sap stream of a tree, cacodylic acid either kills the beetles outright, makes the environment unsuitable for them, or both. Because acid-treated green trees are attractive to beetles under certain conditions, they have been used experimentally to reduce beetle populations by setting up fatal "attractant centers." Application of chemicals for any purpose should be confined to those formulations and methods recommended by specialists and appropriately registered at the time their use is proposed; forest pest control specialists should be consulted whenever direct control is contemplated. (See precautionary statement concerning pesticide use which appears inside the back cover.)

Other control methods, such as piling and burning have also been used. High temperatures (more than 160° F) are fatal to the beetle. Slash piles covered with clear plastic during warm seasons will probably reach temperatures high enough to afford some control. Once the slash is piled, plastic covering costs little extra. Small area treatments, such as around home construction, seem well suited to this technique.

Logging infected trees by conventional methods before the midsummer beetle flights is a feasible control when large-scale outbreaks create sufficient volumes per acre. For areas not accessible by conventional methods, but where beetle control is necessary, helicopter salvage logging may prove successful. Large-scale control by any method is expensive. But helicopters offer, among several advantages, a chance to utilize the wood in infected trees.

There is always some degree of natural control. Two of the most abundant predaceous insects are the redbellied clerid beetle *(Enoclerus sphegeus* Fabricius) and a fly (*Medetera aldrichii* Wheeler). The clerid adults feed on the beetles, each consuming up to one per day, during the emergence and attack period. The clerid larvae feed on all stages beneath the bark—as many as 15 have been found per ft^2 of bark. Only the larval stage of the Medetera fly is predaceous, but each fly larva can consume as many as 10 beetle larvae. Other predators of the beetle, such as woodpeckers and some other predaceous insects, become more numerous during periods of high beetle populations. However, these predators provide only moderate assistance in a control program. They do not provide effective and dependable economic control in themselves. Although extremely low autumn and winter air temperatures may prove fatal to a high percentage of bark beetle broods, the infrequency of low temperatures makes them a relatively undependable control factor.

The ultimate goal would appear to be silvicultural management designed to prevent rather than control epidemics. Among the kinds of stands most susceptible to attack are the overdense, low-vigor pole or small sawtimber classes. The timber sales and thinnings which are currently being made in such stands are major steps toward reducing the likelihood of future epidemics in those areas. A thrifty stand of vigorously growing trees is not so susceptible to bark beetle attack.

Pine Engraver

General Description

Commonly referred to simply as Ips or pine engraver, this beetle is another potential threat to pine stands in the Black Hills. The danger from it, however, is generally localized and short-lived. Wygant and Lara (1967) and Sartwell et al. (1971) have given a complete description of the insect and the damage it causes.

Slash is ordinarily the preferred host material, and pieces larger than 2 inches in diameter are most commonly attacked. When the population becomes so large that available slash will not house them all, some Ips are forced to attack nearby leave trees. Diameter classes from 2 to 8 inches are most often involved. An adult beetle and examples of the pine engraver's galleries are shown in figure 6.

For unknown reasons, outbreaks do not always occur under conditions that appear favorable to the beetles. Ten years or more may pass with no attacks in thinning and logging areas. The beetle is always present, however, and can increase rapidly to destructive levels.

Control

The probability of Ips population buildups can be reduced by (1) continued logging or thinning operations that maintain a uniform amount of slash on the ground, (2) concentration of these operations during the late summer and fall (slash may dry enough to make it unsuitable for beetle occupancy before spring emergence occurs), or (3) prompt salvage of windthrown and fire-damaged trees. When examination of breeding material indicates the presence of a large beetle population (where 150 or more adults can emerge from each ft^2 of infested bark), beetle numbers can be reduced by bunching and burning or chipping the slash. Pieces of slash larger than 2 inches in diameter can be sprayed with a 0.25 percent solution of gamma isomer of benzene hexachloride in fuel oil (Wygant and Lara 1967).

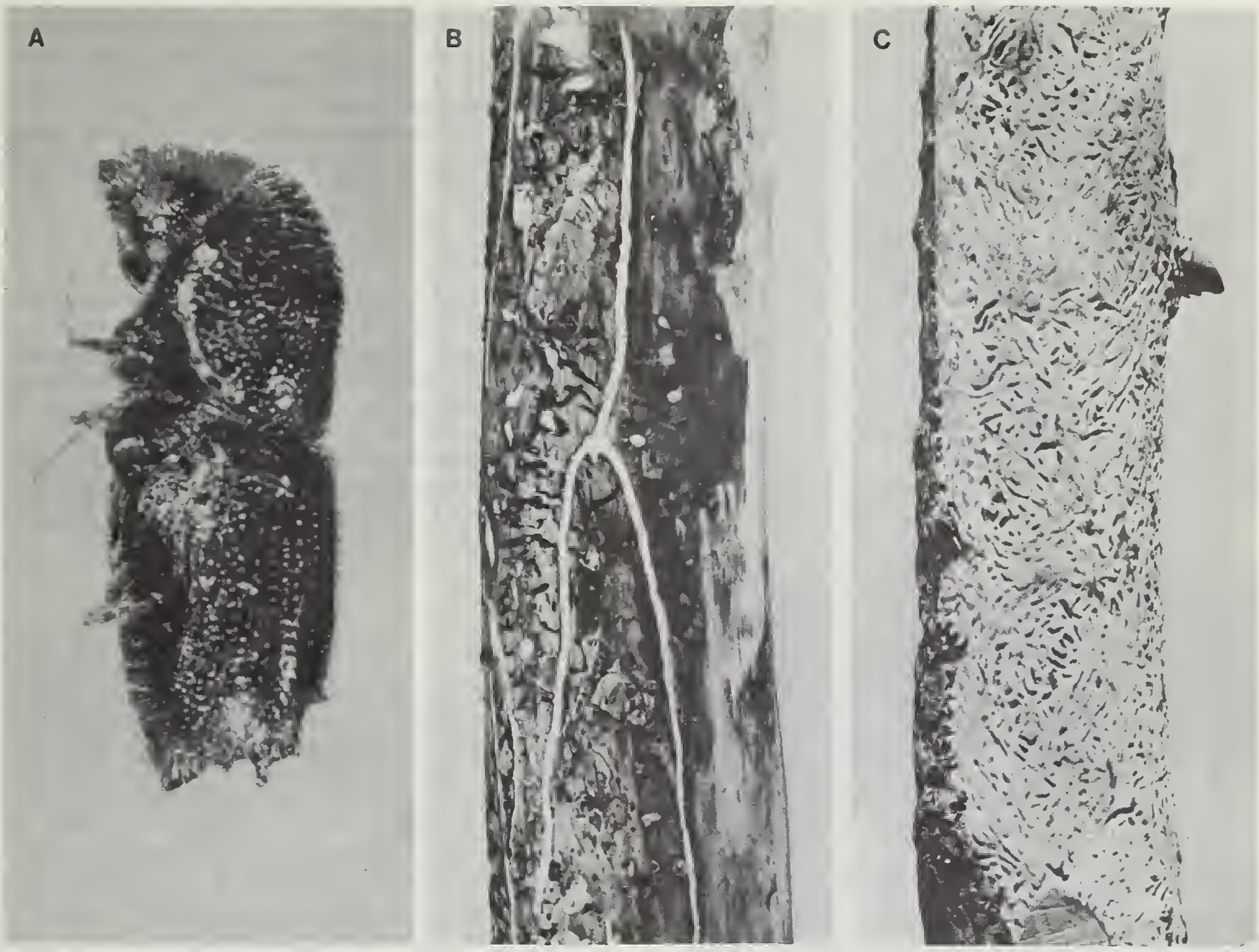

Figure 6.—Pine engraver: *A,* adult; *B,* breeding galleries in ponderosa pine; *C,* feeding galleries in ponderosa pine.

Red Turpentine Beetle

General Description

This beetle, whose size, host preference, and range are the largest of all species in the genus *Dendroctonus*, also is found in the Black Hills. Commonly called the red turpentine beetle (fig. 7a), it is usually not a direct cause of mortality among pines in this area. More often it is a secondary factor, attacking trees that have been weakened by other insects, fire, lightning, logging, or drought (especially on poor sites). Occasionally, however, it does make the primary attack, lowering the trees' vigor and making them more susceptible to damage by other species. Smith (1971) and Eaton and Lara (1967) provide good coverage of the information about this insect.

Standing trees 1 inch in diameter and larger may be attacked. Weakened trees are most often attacked, but those close to freshly cut stumps or green logs are also susceptible. The most conspicuous external indicator of damage is the large whitish pitch tubes the beetles make on the bark surface when they enter the tree (fig. 7b).

The tubes are usually found on the lowest 6 ft of the bole, but may occasionally be seen up to a height of 12 ft. Other damage indicators are small pitch balls and/or coarse reddish frass lodged in bark fissures below the point of attack, or on the ground.

Beneath the bark the pattern of the galleries of this species is distinctive (fig. 7c). The large longitudinal egg galleries and broad larval chambers excavated between the bark and wood distinguish the work of this from other

Figure 7.—Red turpentine beetle: *A*, adult; *B*, pitch tubes; *C*, adult gallery and eggs in inner bark of ponderosa pine.

bark beetles. The phloem and sapwood around these galleries are usually heavily bluestained because the beetle is a vector of various fungi, yeasts, and bacteria.

When adult beetles emerge, they may fly for 10 or more miles to attack new hosts. The female begins the attack and is then joined there by the male. The egg gallery is excavated in the phloem, generally proceeds downward, and is partially filled with frass. The eggs hatch in 1 to 3 weeks, and the young feed gregariously in the phloem away from the gallery. In doing this, they form a fan-shaped cavity with an irregular margin. The cavity may range in size from a few inches^2 to more than a ft^2. When the larvae are fully grown, they make separate cells in which they pupate and transform into adults. The new adults emerge from the pupal cells by boring through the bark. The number of generations per year usually ranges from one to three.

Control

Damage can be minimized by cultural practices that keep trees growing vigorously. Among the practices to be avoided are injuries to roots or stem, deep fills or flooding over the roots, and piling green logs or timber near live trees.

Benzene hexachloride is an effective insecticide with a long residual effect. This chemical, when sprayed on the bark in an oil solution, kills some of the insects in the tree and will prevent attacks for many months. It may also be applied to infested stumps to kill emerging beetles. All chemical applications should be made on the basis of recommendations by experts in that field. Acceptable methods and formulations are changing rapidly.

Pine Tip Moth

Pine tip moths are pests of small trees. At least two species of the moth, *Rhyacionia bushnelli* and *R. neomexicana,* are likely present in the Hills. The damage is usually neither spectacular nor serious. In certain special situations, however, it can be important. Repeated loss of leaders in a seed orchard could negate many man-hours of skilled work.

Damage is caused by the larvae mining in the new shoots. As larval development progresses, the infested tips begin to fade. Though repeated attacks tend to cause the trees to become malformed, most trees outgrow the damage. By the time trees are 8 to 10 ft tall, little evidence of damage remains. No research has been conducted on this insect in the Black Hills, mostly because of its small importance here.

Applied control is unnecessary under most forest conditions. In some parts of the country, infestations appear to be associated with low site conditions.

DISEASES

Only a few fungi of importance to the commercial timber grower are found in the Black Hills and Bear Lodge Mountains. Dwarf mistletoes (*Arceuthobium* spp.) are capable of infecting Black Hills pine, but have never been found on trees in this region. Consensus among pathologists is that climatic factors prevent dwarf mistletoes from becoming established in this area.

Red Rot

Red rot (*Polyporus anceps* Pk.), which causes a white-pocket rot, is one of the major causes for loss of sound wood in commercial stands (fig. 8). When losses from red rot are combined with those from the brown cubical rots, percent of scalable defect rises markedly with increasing tree age (Hinds 1971, fig. 4, table 4).

Comprehensive coverage of red rot in ponderosa pine in the Black Hills is included in Andrews' reports of 1955 and 1971. Both immature and mature, and vigorous and declining trees are susceptible to infection. Even though virtually no economic losses are sustained by immature trees, red rot should be considered a disease of all age classes except seedlings and saplings.

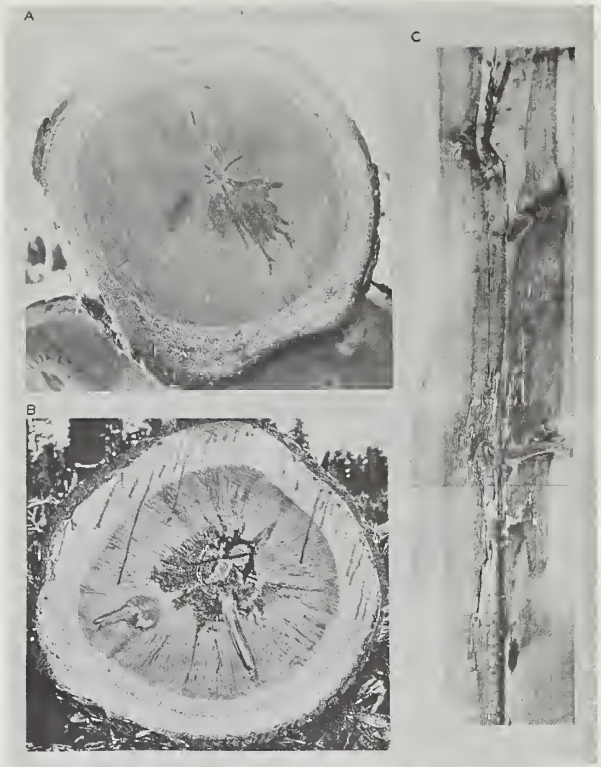

Figure 8.—Appearance of red rot: *A*, incipient decay at end of a saw log; *B*, advanced decay at end of a saw log; *C*, advanced decay bordered by incipient decay in heartwood of a board (the centrally located area of disintegration probably indicates where rot entered the trunk).

Development

Infection becomes established in living trees through the branches. Branches larger than 1.5 inches in basal diameter are 20 times more likely to be avenues through which the infection spreads than are smaller branches. Nearly all the decay develops from airborne spores released by fruiting bodies associated with sap rot of dead material. The sporophores continue to develop annually for about 6 years. The spores lodge in small openings in the bark of dead branches, and probably germinate immediately if moisture is favorable.

After germination, the fungus develops a pad of mycelium between bark and wood, from which the branch wood itself is infected. The infection then spreads toward the bole through both wood and pith of the branch (fig. 9).

Branches can be attacked by red rot fungus from the time they have deadwood (the whole branch need not be dead) until they have been dead about 20 years, provided they have retained their bark. It is very rare for broken, dead branches to become infected. A tree with large, dead, bark-covered branches is a likely candidate for red rot infection (fig. 10).

Since infection occurs through dead branches, the possibility of multiple entrance points throughout the whole tree stem increases with age. Once the rot reaches the heartwood, it may spread up and down the trunk and coalesce with other decay pockets. Thus in older trees the decay may be one long column, many small columns, or a combination of both. There is a lag, however, between the time red rot reaches the heartwood and the development of scalable defect. Hinds (1971) found age classes older than 100 years to have substantially greater percentage of scalable defect due to red rot.

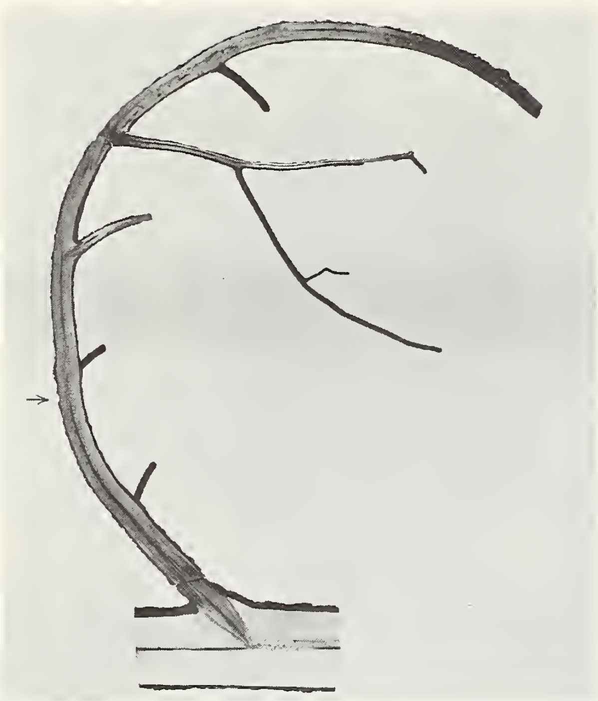

Figure 9.—Longitudinal section through a bark-covered dead branch and adjacent part of the trunk of a small blackjack exposing red rot that apparently entered at about the point marked by the arrow. Decay had extended as far as the pitchy base of the branch where it had concentrated into slender, highly pigmented columns.

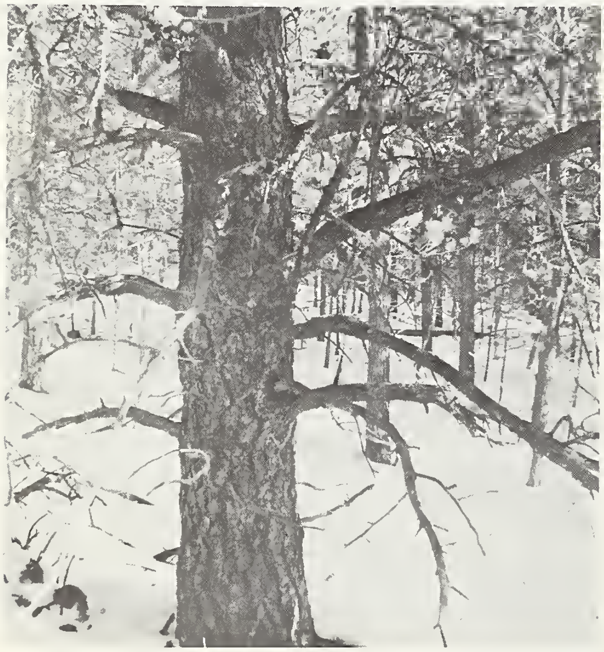

Figure 10.—Large bark-covered, dead branches are likely infection points for red rot fungus.

Detection

Red rot is difficult to detect in living trees because fruiting bodies rarely develop on them, and then only on dead branches where they merely indicate branch decay. The fungus does not require conspicuous entrance courts such as wounds, fire scars, or dead tops. No practical method has been found to identify decayed mature and overmature trees and estimate volume losses before cutting.

In immature trees, dead branches are generally reliable indicators of red rot. Undecayed branches resist pressure or break with a crack. Branches in an advanced stage of decay offer little resistance and break as though waterlogged. Suspected branches must then be pruned flush with the trunk to see whether the knots have been penetrated. Heart rot is likely if red rot occurs in the pith. In immature trees, bark-covered branch stubs usually indicate the presence of red rot.

Red rot can often be identified by the characteristic rot pockets that appear in the pitchy base of the branch. Incipient branch decay can be recognized by a continuous white mycelial pad (fig. 11), that binds bark to wood so tightly that pieces of wood stick to the bark when it is peeled off.

Control

Incidence of infection by red rot can be reduced by sound silvicultural practices. Prun-

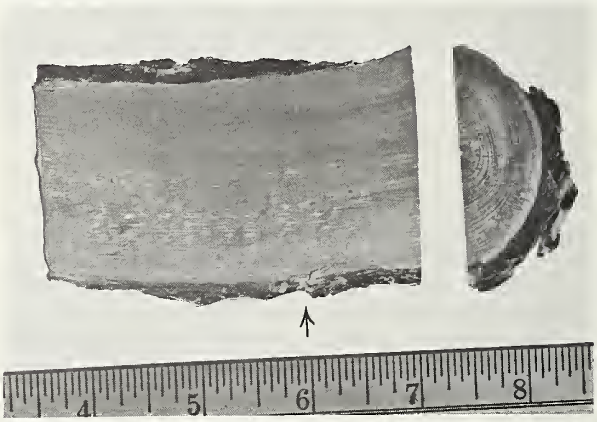

Figure 11.—Cross sections of a dead branch about 2 years after it was inoculated with red rot fungus at a point indicated by the arrow. The incipient stage in the upper half of the longitudinal section is revealed only by a slight discoloration of the wood. The advanced stage in the lower half is characterized by small white pockets running parallel to the grain. The irregular white line between the bark and the wood on the upper side of the section is the edge of the fungus pad. The cross-sectional view illustrates rapid radial invasion from the pad.

ing is probably the best cultural treatment in stands where average diameter is small (less than 7 inches). Removing all branches on the butt log in one operation is desirable, though one or more repeat visits may be needed to prune up 17 ft. Pruned branch stubs are rarely the site of infection by red rot. The earlier pruning is begun, the more complete will be protection against red rot.

Intermediate cuts to improve volume growth rates may also help cut down the incidence of red rot when infected trees and those uninfected trees which have many large branches are removed. Stand densities low enough to promote rapid individual tree growth will not necessarily lead to development of large branches.

Western Gall Rust

This rust is the major component of the *Cronartium coleosporioides* complex in the Black Hills (Peterson 1959) and is the second most troublesome disease on ponderosa pine. It is a serious problem in localized Black Hills areas. Peterson (1959) reported cankers occurring below a height of 32 ft on an average of 7 percent of the dominant and codominant trees in an 1,800 tree sample in the Roubaix vicinity. Nearby in the Windy Flats area, from a third to a half of the potential crop trees had cankers. Nearly all trees at Windy Flats bore galls (often hundreds per tree), which had killed branches and deformed trees. The rust affects the form, lumber content, and growth rate of pines, and kills individual trees, but is not known to destroy whole stands. Peterson (1960) provides more detailed coverage of this disease.

Gall rust infects pine of all ages. It is most serious in plantations, where it may kill young trees. Most infections occur on twigs of the current season. When the rust invades pine bark, cambial cells of the pine shoot begin to divide rapidly. The result is a woody gall, soft at first, but later as resins and other deposited materials solidify, the gall becomes harder and more decay resistant than normal wood. Galls usually live only a few years because when they produce fruiting bodies (aecia) they disrupt the host bark and often kill the shoots and stems which bear them.

Cankers are formed on the trunks of trees through infections from branches or wounds, (fig. 12) and may cause mortality. However, many trees survive and appear to sustain only slight growth loss. Loss of merchantable length and mechanical weakness are the main disadvantages of cankers.

Elimination of the disease from timber stands is not possible, but fortunately such action is

Figure 12.—*Peridermium* canker on bole of ponderosa pine.

not needed. The aeciospores are capable of transmitting the disease directly from pine to pine and these windborne spores can be disseminated for hundreds of miles. Prudent thinning of trees containing trunk cankers and pruning lower branches which contain gall minimize the adverse effects of gall rust. Unfortunately, however, vigorous trees are more apt to be infected than weak ones, partly because the greater surface area of new shoots on the faster growing trees provides a greater chance for infection.

Experiments with antibiotic sprays and selection of rust resistant pines also offer some promise of control.

Shoestring Root Rot

This root rot is common throughout most of the forested areas of the world. Although it had not previously been considered a serious threat to forest stands in the Black Hills, it has caused locally heavy losses in young plantations and scattered mortality of sapling and pole-sized trees in thinning plots. It may well be an unrecognized cause of mortality elsewhere in the Hills.

The greatest trouble may occur in the first decade after plantation establishment on a cleared area, or after a thinning to create specified stand conditions (Swift 1972). *Armillaria mellea* colonizes roots and stumps, and a high inoculum may be built up in thinned areas.

Infection occurs mainly through mycelial strands, or rhizomorphs, which grow through the soil. They can penetrate even unwounded bark by mechanical pressure, aided by enzyme activity. Infection may result also from root contact. Cultivation to reduce competition from surrounding vegetation may increase the likelihood of infection by injuring near-surface roots of planted trees.

Major symptoms of infection begin with a general decline in vigor or abrupt cessation of growth, followed by yellowing of needles and ultimately death of the tree. Whitish mycelial fans, under the bark near ground line, are characteristic evidence of infection. An abnormal resin flow from the root collar is sometimes so great that the litter and soil are cemented into a hard crust. Fruiting bodies (mushrooms) have been noted in midsummer, usually in clusters on stumps, at the base of standing trees, or from the ground. Occasionally, bark beetles attracted to an infected tree that would eventually succumb to root rot, are thought to be the primary cause of death, but are actually secondary causes.

There are no proven methods of direct control of this disease.

Needle Cast

Needle cast (*Elytroderma deformans* (Weir) Darker) causes some defoliation on ponderosa pine in the Black Hills, but is not a serious problem. It is found most often on trees in sheltered situations, such as bottoms or in thickets of reproduction. Lower crowns and interiors of pole-sized and larger trees are usually affected. Trees moderately infected with needle cast have reduced vigor, and are often attacked by bark beetles (Childs 1967).

Open-growing young trees are seldom injured permanently unless the leader is repeatedly infected. Witches' brooms, denser and more globose than those caused by dwarf mistletoe (for which they are sometimes mistaken), often develop in crowns of trees with average or better vigor after several years of light to moderate infection (fig. 13).

Figure 13.—Witches' brooms on pine infected with *Elytroderma*.

FIRE

Wildfire

Because of its potentially destructive nature, wildfire receives a large measure of attention in pine management. The maximum hazard period is midsummer through fall, although fires can burn in any month in much of the Black Hills.

Timber management activities must be conducted so as to minimize the danger from wildfire, in line with good silviculture and economic operation conditions for the woodcutter. Harvesting heavily branched overstory trees produces a greater volume and weight of fuel than what is generated by thinning and intermediate cuts in trees with smaller crowns. Larger branch and stem components of logging and thinning residues do not break down rapidly in the Black Hills, but needles and fine branches decompose after 1 to 3 years on the forest floor, especially under heavy winter snow cover.

The Black Hills National Forest has developed "slash calculators" which permit them to estimate the amount of slash fuel, in tons per acre, created by precommercial or commercial thinning and sawtimber harvesting.

Fortunately, good silvicultural practice is compatible with a high level of fire protection. Concentrations of slash and debris can be lopped and scattered, or piled and burned when conditions permit, to reduce the fire hazard and improve esthetic appearance. Along important travel zones, fire danger can be reduced to a minimum and visual appearance greatly enhanced by chipping the logging and thinning residues.

Ground fires under stands composed of widely spaced trees are less likely to "crown" than fires under closely spaced trees in untreated stands. Bark is thicker on the lower stem of trees in more widely spaced stands, which improves their chance of surviving a moderate ground fire.

Salvage and recovery of trees in the aftermath of a forest fire can be a difficult problem. Deciding which trees should be cut, since they have a poor chance for survival, and which ones can be safely left are decisions that test the managers' skill.

Amount of crown killed by the fire appears to be a workable criterion for selection. Research done in the Southwest (Herman 1954) has produced guides that may be applied in the Black Hills. Mark for removal all trees with (1) more than 60 percent of the length of live crown killed by fire; and (2) all trees with 51 to 60 percent of length of live crown killed if the fire in the vicinity of the tree was a heavy ground or combination ground and crown fire.

Low-vigor trees may be killed by only a small amount of fire damage, and any tree will die if severe scorching of the bark has killed the cambium underneath, even though the crown was untouched. Live, healthy cambium is white and spongy, while the heat-killed tissue turns brown rapidly and has a sour smell.

Controlled Fire

Little research on the use of fire has been done locally. Perhaps the most serious deterrents have been (1) frequent occurrence of hazardous burning conditions essentially the year around, (2) high probability of abrupt, major changes in fire weather, and (3) the common presence of dangerously large accumulations of forest fuels, the result of fire exclusion and naturally slow breakdown of dead plant material. In combination, these factors tend to make prescribed burning a speculative activity in the Black Hills, even in the presence of high-caliber control capabilities.

In managed stands where trees are widely spaced, advance pine reproduction is likely to become established before it is needed or wanted. Light ground fires may be a useful way to destroy unwanted seedlings while they are small, without damage to parent stands. This approach might also reduce fuel accumulations and provide a measure of control over composition and development of understory vegetation.

A current McIntire-Stennis Cooperative Forestry Research Program with the State University of South Dakota is evaluating prescribed burning as a means of reducing or eliminating tree encroachment into Black Hills grasslands. Results from the study could be helpful in developing guidelines for use of prescribed burning as a silvicultural tool. Specifically, it may contribute to solution of the problem of unwanted advance reproduction.

Perhaps the least promising of the several proposed uses of prescribed fire in the Black Hills is for thinning of overstocked, immature pine stands. The reason, of course, is that the selectivity of fire depends upon the amount of intrastand variation in tree size and fire resistance. Since expression of dominance occurs very slowly in Black Hills pine stands, the typically dense ones are apt to stagnate before they develop enough structure for successful thinning with fire.

WIND AND SNOW

Trees that grow for decades in dense stands tend to have slender stems, poorly developed and distributed root systems, and asymmetrical crowns. Rocky and relatively shallow soils over much of the timber growing sites in the Black Hills provide tenuous anchorage for large trees. Taproot formation, plus extension of roots even into rock fissures helps overcome the disadvantage of shallow soils. When stand density is abruptly reduced by a single drastic intermediate cut, many of the reserved trees are likely to be uprooted, broken, or bent (fig. 14). Existing stands that are too dense for trees to reach merchantability in the desired length of time should therefore be thinned in a series of operations.

Stands that are maintained at highly productive densities from seedling size to end of rotation should be much less susceptible to wind and snow damage. Trees in such stands will presumably develop sturdier stems and better anchorage in response to gradual increases in stress, and so be able to withstand normal wind and snowloads.

Snowbend and breakage occurs more often in sapling and small pole-sized trees. Windthrow is a more common hazard to large pole and small sawtimber sizes.

LIVESTOCK AND DEER

Cattle are responsible for most livestock damage. Trampling as the cows walk along plowed furrows is the most common form. Cattle rarely graze or browse on seedlings. Sheep may browse the tips of very young seedlings. Occasionally cattle will rub on individual small saplings, scraping off bark, and breaking

Figure 14.—Trees in this pole stand were whippy saplings when a tardy first thinning was made. Snowbend took a heavy toll of reserved trees.

branches and stems. Fencing out livestock until the trees are small saplings is the most practical protection.

Deer do not ordinarily browse on pine seedlings to the extent that plantation protection is needed. Trees can recover from random browsing with little loss of growth. The mammal repellents ZAC (Zinc dimethyldithiocarbamate cyclohexylamine complex) and TMTD (tetramethylthiuram disulfide) were tested on browse species in the Black Hills (Dietz and Tigner 1968). Initial successes with these chemicals indicates that long-term protection to pines would be available if needed.

RODENTS AND BIRDS

About 15 genera of small mammals that eat pine seed are found in the Black Hills and Bear Lodge Mountains, but only two, *Microtus* and *Peromyscus*, cause serious seed losses. These mice also can cause nearly complete failures among seedlings in plantations by girdling stems under the snow during winter.

Both cottontail and jackrabbits are known to girdle seedlings or to clip off leaders and succulent branch tips. Frequently, the portion nipped off is not eaten, but left on the ground near the original plant.

Of all the rodents, porcupines cause the most damage to trees. The trees are never completely immune to porcupine depredations—seedling to sawtimber sizes may be attacked (fig. 15). The most desirable trees, dominant and codominant crown classes, are the ones most often attacked (Van Deusen and Myers 1962). Where porcupine activity is heavy, large numbers of plantation trees, not just an occasional individual, have been deformed or killed. Porcupines appear to have no redeeming characteristics, while their potential for damage is high.

Poisoning is probably the most effective method for controlling rodent losses in seedings and plantings. Grain treated with compounds such as zinc phosphide, applied at 1 to 3 pounds per acre, apparently offers satisfactory mouse control. In direct seeding operations, the seeds themselves may be coated with rodenticides.

Damage from porcupines and rabbits can be controlled through use of strychnine-treated salt blocks, installed in bait boxes scattered throughout plantations or natural stands. Bait boxes must be constructed so that larger animals such as sheep, calves, or deer cannot be poisoned accidentally. A few losses of squirrels and other animals that are nondestructive to plantations may be unavoidable.

Birds are not known to cause any serious losses of seeds or seedlings in this area. Of the more than 200 species that have been seen in the Black Hills and Bear Lodge Mountains, about 30 are known seedeaters. The seasonal bird populations and number of species that favor pine seeds are both small.

Seeds used in direct seeding operations are coated with aluminum powder to make them less subject to bird losses. Some minor seed losses may occur from birds such as red crossbills and black-capped chickadees taking seeds out of tree-borne cones. Natural reproduction is normally too abundant for such seed losses to be important.

Sapsuckers sometimes bore into ponderosa pine stems to expose the tender tissues of the inner bark, an important component of their diet.

SITE QUALITY

SIGNIFICANCE

Site index is the best method presently available to Black Hills foresters for objectively rating the productive capacity of their forest

Figure 15.—Porcupine damage to ponderosa pine: *A*, seedling—the extensive chewing will ultimately kill it; *B*, pole—merchantability will be limited to a point just below the damage, even though damage probably will not kill the tree.

sites. Two techniques for estimating site quality in the Black Hills give numerical indexes.

Intensive timber management including harvest, regeneration, intermediate cuts, and perhaps even pruning, will depend heavily on a priority-for-action rating so long as financial and manpower resources are limited. Action priorities for any given cultural practice should be based on site quality estimates—the best sites receiving needed treatments first, with lower sites in correspondingly lower priorities.

CONVENTIONAL DETERMINATION

Site index can often be readily determined from the conventional height-over-age curve relationships. Curves prepared under the direction of Hornibrook are suitable for Black Hills pine stands where age of the index trees is at least 70 years and where past crowding has not materially restricted height growth (fig. 16). The height-age relationship can be affected by suppression, as shown by a 70-year-old, naturally stocked stand of about 2,800 trees per acre (4-ft spacing), which underestimated site index by 15 ft. Some reduction in growth from competition can be expected from nearly all stands old enough to use the conventional form of index estimation. Some trees in Hornibrook's sample were adding on more than 20 rings per inch.

Data for Hornibrook's site curves came from nearly 400 trees located at 20 widely separated areas in the Black Hills region. He classified them as vigor class "B" trees which were still making height growth, and had the following general characteristics: "fair to moderately vigorous crowns with average width or narrower, and length less than 55 percent of total

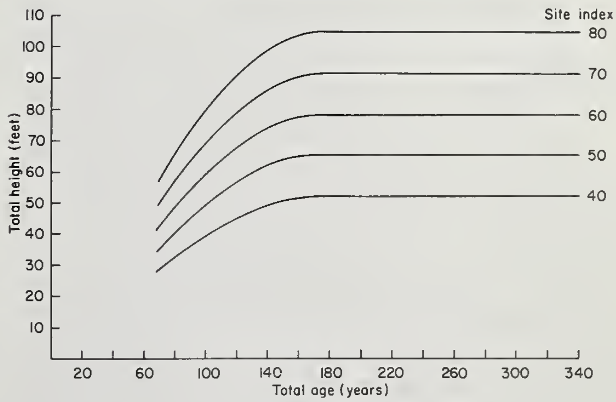

Figure 16.—Site index curves for ponderosa pine.

height; either short wide crowns or long narrow ones, but not sparse nor ragged; occasionally flat on one side; position either dominant or codominant but sometimes isolated."

Height measurements (to the nearest ft) and age counts made from borings taken at the base of the tree should be averaged for several trees when site index curves are used. These averages provide an integrated index value which applies over the area occupied by the trees. Increasing the number of trees measured on a sample area increases the reliability of site index estimates. However, the little improvement in sampling error gained by measuring more than six trees is more than offset by the difficulty in finding suitable trees and the time required for measurements. All trees sampled should be free from diseases or mechanical damage to the upper bole and meet the standards for Hornibrook's vigor class "B".

ESTIMATES FROM SOIL AND TOPOGRAPHY

Very commonly in the Black Hills, the conventional method of site index estimation cannot be used. Either there are no trees present, or the ones that are present are unsuitable for measurements. Site index for crystalline or limestone areas may be estimated from tables 1 and 2 using soil and topographic parameters (Myers and Van Deusen 1960b). Use table 2 where estimates are desired for sites on the hogback ridge. Equations from which the tables were derived may be useful, especially where data are being computer processed. The equations are given in Myers and Van Deusen (1960a).

Two special topographic situations may be encountered in the field, and should be handled in these ways:

1. All bottoms, whether main or side valley, should be called 0 percent of the distance upslope.
2. Sloping ridges with tops more than 3 chains wide should be measured as slopes. A ridgetop should be classified as 100 percent up the slope only when the ridge line is approximately level or less than 3 chains wide.

Suppose a forester planned to plant trees on a burn, but he decided not to put them on any site with an index less than 50. One portion of the burn involved an entire hillside, from creek bottom to ridgetop. Average gradient of the slope was 30 percent and it faced generally east. The upper quarter of the hillside consisted of exposed metamorphic rocks with soil that was obviously only a few inches deep. Downslope from the rocky area, soil depth was unknown.

Two or three scattered soil pits dug below the rocky upper slope each exposed soil depth of at least 20 inches—digging stopped at that depth. Table 1 indicates the site index to be at least 51, probably higher, depending on how deep the soil actually was. Since soil depth normally increases from ridgetop to slope bottom, all of the slope from creek bottom to rocky area at

Table 1.--Site index of ponderosa pine (in ft) in the crystalline area of the Black Hills and Bear Lodge Mountains, northwest and southeast slopes[1]

Distance upslope and soil depth	Site index when slope percent is--				
	0	10	30	50	70
	Feet				
<u>0% upslope</u>:					
5 inches	53	51	49	--	--
10	58	56	54	--	--
15	61	59	57	--	--
20	63	62	59	--	--
30	67	65	62	--	--
40	69	68	65	--	--
60	73	72	--	--	--
<u>30% upslope</u>:					
5 inches	49	48	46	44	42
10	54	53	50	48	46
15	57	56	53	51	48
20	59	58	55	53	50
30	62	61	58	56	53
40	65	64	61	58	55
60	69	67	--	--	--
<u>60% upslope</u>:					
5 inches	46	45	43	41	39
10	51	50	47	45	43
15	54	52	50	48	45
20	56	55	52	50	47
30	59	58	55	52	50
40	61	60	57	54	52
<u>100% upslope</u>:					
5 inches	43	42	40	38	36
10	47	46	44	42	40
15	49	48	46	44	--
20	51	50	48	46	--
30	54	53	50	--	--
40	56	55	52	--	--

[1]Add 1 ft for north and east slopes, and 2 ft for northeast slopes; subtract 1 ft for south and west slopes, and 2 ft for southwest slopes.

Table 2.--Site index of ponderosa pine (in ft) in the limestone area of the Black Hills and Bear Lodge Mountains

Soil depth (inches)	Site index when distance(percent) upslope is--										
	0	10	20	30	40	50	60	70	80	90	100
	Feet										
5	--	--	--	--	--	--	--	40	39	38	37
8	--	--	--	--	--	--	--	44	43	42	41
10	--	--	--	--	50	49	48	47	45	44	43
13	59	58	56	55	53	52	50	49	48	47	45
15	61	60	58	56	55	53	52	51	49	48	47
20	65	63	62	60	58	57	55	54	52	51	50
25	68	66	64	63	61	59	58	56	55	53	52
30	71	69	67	65	63	62	60	58	57	55	54
35	73	71	69	67	65	64	62	60	59	57	56
40	75	73	71	69	67	66	64	62	60	59	57
45	77	75	73	71	69	67	65	64	--	--	--
50	79	77	74	72	71	69	67	65	--	--	--
55	80	78	76	74	72	70	68	66	--	--	--

75 percent upslope could be planted, since it would meet the minimum site index of 50. If there were any doubt about lower slope conditions, more holes could be dug. At 30 percent upslope, a soil depth of only 9 to 10 inches would meet the minimum of site index 50, providing other topographic factors remained the same.

Estimates of site index made from soil and topographic factors are strictly applicable only to the point sampled. The more variable the site is, the more points should be sampled to accurately characterize site quality over the entire area. Quite often all that is needed, however, is an index estimate from what appears on the ground surface to be the extremes in quality.

GROWTH, YIELD, AND QUALITY IN MANAGED STANDS

A roundup and critical analysis of all that has been learned about growth, yield, and quality in Black Hills ponderosa pine leads to the following generalized assessment of the state of our knowledge:

1. Much has been learned about growth responses of trees and stands to single thinnings in overstocked, even-aged, immature stands. We can predict responses across a wide range of stockings and size classes. Influence of site quality on these responses is predictable only in general terms.
2. Preliminary information has been obtained on potential growth and development of trees and stands under prolonged, intensive culture, begun early.
3. Less is known about potential yields, both intermediate and final, in continuously cultured stands.
4. Some good information has been obtained on changes in vertical distribution of increment, hence in stem form, of immature trees released from crowding by light to moderate, single thinnings. Little is known about long-term effect of continuous culture on stem form.
5. Some good, but limited information is available on technical properties of stemwood from fast- and slow-growing trees in thinned and unthinned stands.

PAST RESEARCH ON GROWTH

Results of early, unreplicated studies of thinning and growth in the Black Hills, started between 1906 and 1931, showed that:

1. Thinning of overstocked stands can be expected to improve growth of reserved trees in diameter, volume, and, in most cases, height—even in stands which have been stagnant for several decades.
2. Growth responses tend to be roughly proportional to the relative change in degree of competition produced by thinning. However, none of the early thinning trials included treatments severe enough to reveal potential growth rates for free-growing trees.

3. One-shot precommercial thinnings which leave about 600 1-inch trees, 400 2- to 3-inch trees, and 300 5-inch trees will effectively control subsequent mortality, allow full utilization of the volume growth potential of "average" sites, concentrate increment on the better growing stock, and stimulate improved rates of height and diameter growth for one or two decades (Myers 1958, Myers and Van Deusen 1960a).

Related research, during the 1950's and 1960's, showed that:

1. Release of trees from severe crowding not only increases periodic rates of lower bole diameter growth, but also increases the overall length of the diameter growth season in some years; rate of height growth also increases but with no accompanying change in seasonal duration. Moisture is the environmental factor which most frequently limits tree growth in the Black Hills (Van Deusen 1968).
2. Future basal area, ft^3 volume, and average d.b.h. of existing immature stands can be estimated satisfactorily by regression, using stand and site data from temporary plots as independent variables (Myers and Van Deusen 1961).

CURRENT RESEARCH ON GROWTH

In recognition of the need for more information on control of growth and yield by thinning, and for prediction of responses—particularly for intensively cultured stands—an elaborate study of growing stock levels (GSL) was installed on the Black Hills Experimental Forest in 1964. The local study is part of a coordinated, Westwide investigation of stocking in even-aged ponderosa pine (Myers 1967). Although in its early stages, the study is nevertheless generating some new information—notably data on tree and stand behavior at the low end of the stocking spectrum. The study samples a wide range of stocking levels (fig. 17). Rethinnings are to be made at 10-year intervals to return stands to assigned nominal levels of stocking, with actual reserve stand densities depending on average stand diameter at time of treatment. Tree measurements and stand inventories are to be made at 5-year intervals.

Plots were remeasured for the second time and rethinned for the first time in the winter of 1973-74. Data from this latest remeasurement had not been analyzed completely when this Paper was prepared. However, enough computations had been made to permit a partial report

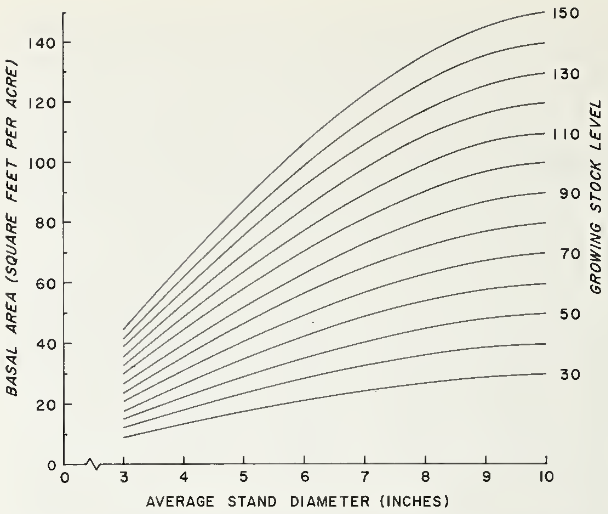

Figure 17.—Standard growing stock levels for ponderosa pine, as established for testing in the Westwide stocking study.

of results at the end of the first decade.

There is evidence that, given adequate growing space and time to capitalize on it, Black Hills poles and saplings can grow fast enough to significantly increase average stand diameters (fig. 18). Across the full range of stocking levels being tested, average 10-year diameter increments for the Black Hills stands were on a par with increments reported for stands of the Interior type in Oregon and Arizona (Barrett 1970, Schubert 1971).

Ten-year basal area increments in the Black Hills stand (fig. 19) were generally somewhat smaller than reported for the Oregon and Arizona stands. This is not surprising, since the latter stands grew on better sites, with index

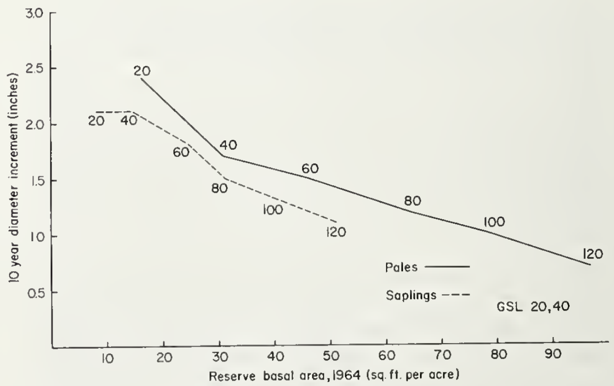

Figure 18.—Ten-year diameter increment for pole and sapling stands thinned to six different levels of stocking in 1964: Black Hills ponderosa pine. (Each plotted value represents average reserve stocking and increment for three replicate plots.)

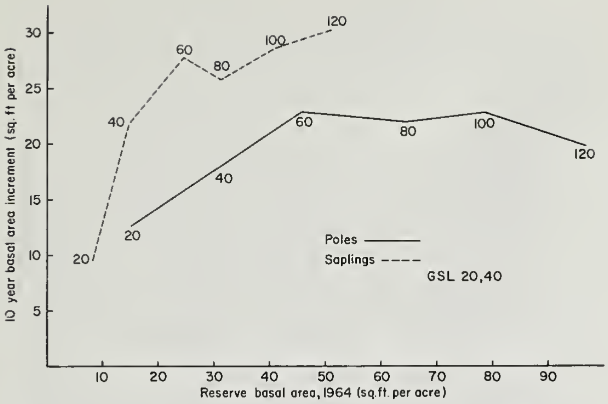

Figure 19.—Ten-year basal area increment for pole and sapling stands thinned to six different levels of stocking in 1964: Black Hills ponderosa pine. (Each plotted value represents average reserve stocking and increment for three replicate plots.)

values about 20 ft higher than the Black Hills sites. More important is the fact that stands maintained at GSL 60 produced practically as much basal area increment as stands at any higher level of stocking. Total ft^3 volume increments followed the same pattern.

Growth responses to repeated thinnings have been indicated by a small-scale demonstration of "sequential thinning" on a single Black Hills site of above-average quality (Boldt 1970). Two thinnings in rapid sequence—the first moderate, the second severe, only 7 years later—transformed a stagnant stand of saplings into a thrifty stand of small sawtimber in only 11 years.

RESEARCH ON YIELDS

The first documented study of yield prediction in the Black Hills was completed by Bates in 1915.[4] He emphasized comparative productivity of the major soil types. During the 1920's, administrative studies of growth and projected yields in cutover stands were made on both the Harney and Custer National Forests.[4] In 1939, Hornibrook published preliminary yield tables for selectively cut stands. A year earlier, Meyer (1938) published his classic yield tables for even-aged ponderosa pine, which included some data from the Black Hills. However, these yield tables were not for managed stands.

Yield tables for managed stands are the basis for timber management planning. Field and computer procedures for preparing yield tables for managed stands have been prepared by Myers (1971) to simulate growth of even-aged stands from regeneration to harvest. The simulation program produces a series of yield tables for different combinations of growing stock levels, cutting cycles, and rotation ages which estimate outcomes in relation to cultural treatments. These procedures were developed from field data on past growth in relation to stand density, age, and site quality obtained from a large number of temporary plots in existing stands of Black Hills ponderosa pine. The GSL study, when completely analyzed, will provide benchmark checks on Myers' predictions of growth and yield in managed stands.

STEM FORM

Manipulation of stocking and live-crown pruning are known to influence stem form of forest trees (Larson 1963, 1964). The principles involved are relatively simple, particularly as they apply to conifers.

The live crown of a tree plays a dominant role in determining the form of the stem which supports it. Maximum diameter increment in the stem is normally added near the base of the live crown. Below this zone, the stem segment free of live branches tends to be relatively cylindrical, except for butt swell. Hence, the bulk of the taper is confined to the segment above the zone of maximum increment, within the live crown. Any factor that significantly alters the size of the live crown and its distribution over the length of the stem can thus be expected to alter the location of the zone of maximum increment and the proportion of the stem length with maximum taper.

Both thinning and live-branch pruning influence crown size and its distribution over the bole. Open-grown trees or stand-grown trees at wide spacings tend to have large crowns occupying a relatively large proportion of their total stem length. As a result, such trees typically have short segments of cylindrical stem and long tapered segments. Closely spaced trees, on the other hand, normally have smaller, shorter crowns due to natural pruning and, consequently, longer segments of essentially cylindrical stem.

In general, then, thinning increases crown width and length and increases stem taper. Pruning has essentially the opposite effect—it reduces both crown length and taper.

Results of Myers' (1963) local study of vertical distribution of annual increment in thinned ponderosa pine generally conformed with these

[4]Unpublished reports on file at Rocky Mountain Forest and Range Experiment Station, Rapid City, South Dakota.

principles. However, the pronounced basal shift in the zone of maximum increment which Myers detected was short lived. His analysis of increment showed that the duration of the shift was only 3 to 6 years in most trees, which was roughly equal to and coincidental with the period of maximum overall growth response to thinning. Myers interpreted the downward shift in zone of maximum increment as a response to increased wind stress in boles of released trees.

STEMWOOD PROPERTIES

Most of the wood harvested from Black Hills forests in the past century has come from trees which grew slowly in crowded stands. Because recent research has shown that Black Hills pines can grow rapidly, wood processors and users have questioned whether rapidly grown wood is apt to have the same technical properties as the slowly grown wood which they have been accustomed to handling. No conclusive answer is available yet, but preliminary research suggests that an increased growth rate is unlikely to cause major changes in wood properties (Boldt and Markstrom 1972).

Analysis of stemwood samples from pole-sized trees in thinned and unthinned portions of a typical second-growth stand showed that: (1) thinned trees had significantly wider rings at all heights from 0.5 to 28.5 ft; (2) there were no significant differences in specific gravity, percent latewood, or percent extractives in wood from the two groups of trees; and (3) the wood from the unthinned trees had slightly, but significantly longer fiber tracheids.

SILVICULTURE AND MANAGEMENT

MANAGEMENT DECISIONS

There are a number of important decisions that the forest manager must make to impart a sense of direction and purpose to the forest enterprise—and to his management team. At the very least, he must arrive at definitive answers to these questions:

1. What mix of products, uses, or benefits is the forest to supply?
2. What are the priorities among the various products and uses, based on values and predicted returns? Which will be the dominant use or uses; which will be subordinate?
3. How will the various uses be physically integrated or separated on the ground? Will zones be established in which certain uses will be dominant and, if so, how will they be delineated? What proportion of the forest will be devoted to any single use or mixture of uses?
4. Assuming timber production will be a major use—
   - What compartments or site classes will be allotted to timber crop culture?
   - What kinds of timber products will be grown—pulpwood only; posts and poles only; some mix of all three; or sawtimber as a final crop with intermediate yields of one or more of the roundwood products? What sort of specifications must each of the selected products meet?
   - What level of timber production is to be attained on acres designated for that purpose—full potential, or some reduced level to accommodate associated uses?
   - How long will the timber crop rotation be—the minimum required to mature the desired final crop, or some longer period?
   - What level of management intensity will be maintained? Will the wood production process be closely controlled through frequent entries for treatment and inventory, or loosely controlled with a long treatment-inventory cycle?

Armed with management decisions on these key questions, the silviculturist will be in a strong position to prescribe optimum cultural treatments from among the silviculturally acceptable treatment options.

SILVICULTURAL CONDITION CLASSES

The foundation of any good forest management plan is a pair of descriptive forest models. One describes the forest as it actually exists at the time the management plan is put into effect. The other is an idealistic model which shows how the fully managed forest should be organized and structured to satisfy management goals. Differences between the two models delineate the scope and size of the silviculturist's job.

Basis for these models is a suitably intensive forest resource inventory, designed to determine at least two things: (1) amount and distribution of forest land within each of several land quality classes, segregated on the basis of apparent productivity and susceptibility to management; and (2) the character of the forest growing stock or other vegetative cover on lands in each quality class.

Methods for evaluating the quality of Black Hills forest sites, and guides for their use, are discussed in another section of the Paper. This section describes a simple, utilitarian scheme for characterizing and classifying vegetative cover for silvicultural diagnosis and prescription. Using the scheme, even an inexperienced forester should find it easy to categorize cover conditions he might encounter in the Hills. Having assigned the condition to a nominal class, he can readily determine the treatment options that research and experience have indicated are appropriate, biologically sound, and environmentally safe. Then, it becomes a matter of technical judgment to select the option that will contribute the most toward overall management goals.

The following simple key may be used to facilitate the first step in the prescription process—condition classification.

Key to Silvicultural Condition Classes in Black Hills Forests

	Class code
TREES ABSENT:	
Recently deforested; signs of previous forest cover clearly evident—	
Site bare of vegetation	09
Site supporting disturbance cover of grass, forbs, or brush	10
No evidence of previous forest cover; permanent or semipermanent park or meadow	11
TREES PRESENT:	
Pine absent or, if present, a scattered or nondominant component in a mixed stand—	
White spruce-pine mixture	05
Pure white spruce	04
Deciduous-pine mixture, pine scattered or subordinate	06
Aspen, aspen-white birch, or bur oak	07
Pine present, in pure stand or as dominant component in mixed stand—	
Pine stand uneven-aged (more than 2 distinct age classes present), usually discontinuous with trees scattered or in clumps	08
Pine stand even-aged, or in transition with remnants of old stand above even-aged regeneration—	
One age (or size) class present—	
Stand immature	02
Stand mature or overmature	03
Two distinct age classes present, parent and progeny	01

Following are more complete descriptions of these silvicultural classes, their variants, and their origins, together with generalized treatment options applicable to each class.

Class Descriptions and Treatment Options

Class 01; Two-Aged Stands

Description.—Stands of this class are called "two-storied" by most Black Hills foresters although the standard definition of the term specifically excludes stands in the process of regeneration (Society of American Foresters 1958). Such stands occupy slightly more than half of the stocked commercial forest acres in the Hills, making them the most widely distributed and most frequently encountered of the several classes.[5]

The two-age or "two-story" structure is a transitory stand condition, representing an overlap between successive even-aged crops. A typical stand of this class is comprised of a light reserve of mature or overmature sawtimber trees scattered irregularly above a well-stocked stand of young pines.

Sawtimber stocking in the upper "story" of a typical stand will usually be quite variable, both in amount and distribution, but over large areas it is likely to average about 3,100 fbm and 35 ft^2 per acre. On all but the very best sites, the upper limit of overstory stocking will probably be about 70 ft^2 of basal area. Beyond that level, if the trees are uniformly distributed, there will usually be too few seedlings established to form a coherent lower story.

Large variations in stocking are also common in the subordinate stands, but overstocking is the normal condition. Frequently, the development of these lower story stands has been severely retarded by heavy and prolonged competition from within and above. As a result, it is not unusual to find "reproduction" stands as old as 50 to 60 years which have not yet advanced beyond large seedling or small sapling size. Trees in such stands generally tend to be slender and whippy, with weak, sparse crowns. The largest and most vigorous trees, or groups of trees, are usually those growing on microsites which are least influenced by competition from the overstory. Where overstory stocking is light and irregularly distributed, there may be enough of these better-developed trees to form a new crop of fair to good quality, after overstory removal and precommercial thinning. In

[5] *Unpublished Timber Management Plan for Black Hills Working Circle, USDA Forest Service, 1963.*

other cases, there may be a critical shortage of good crop trees. Snowbend and windthrow are the principal threats to tall, whippy trees after release.

Origins.—Most of the two-aged stands in the Black Hills have developed in response to repeated partial harvest cuttings. A few of them have resulted from moderate to heavy natural mortality in uncut old-growth stands, brought on by combined impacts of bark beetles, wind, and lightning.

On National Forest land, at least, two-age stands of recent origin are in the minority, simply because the heavier initial partial cuts which triggered regeneration were made several decades ago in most stands. Subsequent partial cuts, made from the mid-1920's through the early 1960's, were largely light selection cuts in stands which had received their first shelterwood cuts 2 or 3 decades earlier (fig. 20). For more detail on past harvest cutting practices in the Black Hills, see the section on regeneration cuttings.

Figure 20.—Steps in the evolution of a typical two-storied stand: *A*, 1931, after first partial cut; *B*, 1967, 10 years after a second partial cut.

Treatment options.—The silviculturist has little freedom of choice in dealing with most two-age stands. Ordinarily, the overstory will be made up of old, yellowbark trees which are growing slowly, losing volume and value to defects, susceptible to mortality agents, and generally ripe for harvest. Development of the understory stand is probably being heavily penalized by the presence of the overwood, even though it amounts to only a few large trees per acre.

Consequently, if the replacement stand is stocked with at least 600 well-distributed trees per acre of fairly good vigor and quality, mostly 3 ft tall or taller, the only reasonable prescription is complete overstory removal, followed by a precommercial thinning.

To improve appearance and minimize fuel buildup, the thinning may well be delayed until the slash from the overstory trees has had a chance to lose its needles and settle closer to the ground. A relatively heavy overwood may be removed in two stages, where it is necessary to control fuel buildup and minimize damage to a dense, overdeveloped replacement stand. The second stage should be completed within 4 to 5 years, however.

In those cases where a doghair understory stand has stagnated under severe two-level competition and has little if any potential as a replacement stand, the silviculturist should consider the advisability of destroying it and starting anew. This might be done by clearcutting the overstory, eliminating the residual understory with a brush-chopper or other device, then seeding or planting. Such a treatment should probably be restricted to small blocks where site denudation would not be esthetically objectionable. Under other conditions, natural regeneration may be the better choice. If the latter option is chosen, (1) the overstory stand should be partially cut to leave no more than 10 to 15 good quality, windfirm seed trees per acre; (2) the existing understory should be eliminated; and (3) the site should be sufficiently disturbed to create seedbed conditions favorable to seedling establishment, just prior to a good seed year.

Class 02; Pine, Even-Aged, Immature

Description.—For this classification, an even-aged stand is one in which at least 75 percent of the trees fall within the extremes of a 20-year age range. An immature stand is not yet ready for final harvest, according to management criteria. Age in itself may not be an important factor in judging maturity, except in continuously managed stands.

Stands of this class occupy a little less than half of the stocked commercial forest land in the Black Hills. On publicly owned lands within the class, about 9 out of 10 acres support pole stands while the remaining acres carry stands of seedlings or saplings.

These stands differ from the classical, textbook variety of even-aged stands in that crown class differentiation tends to be slow and stem diameter distributions are apt to be skewed toward the smaller classes at all ages. These traits are structural reflections of the inherent tolerance of Black Hills pine to intrastand competition and its tendency to stagnate.

In stands which are typically dense at the time of establishment, and left to develop naturally, more than 50 percent of the trees may be expected to remain in stem diameter classes below the stand mean d.b.h. from **youth to biological maturity** (fig. 21). As the plotted distributions show, the proportion of trees smaller than stand mean d.b.h. may be as high as 85 to 90 percent in dense sapling stands, and remain as high as 60 percent in large pole stands more than a century old. It is because of the abundance and remarkable persistence of subordinate trees in these stands that thinnings from below are so successful.

Diameter distributions tend to assume a more normal, bell shape in stands which have been thinned moderately one or more times (fig. 22). Heavy thinnings, if repeated, can produce stands with very narrow diameter distributions (Boldt 1970).

In stands that have remained heavily overstocked for several decades, the typical trees have (1) slender, whippy stems with height-

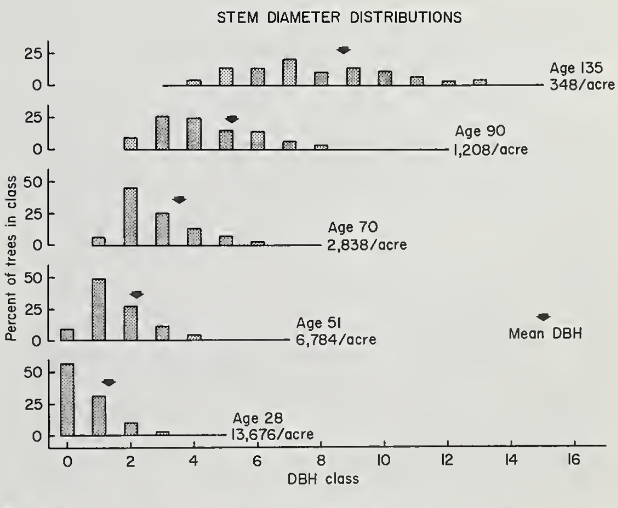

Figure 21.—Stem diameter distributions for typical, dense stands at various ages.

Figure 22.—A classic even-aged, immature stand: 60 years old, thinned lightly in 1934 and again in 1964.

diameter ratios of from 75 to 125+; (2) boles with relatively little taper, and absolute form quotients in the range 0.70 to 0.75; (3) sparse short crowns, usually occupying only 30 to 40 percent of stem length; and (4) poorly developed, often asymmetrical, root systems. Risks associated with these characteristics complicate the selection of trees to leave in initial thinnings.

In contrast, typical trees in uncrowded but fully stocked stands have (1) stems with height-diameter ratios of 60 to 85; (2) more tapering stems with form quotients in the range 0.60 to 0.70; (3) fuller, longer crowns occupying 50 to 60 percent of stem length; and (4) better developed, more symmetrical root systems.

Origins.—The vast majority of stands of this class originated as natural reproduction following heavy harvest cuts, fires, and massive bark beetle epidemics shortly before and after the turn of the century. The remainder has been created by seeding and planting of burns and other deforested sites, and by a few recent complete overstory removals in two-storied stands.

Treatment options.—"No treatment" is a valid option in stands of this class which are (1) properly stocked or understocked according to management criteria; (2) satisfactorily vigorous, healthy, and pest-free; (3) growing at acceptable rates on both an individual tree and stand basis; and (4) comprised largely of trees of acceptable technical quality.

In most other stands of the 02 class which do not meet the foregoing specifications, an intermediate cutting will be appropriate. Purposes of the treatment should be to (1) adjust stocking to a desired level; (2) remove poor-quality, low vigor, under-sized, over-sized, or high-risk elements of the growing stock; and (3) if possible, obtain an intermediate yield of salable rough products. Aids for tailoring prescribed intermediate cuts to silvicultural and management objectives are given in the section on growth, yield, and quality.

In some instances, complete destruction and replacement of an immature stand may be the only reasonable option. This might be prescribed for stands which contain little, if any, acceptable growing stock because of prolonged overstocking, stagnation, and impacts of disease (gall rust) and weather (snowbend and breakage). There is no point in investing time and money in a hopelessly deteriorated stand, especially if it is occupying a high-quality site.

Reinforcement planting or seeding may be appropriate for small, young stands which are inadequately stocked.

Finally, pruning to enhance stem quality may be prescribed in large sapling and pole stands if the treatment is consistent with management aims and defensible economically. See sections on growth, yield, and quality and red rot for remarks on pruning.

Class 03; Pine, Even-Aged, Mature or Overmature

Description.—As indicated for the previous class, stand maturity must be judged primarily on the basis of product goals. Overmaturity, on the other hand, is primarily a biological condition signaled by such symptoms as cessation of height growth, loss of vigor, reduced diameter growth, and increased susceptibility to disease and insect problems.

On forest properties which have been and are managed for sawtimber as the final crop, stands of this class are uncommon; past harvest cutting has opened most of the older stands sufficiently to stimulate reproduction and produce a two-storied structure. However, the class is widely represented in Black Hills forests by large numbers of "inclusions;" that is, stands which are discrete, but too small in area to warrant segregation and separate accounting in any but the most intensive timber management inventory. Common examples are isolated small patches of yellowbark poles or small sawtimber scattered through a matrix of more extensive stands of the 01 to 02 class (fig. 23). Typically, these are crowded groups of old-growth trees which were bypassed in past harvest cuts for saw logs, because of small stem size and/or poor quality. Some such patches have received light intermediate cuts for posts or poles; many others have not been cut in at all.

On forest properties being managed for large poles or other round products as a final crop, "mature" even-aged stands may constitute a large proportion of the growing stock. For example, large pole stands of the 100- to 125-year age class, with mean stand diameters of 10 to 14 inches, are common and extensive. If by management decision these stands are declared mature and ripe for harvest, they properly belong in this class. Figure 24 shows a typical stand of this kind a few years after it had been given the equivalent of a seed-tree harvest cut.

Figure 23.—A small group of mature poles, 150 years old, left untouched by past harvest cuts in surrounding stand.

Origins.—Most of these stands appear to have originated as reproduction following the killing of patches of mature trees in virgin, old-growth stands by bark beetles, localized wildfires, lightning, and wind.

Figure 24.—Previously dense stand of small sawtimber, 130 years old, a few years after harvest by the seed-tree method.

Treatment options.—Unless management desires to perpetuate existing small inclusions for some special purpose, the silviculturist will probably want to convert them to blend with the matrix stands surrounding them.

If the trees forming the inclusion are substantially larger than the trees in the matrix stand, the best option is to maintain a moderately high level of stocking in the inclusion until the trees in the surrounding stand reach about the same size. Removal of a few high-risk, low-vigor individuals may be the only treatment required during the catchup period. After stand sizes have equalized, the included stand should be opened gradually to match the stocking of the matrix stand, and then may be treated similarly to the end of the rotation.

If the inclusion occurs in a two-storied stand with a lower story of seedlings or small saplings, it should be given a harvest-regeneration cut 10 to 20 years before the overstory removal treatment in the matrix stand. If the inclusion is larger than 3 acres, it should be given a shelterwood seed cut. The overwood should be removed at the same time as the overwood in the two-storied matrix stand. If the inclusion is 3 acres or less, another harvest option is a clearcut, with seeding from the side by overwood trees in the matrix stand. A seed-tree cut should probably be avoided because of the risk of windthrow after drastically opening a previously crowded, older stand.

Treatment options for sub-sawtimber stands which are declared mature by management decision are the same as for biologically mature stands. Trees may be harvested by any of the three even-aged methods; the two-cut shelterwood will be best in most cases. See section on regeneration cutting for general guides and prescription details.

Class 04; Pure White Spruce

Description.—Lack of demand for white spruce wood has largely precluded commercial cultural treatment in stands of this species in the Black Hills. Consequently, most stands are natural in origin and remain essentially natural in condition.

Even-aged stands are by far the most common. However, occasional stands show enough vertical stratification in their structure to be classed as uneven-aged. Evidently, the process of breakup of overmature stands usually proceeds fast enough to result in mass establishment of an even-aged replacement stand. However, in those less frequent instances where breakup occurs more gradually, spruce reproduction is sufficiently tolerant to establish and develop in the resultant small openings.

On the cool, moist sites which it prefers, white spruce is a postclimax type which is capable of maintaining site dominance even in the presence of a ponderosa pine seed source. Not only is spruce more tolerant than pine, but it is also capable of faster height growth during early life, at least in the better spruce habitats. In more xeric situations where spruce is offsite, pine will typically survive better and grow faster than spruce, and will eventually replace or dominate it.

Origins.—Except for man-caused wildfires, selective harvest of pine in pine-spruce mixtures, and possible effects of prolonged fire protection, origin of existing spruce stands in the Black Hills has been little influenced by human activities.

Most plant ecologists familiar with the Black Hills subscribe to the idea that spruce stands were much more prevalent in the area during the early postglacial period, when conditions were cooler and more moist. As the environment has become progressively warmer and drier, spruce has retreated to the milder sites which it now occupies; hence, its designation as a postclimax forest. The natural shrinkage of the spruce type is, presumably, still underway.

Treatment options.—No research has been done on spruce culture in the Black Hills, nor has much been learned by experience. Therefore, the options identified here should be viewed only as promising, but unproven, possibilities.

No treatment will be the only valid option wherever cultural work depends on commercial sale of spruce stumpage for which no market exists.

In overstocked, young stands where management is willing to invest cultural funds, light to moderate precommercial thinnings will be appropriate. No guides can be given for desirable stocking or spacing in such stands, but tolerance of spruce and its preference for mild, moist sites suggest that it may grow satisfactorily at somewhat higher stand densities than ponderosa pine. If properly planned and controlled, Christmas tree harvest may make thinnings economically feasible in some young stands. However, present demand for this special product is limited because few spruce Christmas trees are sent to outside markets.

Intermediate cuts in stands of pole size and larger should also leave higher reserve densities than would be left in pine. Spruce's shallow rooting habit makes it susceptible to windthrow, especially where heavy cutting exposes formerly protected trees.

If and when harvest cutting becomes feasible in mature spruce stands, a two- or three-cut shelterwood will probably be the safest method. The first cut should probably reserve at least 70 to 80 ft^2 of basal area per acre to minimize blowdown in the overwood.

Where the management objective is to convert a spruce stand to pine or some other species, the proper approach, obviously, will be a complete clearcut of the spruce. If the stand is 5 acres or less and is surrounded by a pine stand of seed-bearing age, the opening can probably be regenerated naturally. Otherwise, seeding or planting will be required, at least in the central portion of the clearing.

Because of the high incidence of rot defect in most of the older spruce that has been cut in the Black Hills, that species should probably be managed on a pathological rotation of 125 years or less.

Figure 25.—Young, mixed stand of spruce and pine on the margin of a burn.

Class 05; White Spruce-Pine Mixture

Description.—Most commonly, stands of this class are distinctly two-storied. Upper story trees are usually of sawtimber size, either all pine or mostly pine, forming an overwood of low to medium density—5 to 50 ft^2 of basal area per acre. The lower story is pure spruce or a spruce-pine mixture of seedling, sapling, or pole size, even-aged, and typically well stocked to overstocked.

A less common variant of the class is a single-storied, intimate mixture of pine and spruce with trees of both species about the same age and stature (fig. 25). This structural condition tends to be limited to young stands and is temporary, since one species or the other will ordinarily assume dominance with advancing stand age. On sites favorable to spruce, trees of that species will ultimately overtop and suppress associated pines. Conversely, on warmer, more xeric sites, the pine will normally assume dominance. However, the tolerant spruce may persist for many years as a subordinate stand component, giving rise to a two-storied structure. Pine heavily suppressed by spruce, on the other hand, is more likely to drop out of the mixture.

Origin.—Stands with an overstory of mature pine and an understory of young spruce, or spruce and pine, typically result from opening up a well-stocked pine stand on a mild site in the presence of a nearby spruce seed source. Composition of the understory is simply a reflection of relative regeneration success for the two species. The reduction in overstory stocking may be caused by partial cutting, heavy selective killing by bark beetles, or natural breakup of an overmature stand.

The young, even-aged mixtures typically establish in newly created forest openings which have both pine and spruce seed sources on their margins (fig. 25). Removal of the overwood in a two-storied stand with a mixed understory produces a similar result.

Treatment options.—In two-storied stands with a pure spruce understory, the silviculturist may opt to (1) remove the pine overwood and culture the young spruce stand; (2) perpetuate, for a time, the two-story structure; or (3) somehow eliminate the spruce and work for a new stand of pine regeneration. Where the understory stand is of mixed composition, essentially the same options are open, but the silviculturist may also have to decide which understory species to retain and which to eliminate.

If management strategy should favor option 2, the silviculturist may find it necessary to reduce stocking in both the overstory and understory to achieve and maintain a healthy stand. Of course, stocking control is almost certain to be needed, also, in the immature stands that would result from implementing either of the other options.

Valid treatment options for the young, even-aged mixtures include (1) no treatment if stocking and composition are satisfactory; (2) cleaning or weeding to hasten attainment of dominance and improve growth of one species favored by management strategy; and (3) thinning to wide spacings that may permit maintenance of a mixed stand despite differential growth rates between species.

Class 06; Deciduous-Pine Mixture, Pine Scattered or Subordinate

Description.—In these stands the major tree component is a hardwood. Normally, the hardwood component is solely aspen or bur oak. The pine usually occurs as scattered individuals throughout the stand, or may sometimes be found in small pockets of more or less mature trees. Crowns of the scattered pines may be either above or below the relatively low crown canopy of the deciduous species. Because of the seral nature of this class, its appearance may range from the early beginnings of sprouts to full grown oak brush or aspen trees.

Origin.—Most commonly, this class develops as a result of extensive destruction of an existing pine stand. Fire is probably the most frequent causal agent, although bark beetles or tornadoes may be responsible. Occasionally a heavy harvest cut, which has left the site largely unoccupied by pine, will provide the opening for expansion of a latent crop of aspen sprouts or oak.

Treatment options.—Sites occupied by stands of this class are often better than average, with relatively deep soils and more mesic conditions. Conversion to pine is often a preferred option because of the high potential of the site. The oak or aspen competition must be reduced if planted pines are to regain control of the site.

Several factors must be considered in deciding whether to attempt conversion to pine. Expense of the conversion is high, often accompanied by undesirable esthetic disturbances. The condition of the aspen or oak must be considered in relation to its utility for other purposes. Some hardwood stands will be old and tall enough so that their usefulness as wildlife browse is negligible. Other stands will be younger sprouts of great importance to wildlife. Apart from their value as food and cover for wildlife, deciduous stands provide striking contrasts of autumn colors against the evergreens. Thus, esthetic considerations also enter into deliberations on type conversion.

If conversion to pine is the option chosen for whatever reasons, the existing pine trees will not adequately stock the site. Removal or deadening of the deciduous species and planting to pine is recommended. Choice of methods for site preparation must be left to the manager. Planting recommendations are found in the section on reforestation. Scattered pine trees are usually not abundant enough to be considered in the planting operation.

In the Bear Lodge Mountains and portions of the northern Black Hills, oak brush is an aggressive occupier of sites not continually dominated by pine. Once established, oak is difficult to eradicate. Consequently, unless oak brush is desired, extra care should be taken in timber sale prescriptions and logging operations to see that pines do not lose control of the site.

If the area chosen for timber production has adequate stocking of pines, but the pines are overtopped by aspen or oak brush, chemical treatment of the hardwoods seems the brightest prospect to permit pines to regain dominance of the site. Selective silvicides can be applied to the overstory without serious effects on the pine. If hardwood stems are relatively large and few in number, poisoning individual trees offers a good possibility for control. Mechanical control by plowing, bulldozing, or clearing around individual pines probably does not provide as effective a treatment as herbicides, and may be unsightly. Protecting the understory pines from mechanical damage is apt to be difficult and costly. Furthermore, mechanical treatments alone are unlikely to prevent hardwood reestablishment, and may even stimulate it.

Class 07; Aspen or Aspen-White Birch

Description.—This class contains no pine trees or at most only isolated individuals. Pure aspen stands may cover large acreages, generally occupying the more productive sites. The white or paper birch is usually a minor component in aspen-birch mixtures. The birch forms multiple stems or clumps by sprouting, and normally is confined to lower slopes, bottoms, and moist, cool sites.

Origin.—This class, like 06, most often develops as a result of major disturbance of an existing pine stand.

Treatment options.—More than one management goal may be considered with this class. Since wildlife habitat or scenic qualities may dictate maintenance of stands of this class (fig. 26), one option may be to do nothing at all. If pine culture is the goal, the aspen and birch will have to be eliminated or closely controlled, and pines seeded or planted.

Figure 26.—Picturesque aspen stand of poor technical quality, on an unfavorable site. Offsite character is common for aspen in the Black Hills.

Class 08; Pine Stand, Uneven-Aged

Description.—In nearly all cases, stands of this class have developed as a result of gradual invasion by pine into upland parks and abandoned fields. Typically, the stands are composed of several ages of pine progeny clustered around scattered parents. In later stages of the invasion process, clumps may merge to form more or less continuous stands of irregular structure. The openings into which the pines are expanding usually support grasses and forbs, with few shrubs or deciduous trees.

Origin.—Most of these stands are developing on an ecotone. They tend to wax and wane with cyclic changes in the climate and other environmental pressures. Prolonged protection from fire has evidently favored invasion by pine in many upland parks.

Treatment options.—In the few cases where pine culture is desired, site preparation and seeding or planting will restore the site to pine cover. Isolated seed parents should be harvested or killed first.

Because of the shortage of grasslands in the interior Black Hills, management strategy may call for park restoration for forage production. Where elimination of the invading pines is the objective, harvest of merchantable trees plus burning may be a good combination of treatments. Periodic burning may also be a good way to maintain pine-free parks. More needs to be learned about burning prescriptions, however, before the technique can be broadly recommended.

Class 09; Site Bare of Vegetation

Description.—These sites have been very recently devastated by fire. Both tree and ground cover have been burned. The fire was either so recent that vegetation has not had time to appear during the current growing season, or the fire occurred after one growing season but the following growing season has not yet begun.

Origin.—Fire.

Treatment options.—If the management objective is to return the area to pine production, seeding or planting can begin in the spring. The possibility of soil washing should be considered from two standpoints: method of reforestation, and need for soil stabilization during early phases of rehabilitation. Wagar and Myers (1958) found that seedings the first year after a burn in the Black Hills suffered the greatest losses from seed and soil washing. Severe erosion occurred on limestone soils with slopes as gentle as 12 percent, and on soils from metamorphic rocks on slopes of 20 percent or more. On the other hand, early establishment of tree cover is necessary because ground cover competition develops rapidly.

Class 10; Site Supporting Disturbance Cover of Grass, Forbs, or Brush

Description.—Pine cover is entirely lacking or represented by isolated individuals. No seed source is near enough to restock the area, or source is too scanty to effectively restock the area with an even-aged stand.

Origin.—Catastrophic elimination of an existing pine cover generally creates this class; fire, tornado, or insects are causal agents.

Treatment options.—Site quality will be a major consideration in deciding upon a treatment. If the productive capability is adequate and a return to pine cover is the management objective, site preparation followed by seeding or planting is indicated. If brush is well established, regeneration of a pine stand will be difficult. Contour plowing or bulldozing does not seem to adequately prepare heavy brush sites. Chemical treatments, developed in other areas to control similar species, may be adapted to Black Hills conditions. Grass or forb ground cover does not present so much of an obstacle. Site preparation techniques commonly used in the Black Hills are effective.

Class 11; No Evidence of Previous Forest Cover

Description.—These are areas of permanent or semipermanent parks or meadows, with no evidence of stumps or standing trees. There are no remnants or pieces of charcoaled wood indicating earlier tree cover.

Origin.—No readily apparent reason for historical absence of tree cover. On bottom land stringers, sod competition and heavy livestock grazing probably do not allow pine seedlings to get started or become established.

Treatment options.—Few sizable, consolidated areas are found in this class. Much of the land is in private ownership. The need and benefits to be derived should be seriously considered before deciding upon afforestation. If afforestation is to be attempted, try a small-scale planting or seeding trial, first, using the best techniques currently known. If the trial produces good survival and establishment, then operational programs can be started.

REGENERATION CUTTINGS

Regeneration cuttings serve two purposes. First, they harvest crop stands that are mature according to management criteria and/or are due for removal as a silvicultural necessity. Second, they create conditions favorable for establishment of a new crop stand, usually by natural regeneration.

Because the several classic regeneration cutting methods are named for the manner in which the mature stand is removed, subsequent discussion will follow the usual custom and use the terms "harvest" and "harvest cutting" interchangeably with the terms "regeneration cutting(s)." Furthermore, in this Paper, the term "harvest" is reserved for a cutting or series of cuttings that results in the complete removal of a mature stand. It is not applied to intermediate, partial cuttings in immature stands, even though such cuttings may, in fact, yield a harvest of usable wood.

Guiding Principles

Final harvest is inevitable—no forest stand can be perpetuated forever. If not harvested by man, it will eventually be harvested by nature.

Final harvest is also the most drastic silvicultural treatment that can be prescribed, biologically and esthetically. Hence, the decision to harvest a stand should be based on a thorough analysis of management and silvicultural needs.

Choose a harvest method that is compatible with ponderosa pine's strong natural tendency, in the Black Hills, to form even-aged stands. In most harvest situations, the shelterwood method will be the best choice.

Where efficient production is a timber management goal, follow the rule: "only one crop of trees on the ground at a time, for as much of the rotation as is possible."

Background

Most of what is known about harvest cutting in the Black Hills has been learned by experience rather than research. Fortunately, the experience has been abundant, varied, and instructive.

During the mining boom—when there was a brisk demand for wood products of all sizes and shapes, and no harvest restrictions—clearcutting was the usual harvest method. Following establishment of the Forest Reserve and imposition of rudimentary harvest controls, a few large sales (including Case 1, see footnote 2) specified harvest of all timber, alive and dead, larger than a minimum diameter limit. Because this approach led to virtual clearing of sizable areas, most subsequent sale contracts for the next few years required retention of two or more seed trees on each cutover acre. This sort of harvest persisted until about 1908, when a two-cut shelterwood was adopted as standard practice.

Beginning in the mid-1920's, the shelterwood method was no longer recommended in National Forest marking guides; rather, individual-tree selection was favored. The main reason for this change, evidently, was to permit rapid coverage of large acreages of overmature timber urgently in need of silvicultural treatment to reduce risk and anticipated mortality. Use of the selection method continued until the mid-1950's, when revised guides once again acknowledged the suitability of even-aged management and prescribed shelterwood harvest. In initial form, the revised guides called for gradual removal of mature stands in three light cuts spaced 20 years apart, with retention of a few "insurance" trees above the replacement stand for an additional 20 years. On the ground, this conservative version of the shelterwood method was barely distinguishable from the individual-tree selection practice which it replaced. Within a decade, however, the guides again prescribed a two-cut shelterwood with timing of the removal cut contingent on underwood establishment and development. With this most recent change in practice, harvest experience on the Black Hills National Forest came full-circle back to where it started at the turn of the century (Newport 1956).

Lessons

Although the evolution of harvest practices in the Black Hills was largely a trial-and-error process, it entailed remarkably few errors. Only in rare instances have past harvest operations produced silviculturally damaging results. Most have been reasonably successful, as evidenced by the scarcity of poorly or non-stocked forest acres and the absence of any pronounced fall-down in growth or allowable cut during the old-growth liquidation period, now drawing to a close.

Perhaps the most important lesson to be learned from all this varied harvest experience is that, from the ecological standpoint, no high forest method can be considered wrong or wholly inapplicable in Black Hills ponderosa pine. Any one of the standard methods may be a silviculturally acceptable option under the proper circumstances. This does not mean, however, that all of the methods are equal in their range of applicability, probability of success, efficiency, and esthetic appeal.

Observations of the outcomes of many harvest operations, old and new, interpreted in the light of silvical knowledge, have led us to the following conclusions about the suitability of each of the four basic methods. The methods are ranked and discussed in order of decreasing usefulness.

Shelterwood Method

Experience indicates that this should be the primary regeneration method for Black Hills ponderosa pine. It is ideally suited and widely applicable. It capitalizes on the species' strong, natural tendency to form even-aged stands. Furthermore, it combines the advantages of continuous vegetative protection of the site; assurance of an adequate, well-dispersed seed supply; fair control over development of competitive ground cover; good control over accumulations of hazardous and unsightly logging residue; and an esthetically acceptable appearance, provided the harvest job is skillfully planned and executed.

The only important disadvantage is that the parent overwood will hamper development of the replacement stand if it is too dense or left in place too long.

A uniform, two-cut shelterwood is the most efficient and silviculturally acceptable variant of the method. The seed cut should be heavy enough to interrupt the competitive continuity of the mature stand and the removal cut should be timely.

A three-cut variant may be used in situations where the two-cut approach would create unusual problems of visual impact, residue buildup, risk of windthrow, or logging damage to reproduction.

Since the shelterwood method is recommended for general use in the Black Hills, additional details of its application are given in subsequent sections.

Seed-Tree Method

Many thousands of Black Hills forest acres have been harvested and regenerated successfully by this method. In a typical application, a heavy first cut removes the bulk of the volume in a mature stand—usually 90 percent or more—and leaves a light reserve stand to reseed the site. In medium to large sawtimber stands in the Black Hills, the seed-tree reserve will normally contain 5 to 10 trees per acre. This light residual stand is cut, or sometimes killed standing, after the replacement stand is firmly established.

The seed-tree method has one probable and two certain advantages, and at least three disadvantages, relative to the shelterwood.

On the plus side, a few widely spaced seed trees offer less interference to development of the replacement stand than a more heavily stocked, more competitive shelterwood. Also, final removal of a small number of seed trees will be less damaging to the new stand. Finally, because of its limited potential for seed production, a seed-tree stand is less likely to spawn excessively dense reproduction.

The method also has some disadvantages which deserve consideration. The heavy first cut will inevitably leave large amounts of residue on the ground. Accumulations may reach 20 tons per acre, dry, when more than 100 ft^2 of basal area is cut in a large sawtimber stand. Although this slash offers some protection to the site and developing seedlings, it represents a worrisome fire hazard and can be unsightly, even when carefully lopped and scattered.

Of all the methods, the seed-tree approach involves the highest risk of loss of seed source. Unless the few reserved trees have grown at a relatively wide spacing for several decades, they will be vulnerable to windthrow or wind breakage after the protection of the surrounding stand is removed. Few, if any losses can be tolerated in a seed-tree stand, so leave trees must be chosen for windfirmness. Even then, their survival is a gamble on windswept sites.

The limited competition which favors development of pine seedlings under a seed-tree stand also favors development of other kinds of vegetation. Consequently, there is considerable danger of site capture by grasses, forbs, and brush unless a complete stand of reproduction becomes established promptly after the seed cut. Once a site is captured by other vegetation, pine regeneration becomes a slow and uncertain process. Even if tree seedlings manage to become established in heavy ground cover, their growth is apt to be hampered.

The seed-tree method is thus less appealing esthetically and more risky silviculturally than the shelterwood. However, it remains a legitimate harvest option which may be used to satisfy special management objectives.

Clearcut Method

This method removes a mature stand, or a portion thereof, in a single, clean cut. If the stand is to be regenerated naturally, either (1) the cut should be made during or shortly after the fall of a good crop of seed, or (2) the cutover area should be limited in size to permit adequate seed dispersal from the surrounding, uncut stand. In the Black Hills, where site quality restricts mature stand heights, adequate numbers of seeds cannot be expected to fly beyond about 2 chains on level ground. Hence, the maximum width of clearcut openings should be no more than 4 chains when there are seed-producing stands on both sides, and 2 chains when seeding will be from one side only.

Clearcuts can take the form of either blocks or strips. For improved appearance, openings should have irregular boundaries. Also, the long dimension of oblong blocks or strips should follow the contour, when situated on moderate to steep slopes.

Like the seed-tree method, clearcutting is an acceptable option from the silvicultural standpoint. Its best features are that it (1) entails little risk of loss of seed source, and (2) allows the replacement stand to develop free of both overhead competition and the threat of logging damage.

Its major disadvantages are that it generates maximum volumes of logging residues, and it affords little control over development of ground cover. Where large areas are cut over and regeneration depends heavily on seed dropped by the cut trees, the operation must be rated a long gamble. Odds of success can be improved by controlling seedeating rodents.

Despite its disadvantages, clearcutting will be the only appropriate method where natural stands are to be replaced by stands of genetically improved or introduced growing stock. In these cases, maximum size of clearing will not be limited by seed flight. Other management objectives, such as increased water yield and creation of wildlife openings, may also dictate some use of clearcutting in the Black Hills.

Selection Method

This method is designed to create and/or maintain uneven-aged stands. As a regeneration method, it is out-of-place in the naturally even-aged forests of the Black Hills—at least in regulated stands being managed for timber production. It can, however, be used effectively for late intermediate cuttings, of the sanitation salvage type, in mature or overmature stands which for some special reason cannot be harvested on schedule. Thus applied, selection cutting is simply a delaying tactic, aimed at maintaining the health and appearance and capturing the volume and value of a few high-risk trees in an overmature stand. Its use is not an alternative to eventual harvest and regeneration by one of the even-aged methods.

This kind of treatment might be appropriate in stands which are (1) especially scenic, (2) critically located near campgrounds or other recreation facilities, (3) temporarily inaccessible, (4) likely to gain bonus values if grown to larger size, or (5) scheduled for harvest during a period of low demand and prices for stumpage.

Selective removal of a few individual trees in a mature stand will not ordinarily promote establishment and development of much advance reproduction.

It has been suggested that the group-selection method might be used to convert even-aged stands of Black Hills pine into uneven-aged stands. This is silviculturally feasible, if one's definition of uneven-aged is broad enough to include a patchwork forest comprised of intermingled even-aged stands. A forest of this kind would simulate the natural structural arrangement resulting from the killing of patches of trees by bark beetles, fire, and wind.

The difficulty with this scheme is that conditions in the Black Hills are not conducive to the successful culture of the very small even-aged stands which characterize the group-selection forest. Even on the most productive sites, small trees do not develop satisfactorily under the competitive influence of older, larger trees (fig. 27). Because of their elaborate root systems and extravagant demands for moisture, large trees can exert a suppressive influence over radial distances as great as 50 to 60 ft. Consequently, growth of reproduction is almost certain to be retarded over all or most of any opening less than an acre in size, if it is set in a matrix of mature trees. It is questionable whether a forest comprised of even-aged patches larger than an acre still qualifies as uneven-aged. Certainly, once the uneven-aged structure has been compromised to that degree, most of the advantages peculiar to the selection forest will have been lost.

The same conditions that restrain the culture of even-aged forests in the Black Hills summarily preclude culture of all-aged stands. Such stands, comprised of trees of many ages and sizes intimately mixed on each acre, are the cultural goal of harvest and regeneration by the single-tree selection method. Successful development and maintenance of this structural type requires (1) trees that are tolerant enough to grow at acceptable rates in proximity to others in superior crown positions, and (2) sites that are capable of supporting a deep canopy of moisture-dispersing foliage. These exacting requirements cannot be met by ponderosa pine on Black Hills sites, except in stands spaced widely enough to make all stand components free growing.

Figure 27.—Stunted 25-year-old seedlings struggling to survive in a small stand opening.

Shelterwood Method: Guides for Use

Because previous partial cuts have already produced regeneration in most mature pine stands in the Black Hills, opportunities to initiate shelterwood cuttings are currently quite limited. However, this situation will change in the next few decades as extensive stands that are now in the large pole and small sawtimber classes come due for harvest and regeneration.

The majority of these stands will be ideally structured and conditioned for regeneration by the shelterwood method. Most will have had two, three, or more intermediate cuts. They will be uniformly stocked with trees which have grown at moderate to wide spacings for several decades—vigorous trees with good crowns, stout stems, and proven resistance to windthrow. Most stands will contain 80 to 130 ft^2 of growing stock in trees averaging 14 to 18 inches d.b.h. Ground cover of herbs and shrubs, dominated by grass, will be present under stands at the lower end of the stocking range, but the cover will not ordinarily be dense enough to hinder pine regeneration. Advance pine reproduction, if present, will be sparse and nonvigorous.

Prescription for Seed Cut

If possible, mark the stand for treatment a few years before it is due for cutting, and arrange for flexibility in timing so that the logging can be done on demand, with about 1 year's advance notice. Specify logging during late summer and early fall.

Select and leave-mark 12 to 18 trees per acre. Aggregate basal area of leave trees should not exceed 35 ft^2 per acre. This restraint should pose no problem in most managed stands, since maximum d.b.h. at harvest is unlikely to exceed about 20 inches.

Select leave trees with special care. Insofar as possible, they should be superior trees:

- Dominants or codominants with long, full symmetrical crowns.
- Prolific cone producers, as evidenced by numerous shed cones at their bases.
- Phenotypically desirable with respect to growth rate, vigor, stem quality (form, straightness, branch size and angle), and freedom from insect and disease infestations.
- Uniformly distributed over the acres on which they occur. In cases where tree distribution forces a choice between leave tree quality and spacing, greater weight should be given to quality. However, avoid leaving trees in closely spaced pairs or groups.

Finally, prescribe a slash treatment that will result in a slash layer of minimum depth and maximum uniformity. Piling and burning, or chipping, may be justified for fire hazard reduction along the road, if it carries much traffic. Elsewhere, a lop and scatter treatment will suffice, if the lopping reduces the residue to short pieces and scattering is uniform.

Prescription for Removal Cut

The shelterwood should be removed completely as soon as a well-stocked replacement stand has become solidly established. Stocking in the new stand can be rated satisfactory when 80 percent or more of the mil-acres support at least one good pine seedling. Seedlings can be rated solidly established when they average 1 ft tall or taller. The removal cut can be made any time after the replacement stand meets these criteria. It should not be delayed beyond the time when most seedlings reach a height of about 3 ft (fig. 28).

The cut should remove all overstory trees with minimum damage to the replacement stand. Slash should be treated as prescribed for seed cut, but residue volume will be much less.

Basis for Prescriptions

The seed cut should be pre-marked and flexibly timed so that it can be made during the growing season just prior to maturation of a good to excellent seed crop. Such a crop can be forecast a year ahead from presence of first-year cones—visible through binoculars.

Late summer-early fall logging is best because it assures maximum disturbance of the seedbed just prior to seedfall. Disturbance breaks up the litter layer, exposes mineral soil, and uproots existing vegetation. Seed dispersal onto a freshly disturbed seedbed maximizes chances of getting a replacement stand started the first spring after logging. This, in turn, minimizes the regeneration period and gives the seedlings a competitive advantage over developing ground cover.

Stocking is relatively critical in the shelterwood stand left by the seed cut. Enough windfirm trees should be retained to (1) assure uniform dispersal of adequate numbers of seeds over the entire area to be regenerated, and (2) provide some protection to the site and some impediment to development of ground cover. At the same time, stand density should be low enough to inhibit excessively dense reproduction and permit reasonably rapid development of the new stand for the first several years after its establishment.

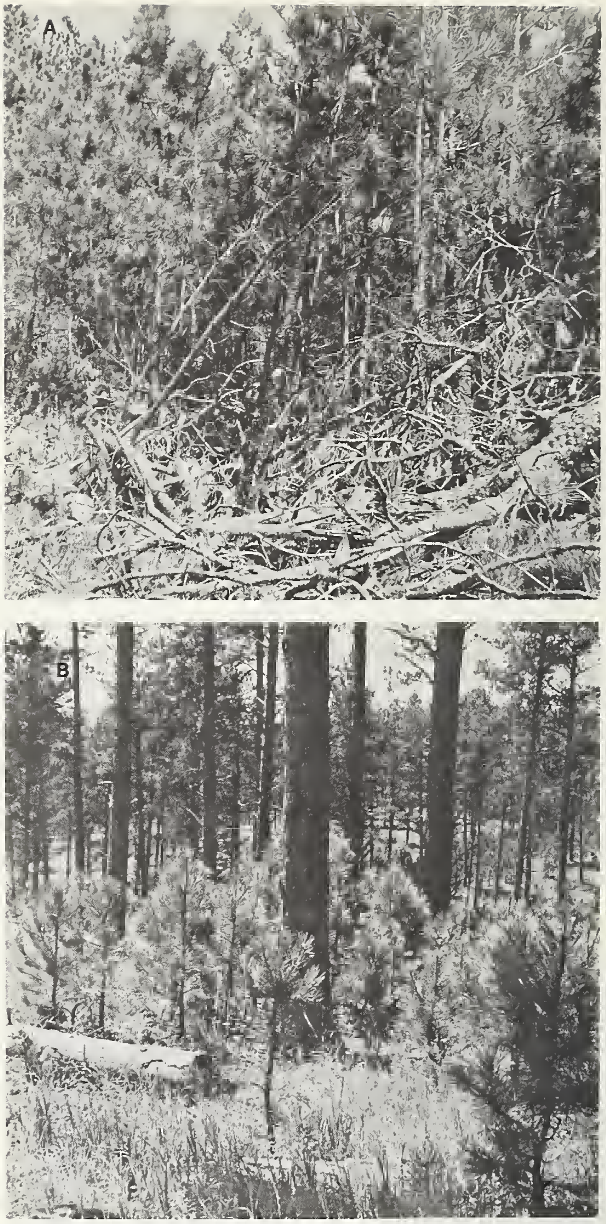

Figure 28.—*A*, Sawtimber harvest in dense stands of overgrown reproduction is difficult, damaging, and unsightly. Here, overwood should have been removed 15 to 20 years earlier. *B*, Shelterwood with 10-year-old reproduction below; ready for overwood removal.

Stocking and seed supply.—We have no reliable, direct evidence of how many parent trees must be reserved in a shelterwood to assure uniform dispersal of enough seed to establish a well-stocked new stand. However, there is some indirect evidence that will support a general estimate.

First, how much seed is needed to restock an acre of reasonably hospitable forest site? A probable indication can be found in Wagar and Myers' (1958) evaluation of factors influencing success of direct seeding of ponderosa pine in the Black Hills. Based on results in some 150 seeding operations, they concluded, that, under generally favorable conditions, 4 to 6 pounds of broadcast-sown pine seed per acre is as likely to produce a satisfactorily stocked seedling stand as any larger amount, up to 16 pounds. Four to six pounds is about 48,000 to 72,000 seeds.

If a one-shot, artificial sowing of that amount of seed is normally enough to restock a deforested acre, it seems reasonable that a like amount, sown naturally on a freshly cutover acre, would also be apt to produce the desired results. It seems especially reasonable in view of the backup feature of periodic natural seeding.

How many shelterwood trees must be retained on an acre to disseminate 48,000 to 72,000 seeds in a good crop year? The only relevant local study was made by Carlos Bates in a single "moderately stocked" mature stand near Custer, during the 14-year period 1912-25.[6] He made annual, direct determinations of cone and seed numbers and seed viability by collecting all cones from felled sample trees. Bates' data revealed that (1) good to excellent cone crops occurred in 5 of the 14 years, with an average frequency of 3 years; (2) few, if any, cones were produced in the other 9 years; (3) dominant and codominant trees were consistently the heaviest cone producers; and (4) average yield per tree for these best producers in the best crop years was 125 cones, containing 4,100 seeds, of which about 50 percent were viable.

The data suggest that 12 to 18 trees per acre should suffice to supply adequate seed for regeneration in a good crop year. It is possible, of course, that the single stand studied by Bates was not typical in terms of amount and/or quality of seed produced. Even so, the risk of an inadequate supply seems to be minimal, because the prescribed number of trees is based on an assumption of full satisfaction of expected seed requirements in a single year, with no allowance for subsequent reseeding.

If the 12 or more trees are distributed over an acre with fair uniformity, no tree should be much more than 1 chain distant from its neighbors. Consequently, all points within the acre should be within easy flight distance from ponderosa pine seed.

[6]*Unpublished data on file at Rocky Mountain Forest and Range Experiment Station, Rapid City, South Dakota.*

Stocking and competition.—A stand of 12 to 18 mature trees per acre will probably provide an acceptable compromise between wanted competition for control of ground cover and unwanted excessive competition that would seriously retard development of the young replacement stand. If grown at spacings conducive to good crown development, such a stand can be expected to provide a crown canopy density within the range of 15 to 25 percent.

Any mature stand which has been sufficiently well stocked to exclude advance pine reproduction will have a sparse, nonvigorous ground cover below it. Most of the plants persisting will be shade tolerants not likely to benefit much from sudden, drastic exposure. Thus, the problem of herbaceous competition will be minimal immediately after the seed cut is made. Obviously, the replacement stand should be established as soon as possible, while this favorable situation still prevails.

Once a heavy seed cut is made, as prescribed here, invader-type ground cover—mostly grasses and forbs—will move in rapidly to capture the site. If pine regeneration is delayed, the speed and success of the regeneration process will depend heavily on the degree to which overwood competition controls ground cover density, vigor, and growth.

What about the impact of overwood competition on the pine seedlings themselves? Observations indicate that seedlings can establish themselves readily and grow satisfactorily for several years under a freshly cut, uniformly spaced parent stand containing less than 40 ft^2 of basal area per acre. Tolerance of young Black Hills ponderosa pine is great enough that light shading poses no problem. Competition for moisture, on the other hand, may be critical in some years. It will be least limiting, however, during the first few years after the seed cut—prior to extension of parent-tree root systems into growing space vacated by cut trees.

INTERMEDIATE CUTTINGS IN MANAGED STANDS

A managed timber stand implies that goals have been established by management decision, plans have been made for goal attainment, and some action has been taken to implement these plans. Effective action will necessarily include some level of silvicultural control over (1) growth and development of the stand and its components, (2) intermediate and final harvest yields, and (3) the technical character, or quality, of the material removed and retained during each stand entry.

In the Black Hills, as elsewhere, the silviculturist's most powerful tool for controlling growth, yield, and quality of managed stands is the manipulation of amount and kind of growing stock and its distribution on the site. Manipulation takes form of repeated intermediate cuttings, usually of the type technically classified as thinnings (fig. 29). Other types of intermediate cuts, such as cleanings or weedings, are infrequently needed in the Black Hills because most stands are essentially pure ponderosa pine.

Guiding Principles

In every thinning, select leave trees primarily on the basis of vigor, health, growth rate, and stem quality. Their growth potential and character will determine the value of the final crop. Retain the best growing stock in every intermediate cut. Do not overemphasize uniform spacing, but avoid leaving close pairs of trees or tight clumps.

Thin and rethin each stand before any serious, general decline in tree growth and vigor due to excessive intrastand competition. Make precommercial thinnings in dense, young stands as soon as possible after trees are solidly established—preferably by or before the time they reach breast height. The problems of excessive slash and risk of loss of reserved trees become steadily more troublesome with increasing tree size.

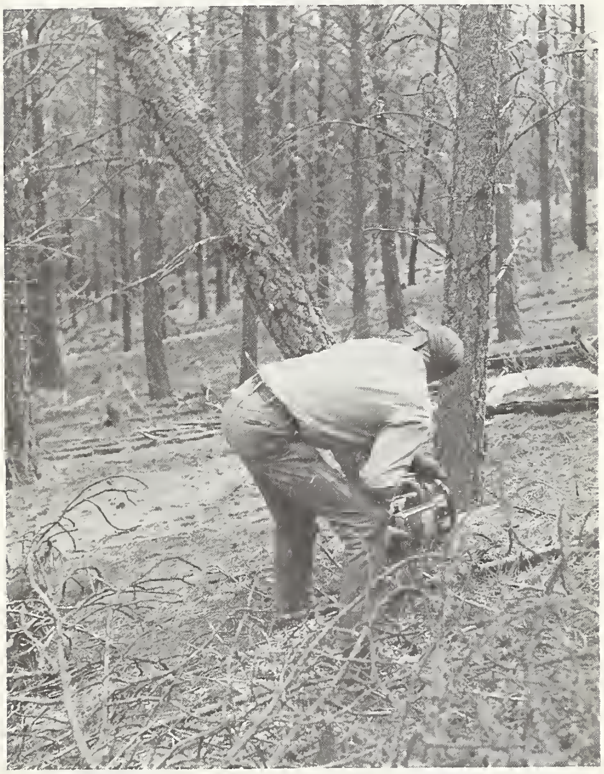

Figure 29.—Thinning is the silviculturist's most powerful tool for controlling growth, yield, and quality.

Thin stands primarily from below. Concentrate most of the cut on poor competitors of small size and low vigor, but also remove poor-quality trees from the upper crown classes.

Be sure that prescriptions for reserve stocking and thinning frequency are consistent with management goals for timber production and associated uses. Tailor prescriptions to specific stand and site conditions. Allow for a reasonably well-balanced distribution of stand size classes in a regulated forest.

Watch for opportunities to use differential thinning intensities to consolidate neighboring small stands of nonuniform average diameter into larger, uniform stands of manageable size. Or, conversely, break up undesirably large blocks of uniform stands into small, nonuniform stands.

Be conservative in prescribing initial thinnings in stands which have been excessively dense for long periods. Do not open such stands too much, too fast. Allow for probable losses to windthrow and snowbreak.

Thinning Options

No thinning is intrinsically good or bad. It can be rated qualitatively only on the basis of its value as a means of implementing some well-defined management strategy. Hence, a good defensible thinning prescription must be based on decisive answers to these four questions:

- Will this stand (or class of stands) require thinning in order to satisfy management goals? If so:
- What kind or kinds of thinning?
- When?
- How much growing stock should be removed and retained?

Answering these questions assures consideration of the full array of thinning options: To thin or not to thin, method, timing, and severity. All of these are interdependent, but the relationship between timing and severity is an especially close one.

Thinning Versus No Thinning

To arrive at a sound decision on whether or not to thin a given stand, the silviculturist should first consider the objectives established for that particular stand or the class to which it belongs. Management strategy may selectively exclude some stands from a thinning program to satisfy goals for other than wood production. For example, stands on unproductive sites may be left untreated, together with some stands needed for escape cover for game, special scenic effects, barriers, screening, and other purposes. Conversely, management may decide that intermediate cuts should be made in some stands to meet wood production commitments, to enhance browse or water production, or for a variety of esthetic reasons.

In the more common cases where the choice of thinning versus no thinning is left to the silviculturist, he should determine whether there is a need and justification for the treatment. In most naturally regenerated pine stands in the Black Hills the need for thinning is likely to develop early and recur periodically. Hence, a decision on desirability of thinning will often be made easily, at least where wood production is a primary management goal.

Thinning Method

The choice of a thinning method will depend on the present structure of the stand and the structural changes needed to advance it at an acceptable rate toward final harvest goals. In most previously unthinned stands, the best initial treatment may be a combination of a light to moderate crown thinning and a moderate low thinning. Ordinarily, subsequent rethinnings should be of the latter type. One possible exception might be an unregulated forest where an unbalanced distribution of stand sizes requires temporary maintenance or reduction of average d.b.h. in stands of some classes. Another exception might be where the silviculturist decides, in the interest of management efficiency, to meld two or more small stands of dissimilar development into a single, uniform stand of larger area. In either of these exceptional situations, crown thinnings might be used.

Timing

The silviculturist's options on timing are to thin now, later, or both—as in the case of preplanned thinning schedule. Urgency of the need for thinning will be an important factor. Criteria to consider in assessing urgency include health, vigor, susceptibility to damaging agents, and growth rates of the best elements of the growing stock. The decision on timing will probably also be strongly influenced by underlying management strategy, particularly as it pertains to intermediate and final product goals, rotation length, stage of stand development, stemwood merchantability standards, markets, and management willingness to invest funds in precommercial thinnings.

Timing of treatment will also depend heavily upon severity of and, to a lesser extent, the method used in previous thinnings. As a general rule, the effectiveness of a series of thinnings will be enhanced by timely rethinnings, made while the trees are still actively responding to the preceding density adjustment.

Severity

Factors to be considered in deciding how severe a given thinning should be include: (1) amount of excess growing present in relation to an ideal for any given stage of stand development; (2) the prospect of a subsequent thinning and the probable return time; (3) risk of damage to the stand and/or site; (4) risk of excessive accumulations of thinning residues; (5) minimum salable wood yield per unit area for commercial thinnings; and (6) management goals or desires unrelated to wood production.

OTHER CULTURAL TREATMENTS

In addition to thinning, the Black Hills silviculturist has two other cultural treatment options which he may exercise to influence growth, yield, and quality. First, he may use artificial pruning to increase production of knot-free stemwood, reduce incidence and impact of western red rot, and, possibly, to modify stem form. Second, he may decide on artificial rather than natural regeneration to restock harvested or otherwise deforested acres, using improved strains of ponderosa pine or trees of other species, native or exotic.

Unfortunately, as with application of supplemental water or nutrients, the value of these practices remains unknown in the Black Hills. The biological and technical desirability of pruning some of the best trees on good sites is fairly well accepted, but the economic desirability of the practice remains to be demonstrated. Even less is known about the potential value of new or improved growing stock to replace natural stands. Furthermore, no seed or stock of predictable adaptability and performance is currently available for use here.

REFORESTATION OF PINE SITES

Principles

Ponderosa pine is the predominant overstory vegetation on most Black Hills sites. It grows so extensively throughout this region that almost any site on which artificial regeneration is contemplated formerly has supported pine. Three notable exceptions to the nearly complete pine cover are the Reynolds and Gillette Prairies and the Bald Hills, all located in the central Black Hills.

Because of the favorable climatic factors that assist natural regeneration successes, artificial regeneration, too, can normally be expected to succeed. Both seeding and planting are common regeneration practices in the Black Hills. Seeding has received only intermittent attention, while planting has gained solid acceptance. Both techniques, however, have been employed here since at least the early 1900's. Success has been evaluated primarily through empirical trials, though a limited number of research studies have been conducted.

Planting often produces a better success ratio than seeding, though Wagar and Myers (1958) identified some of the factors affecting results of direct seeding.

Artificial regeneration of pine stands is now largely confined to areas recently devastated by fires, tornadoes, or other catastrophies. Most of the large, old burns have already been reforested as completely as is practical. Costs of reforestation and unsatisfactory growth rates ordinarily preclude regeneration of sites with indexes less than 50, unless esthetics, wildlife habitat, or stabilization of soil are primary objectives.

Choice of either planting or seeding depends on a number of factors. Two points about direct seeding, however, must be kept in mind: (1) while per-acre costs are often less than half of those for planting, a second seeding—in case the first is not successful—will be more expensive because the benefits of a site preparation job fade rapidly; and (2) with the exception of limited areas of rocky sites, one should not attempt to direct seed any site that would be unsuitable for planting—at least, for purposes of timber production.

Site Preparation

Experience has shown that wherever ground cover of grass, forbs, or shrubs has become established on potential planting or seeding sites, preparation of those sites is essential. Hardwood overstory must also be reduced or eliminated on sites to be reforested by pines.

Mechanical or chemical methods can be used, either singly or in combination. Although no local research has been conducted to evaluate their relative merits and effectiveness under Black Hills conditions, much has been learned about mechanical methods through experience.

Mechanical

Crawler-type tractors, pulling disc-plow attachments, effectively uproot small trees and plow contour furrows through established ground cover. One of the plus features of such plowing is that the furrows will catch and concentrate surface water runoff. An obvious disadvantage is that virtually the entire "A" soil horizon may be removed, which is especially undesirable where soils are shallow. Furthermore, critical moisture may be evaporated through the exposed soil. Sometimes the furrow forms a water channel, and a number of seeds can be washed along in the stream, collecting in small settling basins.

It is usually necessary to fence out livestock for a few years from sites that have been prepared with contour furrows. The furrows are favored by livestock as pathways, and many seeds or seedlings are trampled.

Chemical

Herbicides offer promise both to control ground cover and to eliminate tree and shrub overstory.

Heidmann (1967) found a rate of 5 pounds of dalapon per acre killed 86 to 94 percent of the two grasses to which it was applied. Cost per acre in this Arizona trial was only $6.78. Herbicide treatment has the advantage of leaving the "A" horizon undisturbed, while the dead ground vegetation serves as a mulch to conserve soil moisture (Heidmann 1969). Repeated annual treatments may interfere with normal growth and development of the trees, however.

There is some uncertainty about the use of herbicides because of concern over dangers to the environment. Many can still be used, and the search continues for new formulations that will be more effective, more selective, and safer. Any herbicide use should be preceded by a careful study of suitable types and their possible effects on the local environment. Refer to the pesticide precaution statement on the inside back cover.

Planting

Stock should be grown from seed collected from as close to the site to be planted as possible. Presently, seed identified simply as coming from the Black Hills is used for reforestation throughout the Black Hills and Bear Lodge Mountains. Research now underway will indicate whether more specific matching of seed collection to planting site is advantageous.

During years of favorable moisture, 2-0 root-pruned planting stock may be expected to provide the best combination of ease of planting, economy, and performance (Boldt 1968). Conclusive evidence about performance of this and other classes, such as 1-0, 1-1, and 2-1, during years of unfavorable moisture is lacking, but the best choice appears to be 2-0.

Recommendations concerning seedling size and quality for the Southwest (Schubert et al. 1969) appear to be valid for the Black Hills as well. They suggest using seedlings with a vigorous top of 4 to 6 inches, root-collar diameter of at least 0.16 inch, and a well-developed root system of 8 to 10 inches (fig. 30). Grading to a standard such as this may be expected to pay large dividends in seedling survival.

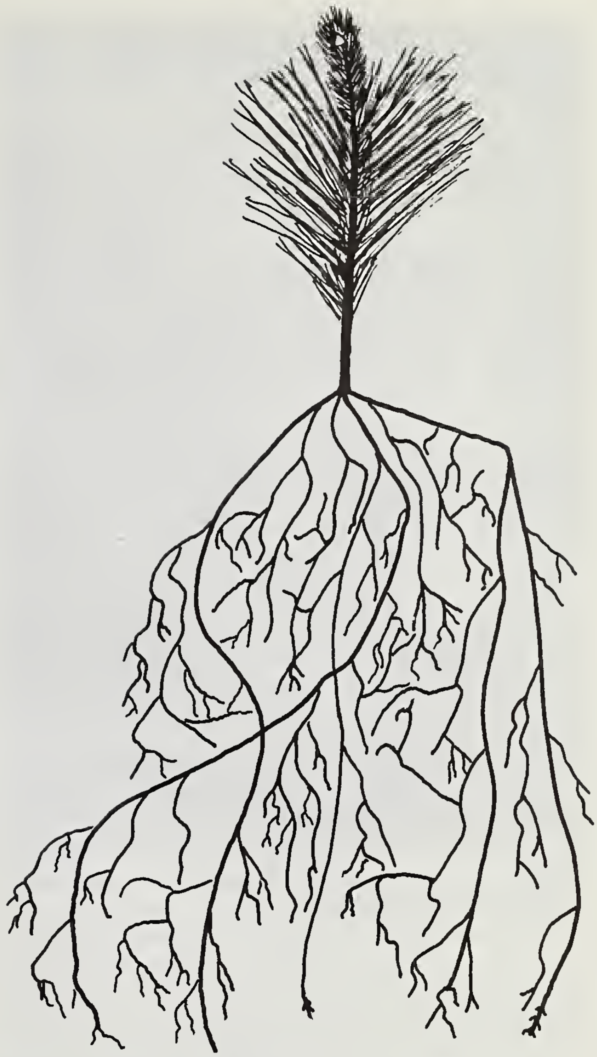

Figure 30.—High quality planting stock that should yield large dividends in seedling survival and growth.

Hand Planting

Some sites too rough or precipitous for machine planting, although of high enough quality to warrant reforestation, must be planted by hand. A mattock that will dig a hole large enough to accommodate the seedling's root system, without doubling back the ends of the roots, is the best tool to use. One cannot emphasize too strongly the need to plant high-quality, healthy trees carefully and properly. Failure to make good contact between mineral soil and roots, or planting seedlings whose roots have dried out, will ordinarily negate the time and money spent in planting them. First-year seedling survival of more than 90 percent can be attained by careful planting of well-cared-for stock (fig. 31).

Machine Planting

Planters that are attached to crawler-type tractors can be successfully used in the Black Hills, and will accommodate the same seedling sizes that are used for hand planting. Precautions to be observed in machine planting are much the same, regardless of where the plantings are made. Schubert et al. (1969) summarized them as follows:

- Planting depth—adjust coulter and trencher so trees can be placed at correct depth with roots fully extended.
- Pack soil—adjust packing wheels so soil is pressed firmly around roots.
- Trees in hand—remove no more than 10 to 15 trees from tray at any one time.
- Trees in tray—keep roots moist at all times.

Spacing Guides

Site preparation by contour furrowing imposes some restrictions on spacing, because the

Figure 31.—Careful planting on a well-prepared site is usually successful in the Black Hills.

furrows can seldom be plowed closer than about 10 ft apart. Distance between trees within the furrow should not be closer than about 8 ft. A spacing of 8 by 10 ft yields roughly 540 trees per acre.

If some other technique of site preparation is used—such as chemical treatment—the silviculturist will have more freedom in choosing spacing and number of trees per acre. The goal, however, should be reasonably full-site occupancy by trees. From 500 to 800 seedlings per acre is a reasonable number to plant on moist sites.

There is no economic advantage to complete site occupancy by trees at plantation establishment, even where wood production is the primary goal. Where the ultimate objective is timber production, however, some sites may require nearly full stocking at the outset as a defensive measure against excessive competition from undesirable trees or other shrubby vegetation.

Seeding

Seed Collection

Insofar as possible, seeds should be collected from trees that exhibit desirable traits of growth, form, and resistance to pests. Ideally, trees to be favored in silvicultural treatments, and trees from which seed is collected, should have the following characteristics:

1. **Growth rate:**
   - Height—should equal or exceed index curve values for the site at tree age.
   - Diameter—average 2.0 inches or more per decade.
2. **Age:** 75-150 years (for seed collections only).
3. **Stem:** Straight, without forks or excessive taper.
4. **Branches:**
   - Small in diameter.
   - Short in length.
   - Horizontal in projection from bole.
   - Average four or less per whorl.
   - Live crown 40 to 60 percent of total tree height.
   - Nonpersistent after death.
5. **Bark:** If candidate has black bark, wide fissures should show bright orange color, indicating vigorous growth.
6. **General health and vigor:** Candidate should show no evidence of successful attack by insects, diseases, or porcupines; should have dark green needles; should show evidence of good cone production in the past (old cones on the ground).

Hopefully, most of the local requirements for pine seed during the next decade will be met by collections from a seed production area recently established by the Black Hills National Forest near the Buskala Burn in the northern Hills. Successive thinnings in this 40-acre tract will be aimed at leaving only the best trees for growth, quality, and seed production. Best quality seed is obtained by collecting cones directly from the trees rather than from squirrel caches.

Seed Treatment

Present practice on the Black Hills National Forest is to ship green or partially open cones to the Mount Sopris Nursery in Colorado for extraction, treatment, and storage.

Seed treatment for field sowing normally includes application of a fungicide, rodenticide, and bird repellent. New formulations for seed treatment chemicals, as well as chemicals for all purposes, are continually being developed. Some potent and persistent chemicals are occasionally withdrawn from accepted usage. It is not practical, therefore, to recommend prescribed dosages of specific chemicals where the research and development field is so dynamic. Again, consultation with specialists and regulatory agencies for up-to-date recommendations and registrations is necessary.

Sowing Techniques

A number of devices and techniques have been used or considered in the Black Hills, but none have been evaluated by research. Site preparation, which is necessary to reforest most Black Hills sites, limits the techniques that can be used. A system that will place one seed per unit distance in the furrow or one seed per place in prepared spots is the most satisfactory. Multiple placement of seeds does not work well because climatic factors favor germination and survival of all seedlings, while natural competition does not "thin out" multitree spots. Broadcast seedings have been successful (fig. 32).

Seeds should not be deeply covered by soil. A sowing depth equal to the diameter of the seed is satisfactory. Some soil covering over the seed offers physical protection, both from rodent depredations and from inclement weather. Too great a depth of sowing will either prevent germination or limit the number of seedlings which emerge through the ground surface.

Figure 32.—A highly successful broadcast seeding in 1941 on a 2-year-old burn resulted in this stand in 1957.

NEEDS FOR ADDITIONAL RESEARCH

Because of rapidly mounting pressures from an assortment of forest resource uses, the day has past when silviculture in the Black Hills can be aimed solely or even primarily at improved timber production. As this Paper shows, much has been learned about timber-oriented, single-purpose silviculture. This knowledge is valuable, but no longer sufficient. Instead, the challenge for research, now, is to develop a much wider range of cultural options so that silvicultural practices can simultaneously serve the needs of various combinations of integrated forest uses.

As a prerequisite to further work on prediction of responses to cultural treatments, both of trees and associated vegetation, we need to develop a better method for rating site productivity. The currently used method—site index based on tree height and age—has not proven a satisfactorily sensitive indicator of differences in site productivity. Its limitations are evident in the remarkable variations in periodic volume production observed among stands of similar age, size, and stocking on sites with similar indexes. Ideally, the new method should be only partially dependent upon, or independent of, existing vegetation. It should enable resource managers to rate the productive capacities of forest sites precisely and directly, using soil and other environmental factors as determinants. Resultant productivity ratings should be applicable to subordinate vegetation as well as trees.

We need to develop a refined model of the forest production system, capable of simulating the behavior of the intensively cultured stands of the future. To be most useful to forest managers, the simulator should forecast both the biologic and economic consequences of various kinds and levels of cultural activity throughout a rotation. It should be able to accurately predict the growth, structural development, and yields of stands maintained under various cultural regimes, thus enabling managers to select those regimes which produce outcomes most closely matching management goals. Projected yields should reflect multiple product potentials and be qualified by statements of statistical confidence. Finally, the model should be adaptable to the larger, more complex problem of simulating mixed vegetative production for entire plant communities under management.

We need to continue our search for superior strains of forest trees. The goal should be to develop breeding stock of proven superiority, for propagation to upgrade forest productivity and quality. The search should be focused primarily on ponderosa pine, both from local and nonlocal provenances. Criteria of superiority should include growth efficiency, stemwood quality and value, and resistance to pests and environmental stresses. Secondarily, we should also search for outstanding strains of other, non-native tree species which are adapted to the Black Hills environment and might be suitable for enriching the composition of our largely monotypic forest.

Other important, but less urgent problems needing research study are:

- Refinement of regeneration cutting practices to provide better control over speed of establishment and initial stocking in reproduction stands.
- Relation between growth rates of trees and the technical properties and value of their stemwood.
- Relations between soil moisture, stocking, and growth in cultured stands.
- Silvicultural uses of prescribed burning.
- Potential effectiveness of silvicultural practices for indirect control of bark beetles.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1974 — 678-255 /25 REGION NO. 8

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This Paper, intended as a guide for professional foresters, describes major silvicultural conditions likely to be encountered in the Black Hills, reasonable treatment options, and probable results and implications of these treatments. It also describes silvical characteristics and behavior of Black Hills ponderosa pine, and a variety of proven silvicultural tools.

Oxford: 181$174:187. **Keywords:** Timber management, silviculture systems, Black Hills ecology, *Pinus ponderosa.*

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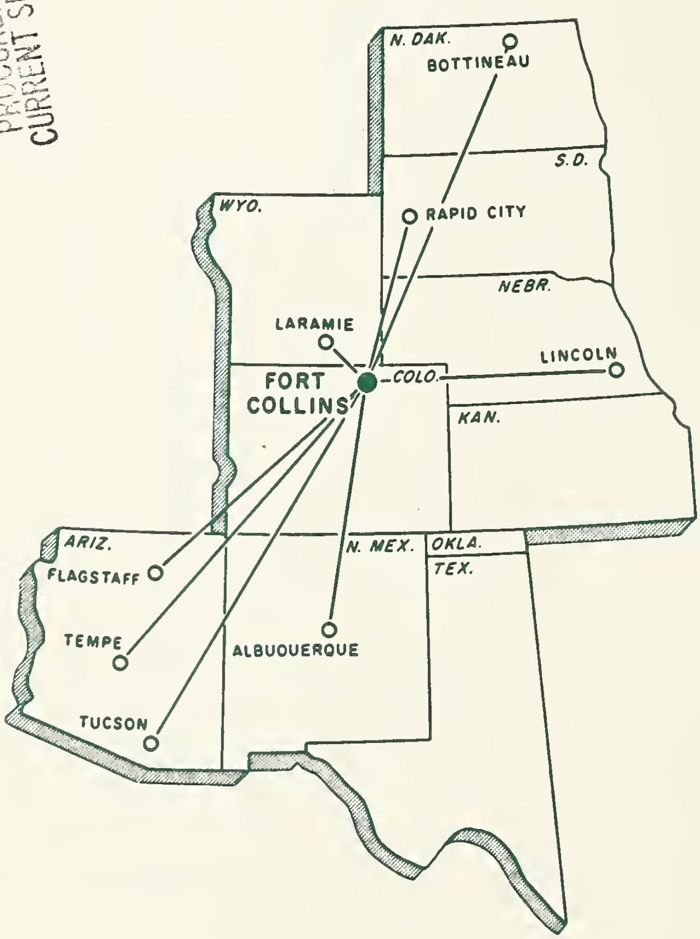
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