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SILVICULTURE OF CENTRAL AND SOUTHERN ROCKY MOUNTAIN FORESTS:

**A Summary of the Status
of Our Knowledge by Timber Types**

Robert R. Alexander

**USDA Forest Service
Research Paper RM-120
April 1974**

**Rocky Mountain Forest and
Range Experiment Station**

Forest Service

U.S. Department of Agriculture

Fort Collins, Colorado 80521

ABSTRACT

Summarizes a series of comprehensive reports on the silviculture of lodgepole pine, ponderosa pine, mixed conifer, and spruce-fir timber types. Includes what is known, what can be recommended, and what additional information is needed for each timber type.

Oxford: 614. Keywords: Silviculture; forest regeneration; growth-yield; *Abies lasiocarpa*, *A. lasiocarpa* var. *arizonica*, *A. concolor*; *Picea engelmannii*, *P. pungens*; *Pinus contorta*, *P. ponderosa*, *P. strobiformis*; *Populus tremuloides*.

The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.

Dale Bortos

**SILVICULTURE OF
CENTRAL AND SOUTHERN ROCKY MOUNTAIN FORESTS:**

A Summary of the Status of Our Knowledge by Timber Types

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Rocky Mountain Forest and Range Experiment Station¹

¹*Central headquarters is maintained in cooperation with Colorado State University, Fort Collins.*

PREFACE

Comprehensive reports of the status of our knowledge in timber management, applicable to the important central and southern Rocky Mountain forest types, have been prepared as Research Papers by the Rocky Mountain Forest and Range Experiment Station. These include:

“Silviculture of Subalpine Forests in the Central and Southern Rocky Mountains,” by Robert R. Alexander, (RM-121),

“Silviculture of Southwestern Mixed Conifers and Aspen,” by John R. Jones, (RM-122),

“Silviculture of Southwestern Ponderosa Pine,” by Gilbert H. Schubert, (RM-123), and

“Silviculture of Ponderosa Pine in the Black Hills,” by Charles E. Boldt and James L. Van Deusen (RM-124).

These papers have been condensed in this report to provide a general summary of the current status of our knowledge for all forest types in the central and southern Rocky Mountains. Acknowledgments and literature cited are included in the full-length papers.

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SILVICULTURE OF CENTRAL AND SOUTHERN ROCKY MOUNTAIN FORESTS:

A Summary of the Status of Our Knowledge by Timber Types

Robert R. Alexander

INTRODUCTION

Management goals for timber production and other forest uses are met through manipulation of forest cover. The degree of success depends on how well management decisions conform to the inherent characteristics of a particular species, existing stand conditions, and the environment, all of which affect the ability of a tree species to reproduce, survive, and grow. Since inherent characteristics are relatively unchangeable limitations, the resource manager must be certain that existing stand conditions and environmental factors are not altered by cultural practices to the extent that inherent species limitations are exceeded.

Although not all limiting factors and optimum conditions have been identified for tree species in the central and southern Rocky Mountains, Timber Management Research has been gathering data and providing forest managers with ecological and silvicultural information important to the management of commercial forest tree species for the past 60 or more years. A few summary publications on regeneration, silvics, silviculture, and management have been prepared for individual species, but most research results and observations have been presented as individual articles, papers, and notes in a variety of publications. Furthermore, some of what has been learned incidental to studies or from observations has never been fully documented. It is desirable therefore, for the research silviculturist to periodically pull together and organize all information which is scattered in various publications, as well as

unpublished information, and make this knowledge available to the forest manager in one source.

The detailed status of knowledge summaries prepared for each forest type are intended to guide professional foresters and land managers responsible for supervising the application of silvicultural treatments by providing information on (1) what is known about the principal tree species, and (2) how this knowledge can be applied in the field to meet management objectives. Spinoff benefits include intensive literature reviews and the identification of knowledge gaps where additional research is needed.

The purpose of this document is to provide a general overview and evaluation of the more detailed reports. The forests of the central and southern Rocky Mountains are too extensive and complex, and the status of current knowledge and management practices too varied, to be handled as a homogeneous unit. Therefore, this Paper has been subdivided into five main sections: The Spruce-Fir Type, The Lodgepole Pine Type, Southwestern Mixed Conifer Forests—Including Aspen, The Southwestern Ponderosa Pine Type, and Black Hills Ponderosa Pine Forests. A discussion of timber resource priority problems is also included. Literature reviewed is not cited in this summary Paper, but is included in each of the four detailed reports as listed in the Preface (spruce-fir and lodgepole pine are combined in one report on subalpine forests).

THE SPRUCE-FIR TYPE

Engelmann spruce-subalpine fir forests occupy the highest forest environment in Wyoming, Colorado, and northern New Mexico (fig. 1). Spruce and fir are the principal species above 9,000 feet elevation on north-facing slopes, and above 10,000 feet on all other aspects. These forests are the largest and most valuable timber resource in Colorado and Wyoming (table 1). They are less important in terms of total forest resources in New Mexico. One of the features of spruce-fir forests is the large proportion of area in sawtimber-sized stands (table 2).

WHAT DO WE KNOW ABOUT SPRUCE-FIR FORESTS

Habitat Conditions

The climate of the spruce-fir zone is characterized by extremes that limit growth and reproduction. It is cool and humid, with long cold winters and short cool summers. Mean annual temperature is below 35° F, and frost can occur any month of the year. Precipitation, largely snowfall, is usually greater than 25 inches annually. Winds are predominantly from the west, and may be highly destructive.

Soils in the spruce-fir zone are young and complex. Soil parent materials vary according to the character of the bedrock from which they originated. Crystalline granitic rocks predom-

Figure 1.—Distribution of spruce-fir and lodgepole pine in the central and southern Rocky Mountains.

Table 1.—Acreage and volume (International 1/4-inch log scale) of sawtimber on commercial forests in the central and southern Rocky Mountains, by species and States

Species	Colorado		Wyoming		New Mexico		Arizona		South Dakota	
	M acres	MM bm	M acres	MM bm	M acres	MM bm	M acres	MM bm	M acres	MM bm
Engelmann spruce and true firs	3,393	33,260	847	9,541	525	5,257	110	2,147	0	0
Ponderosa pine	2,347	3,783	992	2,072	4,334	16,188	3,658	22,883	1,330	3,268
Douglas-fir	1,451	5,411	701	3,566	1,000	5,025	130	1,476	0	0
Lodgepole pine	2,068	6,024	1,802	5,798	0	0	0	0	--	--
White pines	139	472	166	1,256	43	640	--	186	--	--
White spruce	0	0	--	13	0	0	0	0	23	201
Aspen	2,794	3,482	320	159	367	1,233	79	259	0	0
Total	12,275	52,731	4,853	22,632	6,269	28,343	3,977	26,951	1,534	3,716

Table 2.--Percentage of commercial forest land area in the central and southern Rocky Mountains, by species, stocking classes, and States

Species and stocking class	Colorado	Wyoming	New Mexico	Arizona	South Dakota
Engelmann spruce and true firs:					
Sawtimber	81	82	85	100	0
Poletimber	14	14	5	--	0
Seedlings and saplings	1	1.5	7.5	--	0
Nonstocked	4	2.5	2.5	--	0
Ponderosa pine:					
Sawtimber	64	73	90	95	53
Poletimber	23	20	3.5	2.5	41.5
Seedlings and saplings	1	3	2	1	4.5
Nonstocked	12	4	4.5	1.5	1
Douglas-fir:					
Sawtimber	72	72	90	100	0
Poletimber	27	22	8.5	--	0
Seedlings and saplings	0.5	3	--	--	0
Nonstocked	0.5	3	1.5	--	0
Lodgepole pine:					
Sawtimber	34	47	0	0	0
Poletimber	60	45	0	0	0
Seedlings and saplings	5	6.5	0	0	0
Nonstocked	1	1.5	0	0	0
White pines:					
Sawtimber	45	46	100	0	0
Poletimber	52	44	--	0	0
Seedlings and saplings	2	6	--	0	0
Nonstocked	1	4	--	0	0
White spruce:					
Sawtimber	--	100	0	0	100
Poletimber	--	--	0	0	--
Seedlings and saplings	--	--	0	0	--
Nonstocked	--	--	0	0	--
Aspen:					
Sawtimber	7	18	49	44.5	0
Poletimber	80	57	43.5	49.5	0
Seedlings and saplings	13	16	7.5	6	0
Nonstocked	--	--	--	--	0

inate, but sedimentary, and basaltic and acidic volcanic rocks commonly occur. Most valleys have been glaciated and glacial deposits are common.

Climax and Succession

Spruce-fir forests are considered the climax forests where they grow in the central and

southern Rocky Mountains. Climax forests are not easily displaced by other vegetation, but complete removal of a spruce-fir stand by fire or logging results in such a drastic environmental change that spruce and fir are usually replaced by lodgepole pine, aspen, or shrub and grass communities. The kind of vegetation initially occupying the site usually determines the length of time required to return to spruce-fir forests (fig. 2).

Figure 2.—
Succession in
subalpine forests
after fire.

Stand Conditions

Old-growth spruce-fir forests grow on a wide range of sites with a great diversity of stand conditions and characteristics. This diversity complicates the development of silvicultural systems needed to convert old-growth to managed stands for a variety of uses. Some stands are single-storied, indicating that spruce-fir can be grown under even-aged management. Others are two-, three-, and multi-storied stands. These latter stands frequently have a manageable stand of advanced growth. Associated understory plant communities are also diverse. The distinctive overstory-understory combinations or habitat types each have a distinctive ecology and management potential.

The composition of spruce-fir forests varies considerably with elevation. At high elevations, spruce may form nearly pure stands while at mid elevations spruce usually predominates in the overstory and fir in the understory. At lower elevations where the sites are drier, the ratio of spruce to fir may be low and lodgepole pine may replace spruce in the overstory. Aspen is also a common associate at mid to lower elevations.

Damaging Agents

Windfall, a common cause of mortality in old-growth spruce-fir stands, limits the way stands can be handled (fig. 3). Partial cutting

Figure 3.—Spruce-fir blowdown
in an uncut stand. San Juan
National Forest, Colorado.

increases the risk of windfall because the entire stand is opened up. Less damage is usually associated with clearcutting because only the boundaries between cut and leave areas are vulnerable. Susceptibility to windthrow is also related to topographic exposure, soil depth and drainage, and age, soundness, size, and stand density.

The spruce beetle is the most serious insect pest of spruce-fir forests, and it limits the options open to the manager. Overmature spruces are attacked first, but if the infestation persists, beetles will attack smaller trees after the larger trees are killed. Epidemic attacks usually have been associated with extensive windthrow where down trees have provided an ample food supply needed for a rapid buildup of beetle populations. Cull material left after logging also has started outbreaks. Felling and salvaging attacked or the larger susceptible, overmature trees, and disposing of green cull material, are the most effective silvicultural controls, especially in stands with a good stocking of trees in the smaller diameter classes.

The most common diseases in spruce-fir stands are caused by wood-rotting fungi and broom rusts. They result in loss of volume and reduced growth, and predispose trees to windthrow and windbreak.

Natural Reproduction and Early Survival

Engelmann spruce reproduces almost entirely from seed. It is only a moderate seed producer, and crops vary from year to year. Infrequent seed crops mean that natural reproduction cannot be expected every year. Spruce seed is light and is dispersed by wind and gravity. Seedfall diminishes rapidly as distance from source increases, with about half of the seed falling within five to six times tree height. This rapid decrease limits the size of opening that will restock to natural reproduction.

Seed sources available for natural reproduction include (1) trees left around the perimeter of cleared openings, (2) residual trees left on the cut area, and (3) seed produced by trees cut on the area. One of the significant considerations in leaving a seed source is the capability of the trees in the residual stand to produce seed. Another consideration is resistance to windthrow.

Viable seeds that survive overwinter normally germinate in early summer following snowmelt. In the undisturbed forest, spruce germinates and becomes established on a variety of seedbeds. Removal of part or all of the overstory produces new microenvironments, some

of which are unfavorable to germination and initial survival. Seedbed preparation is one way to modify limiting factors sufficiently to enable seedlings to become established.

Spruce germination and initial survival are usually better on exposed mineral soil and mineral soil with incorporated organic matter than other seedbed types. The natural forest floor, duff, litter and undecomposed humus, decayed wood, and burned areas are generally poor seedbeds even when moist, because either seeds cannot absorb sufficient water to germinate or the rate of seedling root growth is too slow to keep up with the rate of drying.

Engelmann spruce is restricted to high elevations because of low tolerance to high temperatures, but light intensity and total solar radiation are high where spruce grows. Light is essential to seedling survival, but spruce does not establish readily in the open at high elevations. High light intensity is one of the factors contributing to mortality. Solar radiation at high elevations also heats exposed soil surfaces and increases water losses from both seedlings and soil, especially during periods of clear weather in years when precipitation during the growing season is low or irregular. Few seeds can imbibe sufficient water to germinate, and most newly germinated seedlings are killed by drought or heat girdle. Shade reduces mortality from high light intensity, drought and heat girdling, and increases germination by reducing temperatures, thereby conserving moisture. However, low temperatures on shaded seedbeds in the spring following snowmelt may also delay germination so that, by the time seedbeds are warm enough, they are too dry.

Frost can occur any month where spruce grows. It is most likely to occur in depressions and cleared openings because of cold air drainage and radiation cooling (fig. 4). Newly germinated seedlings are especially susceptible to damage from early fall frosts. Older seedlings are most susceptible to frost early in the growing season when tissues are succulent. In the early fall, alternate freezing and thawing and saturated soils unprotected by snow cover are conducive to frost heaving. Shade reduces mortality by reducing loss of radiant energy from soil and seedlings.

Spruce regeneration success is also limited by biotic factors. Cone and seed insects and small mammals reduce available seed supply. Newly germinated seedlings are killed by damping-off fungi on all seedbed types if they remain damp for long periods of time. Snowmold fungi may damage or kill both natural and planted seedlings if they remain under the snow too long. Birds clip the seedcoats of newly

Figure 4.—Frost damage to an open-grown, planted Engelmann spruce seedling.

germinated seedlings, and voles and pocket gophers debark and kill established seedlings. Young seedlings are also vulnerable to trampling.

Spruce seedlings become established more readily on sites protected by such understory plants as willows, shrubby cinquefoil, fireweed, and dwarf whortleberry than in the open. These plants shade seedlings without seriously depleting soil moisture. In contrast, seedlings do not survive near clumps or scattered individual plants of grasses or sedges or herbaceous plants such as bluebells. Death is due to root competition for moisture, and smothering by cured vegetation compacted under dense snow cover.

Site Quality

Site index is the conventional method for estimating potential productivity. Such estimates are essential to the land manager as a means of identifying and intensifying management practices where timber production has the greatest potential. Curves of the height-age relationship of dominant spruce have been prepared that are suitable for estimating site index at base age 100 years in spruce-fir stands (fig. 5).

Frequently the conventional height-age method cannot be used to estimate site index because there are no trees present, or they are either too young or unsuitable for measurement. Site index for granitic soils in northern Colorado and southern Wyoming can be estimated using the depth of soil to the top of the C horizon and elevation in feet (fig. 6). This method is

not suitable for other areas in the central and southern Rocky Mountains, however.

Growth and Yield

With the high proportion of spruce-fir still in old-growth stands, the forest manager must largely accept what nature has provided during the period of conversion to managed stands. Growth estimates based on Forest Survey inventories indicate that average annual growth over all sites in old-growth spruce-fir forests is only about 80 to 100 board feet (fbm) per acre.

As areas of old-growth spruce-fir are converted into new stands, they must be managed from the regeneration period to final harvest. The only growth prediction tool now available for spruce-fir stands in the central Rocky Mountains was developed 30 years ago for selectively cut stands, for sawtimber only, and for stand structures that are no longer management goals. Field data are now being collected in the central Rocky Mountains that will use established computer simulation procedures to develop yield tables for managed spruce-fir stands. The program produces a series of yield tables which show how projected growth will vary in response to changes in cultural treatments and/or variations in original stand and site conditions.

WHAT PRACTICES CAN WE NOW RECOMMEND

Regeneration Silviculture

The recognized harvest cutting methods applicable to spruce-fir forests include clear-cutting, and shelterwood and selection cutting and their modifications. The choice of cutting method depends basically on management objectives and environmental considerations, but stand conditions, associated vegetation, and windfall and spruce beetle susceptibility — which vary from place to place on any area — impose limitations on how stands can be handled. For example, partial cutting should not be used in high wind risk situations or in stands where spruce beetle infestations are building up. Cutting to bring old-growth under management on many areas is likely to involve a combination of several partial cutting treatments, clear-cutting, and sanitation salvage cutting. To restock these cutovers, managers should first consider the cultivation of existing **acceptable** advanced reproduction, and secondly, inducing subsequent restocking by natural or artificial means.

Figure 5.—Site index curves for Engelmann spruce in the central Rocky Mountains.
Base age: 100 years, breast height.

Management With Advanced Reproduction

Many spruce-fir forests have an understory of advanced growth. However, because of variations in age, composition, quality, and quantity of advanced reproduction, its potential for future management must be carefully evaluated before harvesting begins. One course of action is followed if advanced reproduction is to be managed, another if it is not. Furthermore, the manager must reevaluate the stand after the final harvest and slash disposal to determine the need for supplemental stocking.

The size, shape, and arrangement of clear-cut openings is not critical from a regeneration standpoint, but to be compatible with other key uses, openings should not be greater than about five to eight times tree height, irregular in shape, and blend into the landscape. The overstory will generally be removed in one step.

On partially cut areas, shelterwood cutting should be used where trees are uniformly spaced, and group selection where they are clumpy in single-, two-, and three-storied stands. The overstory will be removed in more than one step. An overwood removal in one or two steps is usually appropriate in multi-storied stands, while individual tree selection is appropriate in multiple-use areas where management objectives include maintenance of high forests. The amount of basal area that can be removed at each entry, the number of entries, and the size of group openings is determined by stand characteristics and windfall risk.

Figure 6.—Site index for Engelmann spruce on granitic soils in southern Wyoming and northern Colorado, determined from soil depth to the top of the C horizon and elevation.

Protection of the residual stand — merchantable trees left after partial cutting, and advanced reproduction in both clearcutting and partial cutting — from logging damage at each cut is of primary concern (fig. 7). Protection begins with a well-designed logging plan at the time of the first cut. To minimize damage, skid roads must be laid out and marked on the ground, travel of skidding and other logging equipment restricted to the skid roads, and trees felled into openings as much as possible in a herringbone pattern that will permit logs to be pulled onto the skid roads with a minimum of disturbance.

Slash treatment after each cut should be confined to areas of heavy concentrations as required for protection from fire and insects or preservation of esthetic values. Slash must be treated carefully to avoid unnecessary damage to advanced reproduction and residual trees — if they are destroyed during slash disposal, care taken in logging is wasted.

Management With Reproduction After Cutting

On clearcut units, layout, logging plans, and slash disposal and seedbed treatment should be designed to facilitate seed dispersal, and to create favorable conditions for germination and seedling establishment. Clearcutting can be by patches, blocks, or strips. Requirements for seed

Figure 7.—Advanced spruce and fir reproduction after clearcutting and slash disposal. Fraser Experimental Forest, Colorado.

dispersal, site preparation, and aspect will influence the size of opening that will restock to natural regeneration. The cutting unit must be designed so that seed from the surrounding timber margin reaches all parts of the openings. Furthermore, cutting unit boundaries must be located where they will be most windfirm.

In general, clearcutting for natural regeneration is most likely to succeed on north and east aspects, providing the right combination of mineral soil and shade has been created, and openings are no larger than about five to six times tree height. If larger openings are cut, the area beyond effective seeding distance will have to be planted. Clearcutting on south and west aspects is not likely to result in an acceptable stand of new reproduction in a reasonable period of time without fill-in planting.

Slash disposal and seedbed preparation will be needed after clearcutting. If slash is concentrated for burning, the piles or windrows should be kept small or narrow, and cover a minimum proportion of the area. Mineral soil can be exposed by mechanically scarifying the ground surface, sometimes in connection with slash disposal or by broadcast burning. Careful mechanical scarification or broadcast burning will prepare a satisfactory seedbed if it exposes bare mineral soil and destroys some of the competing vegetation, but leaves shade protection. To provide adequate shade, it may be necessary to rearrange some of the residual slash and the true-fir cull material over 8 inches in diameter.

On partially cut areas to be regenerated by new reproduction, an overstory canopy or trees standing around the margins of small openings provide a seed source within effective seeding distance and an environment compatible with

germination, initial survival, and seedling establishment. The manager must make sure, however, that a suitable seedbed is provided after the seed cut where shelterwood cutting is used, and after each cut where group selection is used. Some slash disposal will probably be needed after each cut, but it should be confined to concentrations and that needed to reduce visual impact because most equipment now available for slash disposal is not readily adaptable to working in shelterwood cuttings. Furthermore, burning of slash will cause additional damage to the residual stand. As much of the down sound dead and green cull material as possible should be skidded out for disposal at the landings or at the mill. Some hand piling or scattering may be needed where slash disposal equipment cannot be used. In group selection cutting, slash can be concentrated for burning in the openings.

Primary concerns on partially cut areas are protection of the residual stand at each cut, and protection of the new reproduction when the final harvest is made. The same criteria used in management with advanced reproduction applies here.

Management With Artificial Reproduction

On clearcut areas, good sites should be planted immediately after logging where (1) there is not a manageable stand of advanced reproduction, and (2) experience has shown that natural reproduction takes a long time. Areas prepared for natural reproduction that fail to restock in a reasonable period of time should be planted. On partially cut areas, planting should supplement natural reproduction

where stocking is inadequate after the final harvest. A minimum goal should be 300 well-established spruce seedlings.

Hand scalping will probably be adequate to prepare the site on most spruce plantations. In areas with a heavy cover of herbaceous vegetation or dense sod, machine methods will have to be used. Broadcast burning can be used where there is no advanced reproduction or residual stand.

Plant only stock meeting Forest Service Regional standards. Spruce planting stock requires exacting care; it should be lifted when dormant and treated as dormant plants during transport to and storage at the planting site. Plant in the spring using the hole method. New plantings should be protected from livestock and rodents.

Until reliable techniques have been developed for the central and southern Rocky Mountains, direct seeding of spruce is not recommended as an operational practice.

Multiple-Use Silviculture

In addition to being the most productive timber type in the central Rocky Mountains, spruce-fir forests are also the highest water yielding, and are valuable wildlife, recreation, and scenic areas. Because of increasing demands on limited forest lands from a rapidly expanding population, management must consider all key land uses. The kinds of stands that appear desirable for increased water yields, preservation of the forest landscape, maintenance of scenic values, and improvement of wildlife habitat have been suggested in a general way by both research and observation.

For water production, about one-third of a drainage or Working Circle should be in cleared openings five to six times tree height. These openings would be maintained by recutting the trees when they reached about one-half their original height. The remaining two-thirds of the area should be retained as continuous high forest where trees would be periodically harvested on an individual tree basis. Big-game use of spruce-fir forests is also improved by the combination of cleared openings and high forests. However, since natural succession is likely to replace the more palatable forage species that initially come in the openings, one way to integrate timber, water, and wildlife production is to periodically cut new openings about four to five times tree height while allowing older openings to regenerate.

Permanent forest cover at least in part is preferred in recreation areas, travel influence zones, and scenic view areas. With some form

of partial cutting, forest cover can be retained while at the same time replacing the old with a new stand. However, the visual impact of logging must be minimized. To reduce the sudden and severe visual impact on the landscape viewer, openings cut in stands should be a repetition of natural shapes.

WHAT DO WE NEED TO KNOW

Silvicultural practices are needed that will establish and maintain stands with the form, structure, and arrangement needed to integrate all land uses. For the timber resource these include: (1) classifying spruce-fir forests into categories of similar stand characteristics as the basis for identifying management potentials in existing stands; and (2) testing silvicultural systems and cultural practices in stands of different characteristics.

Classification of vegetation in the spruce-fir zone is needed to guide the manipulation of forests for multiple use. For the timber resource this includes: (1) what species grow together and how to recognize the plant associations; (2) how these species reproduce, grow, and interact in a variety of situations; (3) the response in terms of successional trends and the stability of various plant associations to different management prescriptions; and (4) the extent to which research results can be extrapolated.

Prediction of growth and yield of spruce-fir is needed to provide the basis for decisions on (1) site quality classes that will repay the cost of thinning and other cultural treatments; (2) levels of growing stock—including frequency of thinnings and intermediate cuttings—to meet different management objectives; (3) length of rotation cutting cycles, and allowable cut for different cutting methods, management goals, and utilization standards, and (4) the place of timber management in multiple-use management. Better decisions can be made regarding key uses when the timber potential can be forecast.

Methods of obtaining natural and artificial regeneration have been fairly well developed for Engelmann spruce. What is needed now is information on (1) seed production in relation to source to work out relationships between the source and the amount and periodicity of seed productions; and (2) germination and survival under different environmental conditions to identify limiting factors and provide estimates of the probability of seedling establishment. These data, together with existing information on seed dispersal distances, will permit simulation of the regeneration phase of spruce for different environmental conditions.

THE LODGEPOLE PINE TYPE

Lodgepole pine forests cover extensive areas between 7,500 and 10,500 feet elevation in Colorado and Wyoming, but reach maximum development in the upper montane and lower subalpine zones on south and west slopes between 9,000 and 10,000 feet elevation (see fig. 1). These forests are the second largest timber resource in Colorado and Wyoming (see table 1). The imbalance in age-class distribution is not as serious as in spruce-fir forests, but many of the pole-sized timber stands are either overmature, overly dense, or growing on sites not likely to produce a tree of saw-log size (see table 2).

WHAT DO WE KNOW ABOUT LODGEPOLE PINE FORESTS

Habitat Conditions

The climate where lodgepole pine grows in the central Rocky Mountains is warmer and drier than the higher spruce-fir zone, but is still characterized by extremes. Most precipitation is received as snowfall, and precipitation is likely to be deficient for short periods during the growing season. Best development occurs where annual precipitation is more than 21 inches.

Soils where lodgepole pine grows are young, and the profile is poorly developed. Soil parent materials are varied and mixed. Glacial deposits, alluvial fan sediments, stream alluvium, and materials weathered in place predominate. Crystalline rocks such as granite, gneiss, schist, granodiorite, and rhyolite are the principal bedrocks.

Climax and Succession

Lodgepole pine is an aggressive pioneer and invader, whose occurrence is due largely to fire. Lodgepole pine is considered to be seral in stands that have either a mixed overstory composition or contain appreciable amounts of advanced reproduction of other species. Where lodgepole pine stands are the result of catastrophic fires that have burned so often and so extensively that large acreages are nearly pure pine, it is considered a subclimax because there is no seed for the normal climax species. It is also considered stable when held on an area by factors other than climatic.

Stand Conditions

Lodgepole pine occurs as an even-aged, single-storied, and sometimes overly dense forest only where favorable fire, seed, and climatic conditions once combined to produce a large number of seedlings. Elsewhere, it grows as two-aged, single- or two-storied stands; three-aged, two- or three-storied stands; and even-aged to broad-aged multi-storied stands.

Stands of pure lodgepole pine occur frequently over much of the area it occupies, especially where stands originated after repeated fires. However, mixed stands of lodgepole pine and other species are not uncommon. In mixed stands the overstory can either be pure pine or pine and the climax species, with the climax species in the understory.

Damaging Agents

Lodgepole pine forests are susceptible to windthrow after cutting. While the tendency to windthrow is usually attributed to a shallow root system, susceptibility is related to the kind and intensity of cutting, soil depth and drainage, defect, stand density, and topographic exposure (fig. 8).

The mountain pine beetle is the most serious insect pest in mature to overmature lodgepole pine stands. Usually, outbreaks reach epidemic proportions only in stands that contain at least some older trees 14 inches in diameter and larger. After the larger trees are killed, beetles attack the smaller trees until the outbreak subsides. The only practical silvicultural control in heavily infested stands where the trees are 10 inches in diameter and larger is to harvest the infested trees, burn the unmerchantable material, and regenerate a new stand. In infested stands with a good stocking of smaller diameter classes, removal of the older and larger trees effectively regulates the mountain pine beetle.

Dwarf mistletoe, the most serious disease affecting lodgepole pine, reduces growth and increases mortality. It is most damaging in stands partially opened up by cutting, mountain pine beetles, or windfall, and is of least consequence on regenerated burns. Separation of the old and new stands by clearcutting and felling unmerchantable trees is the best way to control dwarf mistletoe. Partial cutting should be avoided unless the infection is rated class 2 or less (fig. 9).

Figure 8.—Severe blowdown in a lodgepole pine stand after a heavy shelterwood cut that removed 60 percent of the basal area. Fraser Experimental Forest, Colorado.

Figure 9.—The 6-class mistletoe rating system.

Comandra blister rust is a common canker disease in the central Rocky Mountains, but damage has been most extensive in northern Wyoming. Sanitation salvage cutting is about the only practical way of controlling the disease in forest stands.

Natural Reproduction and Early Survival

Lodgepole pine reproduces from seed. It is a prolific seed producer with good crops borne at 1- to 3-year intervals. Throughout much of the central Rocky Mountains, lodgepole pines bear an abundance of serotinous cones that remain unopened on standing trees. However, in some areas, the cone habit is known to be largely nonserotinous. Because the variability in cone habit greatly affects regeneration, each stand must be examined before cutting to determine cone serotiny.

In stands with serotinous cones, seed released from cones attached to the slash and cones scattered on the forest floor is the most important dispersal. Maximum release from this source takes place the first year after cutting. The amount of seed stored in closed cones is usually adequate for regeneration, providing that logging slash bearing cones is carefully handled.

In stands with nonserotinous cones, seed is dispersed from standing trees, largely by the wind. The maximum size of opening that will restock in a reasonable amount of time is probably no greater than about four to five times tree height, because seedfall drops off rapidly as distance from source increases, with most seeds falling within about 200 feet.

The several sources of seed available for natural reproduction include: (1) serotinous cones in the logging slash (a one-shot opportunity), (2) nonserotinous cones on trees either standing around the perimeter of cutover areas or on the area cut, and (3) nonserotinous cones on new reproduction 5 to 10 years old. One of the significant considerations in the kind of seed source to leave in stands with nonserotinous cones is its resistance to windthrow.

Viable seeds of lodgepole pine that survive overwinter normally germinate in the early summer following snowmelt. Lodgepole pine is noted for its ability to establish on burned surfaces after wildfire, but germination and initial survival have usually been better on exposed mineral soil, and disturbed duff and mineral soil than on other seedbed types because of more stable moisture conditions. Germination and early seedling development are usually considered best in full sunlight, but on some sites

radiation intensities under full exposure can create temperature and moisture conditions critical to seedling establishment, especially when precipitation during the growing season is low or irregular. For example, on clear days in early summer, exposed soil surfaces are rapidly dried out and heated to high temperatures. Few seeds can imbibe sufficient water to germinate, and many newly germinated seedlings are killed by stem girdle or drought. Shade either from light slash or a residual overstory reduces excessive heating and drying of the soil surface.

Newly germinated seedlings are especially susceptible to damage from early fall frosts, but older seedlings are seldom damaged by frosts during the growing season. The combination of warm daytime temperatures, nighttime temperatures below freezing, and saturated soils unprotected by snow cover in the early fall are conducive to frost heaving. Shade reduces mortality from frost damage by reducing loss of radiant energy from soil and seedlings. Disease, animals, and vegetative competition also limit regeneration success. Newly germinated seedlings are killed by damping-off fungi early in the growing season when seedbeds are damp. Snowmold fungi occasionally cause damage and death to both natural and planted lodgepole pine seedlings if they remain under the snow too long. Young lodgepole pine seedlings are vulnerable to trampling damage. Birds clip the seedcoats from newly germinated seedlings, and mountain voles and pocket gophers destroy established seedlings. Understory vegetation is usually a major constraint to successful seedling establishment.

Site Quality

The conventional measure of site index is the average height of dominant trees in relation to age. The height growth of lodgepole pine, however, is influenced by stand density probably more than any other North American conifer. The height-age relationship of lodgepole pine is thus a valid estimate of site index only when height growth is adjusted for any reduction due to density. Curves of the height, age, and density (measured as Crown Competition Factor, CCF) relationships of dominant lodgepole pine have been prepared that are suitable for estimating site index (fig. 10).

Conventional methods of site determination cannot be used on lands that are nonforested, or that contain trees either too young or unsuitable for site determination. Site index of lodgepole pine in north-central Colorado and

Figure 10.—Site index curves for lodgepole pine at Crown Competition Factor (CCF) levels of 125 or less. Base age: 100 years, total age.

south-central Wyoming can be estimated from environmental factors, but such site indexes have not been developed for other areas in the central Rocky Mountains.

Growth and Yield

Lodgepole pine often reproduces so abundantly following fire or clearcutting that competition for growing space does not permit good development without artificial thinning (fig. 11). Evidence of stand density control on growth in

young stands is well documented: (1) diameter growth is greatest at the lowest density and slowest at the highest; (2) height growth is reduced by high stand densities, but the response of height growth to thinning has been variable; (3) basal area increment decreases when basal area per acre exceeds about 80 ft²; (4) cubic foot volume increment increases with an increase in stand density, except in stagnated stands.

Growth estimates based on Forest Survey data indicate that average annual growth over all sites in old-growth lodgepole pine is about 25 to 40 fbm per acre. This low productivity is

Figure 11.—Dense 60-year-old stand of second-growth lodgepole pine. Medicine Bow National Forest, Wyoming.

FIGURE 20. Breaking Length vs Freeness (Composite 1)

Tables 25A through 30A of the appendix present data on hand sheet bulk. A general conclusion on the basis of these data is, the one component without bark, i.e., the stemwood shows the lowest bulk for all species. This could be because of the presence of the more bulky bark in the pulp plus any adverse effects it would have on fiber bonding. In general, aspen produced the bulkiest paper and pin cherry, the least bulky.

The levels of strength exhibited by the pulps produced in this phase of the study compare favorably with those of commercial pulps produced from commercial hardwood chips by the sulfate process. Of course, wide ranges of values were realized, from those of the physically inferior willow pulp to those of the strongest pin cherry and gray birch pulps. The components which showed the most promise with respect to strength properties were those which normally would be the easiest to harvest and prepare for pulping, namely the stemwood with or without bark, and Composite 2 (stem and branches, both with bark).

The encouraging results that were obtained in this initial work led to further study.

(B) *Pulping and Bleaching of Composite 2 of Three Puckerbrush Species.*

Composite 2 of three puckerbrush species, gray birch, aspen, and red maple, were pulped under the same conditions as those in (A), and a portion of each of the pulps was bleached. TAPPI Standard beater

FIGURE 21. Breaking Length vs Freeness (Composite 2)

tests were made on both the unbleached and bleached pulps. In addition, commercial hardwood chips were pulped and the resulting pulp was carried through the bleaching and beating operations to serve as a standard of comparison for evaluating the puckerbrush species. The commercial chips contained no bark, whereas the composition of Composite 2 of the three puckerbrush species was the same as shown in Table 3.

Screened yields of the pulps were determined. Kappa Numbers were determined and converted to chlorine demand.

A 4-stage bleaching sequence, chlorination, caustic extraction, hypochlorite, and chlorine dioxide was used. Bleach yields were measured so that *overall* bleached pulp yields, based on dry wood charged to the digester, could be estimated. The bleached pulps were tested for G.E. brightness, cupriethylene diamine viscosity, and alpha cellulose content.

Conditions of the bleaching operations are shown in Table 5. Results of tests on the unbleached and bleached pulps are shown in Table 6.

The results of the bleaching were not encouraging. Shrinkage during bleaching was high, resulting in a very low yield of bleached pulp. It is concluded that the low yield can be attributed to several factors. First, the pulps appeared to be somewhat over-cooked. The cook yields and Kappa Numbers, being on the low side, substantiate this

conclusion. Second, bark components contained in the unbleached pulps are readily attacked and solubilized in the bleaching operation, thus accounting for high bleach shrinkage. Third, small losses of fiber during the bleaching operations, particularly in the washes between stages, can create significant percentage losses in small scale bleaching. The first and third factors certainly are capable of improvement.

Table 5
Bleaching Conditions

VARIABLE	STAGE			
	Chlorination	Extraction	Hypochlorite	Chlorine Dioxide
Percent of Chlorine demand added	60	—	20	20
Consistency (%)	3	10	10	10
Temperature (°F)	75°	160°	100°	160°
pH	2 – 3	11 – 12	11 – 12	—
Time (hr.)	1	1	2	2

Pulp was washed after each stage.

Table 6
Test Results, Bleached and Unbleached Pulps

TEST	SPECIES*			
	Standard	Aspen	Gray Birch	Maple
Cook Yield (%)	46.5	40.3	40.8	42.1
Rejects (%)	0.3	0.1	0.1	0.1
Screened Yield (%)	46.2	40.2	40.7	42.0
Kappa Number	14.5	13.9	17.7	13.6
Cl ₂ demand (%)	4.75	4.46	6.24	4.30
Bleach Shrinkage (%)	15.3	17.8	15.4	19.7
Overall Yield (%) (Cook plus bleach)	39.1	33.1	34.5	33.9
G. E. Brightness	82.8	77.4	79.6	78.8
Cu(EN) ₂ Viscosity (Cp)	19.4	24.3	14.7	14.6
Alpha Cellulose (%)	91.0	92.3	89.1	88.7

* Composite 2 of each of the species, aspen, birch, maple.

The G.E. brightness values were not as high as might be expected for hardwood pulps having such low unbleached Kappa Numbers. Inasmuch as the standard pulp did bleach to an 83 brightness, 4 to 5 points higher than any of the puckerbrush pulps, it is assumed that some bark material, with high resistance to removal by bleaching with chlorine compounds, is the offender in the puckerbrush species.

Further evidence that the pulps may have been over-cooked are the relatively low viscosity values. Generally the cupriethylene diamine viscosity of a normal sulfate pulp is something greater than 30.

The results of beater tests on the bleached and unbleached pulps are shown in Tables 31A-34A and Figures 22-31.

Comparison of the beating characteristics of the red maple, gray birch, and aspen pulps produced in this second series of cooks with those of the first cooks shows good agreement (see Figs. 6 and 22). There are some differences noted between the two series with respect to the initial (unbeaten) freenesses, but the rate of freeness decrease with beating is essentially the same for both series.

The effect of bleaching on beating characteristics may be noted by comparing Figs. 22 and 23. Generally the bleached pulps were slower beating, probably as a result of the removal of hemicellulosic materials

FIGURE 22. Freeness vs Beating Time (Unbleached Pulps)

by the bleaching chemicals. This is usually the effect that is noted unless the pulp is degraded by too severe chemical treatment in the bleaching operation.

FIGURE 23. Freeness vs Beating Time (Bleached Pulps)

FIGURE 24. Bulk vs Freeness (Unbleached Pulps)

FIGURE 25. Bulk vs Freeness (Bleached Pulps)

FIGURE 26. Burst Factor vs Freeness (Unbleached Pulps)

The results in Figs. 26-31 show that the bleached pulps were generally stronger than the unbleached, most significantly in tear and burst strengths.

Fig. 32 is a plot of tear factor versus breaking length for the gray birch and standard pulps in both the bleached and unbleached states. The results show that there is definitely an optimum freeness level or time of beating for each pulp which will give the maximum combinations of tear and tensile strengths. If this maximum is exceeded, there is a rather drastic drop in tearing strength as tensile strength continues to increase. This can be explained by the concurrent effects

FIGURE 27. Burst Factor vs Freeness (Bleached Pulps)

FIGURE 28. Tear Factor vs Freeness (Unbleached Pulps)

of increased bonding and fiber shortening. Both contribute to a decrease in tear strength, whereas the former improves tensile strength.

(C) *Optimizing Cooking Conditions.* At this point in the study it had been established that a good grade of hardwood kraft pulp could be obtained from puckerbrush. The strength characteristics compared favorably with those of commercial hardwood pulps. However, the yields were comparatively low and the pulps were difficult to bleach.

A series of cooks was made to determine optimum conditions, the criteria being yield, and degree of cooking as indicated by the Kappa Number. The cooks were made in the smaller stainless steel digester previously mentioned in this report. Factors that were varied were chemical-to-wood ratio, sulfidity, and time at maximum temperature.

FIGURE 29. Tear Factor vs Freeness (Bleached Pulps)

FIGURE 30. Breaking Length vs Freeness (Unbleached Pulps)

Maximum temperature for all cooks was 345°F, liquor-to-wood ratio was 7 to 9.5 depending on the packing density of the chips, and total chemical concentration of the white liquor at the start of a cook was 38 grams per liter (2.3 #/ft³) as Na₂O.

Gray birch stemwood with bark, and gray birch branches were chosen for this phase of the study because gray birch had generally produced the best pulp in the previous cooks. Nine cooks were made and the conditions and results are shown in Table 7.

FIGURE 31. Breaking Length vs Freeness (Bleached Pulps)

FIGURE 32. Tear Factor vs Breaking Length

The general objective for this series of cooks was to establish a combination of realistic cooking conditions that would produce a pulp at a yield not less than 45% and a Kappa Number not greater than 30. This refers to the gray birch stemwood.

It was decided, on the basis of results obtained, that the conditions of cook #5 (Table 7) most nearly met the objectives which had been set. The conditions of this cook, when compared with those used in the

Table 7
Effect of Cooking Variables on Yield and Kappa Number

Cook #	1	2	3	4	5	6	7	8	9
Species	Standard Chips	Gray Birch	Runs 2 through 9 were Gray Birch.						
Active Alkali-to-Wood Ratio	0.25	0.25	0.20	0.20	0.20	0.20	0.15	0.20	0.20
Sulfidity (%)	25	25	25	25	25	25	25	20	20
Time at Temperature (hours)	2	1	2	1	½	0	2	2	½
Yield (%) Stemwood	46.9	42.8	43.7	45.2	47.7	51.2	48.2	42.9	50.0
Rejects (%) Stemwood	—	—	0.2	1.4	6.2	28.0	8.4	0.8	9.6
Kappa Number Stemwood	12.8	18.9	20.4	21.2	29.4	43.6	40.4	20.7	35.9
Yield (%) Branches	—	33.2	32.6	32.3	34.2	39.5	39.7	33.7	38.4
Rejects (%) Branches	—	—	0.1	0.8	1.6	6.6	4.5	0.6	4.0
Kappa Number Branches	—	27.7	26.4	29.4	33.9	53.6	46.0	28.5	41.8

Max. Temperature = 343 - 345° F
 Liquor-to-Wood Ratio = 7 - 9.5
 Chemical Concentration = 39 g.p.l. (as Na₂O)
 2.3 #/ft³ (as Na₂O)

first phase of the pulping study, show a decrease in the chemical-to-wood ratio, from 0.25 to 0.20, and a substantial decrease in cooking time at maximum temperature, 2 hours to ½ hour. Continuing the comparison, but for results obtained, it is seen (Tables 2 and 7) that the yield of stemwood pulp is increased from 41.9 to 47.7%, and the Kappa Number from 23.2 to 29.4 by the new cooking conditions. The 6.2% rejects that are shown for cook 5 would be reduced considerably under commercial pulping conditions because they were actually "soft" rejects and the high value resulted mainly from the defibering conditions that were arbitrarily established for this study. This would, of course, result in further improvement in cook yield. The Kappa Number of 29.4 compares very favorably with that experienced under commercial pulping conditions and it represents a pulp which is well-cooked, but certainly not over cooked to the point of fiber degradation.

It is interesting to note that the branchwood reacted much the same as did the stemwood to the variations in cooking conditions, although the level of yields is much lower for the branches, and the Kappa Numbers are higher. These effects can be attributed to the higher proportion of bark to wood, and a higher percentage of oxidizable materials in the branchwood pulp.

Using the conditions established in cook 5, Table 7, Composite 2 of four species, gray birch, alder, aspen, and red maple, were pulped in separate cooks, using the larger digester. Yields and Kappa Numbers were determined for each of the pulps. Beater tests were run and hand sheets were made and tested. The results are shown in Table 8. The purpose of this series of cooks was to determine what effects the new cooking conditions would have on yields and properties of pulps from these four prevalent puckerbrush species.

For ease of comparison of results obtained under the new cooking conditions with those obtained in the first cooks, the earlier results are shown in parentheses in Table 8.

Increases in yield obtained when stemwood was pulped under the new conditions did not materialize in the case of Composite 2, although there were slight increases for all species except aspen. One reason for this may be that proportionally there is more bark in Composite 2 than in the stemwood, inasmuch as there are branches present.

Kappa Numbers were higher for all species and this result is in agreement with what was expected on the basis of results shown in Table 7.

It is seen that the new pulping conditions produced pulps with improved strength properties. The differences are not significant in some cases but the trend is toward increased strength. Pulp freenesses also

Table 8
Properties of Composite 2 of Four Species: Gray Birch, Alder, Aspen, and Red Maple
Pulped Under Conditions of Cook #5, Table 7

Beating Time (min.)	0	5	10	20	30
Cook Yield (%)	Gray Birch Alder Aspen Red Maple	39.9 (38.1) 37.0 (35.3) 41.3 (42.7) 45.0 (42.2)			
Kappa Number	Gray Birch Alder Aspen Red Maple	29.6 (21.5) 37.8 (29.3) 32.2 (14.8) 25.9 (15.1)			
C. S. Freeness (ml)	Gray Birch Alder Aspen Red Maple	522 (418) 392 (302) 417 (402) 481 (451)	442 (368) 343 (282) 369 (332) 417 (401)	365 (306) 312 (—) 333 (313) 367 (353)	232 (197) 200 (248) 222 (213) 252 (261)
Bulk ($\frac{\text{cc}}{\text{gm}}$)	Gray Birch Alder Aspen Red Maple	1.9 (1.78) 1.68 (1.42) 1.99 (1.79) 1.82 (1.75)	1.9 (1.62) 1.59 (1.32) 1.93 (1.74) 1.74 (1.62)	1.9 (1.63) 1.56 (1.30) — (1.70) 1.66 (1.54)	1.8 (1.54) 1.56 (—) 1.87 (1.58) 1.61 (1.42)
Burst Factor	Gray Birch Alder Aspen Red Maple	45 (54) 61 (64) 46 (44) 36 (33)	69 (70) 76 (71) 57 (54) 48 (43)	79 (76) 85 (75) 61 (58) 59 (50)	82 (83) 94 (78) 72 (65) 71 (62)
Tear Factor	Gray Birch Alder Aspen Red Maple	76 (80) 63 (84) 66 (76) 65 (69)	93 (88) 72 (80) 71 (75) 91 (79)	92 (85) 92 (76) 73 (71) 97 (79)	89 (86) 89 (75) 71 (—) 84 (78)
Breaking Length (meters)	Gray Birch Alder Aspen Red Maple	10620 (10380) 10970 (11220) 9560 (8780) 7960 (6960)	12330 (11580) 12050 (12330) 10830 (9360) 9320 (8300)	13730 (12260) 12590 (12070) 10950 (10670) 10530 (8800)	14170 (12790) 12850 (12309) 12450 (9820) 11860 (9670)

Values in parentheses are results obtained in first phase of the work.
They were copied from Tables 1A—35 in the appendix

were generally higher, although the response to beating did not appear to change materially.

A portion of the gray birch pulp was bleached using the bleaching conditions shown in Table 5. The bleach yield, overall yield, and G.E. brightness were measured. A standard beater test was run on a sample of the bleached pulp. The results are shown in Table 9.

Again, as in previous bleaching results, there was a considerable shrinkage as a result of the operation and the overall yield was a low 32%. The brightness value of 73.3 is approximately 6 points lower than was previously experienced on pulp from gray birch Composite 2. It is believed that this present value is not accurate and resulted from coloring materials in the water used for pulp washing.

Bleaching resulted in a decrease in freeness of the gray birch pulp. Effects on strength properties were slight and no consistent trend was noted. One exception was the bulk, which decreased significantly as a result of the bleaching.

(D) *Study of Bleaching Conditions.* Several bleaching sequences were used in an effort to produce at least an 80 brightness pulp without abnormal damage to the fiber. The bleaching conditions and resulting brightness values are shown in Table 10. No other tests were made on the bleached pulps.

Three pulps were prepared for the bleach study, using the optimum pulping conditions that had been established previously. The pulps were prepared from Composite 2 of gray birch, gray birch stemwood without

Table 9
Properties of Gray Birch Pulp
Pulped Under Conditions of Cook #6, Table 7

Beating Time (min.)		0	5	10	20	30
C.S. Freeness (ml.)	Unbleached	522	442	365	232	107
	Bleached	485	431	348	208	133
Bulk $\left(\frac{\text{cc}}{\text{gm}}\right)$	Unbleached	1.9	1.9	1.9	1.8	1.7
	Bleached	1.5	1.4	1.3	1.3	1.3
Burst Factor	Unbleached	45	69	79	82	88
	Bleached	50	76	86	84	89
Tear Factor	Unbleached	76	93	92	89	73
	Bleached	69	95	90	81	72
Breaking Length (meters)	Unbleached	10620	12330	13730	14170	14210
	Bleached	11210	13640	14560	14550	13730
Cook Yield (%)		39.1	Overall Yield (%)		32.0	
Kappa Number		29.6	G. E. Brightness		73.3	
Bleach Yield (%)		81.6	Bleach Sequence		CEHD	

bark, and commercial hardwood chips. The latter two were prepared as standards for purposes of comparison.

The first two bleach runs were made on gray birch Composite 2 pulp, using a 4-stage sequence, with 60% of the chlorine demand being used in the chlorination stage (C) and the remaining 40% being divided equally between the hypochlorite (H) and chlorine dioxide stages (D).

A brightness of 80.3 was realized for Run 1. This is much better than the 73.3 value that was obtained previously and the difference can be attributed to an improvement in the color condition of the water used in the pulp washing stages.

In run 2, the percent addition of chlorine was increased by 25%. Inasmuch as the additional chemical did not increase brightness, it was decided to try different sequences of bleaching stages. In runs 3 and 4 the same percent of chemical was used as in run 1 (100%) but it was divided among a different number and sequence of stages. Six stages, two being chlorine dioxide, were used in run 3, and five stages, two being hypochlorite, in run 4. No improvement in brightness, over that obtained in the four-stage treatment, was realized.

In run 5, the percent addition of chlorine was increased by 60% over that indicated by the Kappa Number as being required. The additional chemical was added as a second chlorination stage. This resulted in the highest brightness yet attained for a puckerbrush species pulp, 82.2 points. Further work will be required to determine whether it is the additional chemical, the sequence of addition, or both, that control the brightness development. It is suspected that the chlorine demand, as indicated by the Kappa Number, is too low, and must be increased by some minimum factor, particularly for puckerbrush species that are pulped with the bark intact. The results of run 6 offer some support to this hypothesis. Here the pulp from gray birch stemwood *without bark* attained a brightness of 84.6.

The pulp from a commercial blend of hardwood chips bleached to an 86.6 brightness using the 60% excess chlorine addition, thus providing more evidence that the puckerbrush may be more difficult to bleach than is pulp from the wood of full size trees.

(E) *Fiber Morphology Study.* In the final phase of this study a complete analysis was made of the important dimensions of the fibers of puckerbrush species. The procedure used in measuring these dimensions was described in the experimental procedure section of this report. The results are shown in Table 11.

The strength characteristics of paper are dependent to a large degree on the dimensions and intrinsic strength of the wood fibers of which it is composed. Many studies have been made attempting to

Table 10
Results of Bleach Study

Run #	Wood Species Cook Yield Kappa Number	Percent of Cl ₂ Demand Used	Bleaching Stages	Percent of Cl ₂ Demand Used in Stage	G. E. Brightness
1	Gray Birch Composite 2 39.1% 29.6	100	C E H D	60 — 20 20	80.3
2	"	125	C E H D	60 — 20 20	79.3
3	"	100	C E H D E D	60 — 20 10 — 10	80.0
4	"	100	C E H H D	60 — 10 10 20	79.7
5	"	160	C E C E H D	60 — 60 — 20 20	82.2
6	Gray Birch Stems Without Bark, 47.5% 23.9	160	"	"	84.6
7	Commercial Hwd. Chips, 46.7% 25.1	160	"	"	86.6

develop meaningful relationships between the strength of paper and the criteria mentioned. There have been few such correlations developed. However, it is an established fact that strength properties, particularly tearing strength, increase with increasing fiber length. Also fiber flexibility, which would be enhanced by fibers having a low ratio of cell wall thickness to lumen diameter, tends to contribute to paper strength. The reason for this is the increased degree of contact, and greater opportunity for fiber-fiber bonding, where the fibers conform to their neighbors during water removal in the forming of a sheet.

Table 11
Fiber Dimensions

Species	Length (mm.)	Cell Diameter (microns)	Lumen Diameter (microns)	Cell Wall Thickness (microns)
Aspen Stem w/o bark	0.73	27.5	23.5	2.0
Aspen Stem with bark	0.69	26.6	23.1	1.7
Aspen Branches	0.51	23.4	17.2	2.0
Aspen Stump & Roots	0.77	30.3	26.6	1.9
Aspen Composite 1	0.62	28.0	23.6	2.1
Aspen Composite 2	0.60	26.7	23.1	1.8
Alder Stem w/o bark	0.64	23.9	19.0	2.3
Alder Stem with bark	0.57	23.1	18.0	2.6
Alder Branches	0.48	18.4	13.6	2.4
Alder Stump & Roots	0.68	28.9	23.3	2.8
Alder Composite 1	0.56	21.9	17.3	2.2
Alder Composite 2	0.55	21.5	16.9	2.2
Gray Birch Stem w/o bark	0.73	22.6	16.4	3.1
Gray Birch Stem with bark	0.72	20.5	15.0	2.7
Gray Birch Branches	0.61	18.0	13.2	2.4
Gray Birch Stump & Roots	0.68	24.7	19.8	3.0
Gray Birch Composite 1	0.67	21.5	15.6	2.9
Gray Birch Composite 2	0.64	21.2	15.3	2.9
Red Maple Stem w/o bark	0.62	20.0	13.4	3.3
Red Maple Stem with bark	0.64	20.2	13.6	3.3
Red Maple Stem Branches	0.51	17.3	11.8	2.7
Red Maple Stump & Roots	0.61	27.6	21.9	3.3
Red Maple Composite 1	0.62	21.3	15.8	2.7
Red Maple Composite 2	0.63	18.2	13.8	2.9
Pin Cherry Stem w/o bark	0.64	18.6	12.5	3.1
Pin Cherry Stem with bark	0.57	19.1	13.0	3.0
Pin Cherry Branches	0.50	15.3	9.8	2.7
Pin Cherry Stump & Roots	0.69	24.4	18.4	3.0
Pin Cherry Composite 1	0.58	20.8	15.5	2.7
Pin Cherry Composite 2	0.58	18.7	13.5	2.6
Willow Stem w/o bark	0.47	17.0	10.9	3.0
Willow Stem with bark	0.56	16.5	10.9	2.9
Willow Branches	0.46	15.4	10.0	2.7
Willow Stump & Roots	0.50	22.1	16.7	2.9
Willow Composite 1	0.50	17.6	12.4	2.7
Willow Composite 2	0.48	15.3	9.7	2.8
Standard Pulp	0.84	22.1	13.5	4.3

The puckerbrush fibers are generally shorter, and have a greater lumen-to-wall thickness ratio, than the fibers from deciduous trees.

Aspen stemwood has the best combination of fiber length, and lumen-to-cell wall ratio of the six puckerbrush species. It should be the most flexible of the lot and it is one of the two having the longest fibers, gray birch being the other. It does excel in some respects, particularly in tensile strength, but overall it is somewhat weaker than either the gray birch and pin cherry.

Willow has the shortest fibers and the highest cell wall-to-lumen diameter ratio and as might be expected, it produces the weakest pulp.

The wall thickness of the gray birch, red maple and pin cherry fibers are greater than those of the willow and they are longer and have a larger lumen diameter. Inasmuch as they are much superior to the willow in strength characteristics, it is apparent that no single dimension, but rather a combination of dimensions, is the criterion.

Several such combinations were calculated for the stemwood fibers of all six species and they are shown in Table 12. Included in the table are strength properties from Figures 7, 12 and 17, at a freeness of 300. The derived property combinations are defined at the bottom of the table. The "total length factor" was determined from Fig. 33 and represents the *relative* total lengths of 100 fibers. It is proportional to the area under any curve shown in Fig. 33. Thus, gray birch would have the greatest total length factor and willow, the lowest.

The lack of any consistent relationships between fiber dimension combinations and physical properties indicates that other important factors are contributing to the strength characteristics. Probably one of the most important of those factors, and one that has not been determined in this study, is the inherent strength of the fiber itself. This might explain, in part, the reason that aspen fibers which, according to the results in Table 12, excel in length, flexibility, and total length factor, do not produce the strongest paper in general.

Biomass Studies

Introduction

Foresters commonly use the term "bush" to mean natural forests of commercial tree species in Africa, Australia, Canada and portions of the United States. In the State of Maine, U. S. A., the term "puckerbrush" is commonly used to mean thickets of alder and willow, young aspen birch and red maple or similar stands that are generally less than thirty feet in height. This term seems to be equally appropriate for dense young softwood stands. In the world there are millions of acres of non-commercial woody shrub and tree stands to which the term puckerbrush may aptly be used to differentiate such stands from natural forest stands of species that are commercially important.

Rodin and Bazilevich (8, 9), Whittaker and Woodwell (10, 11) and Young (12, 13) have summarized most of the world literature on biomass studies of individual trees and forest stands that has been published in the past thirty years. The literature indicates that generally satisfactory means have been established for sampling the components of individual trees but many authors have indicated dissatisfaction with their sampling methods for forest stands. Inasmuch as a forest stand

FIGURE 33. Fiber Length Distribution (Stem Without Bark)

consists of more than one tree on some specified area, such biomass studies are more time consuming and therefore encourage considerable sub-sampling to keep the field work within reasonable time limits in terms of the information desired.

The literature does not disclose any biomass studies of forest stands that are statistically sound and economical in terms of time. Therefore, a study of biomass sampling methods for puckerbrush stands is appropriate and timely for there is increasing interest in this segment of the plant world. This study will report on two different sampling methods that have been field tested in Maine.

Table 12
Paper Strength Properties and Fiber Characteristics

Species	Fiber Length (mm)	Fiber Flexibility	Fiber Solids- Length Factor	Total* Length Factor	Burst Factor	Breaking Length (meters)	Tear Factor
Gray Birch	0.73	73	34	1	92	13100	101
Pin Cherry	0.64	67	35	4	97	14500	93
Red Maple	0.62	67	34	5	72	11300	88
Aspen	0.73	85	20	2	84	14500	81
Alder	0.64	81	22	3	78	12800	76
Willow	0.47	64	28	6	50	9900	66

$$\text{Fiber Flexibility} = \left(\frac{\text{Lumen Diameter}}{\text{Cell Diameter}} \right) (100)$$

$$\text{Fiber Solids} - \text{Length Factor} = \left(\frac{\text{Cell Wall Cross-Section Area}}{\text{Cell Cross-Section Area}} \right) (\text{Fiber Length}) (100)$$

$$\text{Total Length Factor} = \frac{\text{Relative Total Lengths of 100 Fibers.}}{\text{See Fig. 33}}$$

* 1 means longest, 6 shortest.

Methods

Puckerbrush stands range from 2-50 feet in average height, include 1-10 species per acre and have from 200-20,000 or more stems per acre. The primary objective of a biomass study of a forest stand is to obtain reliable estimates on a per acre basis of the fresh and dry weight for each component of the shrub or tree for each species present. Inasmuch as this type of study requires destructive sampling, the time required in the field and laboratory is directly related to the number of plant components recognized, the number of woody plants present and the area of the sample plot. The objective of the sampling investigations, therefore, must be to establish sampling and sub-sampling procedures that will yield estimates within the limits of accuracy established by the research worker. Then finally acceptable sampling procedures should minimize the destructive sampling which is so very time consuming.

1969 Methods

Two major considerations in the planning stage were: (1) estimates of dry matter of all vegetation above- and below-ground were to be made and (2) sub-sampling errors would be eliminated by drying all of the vegetation on the plot. With these considerations in mind the basic plot was to be square and as many meters on each side as the stand was meters high to the nearest full meter. Thus, for a stand five meters high the plot would be 5 by 5 meters consisting of five sub-plots each 1 by 5 meters. On each sub-plot the data were to be recorded by one meter squares. Statistical analysis of the major sub-plots would be performed to see if fewer strips would give satisfactory results.

The field work on the square meter sub-plots of the first sub-plot strip of the first basic plot required more than two days for a two-man field crew. Therefore the basic plot was reduced from the square dimensions to a single strip of square meter sub-plots as long as the trees on the plot were high in meters to the nearest meter. Each square meter sub-plot was delineated in the field by a $\frac{3}{8}$ " steel chain with 30-penny nails in the corner as measured with a meter stick. For each species on the sub-plot the material was separated into above- and below-ground portions. The above-ground portion for the perennials was separated into leaves, branches (material smaller than $\frac{1}{4}$ ") and stem (material larger than $\frac{1}{4}$ ") after drying. As a general practice the material from all of the sub-plots of a plot was brought to the laboratory at one time, weighed in the fresh condition and then placed in a drying room at 80° C for at least two days and sometimes longer. All remaining earth and stones were removed from the material after taking it from the drying room. The components were separated before weighing for each species.

1970 Methods

The sampling procedures of 1969 were so time consuming and the plot was so small that considerable thought was given to alternative methods. If the annuals were omitted, the study would be limited to woody vegetation and would not be complete in an ecological sense. If the below-ground material were omitted, the study would be limited but information on below-ground material was simultaneously being collected for a pulping study. If sub-sampling procedures were employed, the field and laboratory work per plot would be considerably less. These were the three major factors in the time required per plot and the plot size in 1969.

To expand the basic plot for 1970 the annuals and the below-ground portions were eliminated and sub-sampling procedures were included. The basic plot would be 25 by 25 feet (1/70th-acre) regardless of the average height of the stand. Surveying pins were to be used to mark the plot corners and a plastic line with a metal corner marked in 25' segments was used to locate the plot. Both diagonals were measured with a specially marked piece of plastic line to insure accuracy of plot size. The two-man field crew then placed the Fairbanks Morse counter beam scales (350 pound maximum with 50 pounds on the beam with quarter pound limits) on a level spot adjacent to and outside of the plot boundary nearest to the road.

The procedure for each species on the plot was as follows:

1. Three trees were selected as the tallest, medium and shortest. A small Homelite chainsaw was used to sever the stems at a three-inch stump. The entire above-ground portion of the three trees was then weighed in a large rigid plastic container of known weight.
2. The length of each was measured and the annual rings counted at the stump end to estimate average age and height for the species.
3. The branches (material less than $\frac{3}{8}$ ") were clipped from the three stems (material larger than $\frac{3}{8}$ "). The branches and stems were then separately weighed to estimate the proportion of each in the above-ground material.
4. All of the trees of the species were severed and weighed in the plastic container in a series of weighings depending on the mass of material present.
5. A random sample of branches was clipped from the pile and placed in a flexible plastic container along with several stem disks.
6. In the laboratory the leaves were stripped from the branches and then the branches and leaves were separately weighed to estimate the proportion of each in the branch component.
7. The stem disks, a random sample of leaves and a random sample of branches without leaves were weighed and placed in an oven at

105°C for at least 24 hours at which time they were re-weighed to estimate the moisture content.

Analytical Procedures

1969 Data

No effort was made to differentiate between species or to separate the above- and below-ground portions for the annuals. By inspection the variation in the dry weight between sub-plots of a single plot was so great that no attempt was made to analyze the sub-plots statistically. The woody shrubs and trees had initially been separated into components by species by sub-plots. The species were combined by components (leaves, stems and stumps and roots) within a sub-plot and the sub-plots of each plot were combined to estimate the components on a per-acre basis.

1970 Data

All of the above-ground portion of the woody shrubs and trees were weighed in successive loads in the rigid plastic container. Therefore the fresh weight of the aerial portion is relatively free of error.

Three sub-sampling routines were used to estimate the dry matter in the leaf, branch and stem components of each species on an acre basis. The proportion of branches with leaves of the aerial portion as estimated (step 2 of procedure) was applied to the total fresh weight of the plot to estimate the amount of branches with leaves and stems on the plot. The proportion of leaves and branches without leaves (step 6 of procedure) was applied to the estimate of the fresh weight of branches with leaves to estimate the fresh weight of leaves and branches without leaves on the plot. By this procedure the actual fresh weight of the plot was cast into separate estimates of the fresh weight of leaves, branches without leaves and stems and these were multiplied by 69.696 and divided by 2,000 to place the estimates on an acre basis in tons. Estimates of the percent of dry matter in each component (step 7 of procedure) were then applied to prepare the estimates of the dry matter of each component per acre for the species. Finally the species were combined by components to estimate the dry matter of each per acre.

Results

1969

Nine stands ranging from 2-5 meters in height were sampled by two young men during a four-week period. The results are shown in Table 13. From the limited amount of data it appears that the mass of annuals decreases as the stand becomes fully stocked with woody vegetation. The leaf mass per acre seems to be relatively constant regardless of species composition or size. The total dry biomass per acre for these young stands ranged from 10.6-31.8 tons per acre with the dry matter pro-

Table 13
Pilot Biomass Study of Weed Tree Species and Woody Shrub Communities - 1969

	Meadow- sweet	Dogwood Meadow- sweet	Alder	Alder	Grey Birch	White Birch	Willow	Aspen	Aspen
Number of square meter subplots	2	2	3	3	3	3	5	5	3
Approximate height above ground in meters	1	2	2	3	3	3	5	5	5
Approximate age	4	8	4	6	12	6	11	7	7
All figures below are dry weight in tons per acre									
Annuals	2.7	2.0	4.4	3.4	3.2	2.5	1.0	0.8	2.5
Trees and Shrubs:									
Leaves	2.0	1.9	1.7	3.0	2.8	3.6	2.2	1.6	1.8
Stems and Branches	8.0	10.9	3.1	7.7	12.8	16.4	22.8	11.8	9.3
Roots	6.0	4.0	1.4	2.4	4.0	5.6	5.8	2.7	2.3
Total Biomass	18.7	18.8	10.6	16.5	22.8	28.1	31.8	16.9	15.9

duction of stems and branches ranging from 0.8-2.7 tons per acre per year.

1970

During a 13-week period two young men obtained data on 61 plots in 50 different stands representing at least 15 species combinations. They did either one or two plots a day with travel time an important factor, as the plots were distributed in central and northern Maine. About one-quarter of that time was spent on another related project.

Because so few have examined biomass data, a selected portion is displayed in Table 14 to give some notion of the actual plots. The data for the 61 plots is summarized as follows:

Factor	Range	Average
Individual average stand age	2 - 59 years	
Individual average stand height	3 - 45 feet	
Estimated dry matter (wood and bark) per acre above ground	2.9 - 55.3 tons	
Dry matter production (wood and bark) per year in fully stocked stands	0.4 - 2.0 tons	1.2 tons
Dry matter production (wood and bark) per linear foot of height in fully stocked stands	0.4 - 1.5 tons	0.8 tons

Only eight of the plots were in stands that had been regenerated by coppicing. Four were on an experimental area of the Penobscot Experimental Forest, U. S. Forest Service, in Bradley and Eddington townships, Maine. These had been clear cut six years previously and ranged from 1.4-2.0 tons of dry matter per acre per year. The other four were on an esker northeast of Orono, Maine in open-grown stands 19-26 years old that ranged from 0.6-1.2 tons per acre per year.

The average height of the sample trees on the plot was 7.9 feet below the height of the tallest sample tree. The range of difference in height from the average to the tallest was 1-20 feet.

The field data were collected over a three-month period during which time the moisture content of the wood vegetation probably changed. To ascertain if any seasonal changes were apparent, the estimated dry matter in the stems and branches without leaves was calculated as a percent of the total above-ground fresh weight of the plot. There was no observable seasonal trend. The average percentage was 52.2 ranging from 42.2-69.1. As a rule of thumb the dry weight of

Table 14
Selected plot Data of Dry Matter Production Study Collected in 1970 Field Season

Plot No.	Dominant Species	Other Species	Ave. Hgt. Feet	Ave. Age	Dry Matter tons/acre Stems & Branches	Dry Matter tons/acre per year	Production tons/acre per ft. hgt.	Leaves tons/acre
3	Aspen	Red Maple, Beech	35	20	33.13	1.66	0.95	0.84
9	Willow		11	9	10.03	1.11	0.91	1.00
10	Alder		9	5	8.46	1.69	0.94	1.93
15	Aspen, Grey Birch	Red Maple	45	41	52.42	1.28	1.16	0.95
17	Meadowsweet		3	2	2.91	1.46	0.97	1.22
23	Sugar Maple, Beech, Yellow Birch		43	49	55.29	1.13	1.29	1.27
26	Pin Cherry	Striped Maple, Grey Birch, Aspen	20	15	14.31	0.95	0.70	1.57
31	Aspen		17	6	10.58	1.76	0.62	1.52
33	Paper Birch, Aspen	Beech, Yellow Birch, Maple	34	24	23.12	0.96	0.68	1.57
35	Aspen, Red Maple		15	6	8.62	1.44	0.57	1.75
44	Sugar Maple, Beech		20	18	19.29	1.07	0.97	1.40
54	Beech		26	26	34.87	1.34	1.34	0.79
55	Paper Birch	Sugar Maple	22	22	13.32	0.61	0.61	0.83
58	Yellow Birch		29	25	26.45	1.06	0.91	0.98
60	Alder		18	20	13.84	0.69	0.77	1.00

the stems and branches without leaves is approximately half the fresh weight of the same material with leaves.

Three of the stands sampled in 1969 were re-sampled in 1970 primarily to learn the effect of increased plot size on the per acre estimates. In all three cases the acre tonnage was less.

Discussion

Biomass sampling of forest stands presents two formidable fundamental questions. How accurately do we need or want to know the dry weight of each component by species on the plot? How accurately do we need or want to know the dry weight of components by species or by combined species for a particular forest stand? These must be resolved for the destructive nature of the basic biomass studies is so much more time consuming for forest stands than similar studies for individual trees species.

If the plot data were devoid of error, each forest stand would have sufficient variation that from 6-30 plots would be required to obtain an error of estimate of the mean that did not exceed 10 percent at 19:1 odds when all components and all species were combined. If it is essential to have the information by species or by component within species, or by component when all species are combined, then the number of plots in a single forest stand might be increased by factors of 3-10. Under such conditions a single two-man field crew might spend an entire summer field season in a single forest stand. For certain scientific objectives this can be justified, but it is unlikely that this would be feasible for an applied study.

Within the plot as described for 1970 there are three levels of subsampling. Are three trees per species extending over the range of tree sizes adequate to determine average height, average age and proportion of branches with leaves to stem? This was not tested, but it is likely that if six sets of three trees had been selected the results would have demonstrated a range of at least 10% from the smallest to the largest of the six sets. Is it important to estimate this error?

In plot number 20 six sets of random samples of branches with leaves and six sets of stem disks were brought to the laboratory. The proportion of leaves and branches were determined by weighing them separately for each set. The proportion of branches without leaves ranged from 37.1-51.4%. All of this material was dried in the oven and then re-weighed to determine the moisture content which was 57.1-61.4% for the leaves, 42.0-51.8% for the branches without leaves and 37.2-43.8% for the stem disks. Is it sufficiently important to know the errors of sub-sampling to take this many additional samples? If so, then if the three sub-sampling routines are increased sixfold in order

to calculate the error of estimate, it is extremely unlikely that more than one plot would be field sampled in one day even if the field crew were expanded to three people.

In some instances it took a half day for the field crew to get to a particular area where a series of plots was to be measured. It is well to point out that contacting forest managers and forest land owners for permission to do destructive sampling and actually locating the plots involves more time and effort than may be apparent. From a fixed location a two-man field crew did one or two plots a day, depending on the size of the trees, including 25 miles travel distance to and from the plot and the essential laboratory work. If the sub-sampling were increased sixfold for each of the three routines and if ten plots were essential for each forest stand, then a minimum of ten crew days with three men in the crew would be required to reliably estimate the above-ground portion of a particular forest stand. If it becomes necessary to sample the under-ground portion of the forest stand with similar error requirements, then the field and laboratory time would be at least doubled for forest stands with trees no larger than four inches in diameter at breast height.

Because there is so little biomass data for puckerbrush stands, the decision was made to employ the sampling procedures outlined in the methods section. By so doing some information was obtained in a number of plots representing a variety of species composition, size classes and regional distribution rather than a precise estimate of a very few forest stands.

Although the 1970 plot data yielded smaller tonnage per acre than the 1969 plot data there is still no certainty as to the proper plot size for puckerbrush stands of different size classes. It is conceivable that 50 by 50 foot plots might have been more accurate. The important point to recognize is that we need a number of biomass sampling studies to determine the proper plot size and shape for biomass studies of forest stands. Such investigations should be conducted in the present and near future as there is evidence accumulating that biomass is a more meaningful way to quantitatively describe an ecosystem.

Summary and Conclusions

Two sampling procedures were tested in successive years. In 1969 all of the vegetation above- and below-ground was weighed fresh and dry from small plots. This is an extremely time consuming process that probably should be used only on small-scale, sophisticated, basic ecological studies. In 1970 three sub-sampling routines were employed on only the above-ground portion of larger plots. These methods introduce greater error, but permit larger plots and more plots as a means of

quantitatively describing puckerbrush stands. These methods, probably with some refinements, are probably applicable to applied studies.

Puckerbrush stands in central and northern Maine appear to be producing about 1.2 tons of dry wood and bark per acre per year on the stems and branches regardless of species composition or age, providing the stand is fully stocked. For convenience this can be expressed as about 0.8 tons of dry matter per linear foot for the average height of the stand above ground.

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APPENDIX

- 1A – 6A. C. S. Freeness (ml.) vs Beating
 7A – 12A. Burst Factor vs Beating Time
 13A – 18A. Tear Factor vs Beating Time
 19A – 24A. Breaking Length (meters) vs Beating Time
 25A – 30A. Bulk (cc/gm) vs Beating Time
 31A – 35A. C. S. Freeness vs Beating Time (Composite 2)

for

Gray Birch, Red Maple, Aspen, Pin Cherry, Alder and Willow

Table 1A
 C.S. Freeness (ml) vs Beating Time
 Alder Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	422	355	303	255	231	
Stem with bark	371	341	305	240	—	
Branches	245	268	—	—	—	
Stump and Roots	370	342	315	260	—	
Composite 1	304	278	258	—	—	
Composite 2	302	282	282	248	—	

Table 2A
 C.S. Freeness (ml) vs Beating Time
 Gray Birch Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	492	464	400	272	155	
Stem with bark	468	396	352	234	122	
Branches	277	224	207	—	—	
Stump and Roots	383	353	290	207	170	
Composite 1	387	349	284	198	77	
Composite 2	418	368	306	197	106	

Table 3A
C. S. Freeness (ml) vs Beating Time
Aspen Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	527	479	410	301	199	215
Stem with bark	446	411	351	245	148	—
Branches	269	268	256	—	—	—
Stump and Roots	467	423	352	233	132	—
Composite 1	388	349	293	192	153	—
Composite 2	402	332	313	213	145	—

Table 4A
C. S. Freeness (ml) vs Beating Time
Red Maple Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	542	—	472	361	269	180
Stem with bark	502	—	481	362	262	170
Branches	316	314	307	—	—	—
Stump and Roots	742	—	—	—	—	—
Composite 1	475	417	365	270	197	—
Composite 2	451	401	353	261	167	—

Table 5A
C. S. Freeness (ml) vs Beating Time
Pin Cherry Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	480	—	421	314	215	—
Stem with bark	452	—	351	242	182	—
Branches	287	247	252	—	—	—
Stump and Roots	504	—	441	332	233	162
Composite 1	442	—	355	237	167	—
Composite 2	406	—	317	237	197	—

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Table 6A

C. S. Freeness (ml) vs Beating Time
Willow Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	436	392	370	335		
Stem with bark	367	351	296	252		
Branches	308	—	—	—		
Stump and Roots	330	297	286	278		
Composite 1	367	333	290	280		
Composite 2	343	322	299	290		

Table 7A

Burst Factor vs Beating Time
Alder Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	59	69	75	82	82	
Stem with bark	55	63	69	76	77	
Branches	63	68	71	—	—	
Stump and Roots	43	47	51	55	57	
Composite 1	56	62	65	69	—	
Composite 2	64	71	75	78	—	

Table 8A

Burst Factor vs Beating Time
Gray Birch Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	59	74	84	93	95	
Stem with bark	60	75	84	90	91	
Branches	52	62	68	—	—	
Stump and Roots	47	51	55	60	63	
Composite 1	58	67	70	80	78	
Composite 2	54	70	76	83	88	

Table 9A
Burst Factor vs Beating Time
Aspen Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	50	65	75	83	89	90
Stem with bark	44	52	59	68	70	—
Branches	39	44	46	—	—	—
Stump and Roots	41	47	53	59	62	—
Composite 1	41	47	52	60	62	
Composite 2	44	54	58	65	68	

Table 10A
Burst Factor vs Beating Time
Red Maple Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	29	—	52	66	74	76
Stem with bark	31	—	48	61	68	72
Branches	40	46	51	—	—	—
Stump and Roots	22	26	—	—	—	—
Composite 1	29	37	45	57	62	—
Composite 2	33	43	50	62	67	—

Table 11A
Burst Factor vs Beating Time
Pin Cherry Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	50	—	78	94	103	—
Stem with bark	48	—	68	82	88	—
Branches	56	63	69	—	—	—
Stump and Roots	40	—	62	72	80	83
Composite 1	43	—	65	78	84	—
Composite 2	48	—	67	78	83	—

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Table 12A

Burst Factor vs Beating Time
Willow Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	33	40	46	57		
Stem with bark	32	42	49	61		
Branches	39	46	—	—		
Stump and Roots	30	35	42	45		
Composite 1	33	40	46	54		
Composite 2	34	41	48	56		

Table 13A

Tear Factor vs Beating Time
Alder Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	69	78	76	71	71	
Stem with bark	72	71	77	76	65	
Branches	71	75	71	—	—	
Stump and Roots	88	88	85	83	84	
Composite 1	90	84	80	76	—	
Composite 2	84	80	76	75	—	

Table 14A

Tear Factor vs Beating Time
Gray Birch Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	84	88	98	100	86	
Stem with bark	108	96	95	93	82	
Branches	82	78	81	—	—	
Stump and Roots	96	86	83	—	84	
Composite 1	83	81	84	79	76	
Composite 2	80	88	85	86	80	

Table 15A
Tear Factor vs Beating Time
Aspen Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	87	83	87	80	74	72
Stem with bark	82	89	—	76	72	—
Branches	82	78	81	—	—	—
Stump and Roots	81	80	86	83	73	—
Composite 1	76	76	—	80	69	—
Composite 2	76	75	71	—	71	—

Table 16A
Tear Factor vs Beating Time
Red Maple Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	59	—	90	87	87	82
Stem with bark	64	—	89	82	76	70
Branches	62	64	59	—	—	—
Stump and Roots	56	59	—	—	—	—
Composite 1	60	71	67	74	69	—
Composite 2	69	79	79	78	71	—

Table 17A
Tear Factor vs Beating Time
Pin Cherry Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	90	—	105	95	91	—
Stem with bark	93	—	92	78	75	—
Branches	70	66	66	—	—	—
Stump and Roots	97	—	102	98	95	86
Composite 1	81	—	90	86	83	—
Composite 2	88	—	83	81	76	—

Table 18A

Tear Factor vs Beating Time

Willow Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	45	52	62	70		
Stem with bark	55	69	66	70		
Branches	56	57	—	—		
Stump and Roots	61	68	71	71		
Composite 1	63	70	67	68		
Composite 2	60	60	67	62		

Table 19A

Breaking Length (meters) vs Beating Time

Alder Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	11780	12330	12800	12450	12890	
Stem with bark	10550	11010	11570	10640	10380	
Branches	10300	10440	11190	—	—	
Stump and Roots	6870	7800	8550	—	9460	
Composite 1	7710	—	7760	9890	—	
Composite 2	11220	12330	12070	12390	—	

Table 20A

Breaking Length (meters) vs Beating Time

Gray Birch Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	9350	11320	12130	13160	13150	
Stem with bark	9870	11550	12540	12820	12510	
Branches	9590	10230	10580	—	—	
Stump and Roots	7550	8000	8600	9160	8810	
Composite 1	9960	10980	10340	11990	12450	
Composite 2	10380	11580	12260	12790	12490	

Table 21A
Breaking Length (meters) vs Beating Time
Aspen Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	10580	11940	13530	14440	14510	14320
Stem with bark						
Branches	8260	8890	9480	—	—	—
Stump and Roots	7190	8030	8920	9970	10190	—
Composite 1	8510	8960	10060	9930	9630	—
Composite 2	8780	9360	10670	9820	9010	—

Table 22A
Breaking Length (meters) vs Beating Time
Red Maple Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	6670	—	8780	10730	11330	11770
Stem with bark	6390	—	8930	10220	10800	10230
Branches	7600	7610	8330	—	—	—
Stump and Roots	3910	4190	—	—	—	—
Composite 1	5280	6810	7220	8100	9140	—
Composite 2	6960	8300	8800	9670	10740	—

Table 23A
Breaking Length (meters) vs Beating Time
Pin Cherry Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	9780	—	13210	14210	15030	—
Stem with bark	9380	—	12040	12920	12670	—
Branches	10210	10920	11040	—	—	—
Stump and Roots	6980	—	9620	10750	11040	12150
Composite 1	9180	—	11680	12620	12530	—
Composite 2	9980	—	12050	13110	13840	—

Table 24A
Breaking Length (meters) vs Beating Time
Willow Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	7180	8330	8820	9470		
Stem with bark	7010	7910	8500	9390		
Branches	7730	8670	—	—		
Stump and Roots	5380	6050	6530	7290		
Composite 1	6720	7840	8590	9570		
Composite 2	7350	8130	8700	9600		

Table 25A
Bulk (cc/gm) vs Beating Time
Alder Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	1.34	1.30	1.26	1.17	1.16	
Stem with bark	1.61	1.52	1.44	1.38	1.28	
Branches	1.46	1.45	1.37	—	—	
Stump and Roots	1.66	0.51	1.49	1.41	1.32	
Composite 1	1.54	1.48	1.44	1.36	—	
Composite 2	1.42	1.32	1.30	1.34	—	

Table 26A
Bulk (cc/gm) vs Beating Time
Gray Birch Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	1.48	1.48	1.43	1.24	1.20	
Stem with bark	1.63	1.62	1.56	1.38	1.36	
Branches	1.61	1.50	1.44	—	—	
Stump and Roots	1.78	1.71	1.65	1.54	1.50	
Composite 1	1.76	1.68	1.59	1.52	1.44	
Composite 2	1.78	1.62	1.63	1.54	1.48	

Table 27A
Bulk (cc/gm) vs Beating Time
Aspen Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	1.44	1.38	1.33	1.20	1.22	1.16
Stem with bark	1.87	1.78	1.66	1.60	1.54	—
Branches	2.00	1.91	1.87	—	—	—
Stump and Roots	1.93	1.79	1.70	1.64	1.62	—
Composite 1	1.94	1.83	1.59	1.53	1.49	—
Composite 2	1.79	1.74	1.70	1.58	1.55	—

Table 28A
Bulk (cc/gm) vs Beating Time
Red Maple Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	1.64	—	1.46	1.32	1.24	1.18
Stem with bark	1.74	—	1.54	1.46	1.36	1.28
Branches	1.56	1.49	1.40	—	—	—
Stump and Roots	1.94	1.80	—	—	—	—
Composite 1	1.80	1.68	1.56	1.45	1.32	—
Composite 2	1.75	1.62	1.54	1.42	1.36	—

Table 29A
Bulk (cc/gm) vs Beating Time
Pin Cherry Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	1.49	—	1.25	1.20	1.18	—
Stem with bark	1.49	—	1.28	1.26	1.18	—
Branches	1.42	1.32	1.28	—	—	—
Stump and Roots	1.67	—	1.47	1.34	1.26	1.21
Composite 1	1.60	—	1.34	1.29	1.20	—
Composite 2	1.48	—	1.32	1.23	1.22	—

Table 30A
Bulk (cc/gm) vs Beating Time
Willow Species

Component of Species	Beating Time (min.)					
	0	5	10	20	30	40
Stem	1.69	1.60	1.48	1.31		
Stem with bark	1.77	1.62	1.44	1.32		
Branches	1.68	1.56	—	—		
Stump and Roots	1.88	1.72	1.61	1.46		
Composite 1	1.74	1.64	1.58	1.45		
Composite 2	1.78	1.66	1.59	1.38		

Table 31A
C.S. Freeness vs Beating Time
(Composite 2)

Species		Beating Time (min.)				
		0	5	10	20	30
Standard	Unbleached	586	549	497	366	224
	Bleached	620	594	482	352	220
Aspen	Unbleached	402	344	282	192	—
	Bleached	434	384	340	238	176
Gray Birch	Unbleached	519	437	391	243	143
	Bleached	515	468	412	300	192
Red Maple	Unbleached	444	424	368	266	194
	Bleached	542	497	438	327	240

Table 32A
Bulk (cc/gm) vs Beating Time
(Composite 2)

Species		Beating Time (min.)				
		0	5	10	20	30
Standard	Unbleached	1.78	1.72	1.59	1.46	1.38
	Bleached	1.79	1.68	1.52	1.38	1.34
Aspen	Unbleached	1.82	1.69	1.66	1.59	1.53
	Bleached	1.59	1.45	1.36	1.26	1.20
Gray Birch	Unbleached	1.73	1.70	1.67	1.49	1.42
	Bleached	1.63	1.38	1.38	1.32	1.26
Red Maple	Unbleached	1.90	1.70	1.60	1.50	1.40
	Bleached	1.90	1.80	1.60	1.50	1.40

Table 33A
Burst Factor vs Beating Time
(Composite 2)

Species		Beating Time (min.)				
		0	5	10	20	30
Standard	Unbleached	30	41	56	69	83
	Bleached	28	44	64	76	80
Aspen	Unbleached	43	50	56	64	67
	Bleached	45	53	63	69	75
Gray Birch	Unbleached	47	65	77	87	90
	Bleached	49	69	82	92	90
Red Maple	Unbleached	35	42	48	57	64
	Bleached	22	35	43	57	63

Table 34A
Tear Factor vs Beating Time
(Composite 2)

Species		Beating Time (min.)				
		0	5	10	20	30
Standard	Unbleached	66	87	99	86	85
	Bleached	89	99	101	96	95
Aspen	Unbleached	76	78	71	66	60
	Bleached	77	79	82	80	75
Gray Birch	Unbleached	94	109	107	103	98
	Bleached	113	120	118	113	103
Red Maple	Unbleached	51	57	58	59	54
	Bleached	32	50	53	61	57

Table 35A
Breaking Length (meters) vs Beating Time
(Composite 2)

Species		Beating Time (min.)				
		0	5	10	20	30
Standard	Unbleached	6560	8150	9650	11,400	12,150
	Bleached	5890	7790	10,340	11,010	11,810
Aspen	Unbleached	9760	10,880	11,300	12,140	11,920
	Bleached	8480	9930	10,680	11,690	11,980
Gray Birch	Unbleached	8380	10,300	11,560	11,670	11,940
	Bleached	7670	10,410	11,850	13,000	13,240
Red Maple	Unbleached	6890	7590	8640	9430	9900
	Bleached	4850	6520	7360	8880	9610