by Roy L. Patton

Effects of Ozone and Sulfur Dioxide on Height and Stem Specific Gravity of *Populus* Hybrids

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Abstract

Unfumigated hybrid poplars (*Populus* spp.) were compared with poplars of the same nine clones fumigated with 0.15 ppm ozone or 0.25 ppm sulfur dioxide. After 102 days, plant height and stem specific gravity were measured to determine whether specific gravity is altered by the fumigants and to compare that response to height suppression, an accepted measure of air pollution stress. Multivariate statistical analysis of the data for each clone revealed that the height of one clone and the stem specific gravities of six clones were suppressed by ozone. Specific gravity is an indicator of wood quality; the results of this experiment suggest that it may be a useful measure of the impact of air pollution on trees.

INTRODUCTION

STUDIES OF INJURY to forest trees caused by air pollutants have traditionally dealt with changes in leaves (color, content, necrosis, size, weight), changes in the volume of wood (tree height and/or diameter), and changes in the weight of wood. Measurements of the wood portions of trees have been used as quantitative indicators of injury caused by air pollutants. When trees are grown for wood products, measures of reduction in wood quality may be useful for assessing damage caused by air pollutants.[1]

Specific gravity may affect or influence the end use, performance, or processing of the wood (Englerth 1966), but it is not commonly used in assessing the impact of air pollutants on forest trees. In this study I investigated the height and specific gravity responses by nine clones of hybrid poplars to fumigations with ozone and sulfur dioxide. The purpose was to determine how the specific gravity of poplar stems is altered by these fumigants and to compare this response to a currently accepted measure of air pollution stress on trees.

[1] The suggestion has been made that air pollutants cause both injury and damage to vegetation. Injury is defined as any identifiable and measurable response of a plant to air pollution. Damage is defined as any identifiable and measurable adverse effect upon the desired or intended use or desired product of the plant that results from air pollution injury (See Heggestad and Heck 1971).

MATERIALS AND METHODS

In early spring, cuttings were taken from ramets of seven hybrid poplar clones and two selections of *Populus deltoides* Bartr. growing in an orchard at the Forestry Sciences Laboratory, Delaware, Ohio (Table 1). One-year-old whips were harvested, cut into 15-cm sections, placed in plastic bags, and stored in a cold room (2°C). In mid-May the basal ends of the sections were soaked overnight in a solution of 50 ppm indole butyric acid. Each cutting was then set into a 25-cm plastic pot that contained a 2:1 soil-sand potting mixture. After budbreak only one bud was allowed to elongate. All plants were watered at least twice a week, depending upon rainfall and the condition of the soil

Table 1.—Parentage of hybrid poplar clones and selections.

Clone	Parentage
42	*Populus maximowiczii* Henry X *P. trichocarpa* Torr. & Gray
50	*Populus maximowiczii* Henry X *P. berolinensis* Dipp
207	*P. deltoides* Bartr. X *P. trichocarpa* Torr. & Gray
215	*P. deltoides* Bartr. X *P. trichocarpa* Torr. & Gray
252	*P. deltoides* Bartr. X *P. trichocarpa* Torr. & Gray
279	*P. nigra* L. X *P. laurifolia*
346	*P. deltoides* Bartr. X *P. trichocarpa* Torr. & Gray
W5	*P. deltoides* Bartr.
W87	*P. deltoides* Bartr.

in the pots. A fertilizer tablet (N:P:K:S, 14:4:6:3) was added to each pot in July. In mid-June, 12 plants of each clone were randomly assigned to each of three treatments: (1) 0.15 ppm ozone, (2) 0.25 ppm sulfur dioxide, and (3) unfumigated control. The treatments were applied to the plants in cylindrical, open-topped field chambers (Heagle et al. 1973) for approximately 12 hours each day for 102 consecutive days. Ozone was generated by passing oxygen through a corona-discharge generator and was monitored with a Dasibi Model 1003-AH ozone monitor.[2] Sulfur dioxide originated from a tank of liquid SO_2 and was monitored with a Monitor Labs Model 8450 Sulfur Monitor. Both monitors were calibrated with a Monitor Labs Model 8500 Calibrator.

At the end of the treatment period, the height of each plant was measured and the specific gravity of the lower 10 cm of the stem was determined. Specific gravity is the ratio of the oven-dried weight of the stem section to the weight of the water that overflowed from a side-arm test tube when the section was submerged.

A one-way multivariate analysis of variance was performed on the data for each clone (Morrison 1967). Where the union intersection test indicated rejection of the hypothesis of equal mean vectors, the determination of whether both response variables were contributing to the rejection was made with a step-down analysis (Kramer 1972). Simultaneous confidence intervals (95 percent) were calculated to compare the control mean to the fumigated means in each clone.

[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval of the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

RESULTS

Limited observations were made of foliar injury in the chambers. By the end of the experiment, all of the fumigated plants exhibited signs of pollutant injury on the leaves, but no estimates of the degree of injury were made.

The hypothesis of equal mean vectors was rejected for each clone at the 0.05 probability level. Tables 2 and 3 show the means for height and specific gravity of each treatment group. The results of the 95 percent simultaneous confidence intervals are also represented in these tables and they indicate that only ozone caused significant suppression in height or specific gravity. The height of one clone and specific gravities of six clones differed significantly from their respective control groups.

The data for plant height (Table 2) indicate that five of the clones (207, 215, 252, 346, W87) were stimulated by at least one of the fumigation treatments, even though these stimulations were not significant at the 0.05 probability level. No similar stimulation is evident in the specific gravity data (Table 3) except for the SO_2 fumigation of clone 50. Aside from this effect of SO_2 in clone 50, the indication is that the clones were suppressed by the fumigants although this suppression was significant at the 0.05 probability level only in six clones fumigated with ozone.

The results of the step-down analyses are presented in Table 4. This step-down procedure depends on the order in which the variables are tested and determines the contribution by each variable to the rejection of the null hypothesis in the multivariate analysis of variance. Since plant height is traditionally used in testing the effects of air pollutants on trees, it was tested as the first variable for each clone. Specific gravity was tested as the second variable and its

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Unfumigated hybrid poplars (*Populus* spp.) were compared with poplars of the same nine clones fumigated with 0.15 ppm ozone or 0.25 ppm sulfur dioxide. After 102 days, plant height and stem specific gravity were measured to determine whether specific gravity is altered by the fumigants and to compare that response to height suppression, an accepted measure of air pollution stress. Multivariate statistical analysis of the data for each clone revealed that the height of one clone and the stem specific gravities of six clones were suppressed by ozone. Specific gravity is an indicator of wood quality; the results of this experiment suggest that it may be a useful measure of the impact of air pollution on trees.

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contribution to the rejection is interpreted as being over and above the contribution by height. The data indicate that height contributed significantly to the rejection of the null hypothesis in three clones and that specific gravity contributed to null hypothesis rejection in eight clones. Only in clone 50 did specific gravity fail to contribute to the rejection of the null hypothesis.

Table 2. Average heights (mm) of hybrid poplar clones fumigated with 0.15 ppm ozone or 0.25 ppm sulfur dioxide, and an unfumigated control.

Clone	Treatment		
	Control	O_3	SO_2
42	609	450(11)[a]	552
50	598	*254(10)	427(11)
207	382(11)	414	448
215	456(11)	533(7)	475
252	357	413(11)	404
279	747(11)	575(11)	666
346	519	505(8)	555
W5	349(11)	333(10)	319
W87	256(11)	304(11)	267

[a]Sample size when less than 12.
*Simultaneous confidence interval (95%) indicates this mean different from control mean in same row.

Table 3. Average specific gravities of stem sections from hybrid poplar clones fumigated with 0.15 ppm ozone or 0.25 ppm sulfur dioxide, and an unfumigated control.

Clone	Treatment		
	Control	O_3	SO_2
42	.837	.771(11)[a]	.806
50	.742	.737(10)	.757(11)
207	.760(11)	*.710	.748
215	.852(11)	.762(7)	.813
252	.836	*.738(11)	.821
279	.763(11)	*.655(11)	.731
346	.769	*.720(8)	.753
W5	.768(11)	*.676(10)	.764
W87	.804(11)	*.714(11)	.782

[a]Sample size when less than 12.
*Simultaneous confidence interval (95%) indicates this mean different from control mean in same row.

Table 4. Calculated beta values and degrees of freedom from step-down analyses with height and stem specific gravity as variates.

Clone	Variate	
	Height	Specific Gravity
42	*.7717(2,31)	*.7927(2,30)
50	**.5168(2,29)	.9561(2,28)
207	.9588(2,31)	**.6667(2,30)
215	.9399(2,26)	**.0519(2,25)
252	.9644(2,31)	**.4737(2,30)
279	*.7753(2,30)	**.4284(2,29)
346	.9402(2,29)	**.4961(2,28)
W5	.9854(2,29)	**.5870(2,28)
W87	.9452(2,30)	**.5963(2,29)

*Significant at 0.05 probability level.
**Significant at 0.01 probability level.

DISCUSSION

The fumigants are apparently capable of stimulating growth in height under the conditions of this experiment. This type of stimulation is not uncommon; ozone has been observed to stimulate elongating shoots of conifers (Lumis and Ormrod 1978), the nutritive effect of low doses of SO_2 has been studied, and growth enhancement has been reported (Ziegler 1975, Maugh 1979). It has also been suggested that some plants are stimulated by controlled fumigations because they have become adapted to naturally occurring low levels of pollution and that control plants growing in filtered air are at a disadvantage (Bennett et al. 1974). Specific gravity measurements in this experiment indicate that the plants did not respond to these possible stimulatory effects but did respond to the detrimental effects of the pollutants.

Whether similar specific gravity responses would be seen in larger trees is difficult to ascertain from the data of this experiment. Differences in plant size cause most of that difficulty. For example, the pith of young, small trees has more influence on specific gravity measurements than the pith of larger trees. And in addition, since the bark was not removed from the stems for specific gravity determinations in this experiment, it is not known whether differences in specific gravity should be attributed to the wood, bark, or buds. However, x-ray measurements of wood from spruce saplings indicate that ring width and late-wood density are altered by fumigations with sulfur dioxide (Keller 1980).

Measuring the specific gravity of wood from trees subjected to air pollution stress may be important in determining possible physiological changes and economic impacts. From the physiological standpoint, the specific gravity of wood gives an indication of the amount of wood substance in proportion to the volume of wood. Cell wall thickness and cell cross-sectional dimensions are directly related to specific gravity, and together with ring widths and the ratio of early wood to late wood, they define variation in specific gravity (Panshin and deZeeuw 1970). The economic impact of changes in the specific gravity of wood is largely dependent upon the management objective for the trees. In terms of strength, a decrease of 0.02 in the specific gravity of southern pines is reflected in a decrease in the modulus of rupture of about 1000 pounds per square inch. In terms of pulp yields, the same decrease in specific gravity means a decrease of 100 pounds in the dry weight of a cord of pulpwood (Mitchell 1963).

The evidence presented here is neither inclusive nor definitive. It does suggest, however, that specific gravity measurements may be useful additions to other measurements made to determine the impacts of air pollutants on the growth of trees. Before further inferences concerning other types of trees can be made, it is necessary that the trends evident in this work be tested with other varieties and ages of trees and at lower pollutant levels for longer periods of time.

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A Method of Selecting Forest Sites for Air Pollution Study

by
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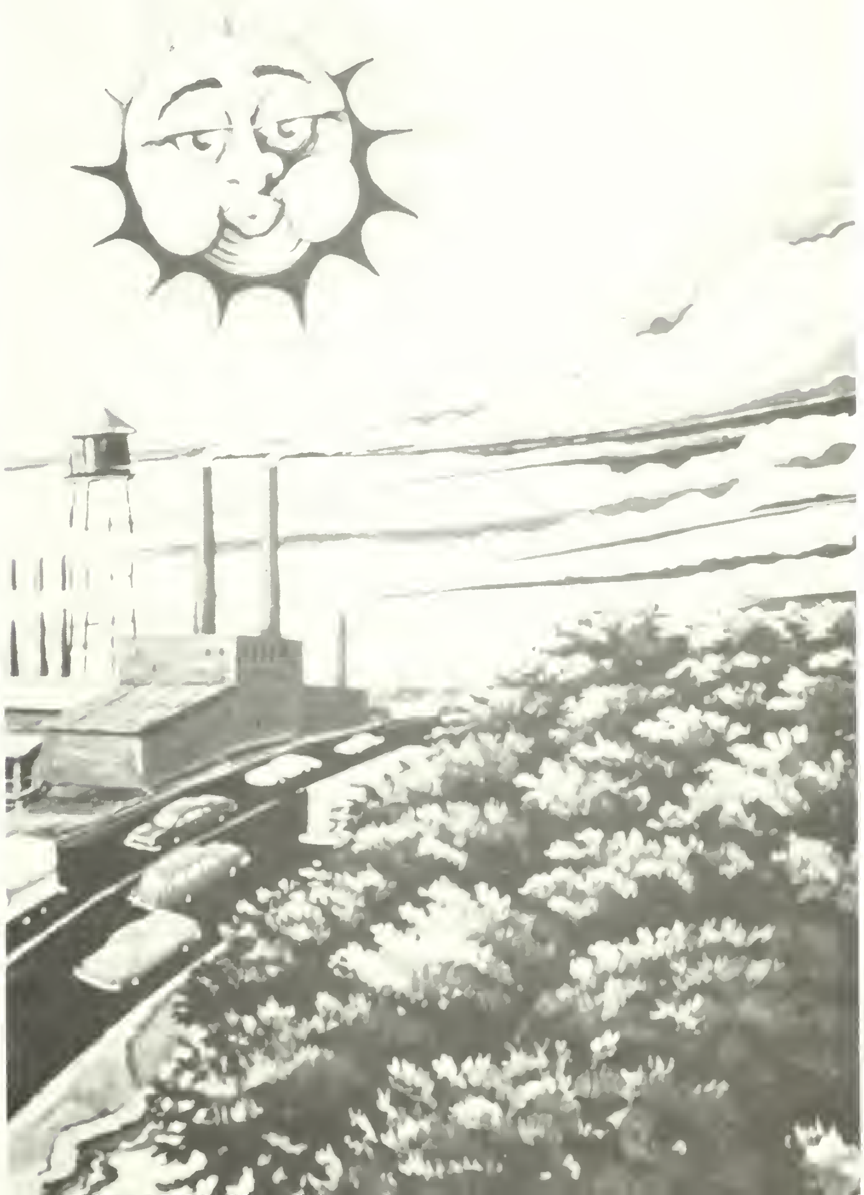

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Abstract

Presents a method of selecting suitable forested areas for meaningful assessments of air pollution effects. The approach is based on the premise that environmental influences can significantly affect the forest-air pollution relationship, and that it is, therefore, desirable to equalize such influences at different sites. From existing data on environmental factors and air pollution monitoring data, a method of placing transparent overlays on maps was developed to identify forested areas that have common environmental characteristics but significantly different potential for air pollution.

The research herein was supported by funds provided by the U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, under cooperative agreement 23-614.

Industrial growth and extensive urbanization over the last 5 to 100 years have caused enormous increases in the rate at which pollutants are emitted into the atmosphere. Such air pollutants include: sulfur dioxide (SO_2) from the incineration and processing of fossil fuels; nitrogen oxides (NO_x) from high temperature combustion processes; hydrocarbons from the combustion of petroleum products; fluorides from mineral smelting; particulates from grinding and manufacturing sources; and oxidants, such as ozone (O_3), which are urban products of photochemical reactions in the atmosphere.

Ozone and SO_2 are widespread and have a great impact on the forest, and it is difficult to control the source of these pollutants (Dochinger and Jensen 1975). Many forest species such as pine, ash, larch, oak, aspen, and birch are susceptible to these two pollutants. For these reasons, this study was restricted to the examination of potential for air pollution associated with the occurrences of O_3 and SO_2.

In assessing the effects of air pollutants on forests, it is desirable to correlate the degree of the observed effect with the relative concentration of the air pollutants (Smith 1974). These dose-response correlations are not available in actual field situations where many environmental factors can influence forest processes, potential for air pollution, and sensitivity of forest species to pollution. Relevant environmental factors include: terrain, forest types, temperature, and meteorology. These factors are examined herein and related to the problem of site selection for assessing of the effects of air pollution on forests.

Assessment strategies must also include knowledge of the sources and types of air pollutants, the atmospheric processes governing their chemical modifications and transport, and their distribution. These factors affect the potential for air pollution in a given location and must be considered along with environmental factors in any site-selection procedure.

To study the impact of air pollution on forests, it is important to nullify the effects of environmental influences on the air pollution-forest relationship and to select forest sites where the probability of discernible effects of air pollution is highest. Our approach was to identify forested areas with common environmental characteristics but with significantly different potential for air pollution. Subsequent field measurements, at sites selected within these forested areas, may provide symptomatic differences in the effects on forests.

Our rationale led to the following objectives for this study: (1) to consider relevant environmental factors influencing forest-pollution interactions, and (2) to develop a methodology for identifying forested regions with similar environmental parameters but different air pollution concentrations.

In our methodology, potential of air pollution was determined by a mathematical steady-state dispersion model. The Climatological Dispersion Model was used to estimate long-term arithmetic, average concentrations of nonreactive pollutants or pollutants that decay by first-order chemical reactions from multiple point sources (U.S. Environ. Prot. Agency 1973). The emitted plume is assumed to have a Gaussian distribution in the horizontal direction and a uniform distribution in the vertical direction. Modifications of the basic Gaussian steady-state dispersion models are used for area sources and line sources after making suitable approximations (Ohio Environ. Prot. Agency 1975).

In general, such steady-state models are used to predict ambient pollutant levels at short distances from the source (within 100 km) when steady-state conditions exist; that is, a well-mixed layer exists and the height of the mixing layer is constant and well defined (Mukammal 1976). Care and judgment must be exercised in applying these models to situations of calm wind where there is a local flow pattern and in areas influenced by local disturbances.

The methodology to select forest regions with common environmental characteristics and significantly different potential for air pollution was implemented by an overlay technique for comparative analysis. The steps in the overlay technique are briefly outlined here and by Bringi (1978) where the application of the general methodology to the State of Ohio is discussed.

General Analysis and Overlay Sequencing for Ohio

The overlay technique is the first step in site selection of forested areas for comparable studies of air pollution. This analysis was done by selecting and interpreting 11 overlays in the sequence which follows.

Ohio was chosen for the overlay methodology since data on environmental factors and pollutant potential were available. In Ohio, this methodology can be used at various geographical scales to identify forested areas where the impact of air pollution is most likely to be seen. Since each scale of study lies within the state, the interrelationships among environmental factors appropriate to the entire state were examined.

A landform map (1:500,000) of Ohio, Division of Geological Survey, Ohio Department of Natural Resources (ODNR), was used as a base reference. The map was a framework to which each factor shown on the overlays could be referenced.

An initial sequence of three overlays defined regions of (1) common forest types, (2) physiography, and (3) soil regions. The first overlay identified the forested land areas and their major forest types. The second overlay indicated that a heavily forested area occurred in the unglaciated plateau region and consisted mainly of oak-hickory forests. The third overlay showed that the oak-hikory forest type was in the sandstone and shale soil region.

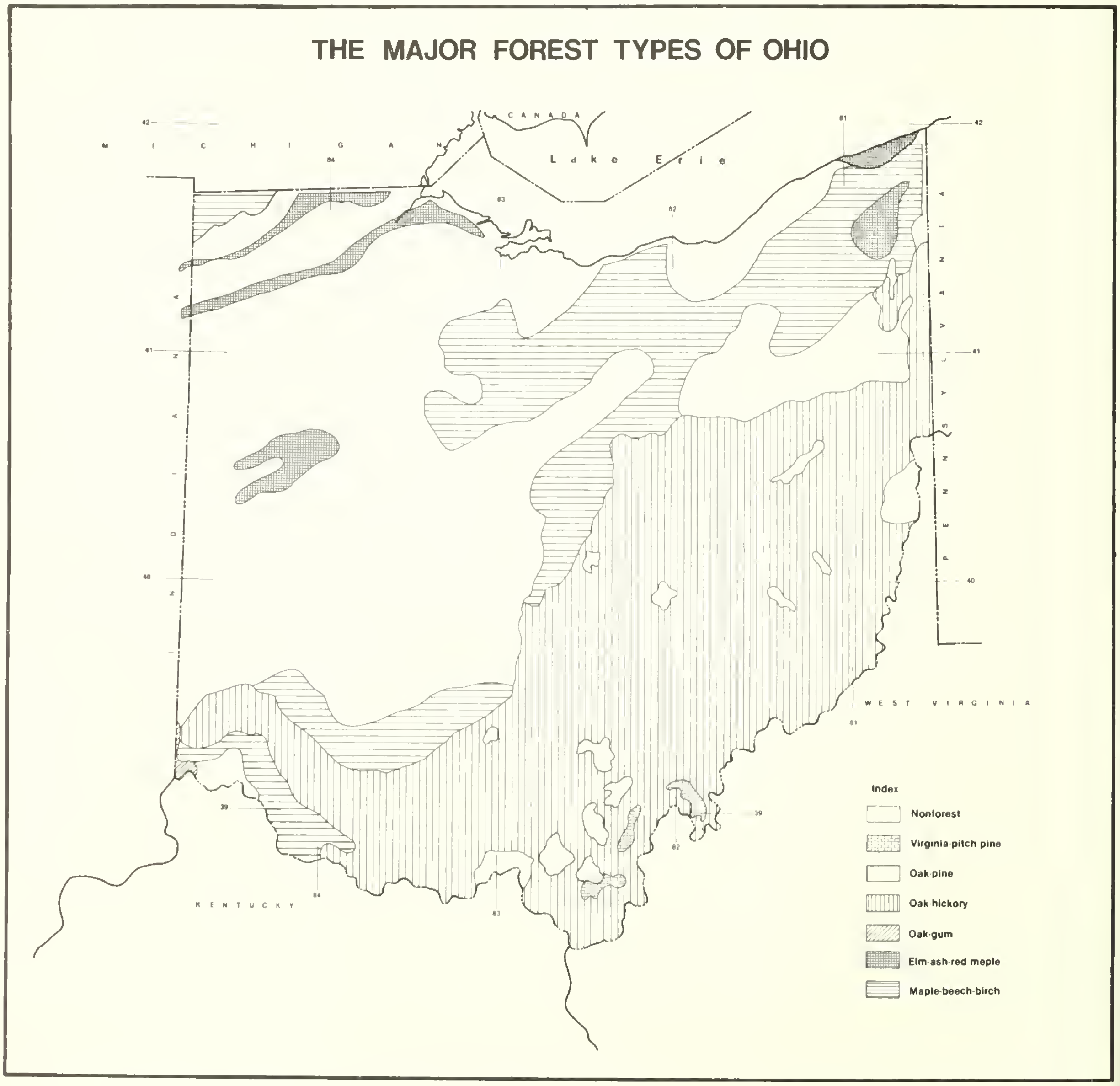
Available data on environmental factors and pollutant potential for the state were collected from atlases and reports. A total of 11 Mylar[1] overlays were made. Black Zip-a-tone symbols depicted various aspects of the different factors. brief description of the collection and modification of dat and overlay construction for some of the relevant environmental factors and pollutant potential follows.

Ohio Forests

To map the major forest types of Ohio, data on forest lan use and major forest types were collected. Data sources w a land use map by the Planning Division of the Developm Department of Ohio, a map of the major forest types in C (Kingsley and Mayer 1970), and a series of slides produce by computer analysis of digitized LANDSAT computer-compatible tapes. Figure 1 represents the overlay of non est land and the six major forest types.

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

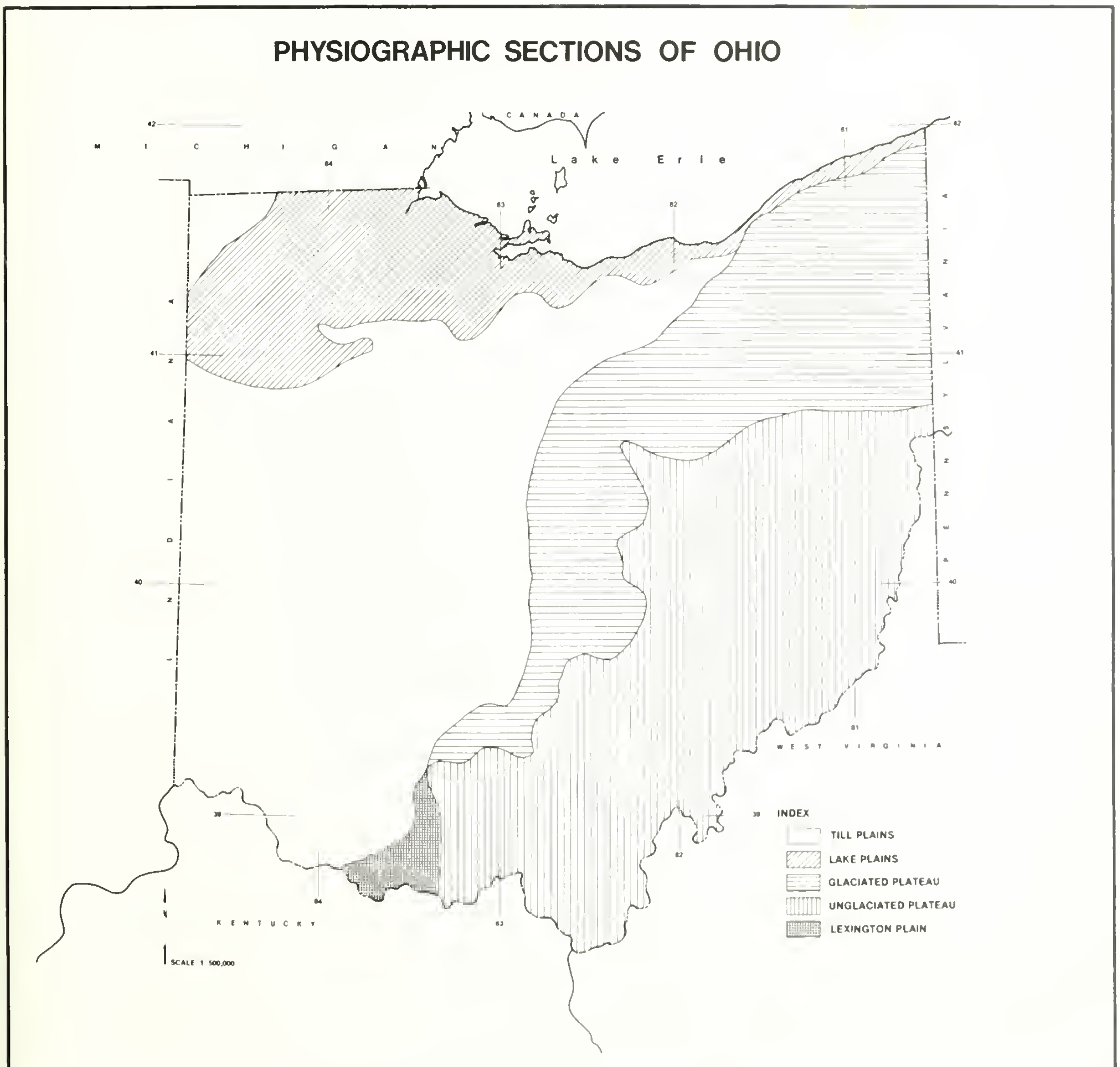
Figure 1



ain Factors

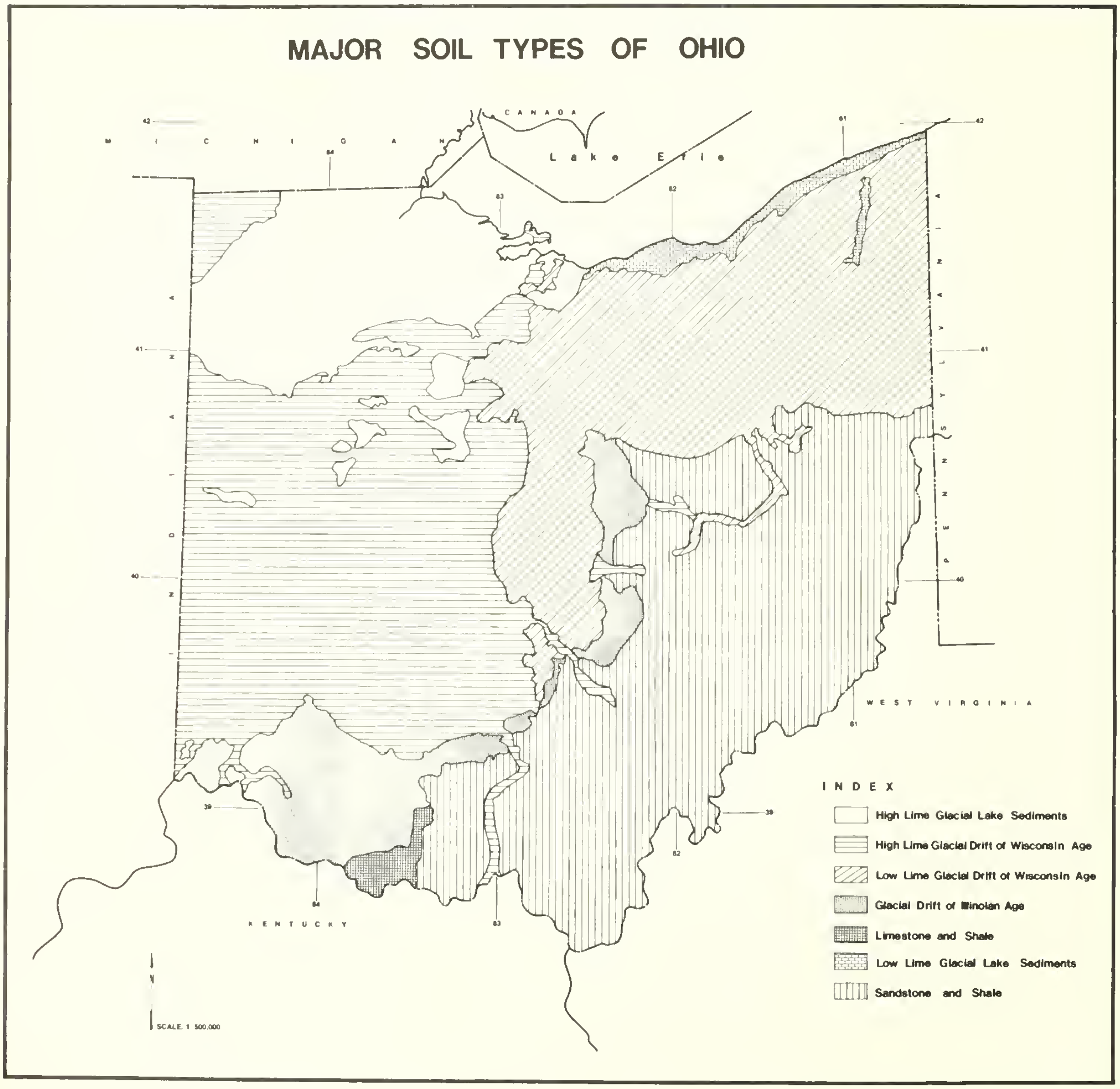
hysiographic sections of Ohio. These data were not modi- because the physiographic regions in the data source adequate. The physiographic map was enlarged photo- aically and a Mylar overlay prepared (Fig. 2, Ohio Dep. Resour. 1962).

Figure 2



Soil types of Ohio. Seven major soil regions were identified and used to make the overlay (Fig. 3, Ohio Dep. Nat. Resour. 1962). The major soil regions included: high lime glacial lake sediments, high lime glacial drift of Illinoian Age, limestone and shale, low lime glacial lake sediments, and sandstone and shale.

Figure 3



ıate

:ipitation. Two modifications of annual rainfall data ͽ made — isopleths were changed from centimeter to .es and the overlay was enlarged to the base scale (Fig. 4, ͻ Dep. Nat. Resour. 1962). A similar overlay was pre- ·d for average annual water loss for four water zones at ch intervals ranging from 20 to 28 inches (Fig. 5).

Figure 4

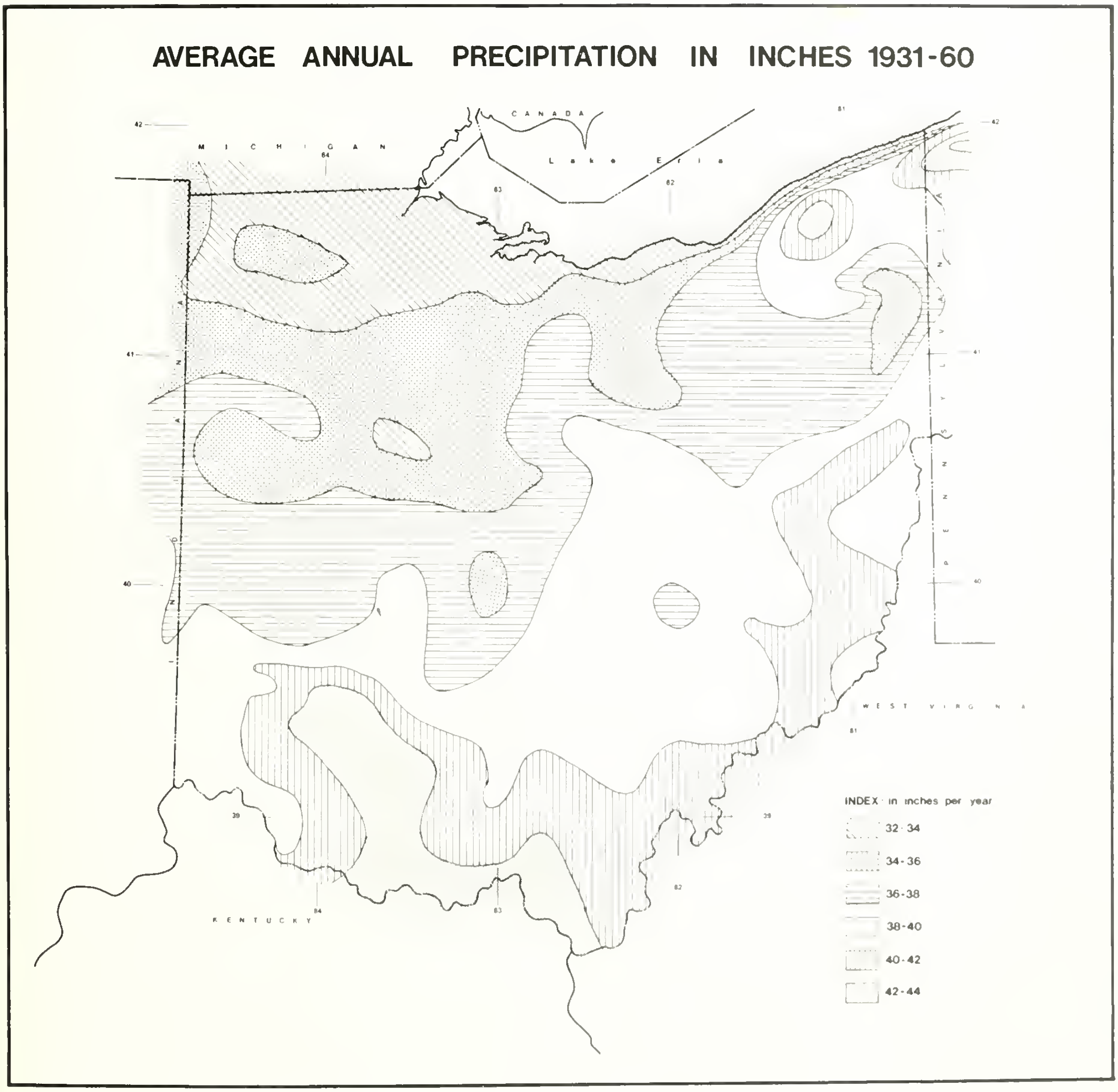
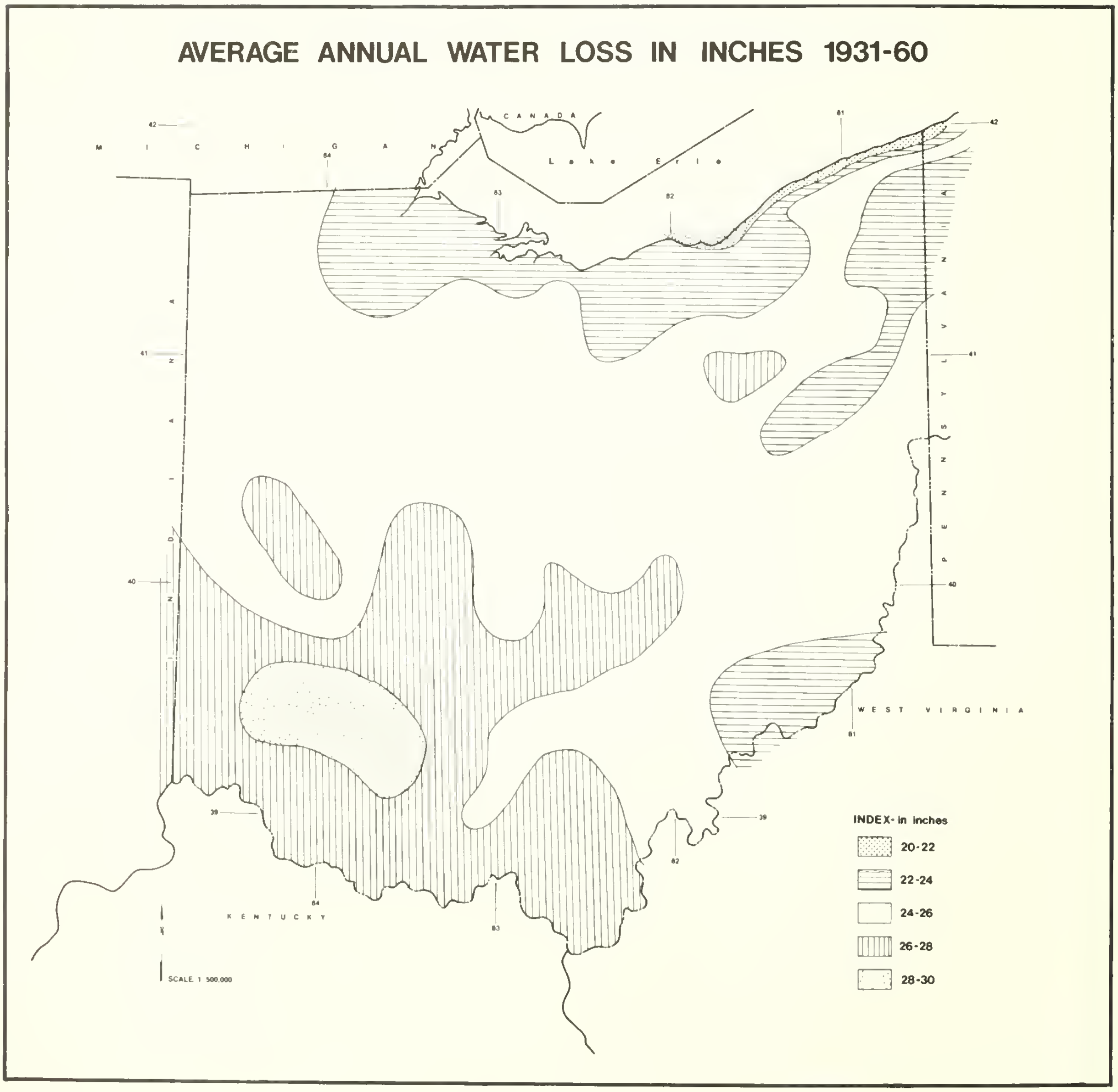
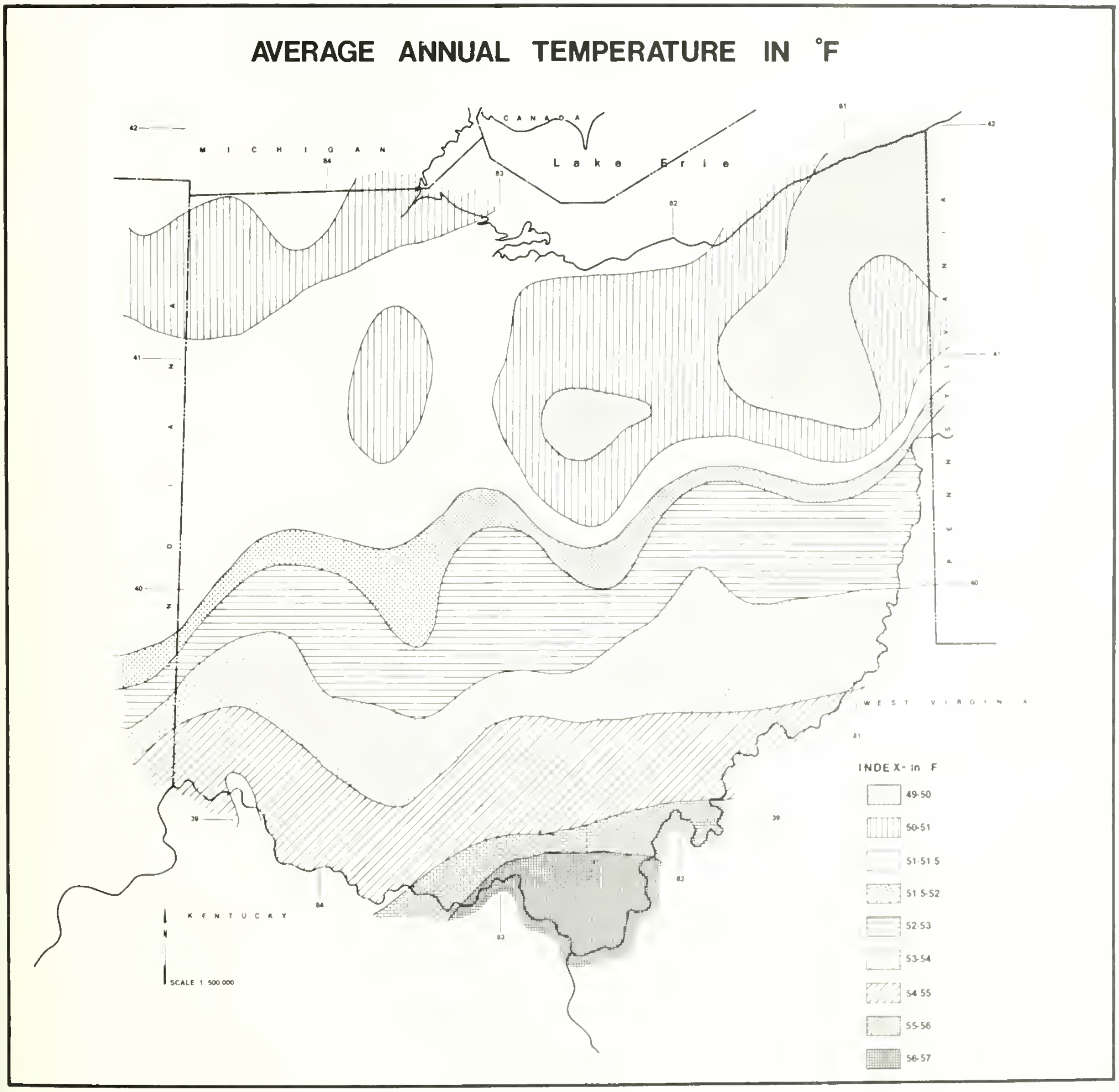


Figure 5


AVERAGE ANNUAL WATER LOSS IN INCHES 1931-60
CANADA
Lake Erie
MICHIGAN
INDIANA
PENNSYLVANIA
WEST VIRGINIA
KENTUCKY
SCALE 1 500,000
INDEX- in inches
20-22
22-24
24-26
26-28
28-30

perature. The data source was a general map of Ohio
; showed the average annual temperature in degrees (F)
the years 1931-60 (Fig. 6, Ohio Dep. Nat. Resour. 1962).
temperature ranges from 49°F to 57°F were modified to
egree intervals, except for the 51°F to 52°F range, which
split into two zones because of its large areal extent.

Figure 6

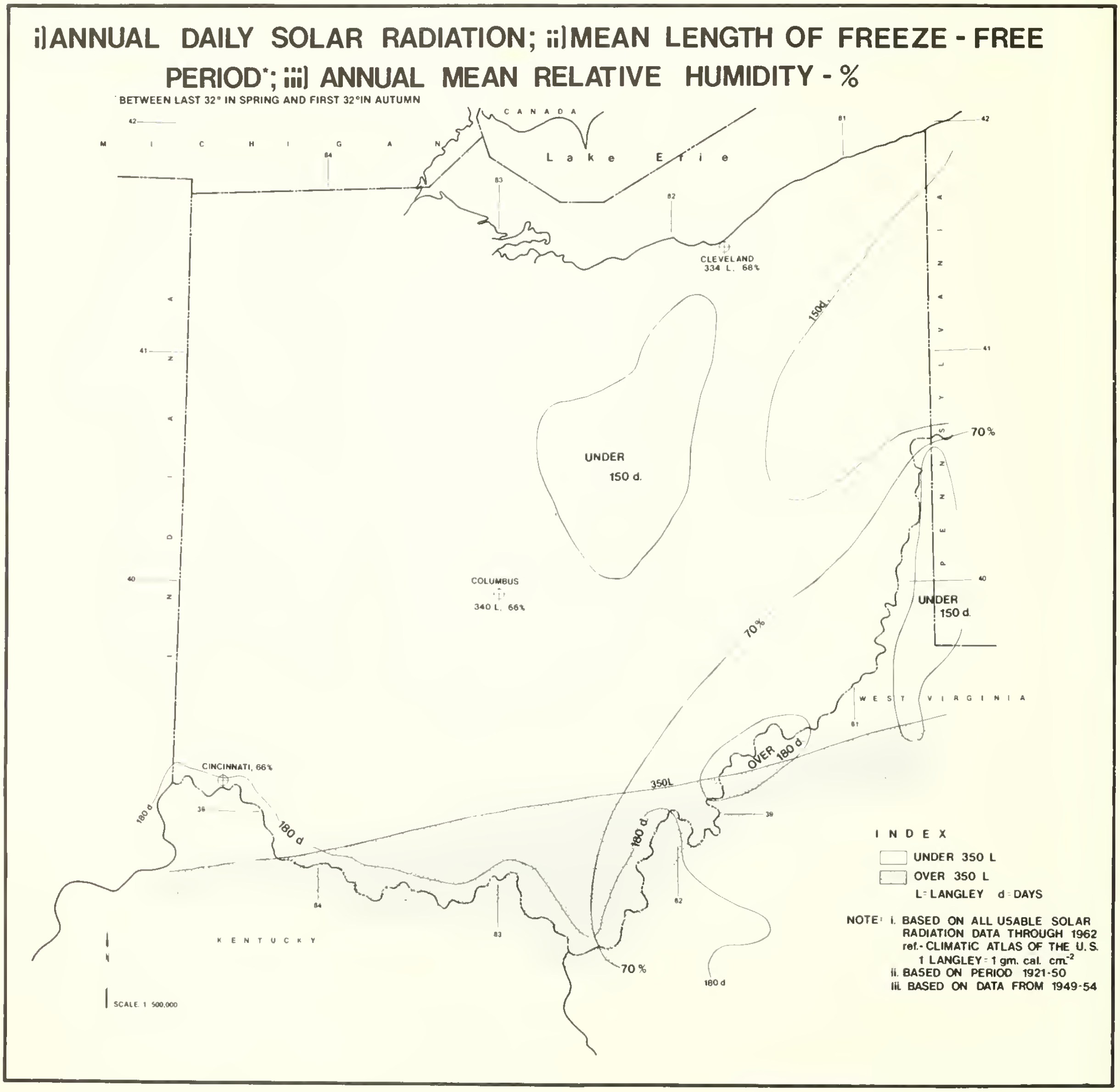


Relative humidity (RH), solar radiation, and freeze-free period (FFP). These factors, based on the period 1921-50, were placed on a single overlay (U.S. Dep. Commer. 1968). The only generalized RH curve in Ohio is the 70 percent line through the southeastern section. Solar radiation divides the state into two broad regions—the southern tip of Ohio receives more than 350 langleys (calories/cm^2/min) and the rest of the state receives less than 350 langleys.[2] The central section of the state has a mean FFP of less than 150 days. Only in the south and southeastern areas does the FFP exceed 180 days (Fig. 7).

Other related climatic factors such as evapotranspiration, days of snow cover, and severe weather phenomena were no represented on the overlays, but could be included if desire

[2] 1 langley = 4.184×10^4 joules per square meter.

Figure 7



Bringi, Sreedevi K., Thomas A. Seliga, and Leon S. Dochinger.
1981. A method of selecting forest sites for air pollution study. Northeast. For. Exp. Stn., Broomall, Pa. 15 p. (USDA For. Serv. Res. Pap. NE-472)

Presents a method of selecting forested areas suitable for meaningful assessments of air pollution effects. The approach is based on the premise that environmental influences can significantly affect the forest-air pollution relationship, and that it is, therefore, desirable to equalize such influences at different sites. From existing data on environmental factors and air pollution monitoring data, a method of placing transparent overlays on maps was developed to identify forested areas that have common environmental characteristics but significantly different potential for air pollution.

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Keywords: air pollution, ozone, sulfur dioxide, forest environment, assessment

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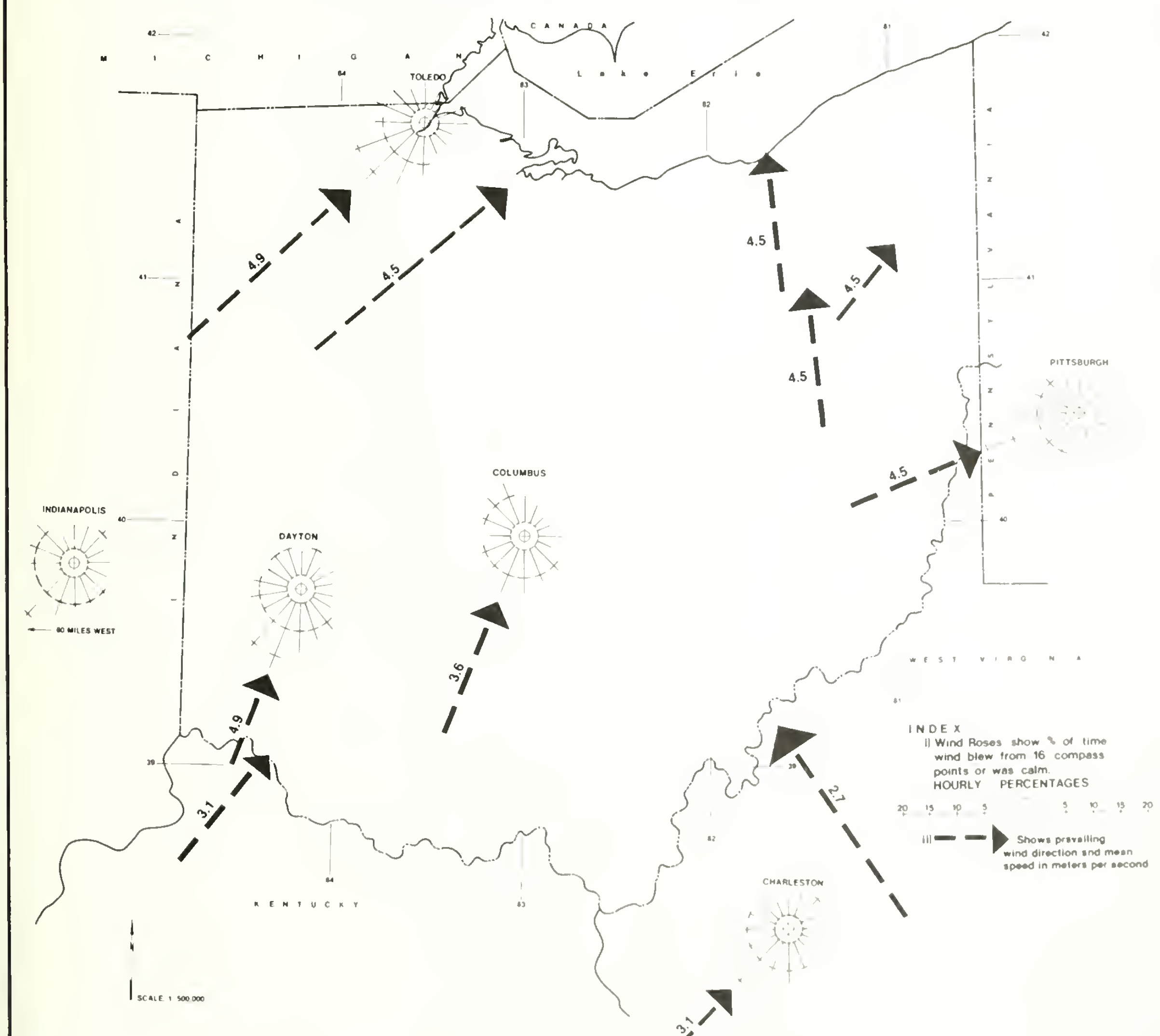
[e]orology

h[e] meteorological factors were considered: annual sur-
[fa]c wind roses, prevailing wind direction, and mean wind
[sp]e[ed]. The mean wind speed is given in meters per second.
he inal environmental factor overlay (Fig. 8) depicts
[re]le[va]nt wind data (U.S. Dep. Commer. 1968).

Figure 8

ANNUAL SURFACE WIND ROSES, PREVAILING WIND DIRECTION AND MEAN SPEED OF WIND

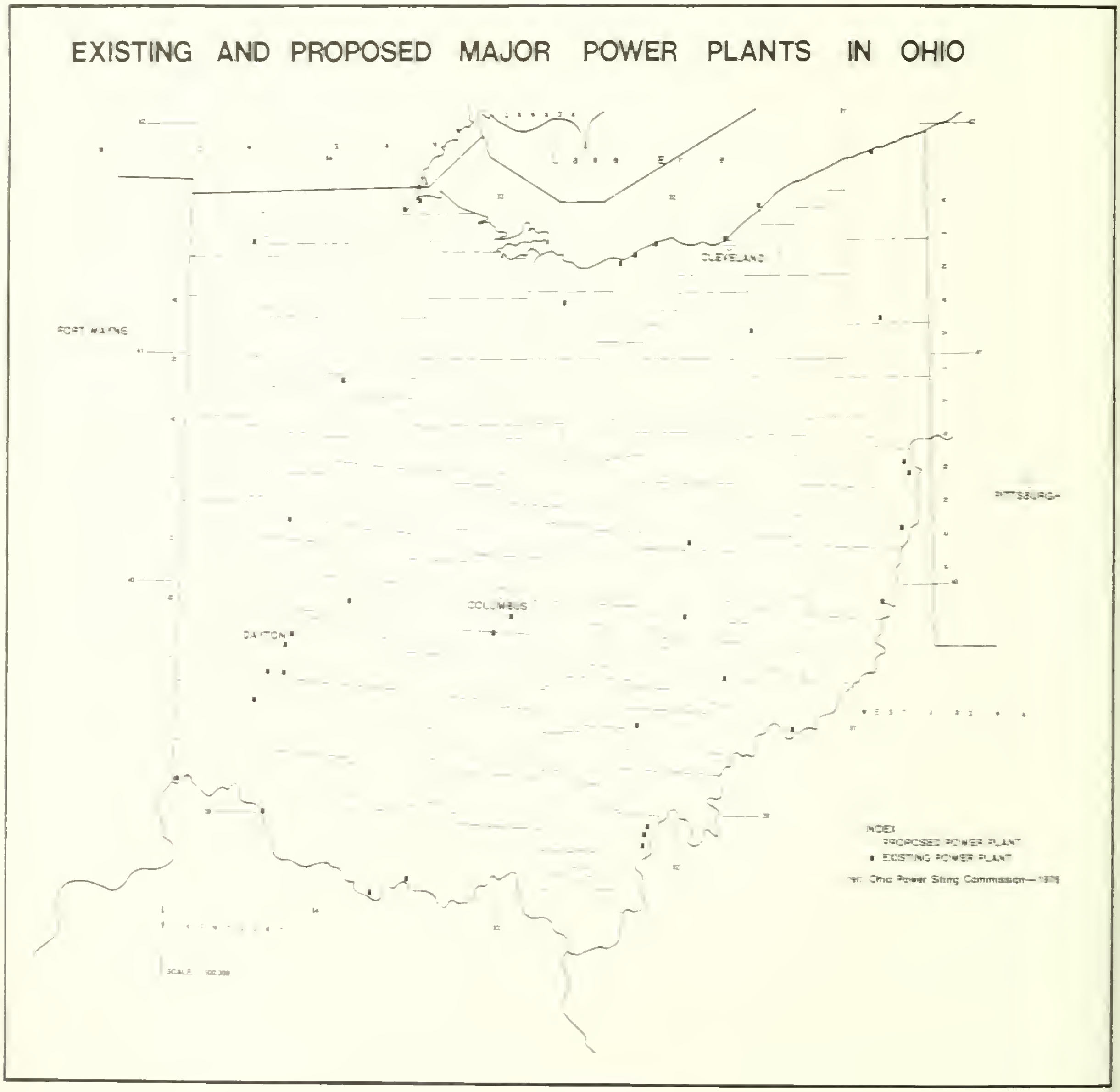


Air Pollution Potential

Consideration of air pollutants in Ohio was restricted to SO_2 and O_3. A graphic description of the air pollution potential was required for this overlay technique.

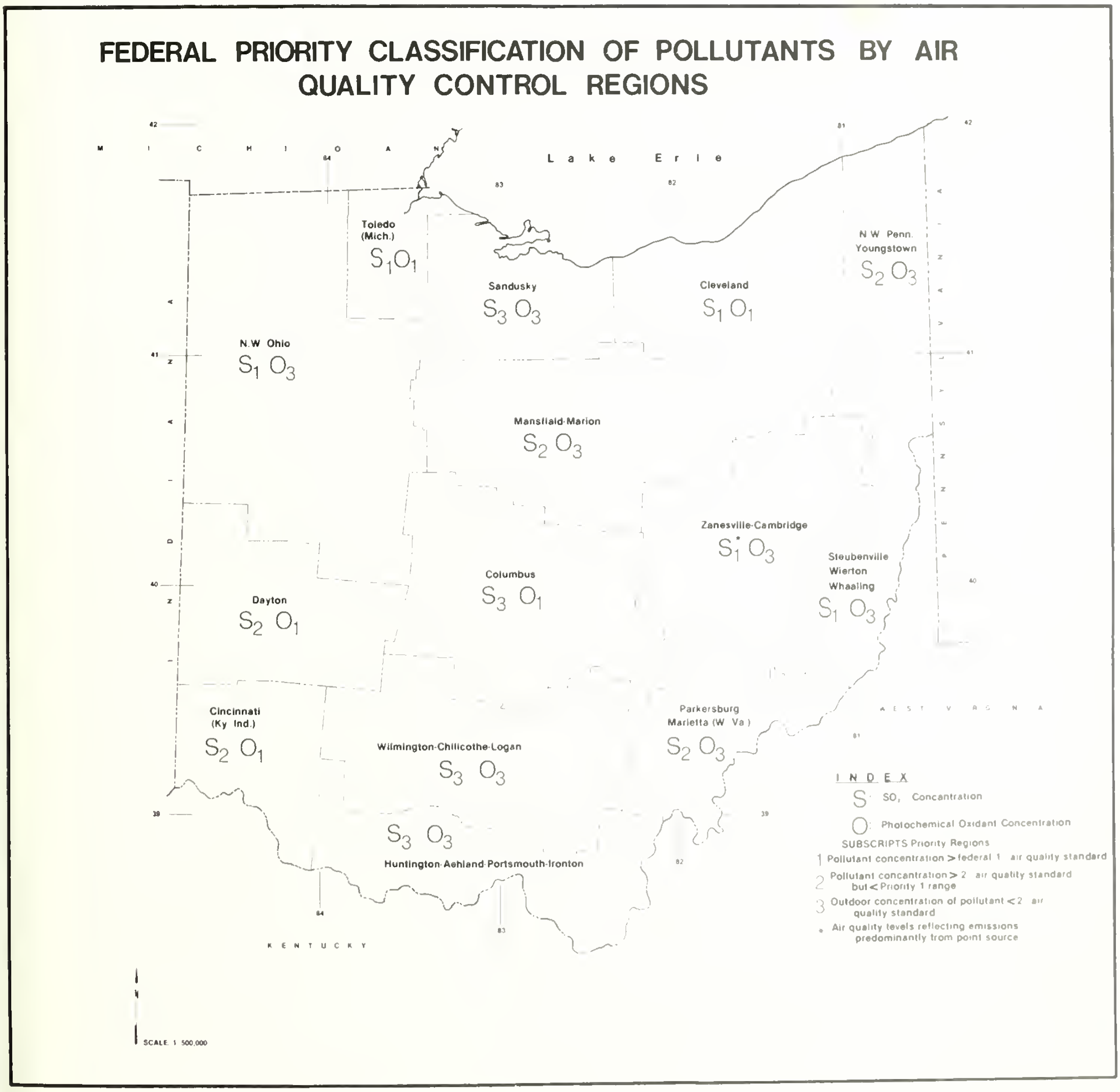
Major point sources of SO_2. Fossil fuel consumers are major sources of SO_2 emission. Thirty-eight major existing power plants and two proposed power plants were designated on overlay (Fig. 9). Typical SO_2 emission rates for such pow plants ranged from 17,000 to 430,000 tons per year. Oth point sources were not included, since power plants contri bute approximately 65 percent of all SO_2 emissions (U.S. Environ. Prot. Agency 1976). The remaining major anthr pogenic sources are correlated with industrial centers and, therefore, could be included as necessary.

Figure 9



de l priority classifications. Ohio has 14 Air Quality Con- ol egions (AQCR) set up by the U.S. Environmental otection Agency (EPA). They were classified into priority ics 1, 2, and 3 depending on the concentrations of SO_2 d oxidants in each AQCR (Ohio Environ. Prot. Agency 75 The priority classifications for each AQCR for both O_2 nd oxidants were then transferred onto an overlay ig. 0).

Figure 10

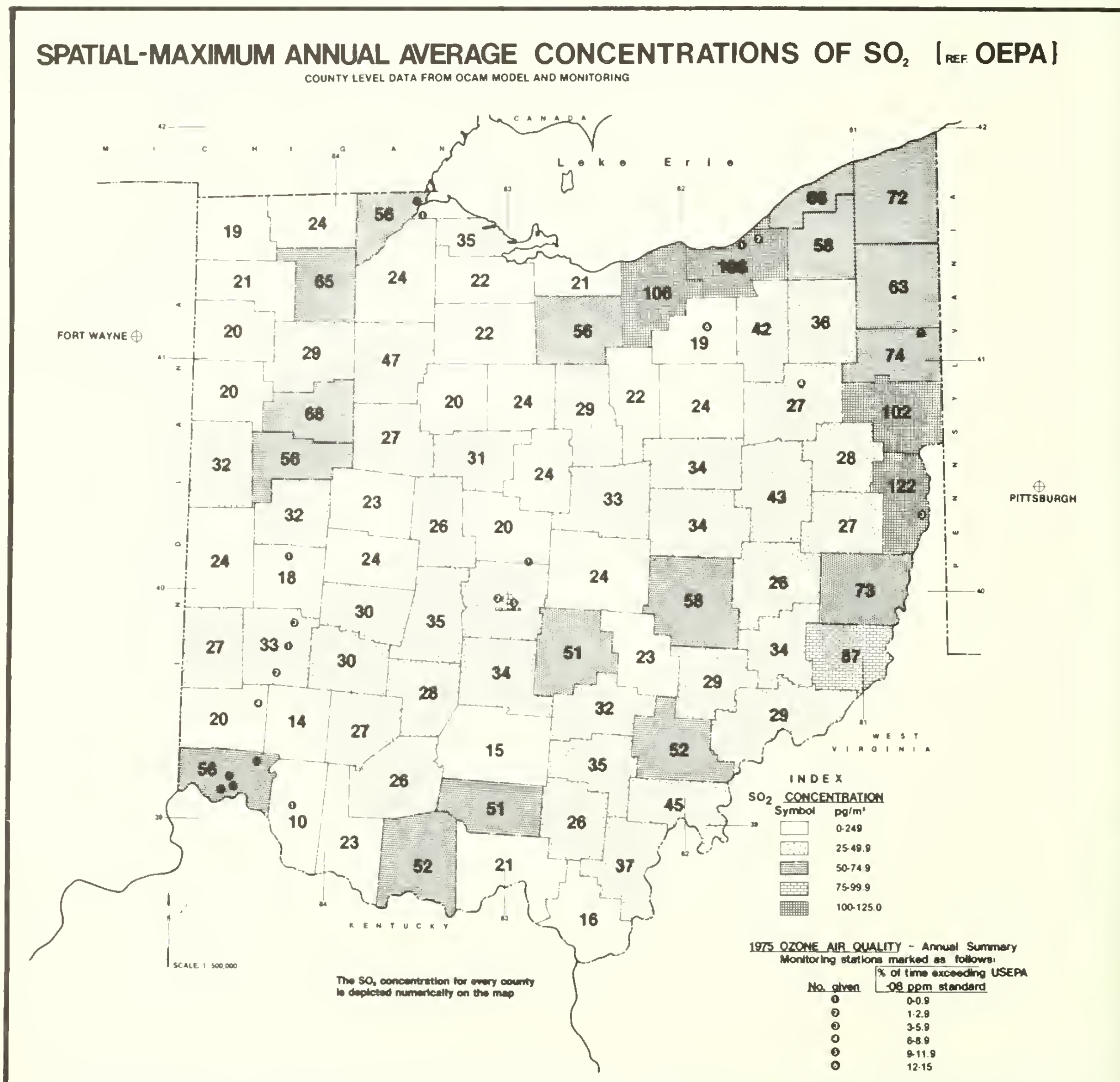


Ozone and SO_2 air quality. In making this overlay, SO_2 concentrations were shown numerically for each county, and the counties were also categorized into five groups by the range of SO_2 concentration experienced. To depict O_3 levels, the percentage of time that each monitoring station exceeded the national and state standard for ambient air quality was tallied. Ozone levels are indicated on the map by numbers ① to ⑥ indicating the range, in percent, from 0-0.9, 1-2.9, 3-5.9, 6-8.9, 9-11.9, or 12-15, respectively (Fig. 11, Ohio Environ. Prot. Agency 1975).

Jefferson and Coshocton Counties. The overlay technique was applied to the Ohio Hill Country (Kingsley and Mayer 1970). The counties of Jefferson and Coshocton exhibited areas of common environmental characteristics but differer potential for air pollution.

Jefferson had annual SO_2 levels of 122 $\mu g/m^3$ and Coshoct had levels of 34 $\mu g/m^3$. After the SO_2 pollution potentials these two counties were established, the remaining overlays were arranged and showed that three areas in both counties had similar environmental characteristics.

Figure 11



ɔ i:ntify suitable forest sites for comparable air pollution uc s between the two counties, the locations of major ɔir sources of SO_2 were considered so that sites could be lei ed both near and far from such sources. An overlay of :is ıg and proposed power plants was used to locate the ɔw: plants in the two counties. Jefferson had four major ɔw: plants and Coshocton one.

nc ıer relavant factor considered for forest-size selection as xisting EPA air monitoring stations. Ohio had 12 air oı :oring stations in Jefferson County—nine stations mea- ıre SO_2 and one measured O_3. Coshocton County had ıre EPA monitoring stations—two stations measured SO_2)h Environ. Prot. Agency 1975). The locations of these oı :oring stations were used as guidelines in selecting ıre sites.

op graphic maps of Jefferson County and Coshocton ouly (1:24,000) showing elevations and woodland areas or with updated Landsat land use data depicting forest ea were then used to complement the data. Another im- ɔrnt consideration in site selection was the existing forest ıry plots established by the USDA Forest Service in its ɔn ıuing program of forest resource inventories in the at (Kingsley and Mayer 1970). By incorporating forest ıry plots into the selection of potential forest sites, pre- oı data on forest growth and management practices ɔu be used in comparable air pollution studies that might ɛ cnducted.

ı ɜinal selection of test plots, further details on common ıa cteristics of forest ecosystem type, species distribu- or age class, and vigor would refine tree response data for r pllution studies on forest sites. Monitoring of O_3 and). ılong with measurements of meteorological factors, in speed, and direction would also help. Detailed examin- io of soil properties, terrain, slope, microclimate, and in- ue ce of severe weather phenomena at each site would be ıp rtant, too.

at obtained from the application of the overlay technique a ounty can also be used as guidelines to extend the et ɔdology of forest-site selection for air pollution studies a ɔcal geographical scale within a county.

ɜl tion of local forest sites. The area near the major power ar in Conesville, Coshocton County, was chosen for po- nt l sites where comparable effects of a point source on ıre s could be studied. The overlay technique showed that ɔs ɔcton County chiefly contained the oak-hickory forest p growing in four major soil regions. Sandstone and shale as ıe most prevalent soil region.

o tablish field plots near the Conesville power plant, the ɔll ving additional data were used:

1. Contact prints, 9 by 9 inches, of black and white U.S. Geological Survey aerial photographs of the general area of the power plant obtained from the Aerial Engineering Division of the Ohio Department of Transportation.
2. A soil map of Coshocton County depicting major soil areas obtained from the Division of Lands and Soil, ODNR.
3. U.S. Geological Survey (USGS) topographic quadrangle maps of the Conesville area depicting woodland area, elevations, and topography.
4. Computer-generated land use quadrangle sheets (from processed Landsat data) corresponding to the USGS quadrangles obtained from the Remote Sensing Group of Resource Analysis Division, ODNR. In such computer-generated land use quadrangle sheets, every symbol represents a cell of dimensions 200 x 250 feet (1 pixel). Each pixel is assigned a specific land use classification such as forest, urban area, water, agricultural land, rangeland, or barren land.

Both the USGS topographic maps and the computer-generated land use quadrangle sheets were divided into grids of 1 km squares, and each square on the grid was numbered by row (R) and column (C) (for example, 7.10 refers to R = 7, C = 10). Forest land use trends were checked with each square of the grid by overlaying the computer quadrangle sheet reproduced on acetate on the topographic map.

This overlay method helped to verify and update forest land use distribution, in which suitable forested areas were also discerned from the aerial photographs. The data from the above sources were then combined with the soil data to identify several potential forest sites located around the power plant. These sites were located on the USGS topographic maps, and their elevation and topography noted. Two distinctions were made in the elevations of the selected forest sites—lower (less than 700 ft.) and higher (700-1,500 ft.).

Location and general characteristics were recorded in a field inspection of six of these sites. All the sites seemed suitable as possible test plots. In addition to the potential sites selected around the power plant, forest survey plots and forest sites already identified in Coshocton County could also be included in the consideration of site selection for comparable air pollution studies on forests.

Applications

The general methodology is a practical technique to use existing data to identify suitable forest sites for comparable assessment studies of air pollution effects. It is applicable to many geographical scales, and therefore, should be useful in assessing both regional and local potential for air pollution impacts on forests. The methodology also applies to different time periods for assessment studies. By selecting other data bases derived from shorter time periods, the methodology can be extended to include identification of forest sites for assessing the effects of climatic variations, season influences, severe weather phenomena, short-term high level pollutant exposures, multiple pollution episodes on forest growth processes, and sensitivity to air pollution.

By developing and incorporating other suitable data bases, the methodology may also be applied to: the study of the effects of pollutants in air, water, and soil on the functioning of ecosystems; the study of forest ecosystems as sinks for pollutants; the study of air pollution effects on agricultural crops; environmental analysis; land use planning; the selection of study regions for remote sensing investigations; and the study of epidemiological effects and human population exposure to air pollutants.

It is apparent that many important problems should benefit from this type of comparative analyses. Furthermore, with recent advances in computer technology—particularly in the area of high-speed, high-volume data storage and retrieval—the data bases could be readily accessed, processed, and displayed for many purposes beyond the scope of this work.

Conclusions

In this study, the primary objective was to select forested regions most suitable for assessments of the impact of air pollution on forests. This methodology identifies forests in regions of similar environmental parameters but with significantly different air pollution concentrations. Subsequent qualitative and quantitative field measurements should give a realistic basis for differential comparisons of foliar, growth and productivity responses associated with air pollution effects. Correlations can then be made between the relative degrees of biological impacts and air pollution concentrations.

There are limitations in the data base of environmental factors and potential for air pollution which limit the degree of resolution that is possible in the site-selection process. Better data are needed for some of the environmental factors such as relative humidity, solar radiation, freeze-free period, and meteorology. These additional data would balance the environmental influences on forests and reduce the number of potential study sites in any given area. More statewide data are needed to improve and update the pollutant-potential maps of SO_2 and O_3 air quality. Current studies by Federal, State, and private institutions using more refined modeling techniques (U.S. Environ. Prot. Agency 1976) to estimate 24-hour maximum concentrations of SO_2 at selected receptor points around point sources may prove valuable.

Potential evapotranspiration, snowfall, severe weather phenomena, and pollutants such as particulates, nitrogen oxides, fluorides, and acid precipitation were not included in the data base. As information on these factors becomes available, they should be added to the map.

The overlay technique is manual and is limited to the consideration of a manageable and general data base. For better resolution, greater flexibility, and rapid modification of data, computer graphics technology could be implemented for the manual procedures.

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Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
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- Warren, Pennsylvania.

United States
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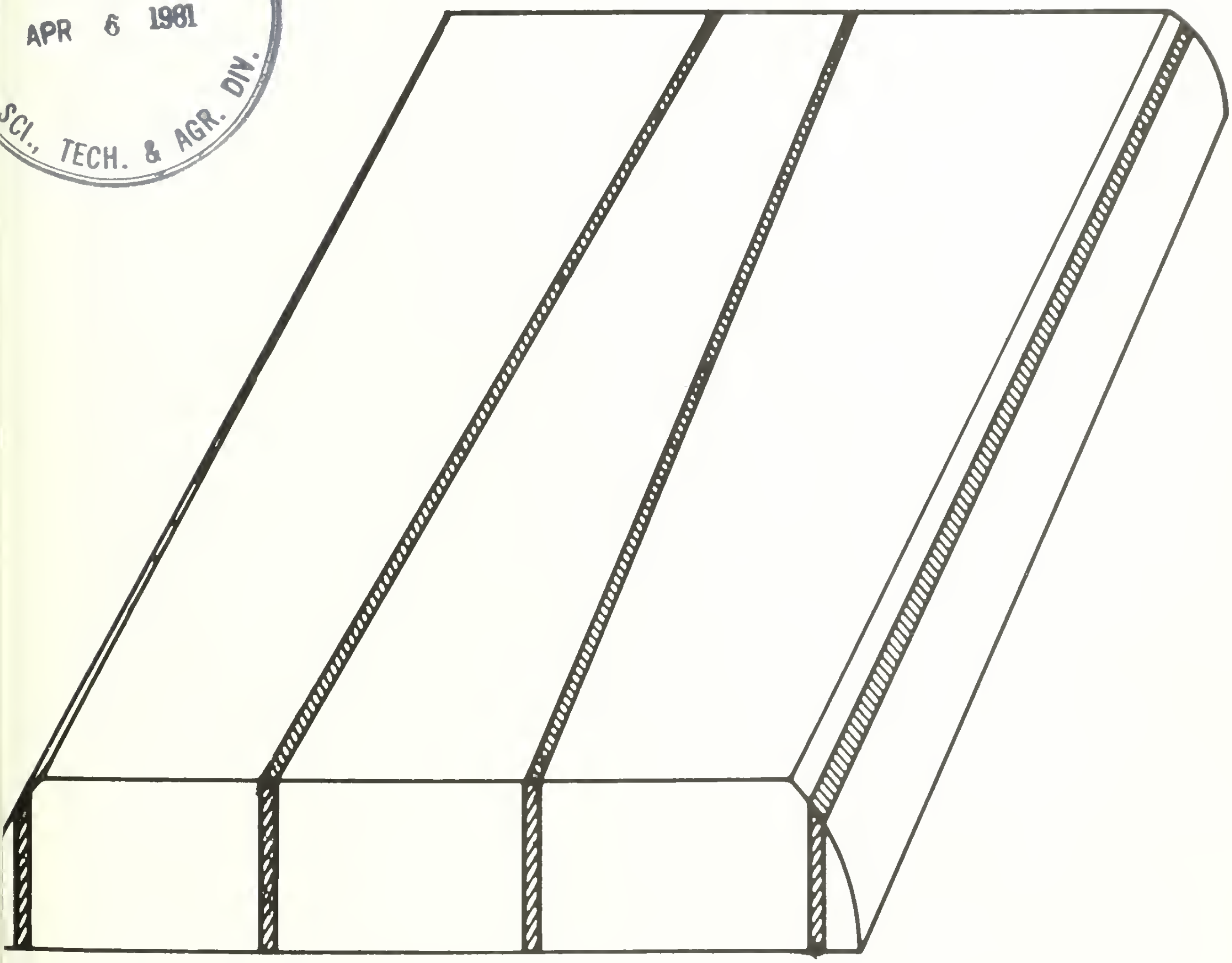
Forest Service

Research
Paper NE-473
1981

Simulated Sawing of Squares: a Tool to Improve Wood Utilization

by R. Bruce Anderson
and Hugh W. Reynolds



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1 AUGUST 1980

Abstract

Manufacturers of turning squares have had difficulty finding the best combination of bolt and square sizes for producing squares most efficiently. A computer simulation technique has been developed for inexpensively determining the best combination of bolt and square size. Ranges of bolt diameters to achieve a stated level of yield are given. The manufacturer can choose which bolt sizes to use for sawing squares based on sawing method used, the range of bolt diameters available, and the size of square to be produced.

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information, please write: Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740.

Introduction

What sizes of bolts are best for producing hardwood turning squares? Does one sawing method produce significantly better yields of squares than another? Until now, these questions could not be answered completely because of the limited analytical techniques. Some manufacturers analyze potential yields by diagraming small-diameter end sections of bolts on paper and plotting squares and kerf to exact scale. But even with this method, manufacturers have difficulty finding the best combination of bolt size and sawing method for squares of different sizes.

We have developed a computer system to determine the yields that can be obtained from sawing bolts into squares of various sizes. The system calculates the amount of material recovered from a bolt. Bolt sizes and square sizes must be specified as input data to the computer. The yield can be calculated from any input combination of bolt and square dimensions. This paper describes how the computer calculates yields, and it compares two sawing methods for a number of bolt and turning-square size combinations.

General Procedure

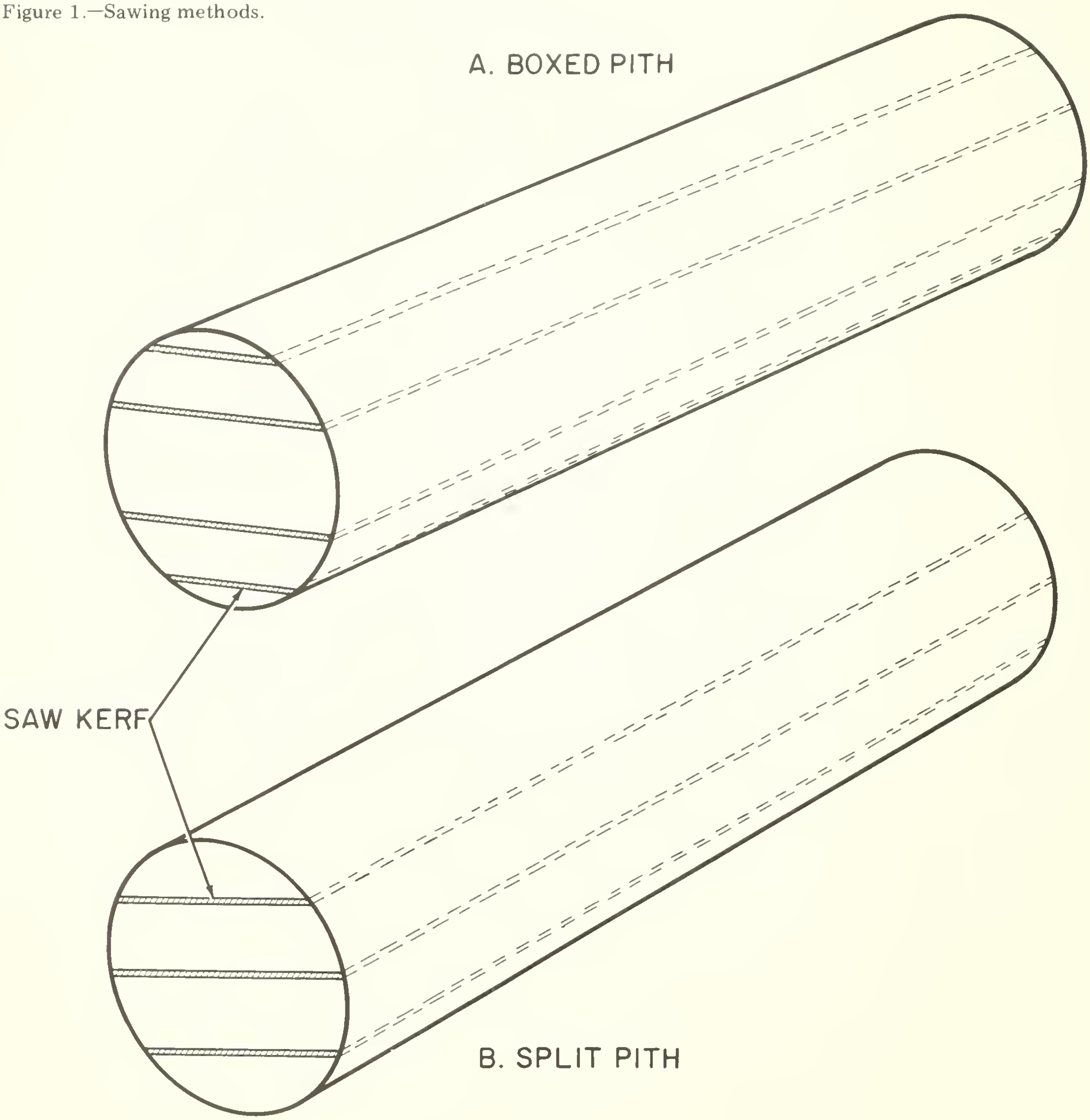
In developing the computer program, we made two assumptions which would not be true in actual sawing of bolts. These assumptions were made so that we could understand clearly the relationship between the number of squares produced and the changes in square and bolt sizes. First, we assumed that the bolts were perfectly clear truncated cones, 4 feet long with a large-end diameter 1/2 inch larger than the small end. Second, we did not consider defects because our main interest was to find how many squares of a specific size could be obtained from a bolt with a given small-end diameter. We considered such factors as bolt sawing patterns, cant sawing patterns, saw kerf, square size, and bolt diameter.

We also assumed that a turning square does not need four square corners, particularly if it is used to make a round. Thus, some wane was allowed. The wane was determined by calculating the size of a round that could be made from a given square. We calculated a width for each cant sawed from a bolt. Then we determined the maximum number of turning squares that could be sawed from the cant if some wane was allowed on the outside squares.

The computer was programed to consider a sequence of circles with diameters ranging from 5.6 to 35.5 inches in 0.1-inch increments. These diameters corresponded to the small-end diameters of the bolts to be sawed by simulation. In our analysis, small differences in bolt diameter are real and important. Bolt diameter limits the width of a cant that can be sawed from the bolt. It also directly affects the number of squares sawed from cants. We used 0.1-inch increments in bolt diameters so there would be no doubt where changes in yield occurred. Because hardwood squares manufacturers are probably not concerned with 0.1-inch variations in bolt diameters, the results were grouped into diameter classes. Circles with diameters from 5.6 to 6.5 inches were grouped into a 6.0-inch diameter class and those from 6.6 to 7.5 inches were grouped into a 7.0-inch class. Diameter classes were grouped the same way up to the maximum of 35.5 inches.

Two techniques for sawing bolts to squares were simulat[e]: the boxed-pith method, in which a center cant containin[g] the pith was sawed from the bolt (Fig. 1A), and the split-[pith] method, in which the bolt was sawed down the middle (F[ig.] 1B). In both cases, all of the bolts were sawed parallel to [the] pith. Outside slabs were resawed to cants if they were lar[ge] enough to yield one or more squares.

Figure 1.—Sawing methods.



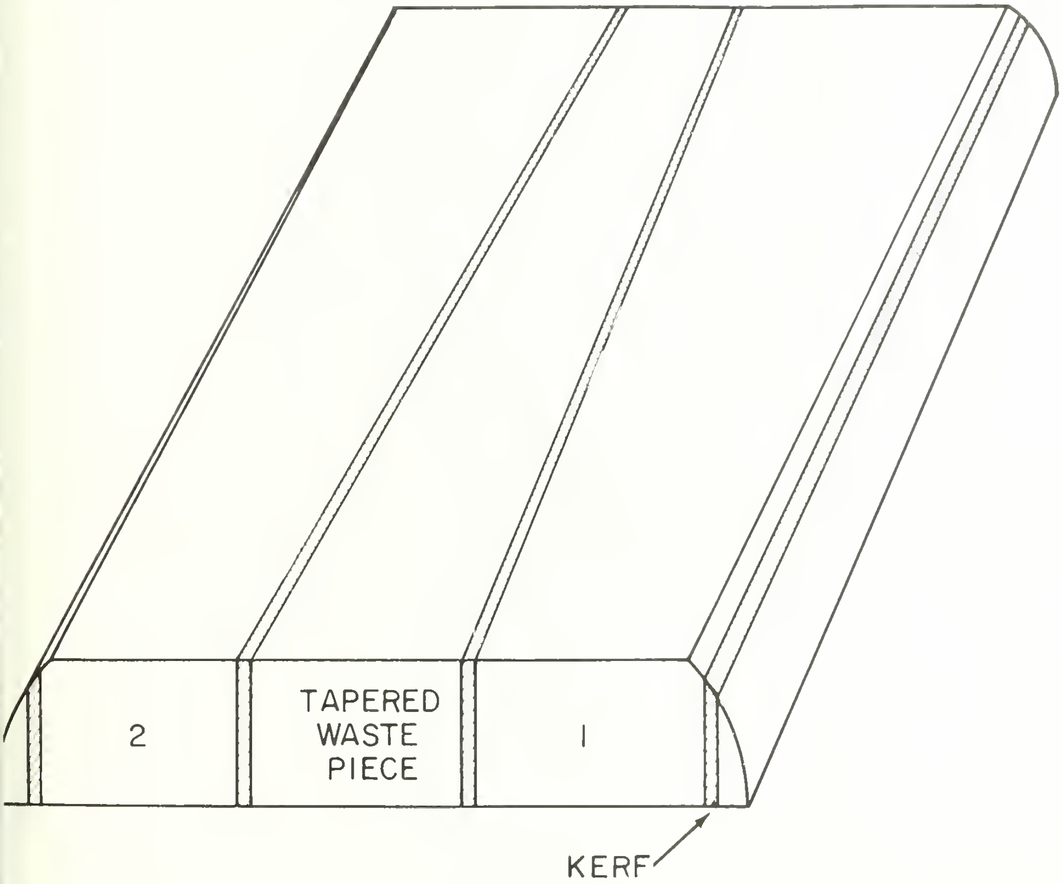
'he simulation of sawing squares from cants was the same or both sawing methods. Squares were sawed from alternate ides of the cant and sawing was parallel to the bark. A ta-ered waste piece occurred in the inside of the cant (Fig. 2). quare sizes were simulated in 0.5-inch increments from 3.0 o 6.0 inches.

aw kerfs were held constant for all runs with a headrig kerf llowance of 0.375 inch, a slab resaw kerf allowance of .3125 inch, and an edger kerf allowance of 0.1875 inch.

Results

Seven different sizes of turning squares ranging from 3 to 6 inches in 1/2-inch increments were evaluated. Because the results were consistent throughout, we chose to report only on the 3- and 6-inch square sizes since they represent the extremes tested. Data for each individual bolt diameter and square size are available from the Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740.

'igure 2.—Squares sawed from alternate ides of the cant.



Comparison of sawing methods

The boxed-pith method produced an initial center cant that had an effective width equal to the bolt's small-end diameter. The split-pith method initially produced two half-round sections from which cants could be resawed only if the sections were thick enough to produce one or more squares. The number and yield of 3- and 6-inch squares from each sawing method are given in Tables 1 and 2. These findings are summarized by bolt diameter class. Because the diameters were increased in 0.1-inch intervals, the number of squares given for each diameter class is the total number of squares sawe from the 10 bolts in that class. The volumetric yields are average yields calculated by considering the total bolt volu in a class and the volume of squares sawed in that class.

No sawing method was best for all sizes of squares or for a diameters of bolts. The total number and distribution of squares from each sawing method were not identical. However, they were too similar to show overall superiority of o method.

Table 1.—Estimated number of 3-inch squares and yield per bolt from each sawing method

Bolt diameter class (inches)	Boxed pith		Split pith	
	Number of squares	Volumetric yield	Number of squares	Volumetric yield
		Percent		*Percent*
6	1.4	40.2	0.4	11.5
7	2.0	42.8	2.0	42.8
8	2.0	33.2	3.8	63.0
9	2.2	29.1	4.0	52.9
10	4.8	51.7	4.6	49.6
11	7.0	62.7	6.0	53.7
12	7.6	57.5	6.0	45.4
13	10.0	64.7	7.8	50.4
14	10.0	56.0	12.0	67.2
15	11.6	56.7	13.4	65.5
16	13.2	56.9	14.8	63.8
17	16.8	64.2	17.4	66.5
18	20.4	69.7	18.0	61.5
19	21.8	67.0	19.2	59.0
20	24.4	67.8	25.0	69.4
21	26.2	66.1	27.4	69.1
22	28.4	65.4	30.4	70.0
23	31.4	66.2	34.0	71.7
24	37.6	72.9	35.2	68.2
25	40.0	71.5	38.0	68.0
26	42.8	70.8	41.8	69.2
27	47.6	73.1	47.0	72.2
28	48.1	68.8	51.2	73.2
29	52.4	69.9	55.6	74.2
30	58.6	73.1	58.4	72.8
31	63.4	74.1	62.0	72.5
32	67.7	74.3	65.4	71.8
33	73.2	75.6	69.8	72.1
34	75.0	73.0	78.4	76.3
35	78.7	72.3	81.6	75.0

Table 2.—Estimated number of 6-inch squares a yield per bolt from each sawing method

Bolt diameter class (inches)	Boxed pith		Split pith	
	Number of squares	Volumetric yield	Number of squares	Volum yield
		Percent		*Percen*
6	0.6	69.0	0.0	00.0
7	1.0	85.7	0.0	00.0
8	1.0	66.0	0.0	00.0
9	1.0	52.9	0.0	00.0
10	1.0	43.1	0.0	00.0
11	1.0	35.8	0.0	00.0
12	1.4	42.3	0.4	12.1
13	2.0	51.7	2.0	51.7
14	2.0	44.8	2.0	44.8
15	2.0	39.1	3.4	66.5
16	2.0	34.4	4.0	68.9
17	2.0	30.6	4.0	61.2
18	2.2	30.1	4.0	54.7
19	4.6	56.5	4.0	49.2
20	5.8	64.4	5.2	57.8
21	7.0	70.7	6.0	60.6
22	7.0	64.5	6.0	55.2
23	7.0	59.0	6.0	50.6
24	8.6	66.7	6.0	46.5
25	10.0	71.5	7.0	50.1
26	10.0	66.2	10.8	71.5
27	10.0	61.4	12.0	73.7
28	10.0	57.2	12.0	68.6
29	12.0	64.0	13.8	73.6
30	12.0	59.9	14.0	69.8
31	13.2	61.7	14.0	65.4
32	15.8	69.4	16.0	70.2
33	17.0	70.2	18.0	74.3
34	19.0	74.0	18.0	70.1
35	21.0	77.2	18.0	66.2

Anderson, R. Bruce, and Hugh W. Reynolds.
1981. Simulated sawing of squares: a tool to improve wood utilization. Northeast. For. Exp. Stn., Broomall, Pa 7 p. (USDA For. Serv. Res. Pap. NE-473)

Manufacturers of turning squares have had difficulty finding the best combination of bolt and square sizes for producing squares most efficiently. A computer simulation technique has been developed for inexpensively determining the best combination of bolt and square size. Ranges of bolt diameters to achieve a stated level of yield are given. The manufacturer can choose which bolt sizes to use for sawing squares based on sawing method used, the range of bolt diameters available, and the size of square to be produced.

831.9:822.1

Keywords: Turning squares, yield, computer simulation

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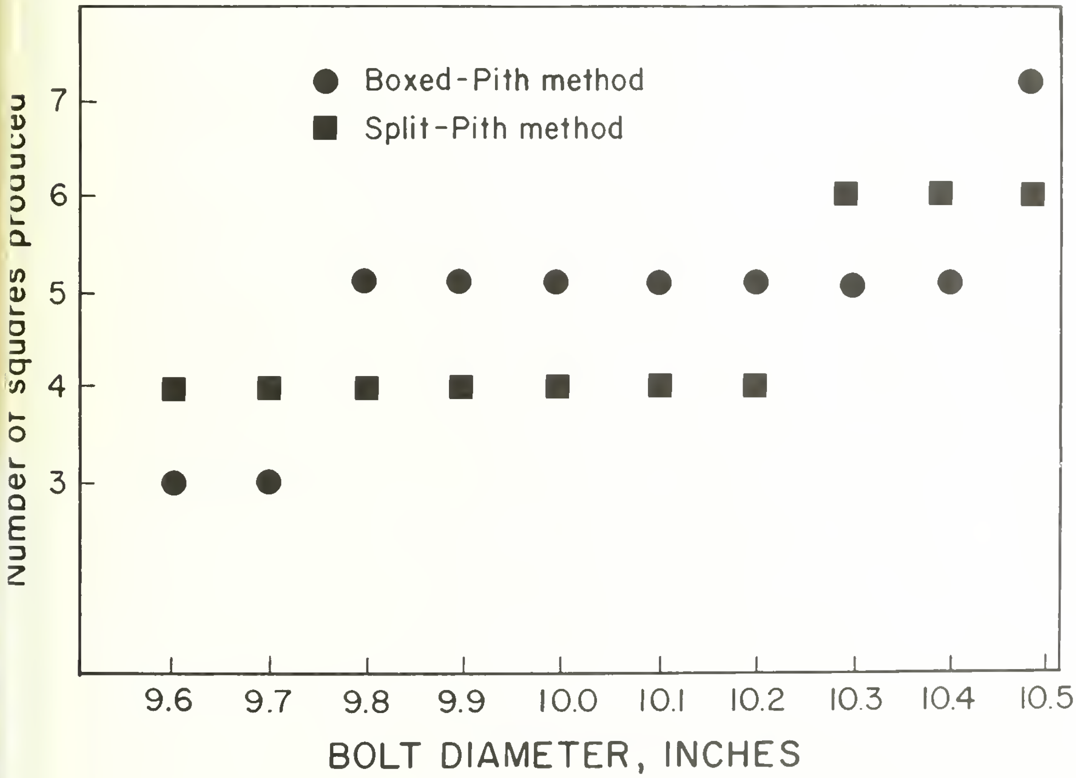
ıthough the overall number and distribution of squares ere not significantly different, the two methods seldom oduced exactly the same number of squares in a given di- neter class. These small differences between the two tech- ques are explained by the relationship between sawing ethod and bolt diameter. From the smallest usable diam- ers, the boxed-pith method will always yield a cant that ın be sawed into squares. The split-pith method will not eld squares from the smaller diameters, particularly when rge squares are produced. As the size of the bolt increases, point is reached where the split-pith method yields two cants while the boxed-pith method is still yielding only one. The apparent advantage in number of squares produced thus alternates between methods as diameter increases. A more specific example of this relationship is shown in Figure 3. In this example, the advantage one method has over the other, in terms of number of squares produced, alternates four times within the bolt diameter class. As a result, the boxed-pith method produced 48 squares while the split-pith method produced 46 squares. The same number of squares is seldom produced, but the differences are not significant.

igure 3.—Comparison of the number of 3-inch squares produced within 10-inch diam- ter class.



Effective squares production

Manufacturers are concerned with getting the greatest amount of usable material out of the raw material input. We have used the number of squares produced to compare sawing methods, but it is not a complete measure of the effectiveness of squares production because it does not define how much usable material was recovered from the total bolt volume. In our analysis, volumetric yield provided the best measure of how much material was recovered in sawing squares from bolts. Expressed as a percentage, this yield was calculated as follows:

$$\text{Volumetric yield} = \frac{100 \times \text{No. of squares} \times \text{Volume of each square}}{\text{Volume of bolt(s)}}$$

In this equation, the number of squares produced directly affects volumetric yield. Bolt diameter, used in calculating volume of bolts, also affects yield although inversely if the number of squares remains the same. As shown in Tables 1 and 2, the number of squares produced did not increase with every 0.1-inch increase in bolt diameter. Thus, volumetric yield decreases when increases in diameter do not produce additional squares.

It would be ideal if a manufacturer could use bolts in the diameter class that had the highest yield of a specific square size. For example, consider the volumetric yields for 3-inch squares shown in Table 1. The highest yield (75.63 percent) from boxed-pith sawing is in the 33-inch diameter class. For split-pith sawing, the highest yield (76.35 percent) is in the 34-inch diameter class. Thus, a manufacturer should produce 3-inch squares by split-pith sawing of bolts in the 34-inch diameter class in order to maximize his volumetric yield.

However, maximizing yields by using a specific bolt size for each square size normally is not possible. An overall lower level of yield must result if the bolts available are only in a few specific diameter classes as typically would be the case. Computer analysis has allowed us to specify ranges of bolt diameters that will insure yields at or above some desired percentage of the total bolt volume. The ranges are defined by specifying a lower limit for bolt diameters depending on the size of square desired. If bolts with diameters larger than this lower limit are sawed, yields will be at or above the desired percentage. Such lower limits of bolt diameters were defined for all square sizes when the boxed-pith sawing method was used. If 50 or 60 percent is the smallest acceptable yield, the lower limits of the range of bolt diameters relate to the square sizes as follows:

Boxed-pith sawing for 50 or 60 percent yield, in inches

Square size (inches)	*Diameter class lower limit for 50% yield*	*Diameter class lower limit for 60% yield*
3.0	10	16
3.5	11	19
4.0	13	21
4.5	14	24
5.0	16	26
5.5	17	29
6.0	19	31

These relationships can be expressed in the following form:

For at least a 50 percent yield:

Lower limit of bolt diameter = 0.8 + 3 x square size required

For at least a 60 percent yield:

Lower limit of bolt diameter = 1.40 + 5.0 x square size required

The split-pith technique can also be used where some specified level of yield will satisfy a manufacturer's requirements. In this case, the lower limits of the bolt diameter range relate to the square sizes as follows:

Split-pith sawing for 50 or 60 percent yield, in inches

Square size (inches)	*Diameter class lower limit for 50% yield*	*Diameter class lower limit for 60% yield*
3.0	13	14
3.5	15	16
4.0	17	18
4.5	19	20
5.0	21	22
5.5	23	24
6.0	25	26

These relationships may be expressed in the following form:

For at least a 50 percent yield:

Diameter class lower limit = 1. + 4 x square size required

For at least a 60 percent yield:

Diameter class lower limit = 2. + 4 x square size required

›nclusions

› decide what bolt size to use for sawing squares you must ›ow what square sizes are desired; what range of bolt diam›ers is available; and if all diameters are available, what level › yield is acceptable in producing the squares. With these ›ctors, predictions of the yield from any distribution of bolt ›es can be generated. The program we have developed is ›xible, and a manufacturer can include as program input ›ta the range and distribution of bolt diameters he has avail›le. In addition, squares of different sizes can be specified ›r production from each bolt. The program does not auto›atically calculate the optimal combination of bolt and ›uare size. But, by varying the combinations of desired ›uare sizes and running these combinations against the dis›bution of available bolt diameters, a manufacturer can de›rmine quickly which combination will result in the highest ›eld.

›rtain levels of yield are attainable by choosing proper bolt ›es for a given square size. Remember that the natural vari›ility of the wood raw material was not considered: each ›lt was considered as a perfect truncated cone containing › defects. Real bolts contain defects and will have lower ›elds than those reported in this paper. This, however, does ›t affect the use of these findings as a general guide for bolt ›d sawing selection.

›mparison of the two sawing techniques shows that, with ›rtain qualifications, either sawing method is suitable for producing an acceptable squares yield. The location of defects in real bolts will influence the selection of a sawing method more than any variation in yield between the two methods. Inclusion of the pith and associated heart knots in a single waste piece is consistent with current industry practices, and this precludes extensive use of the split-pith method by the squares industry. Comparison of these sawing methods was therefore academic. We had assumed that the yields from the two techniques would be substantially different. The study results do not support that assumption.

The influence of the raw material resource on squares yield is not limited to defects in real bolts. One-half of the hardwood resource in the eastern United States is in logs that are 10 inches or smaller in diameter. Thus, the distribution of bolt sizes available to squares manufacturers is limited compared to the distribution of bolts used in this paper. Using the equations relating square size and bolt diameter, the squares manufacturer can determine whether an acceptable yield can be achieved within the range of available bolt sizes.

The techniques outlined provide an inexpensive means of determining the best combination of bolt size and sawing method of producing squares more efficiently. Minimum acceptable levels of yield can be achieved over a wide range of bolt sizes. Ranges of bolt diameters to achieve a stated level of yield are given for both sawing techniques. Specific bolt sizes have been found that maximize the yield for a particular square size. The choice is up to the manufacturer, depending on the sawing method used, the range of bolt diameters available, and the size of square to be produced.

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- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- University Park, Pennsylvania, in cooperation with the Pennsylvania State University.
- Warren, Pennsylvania.

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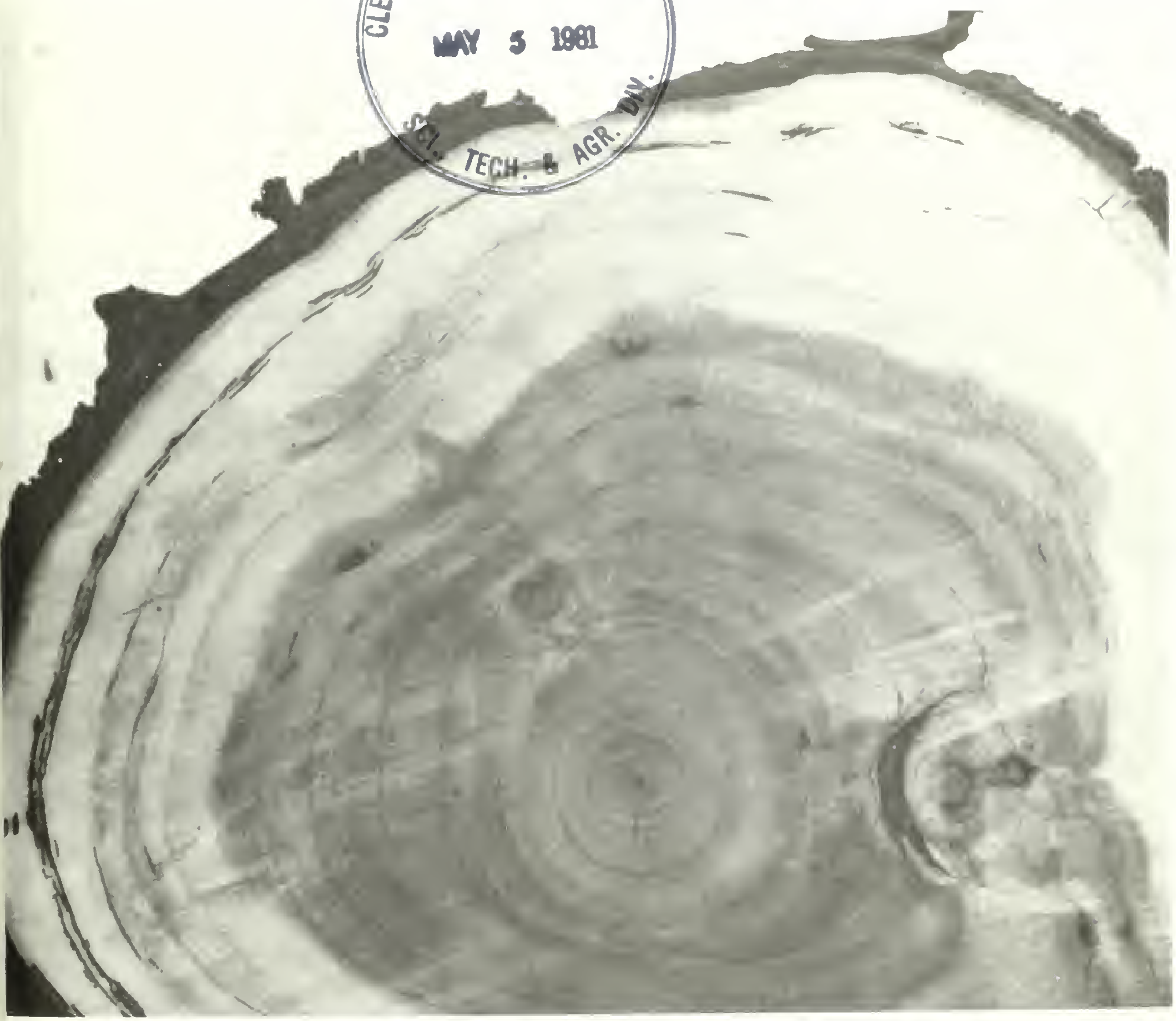
Forest Service

Research
Paper NE-474

1981

Gum Spots in Black Cherry Caused by Natural Attacks of Peach Bark Beetle

By Charles O. Rexrode



The Author

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MANUSCRIPT RECEIVED FOR PUBLICATION
22 SEPTEMBER 1980

Abstract

Peach bark beetles, *Phloeotribus liminaris* (Harris), made abortive attacks on healthy black cherry, *Prunus serotina* Ehrh., trees. The beetle attacks caused five types of gum spots in the wood and a gummy exudate on the bark. The most extensive and common types of gum spot were single and multiple rows of interray gum spots that encircled the lower 3 m of the tree. Three to four attacks per 6.5 cm^2 of bark surface caused enough gum flow to produce a continuous ring of gum spot in the wood.

he peach bark beetle, *Phloeotribus liminaris* (Harris), a ative insect, was first recognized as a pest of peach trees in 850. For the next 65 years, it was a serious pest in peach ıd cherry orchards in Ohio, New York, and Ontario, Canada 3rooks 1916). Baker (1972) reported that it attacks elm, ıulberry, wild cherry, wild plum, and mountain ash. Peach ark beetles have been found in New Hampshire, New York, ennsylvania, Maryland, Virginia, West Virginia, North Caro-na, Arkansas, Ohio, and Michigan and probably occur ıroughout the range of *Prunus*.

ossard (1913) reported that a wild cherry tree 22.9 m tall ıd 35.56 cm in diameter was killed by peach bark beetles. ossard also cited that the peach bark beetle and the shot-ole borer, *Scolytus rugulosus* (Ratz.), cause gummosis in *runus* in Ohio. He stated that although both bark beetles are ıore commonly associated with weakened and dead trees, it as not unusual for them to attack healthy trees. Attacks on ealthy trees were usually unsuccessful and the beetles were ımetimes found in balls of gum that were abundant on at-ıcked trees. However, Gossard made no mention of gum ıots in the wood. Craighead (1950) also reviewed the activ-ies of the peach bark beetle but did not mention gum spots wood.

ı 1953, near Parsons, West Virginia, C. K. Dorsey observed ack cherry trees that produced large quantities of gum Kulman 1964). The gum was so abundant that it flowed om the trees and accumulated on the ground around the ee trunks. In 1958, Kulman (1964) found a continuous ring f gum spots in the 1954 and 1955 wood of these trees. He ıspected that the gum exudate on the surface of the trees ıd the associated gum spots in the wood were due to hiber-ıting galleries constructed by peach bark beetles.

ıker (1972) stated that *P. liminaris* usually attacks only eakened species of *Prunus* and, therefore, is normally con-ıed to suppressed trees and shaded branches. Schultz and llen (1977) found that *P. liminaris* attacked and killed ack cherry trees after 2 to 3 years of defoliation by the ıerry scallop shell moth, *Hydria prunivorata* (Ferguson). owever, they did not mention absortive attacks on trees at did not die or gum spots associated with abortive at-cks.

ıis paper is a report on the abortive attacks by peach bark etles on apparently healthy black cherry trees and shows e types of gum spots in the wood that result from such tacks.

Materials and Methods

During the spring of 1979, several cords of black cherry, *Prunus serotina* Ehrh., wood infested with peach bark beetles, *P. liminaris*, were piled near a plantation of black cherry trees. The trees were 20 years old, 15 to 25 cm in diameter, 7 to 9 m tall, and apparently healthy (Fig. 1). In the early summer of 1979, adult peach bark beetles emerged from the infested wood and made abortive attacks on the plantation-grown trees.

Figure 1.—Healthy black cherry, *Prunus serotina*, attacked by peach bark beetles, *Phloeotribus liminaris*.

The number of beetle attacks and the extent of exudation at the attack sites were measured. In July 1980, two trees were felled and several cross sections 5 to 30 cm thick were taken from the attack areas for a study of the internal defects caused by beetle attacks.

After the cross sections were air dried for 2 weeks, portions containing gum spots were sanded to a smooth surface. The gum spots were examined under a stereozoom binocular microscope and grouped into definable types, and photomicrographs were made of each type of gum spot. Some cross sections were split tangentially and radially and each type of defect was classified, measured, and photographed.

Results and Discussion

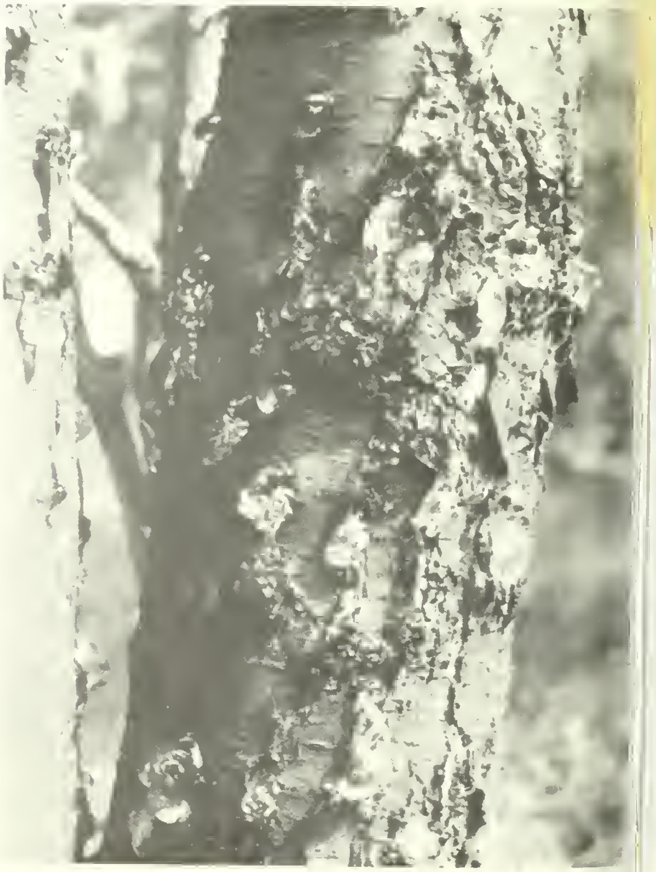
Trees nearest the source of emerging beetles sustained the greatest number of attacks. Beetle attacks were concentrated on the basal 20 to 25 cm of the trees where the bark was roughest (Fig. 2). The attacks lasted for about 3 weeks, and some sections sustained up to 10 attacks per 6.4 cm^2.

Trees exuded gum at the attack sites when the beetles reached the cambium and then the beetles were either "pitched out" or killed by the following gum and rarely reached the xylem. Trees continued to exude gum at the attack sites throughout the summer, and balls of gum as large as 25 mm in diameter were often formed at individual attack sites (Fig. 3). When attacks were numerous, the gum flowed down the boles and accumulated 5 to 10 cm deep around the base of the trees. The gum dried and hardened during the winter and did not continue to flow the following spring. However, the dried gum was present on the surface of the bark the following summer.

Several types of gum spots were present on transverse sections and two types were present on tangential sections of trees felled in July 1980. The most extensive type of gum

Figure 2.—Peach bark beetle, *Phloeotribus liminaris*, attacks on boles of black cherry, *Prunus serotina*.

Figure 3.—Black cherry, *Prunus serotina*, produces gum at peach bark beetle, *Phloeotribus liminaris*, attack sites.



Rexrode, C.O.
1981. Gum spots in black cherry caused by natural attacks of peach bark beetle. Northeast. For. Exp. Stn., Broomall, Pa.
5 p. USDA For. Serv. Res. Pap. NE-474)

Peack bark beetles, *Phloeotribus liminaris* (Harris), made abortive attacks on healthy black cherry, *Prunus serotina* Ehrh., trees. The beetle attacks caused five types of gum spots in the wood and a gummy exudate on the bark. The most extensive and common types of gum spot were single and multiple rows of interray gum spots that encircled the lower 3 m of the tree. Three to four attacks per 6.5 cm^2 of bark surface caused enough gum flow to produce a continuous ring of gum spot in the wood.

416.5:453—145.7X19.92

Keywords: Defects, *Prunus serotina*, *Phloeotribus liminaris*

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ɩot was single and multiple rows of interray gum spots that ɩcircled the tree (Fig. 4). The rings of gum were often 5 mm ide and extended 2.4 to 3 m on the tangential surface om the highest point of mass attack to the base of the tree.

Three to four attacks per 6.5 cm^2 of bark surface were considered mass attacks, and this density caused enough gum to soak the bark. Single attacks caused four types of gum spots on the transverse section: (1) T-shaped spot (Fig. 5),

igure 4.—Multiple rows of interray gum ɩots that encircle the tree.

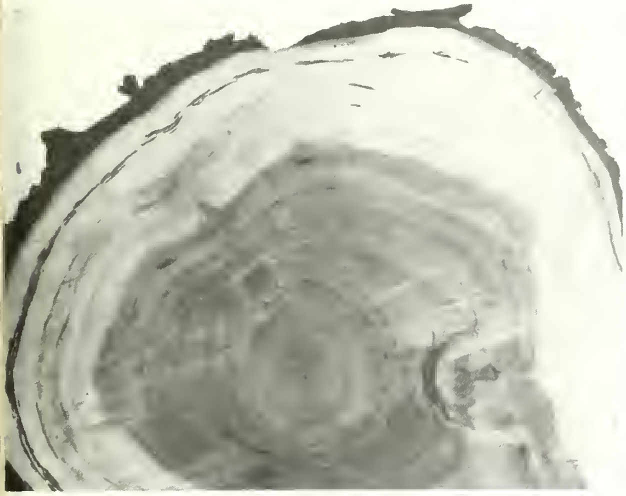

Figure 5.—T-shaped gum spot on transverse section.

(2) T-shaped spot with bands of interray gum spots (Fig. 6), (3) round to oblong gum spot (Fig. 7), and (4) multiple rows of gum (Fig. 8). Streaks of gum 5 mm wide and 80 mm long (Fig. 9) on the tangential section were commonly associated with the gum spots on the transverse section. On the radial surface, gum spots were 2 to 5 mm wide.

The attacks were abortive breeding attacks because they occurred during the height of beetle emergence. Also, no beetles were observed overwintering under the bark, and there was no gum flow the following spring from the construction of hibernating adults.

Abortive attacks by peach bark beetles are important in the management of quality black cherry. Peach bark beetles may build up in large numbers in tree tops after a timber harvest and emerging progeny may make abortive attacks on the residual crop trees, causing permanent gum spots in the boles—the most valuable part of the tree.

Figure 6.—T-shaped gum spot with bands of interray gum spots.

Figure 7.—Round to oblong gum spot.

igure 8.—Multiple rows of interray gum ots.

Figure 9.—Vertical streak of discoloration in the xylem at attack site.

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- University Park, Pennsylvania, in cooperation with the Pennsylvania State University.
- Warren, Pennsylvania.

United States
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Forest Service

Research
Paper NE-475

1981

Effect of Deer Browsing on Timber Production in Allegheny Hardwood Forests of Northwestern Pennsylvania

by David A. Marquis

The Author

DAVID A. MARQUIS received a bachelor of science degree in forestry from The Pennsylvania State University in 1955, and master's and doctoral degrees in forest ecology and silviculture from Yale University in 1963 and 1973 respectively. In 1957, he joined the Northeastern Forest Experiment Station's silviculture research unit in New Hampshire, where he studied problems of regeneration and thinning in northern hardwoods. Between 1965 and 1970 he served on the timber and watershed management research staff at the Station's headquarters. Since 1970, Dr. Marquis has been project leader of the silviculture research unit at Warren, Pennsylvania, where he heads a program of research on problems related to the regeneration and culture of high-value hardwoods on the northern Allegheny Plateau.

MANUSCRIPT RECEIVED FOR PUBLICATION
22 SEPTEMBER 1980

Abstract

Regeneration surveys in fenced and unfenced portions of thirteen 9- to 22-year-old clearcuts on the Allegheny Plateau of Northwestern Pennsylvania show that deer browsing has resulted in (a) inadequate stocking of tree species, (b) delay in establishment, and (c) less valuable species composition. Ninety-two percent of the fenced areas, but only 38 percent of the unfenced areas, are considered satisfactorily stocked. The value of timber production lost as a result of browsing during the regeneration period is estimated to average $1,075 per acre.

:owsing of tree seedlings by white-tailed deer in heavily-rested regions of the Allegheny Plateau in Pennsylvania riously interferes with tree regeneration. As a result, estab-hment of a new stand following harvest cutting is often layed and sometimes prevented entirely. Even where re-neration does occur, timber yields may be diminished by ifts in species composition, reduced stocking, or extended tations.

ıe effects of deer on regeneration establishment, species mposition, and density have been abundantly documented. summary of many of these articles is available,[1] and a his-ry of the problem has been published (Marquis 1975). owever, information on the value of timber production lost ie to browsing is scarce. Records on the long-term develop-ent of stands damaged by deer have not been available to rmit calculations of yield losses, and data have not been ailable to estimate the proportion of stands affected.

though good data remain limited, a series of deer exclos-es created in clearcuts on the Allegheny National Forest 9 22 years ago now provide records on stand development er a long enough period for crude estimates to be made on timate timber yields of the fenced and unfenced stands. iis is a report on those stands and the projected losses re-lting from deer browsing.

Marquis, David A., and Ronnie Brenneman. The impact of leer on forest vegetation in Pennsylvania. USDA For. Serv. Gen. Tech. Rep., Broomall, Pa. (in preparation).

Study Methods

During the 1950's and 1960's Allegheny National Forest personnel installed a series of deer exclosures in various stands throughout the four-county area included within the Forest boundary in northwestern Pennsylvania. Most of the exclosures were located in recently cutover areas. In 1971 and 1977, vegetation surveys were made on plots both inside and outside 13 of the exclosures. The three oldest clearcuts had also been surveyed in 1960. All fences in the 13 areas had been erected shortly after clearcutting of the second-growth Allegheny hardwood stand that previously occupied the site (Table 1).

A cluster of nine sample plots was located inside and another cluster outside of each exclosure. The sample plots were arranged in three rows of three plots each, with 40 feet between plots. The cluster outside of the exclosure was located in an area as similar as possible to that inside the fence, based on topography, drainage, and residual stand density. The center plot of the outside cluster was located at least 100 feet from the fence to avoid atypical conditions that sometimes exist in the heavily traveled zone near the fence.

The nine sample plots used in each stand in this study would not provide an adequate sample on which to evaluate regeneration on an entire clearcut, but were considered satisfactory here because the total area evaluated was limited to the 1/2-acre inside or the similar area outside the deer exclosure.

Table 1.—Exclosures surveyed

tand No.	Sale area	Cutting complete	Fence built	Fence height	Acres exclosed	Acres clearcut
.01	Railroad Run	1966	1966	6′	0.5	3
.02	North Branch Sugar Run	1965	1966	6′	0.5	30
.03	Hemlock Run	1966	1966	6′	0.5	39
.04	Wolf Run	1969	1969	8′	8.0	15
.05	Slide Run No. 2	1963	1963	8′	0.5	35
.06	Long Hollow	1965	1966	8′	0.5	26
.07	Lower Morrison	1965	1966	8′	0.5	16
.08	Fork Run	1966	1966	8′	0.5	28
.09	Farnsworth	1965	1966	8′	0.5	16
.10	Kinzua Trail	1965	1966	8′	0.5	2
13	Chappel Fork	1957	1957	8′	1.0	3
.14	Cherry Grove	1957	1957	8′	1.2	3
20	Silver Creek	1956	1957	8′	1.0	3

Sample plots were circular, with a radius of 6 feet. The number of stems was recorded by species and height classes in all the inventories, and the exact height of the tallest individual of each important species was recorded in 1971. Percentage of ground area covered by six major groups of herbaceous ground-cover plants was also recorded. During the 1977 survey, a 100 percent tally was made of all trees 0.5 inch dbh or larger, by species and diameter class, on the four oldest areas. Data from the 1960 and 1971 surveys were published (Marquis 1974, Jordan 1967).

The Student's t-test for paired observations was used to make statistical comparisons between fenced and unfenced plots. Several species groups are mentioned throughout the data tabulations that follow. Preferred species are those preferred for timber production; they include black cherry, sugar maple, red maple, yellow-poplar, cucumber tree, and red oak. Other commercial species include beech, yellow birch, black birch, other oaks, hickory, aspen, and hemlock. Noncommercial species include pin cherry and striped maple.

Deer populations in the four-county area of the Allegheny National Forest during the time that these clearcuts were made are not precisely known. Estimates made by the Pennsylvania Game Commission in 1980 place the current prehunting-season population at 28 to 30 deer per square mile. Records of antlered deer harvest indicate that deer populations during the mid-1950's and mid-1960's—when the study stands were clearcut—were approximately the same as now (about 25 deer per square mile). Deer populations rose to between 36 and 39 deer per square mile during the early 1970's, but the cuttings were made much earlier.

Results and Discussion

Tree regeneration

The total number of stems of regeneration present 9 to 22 years after clearcutting did not differ significantly between fenced and unfenced areas. However, there were important differences in species composition and large differences in the number of stems that had grown above 5 feet in height (Table 2).

Table 2.—Average number of stems 9 to 22 years after clearcutting (1977), in thousands per acre

Species	All stems		Stems over 5 feet	
	Fenced	Unfenced	Fenced	Unfenced
Black cherry	7.5	6.5	3.4[a]	0.8
Sugar maple	0.7	0.6	0.3	0.2
Red maple	2.0	1.5	0.4*	0.1
White ash	0.4	0.4	0.1	0.1
Total preferred species	10.7	9.1	4.2[a]	1.2
Beech	1.0	1.7	0.5*	1.0
Birch	0.9	1.2	0.6	0.6
Total other commerical species	2.0[a]	3.0	1.1	1.6
Striped maple	0.4	1.3	0.1	0.5
Pin cherry	0.8	0.1	0.7*	0.0
Total noncommercial species	2.2	4.3	1.1	1.2
TOTAL ALL SPECIES	16.2	16.8	6.8	4.0

[a] Differences between fenced and unfenced areas statistically significant at 0.10 level.
* Differences between fenced and unfenced areas statistically significant at 0.05 level.

The preferred species had been dramatically reduced by browsing outside the fences. There were over three times as many preferred stems over 5 feet tall inside the exclosures as outside. Noncommercial pin cherry was also affected; it was nearly eliminated by browsing in the unfenced areas.

Conversely, less desirable beech and noncommercial striped maple were favored by preferential browsing on the other species. There were about twice as many stems of these species in the unfenced plots as in the exclosures.

The total number of stems over 5 feet tall in the fenced plots was 150 percent of that in the unfenced ones. However, there were still 1,200 stems per acre of preferred species over 5 feet tall in the unfenced plots—on the average. If evenly distributed, that would be enough stems to establish desirable new stands. To evaluate the impact of deer in delaying or preventing establishment, we needed to determine how many of the clearcuts were adequately stocked.

Current guidelines for evaluation of regeneration stocking after clearcutting require that 70 percent of the 6-foot radius plots in a stand contain at least two stems over 5 feet in height. The terminals of such stems are considered tall enough to escape further browsing (although occasionally damage does occur on stems taller than 5 feet, especially where the stem is isolated and other adjacent browse is scarce). For stands that have not yet achieved this level of stocking (usually because they are too young), the potential for success is assessed by calculating the average of (a) the proportion of plots that are stocked with 5 stems over 3 feet tall and (b) the proportion of plots that are stocked with 25 stems total. All of the above stocking criteria are calculated for preferred species alone, and for the commercial species together.

During the first 5 years or so after clearcutting, regeneration is small and the percentage of plots stocked with 2 stems over 5 feet is still increasing. At this time, the percentage of plots stocked with 5 stems over 3 feet and 25 stems total is ususally higher, and indicates how much the stocking of stems over 5 feet is likely to increase in the future. However, after 5 to 10 years, as the canopy in portions of the stand closes and crowding reduces the total number of stems, the proportion of plots with 5 stems over 3 feet and 25 stems total decreases, and drops below the proportion of plots stocked with 2 stems over 5 feet. Between 5 and 15 years, the total number of stems over 5 feet tall also begins to decline (Fig. 1), and this indicates that further improvement in stocking is unlikely. Those plots not stocked at this time are usually dominated by noncommercial species or are open; in either case, stocking is usually fixed.

Figure 1.—Change in regeneration with stand age. Dashed line indicates expected trend—no data collected during that period.

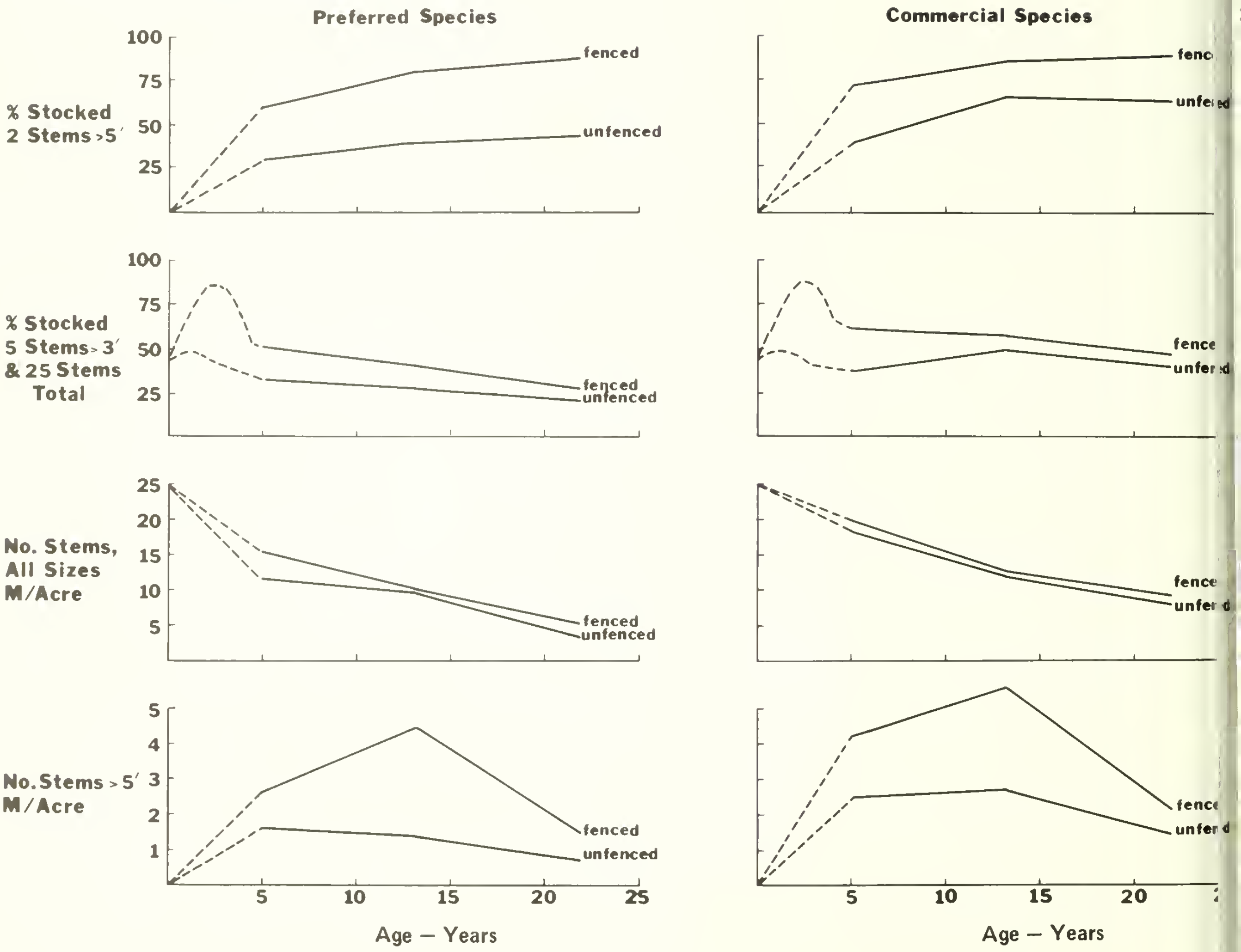

Table 3.—Percentage of plots stocked to given levels with preferred and commercial species 9 to 22 years after clearcutting

Stand no.	Fenced: Two stems over 5 feet		Fenced: Five stems over 3 feet and 25 total		Unfenced: Two stems over 5 feet		Unfenced: Five stems over 3 feet and 25 total	
	Preferred species	Commercial species	Preferred species	Commercial species	Preferred species	Commercial species	Preferred species	Commercial species
101	78	89	39	72	56	89	56	78
102	22	22	11	11	0	22	0	6
103	56	67	22	22	0	22	0	11
104	100	100	94	100	44	44	78	84
105	67	78	44	56	0	0	0	0
106	67	89	39	66	89	100	34	56
107	56	100	16	66	0	100	0	44
108	89	100	16	66	11	78	11	78
109	100	100	44	72	67	100	28	61
110	100	100	72	84	100	100	94	100
113	89	89	22	28	100	100	50	62
114	78	89	44	56	22	44	16	38
120	78	89	22	56	8	46	0	27

In the 9- to 22-year-old clearcuts, nearly all stands have reached the condition where further improvement in stocking is unlikely. Only one stand, the unfenced portion of stand 104, has potential for significantly improved stocking (Table 3). Thus, estimates of the impact of deer browsing on regeneration in these clearcuts can be made with reasonable assurance that the stocking observed now will not change appreciably in the future.

Table 3 shows that stocking of preferred species and of all commercial species is dramatically higher in the fenced plots. Less than one-third of the clearcuts where deer were able to browse are staisfactorily stocked with preferred species, whereas most stands are staisfactorily stocked inside the exclosures (Table 4).

Table 4.—Percentage of clearcuts satisfactorily stocked with two stems over 5 feet[a]

Species	Fenced	Unfenced
Preferred	77	31
Commercial	92	54

[a] Although 70 percent is usually considered the minimum for acceptable stocking, 67 percent was accepted in this study. This is equivalent to 6 of 9 plots—7 of 9 plots (78 percent) would have been unnecessarily restrictive.

Differences between fenced and unfenced areas statistically significant at 0.05 level.

Although only four of the 13 clearcuts were old enough to have formed a closed stand (with a few trees as large as 10 to 11 inches dbh and average stand diameter for all four stands of 2.5 inches), they provided a means of comparing stocking estimates from the regeneration surveys with traditional stand data used in silvicultural operations.

Stocking values from the 100 percent tallies are remarkably well correlated with stocking values for commercial species from the regeneration surveys (Table 5). The number of stems and basal area in preferred species (100 percent tally) are also very closely related to the stocking of preferred species (regeneration tally).

The effects of browsing on ultimate species composition are reemphasized by these stand data. Note that the basal area in preferred species is nearly three times higher in the five stands with 70 to 100 percent regeneration stocking (four of which were fenced) than in the three stands of lower stocking (all of which are unfenced). Conversely, the basal area of less desirable beech, birch, and hemlock is three times lower. The most extreme effect is on pin cherry—25 square feet of basal area versus only 1 square foot. Pin cherry is diminished drastically by preferential browsing in all of the unfenced stands, probably because it is a fast-growing species that is succulent and attractive to deer and it grows above the other vegetation quickly where it is naturally singled out. A common observation is that the presence of large amounts of pin cherry (or *Rubus*) indicates that browsing pressure is not severe and that desirable regeneration will probably emerge.

Table 5 also shows that browsing in an area of very high regeneration potential can actually be beneficial. Stand 113 is such a stand—it contained about 70,000 stems per acre of preferred species at 4 years of age, far more than any other stand (the average was 16,000 and the second best stand had 40,000). In stand 113, there were far too many seedlings present for deer to prevent the establishment of a new stand. But browsing has drastically reduced the very dense stocking of pin cherry from 45 square feet of basal area in the fenced stand to 9 square feet in the unfenced one. The dense pin cherry in the fenced area adversely affected preferred species —leaving only 33 square feet of preferred species as opposed to 81 square feet in the unfenced area. These differences will probably decrease as the pin cherry begins to die out and previously suppressed stems of other species grow into the 1-inch class. But deer browsing in this unusual case will probably result in higher proportions of black cherry in the unfenced stand and slightly better early growth.

Average stand diameter is slightly greater where browsing has occurred. Presumably the lower overall stocking and lack of overtopping pin cherry permit those few trees that escape the deer in the unfenced areas to grow faster than the larger number of stems that are subject to more severe competition in the fenced areas. However, this slightly larger stand diameter cannot offset the poor stocking and scarcity of preferred species in most unfenced areas. Furthermore, data on average height show that the preferred species averaged 9.2 feet in the fenced areas in 1971 versus only 5.7 feet in the unfenced areas (Marquis 1974)—a good indicator that overall stand development had been delayed by browsing.

From preceding data on all 13 stands, it is apparent that excessive deer browsing can have three major effects on the establishment of tree regeneration: (a) inadequate stocking of commercial tree species; (b) delay in establishment, which

Table 5.—Comparison of stocking as estimated from regeneration plots versus 100 percent tallies by dbh class—four oldest clearcuts, 1977

Percent stocking	Stand no.	Regeneration plots: Two stems over 5 feet: Preferred	Regeneration plots: Two stems over 5 feet: Commercial	100 percent tally: Stocking[a]	Average stand diameter	No. trees/acre: All	No. trees/acre: Preferred	Basal area: All	Basal area: CAPs[b]	Basal area: Red maple	Basal area: All Preferred	Basal area: Beech Birch Hemlock	Basal area: Pin cherry
		Percent			*Inches*			*Sq. ft./acre*					
70-100	105F	67	78	79	1.9	3,060	2,180	63	19	18	37	3	23
	113F	89	89	86	2.7	2,024	1,428	78	20	13	33	1	45
	113UF	100	100	84	3.0	1,892	1,664	92	56	25	81	2	9
	114F	78	89	79	2.3	2,313	1,244	67	16	17	33	18	15
	120F	78	89	86	2.1	2,828	964	69	13	2	15	19	34
	Average	82	89	83	2.4	2,423	1,496	74	25	15	40	9	25
50-70	None												
30-50	114UF	22	44	68	3.0	2,312	280	61	8	15	23	34	1
	112UF	8	46	66	2.8	1,424	196	59	10	1	11	45	3
0-30	105UF	0	0	10	—	108	36	9	0	7	7	2	0
	Average	10	30	48	2.9	932	171	43	6	8	14	27	1

[a] Roach, 1977.

[b] CAPs are black cherry, white ash, and yellow-poplar (nearly all cherry in these stands).

increases the time required to grow trees to merchantable size; and (c) less valuable species composition. Each of these effects may occur in varying degrees.

To provide a measure of the overall impact of deer browsing on Allegheny hardwood timber production, I used the stocking information in Table 3 to estimate the final stocking and species composition and the amount of increase in rotation age for fenced and unfenced portions of the 13 clearcuts.

Without deer browsing, regeneration would become established within 10 years after cutting, so I did not assign a delay in establishment to any stand stocked with at least two commercial stems over 5 feet tall on at least 67 percent of the plots by age 10. Stands not stocked at 10 years of age but stocked at 20 years of age were assigned a 10-year delay. Stands not stocked at the last tally, but showing potential for improvement in stocking (as evidenced by more plots stocked with 5 stems over 3 feet tall and 25 stems total than currently stocked with 2 stems over 5 feet tall) were assigned an additional 10-year delay. In these plots with potential for improvement, final stand stocking was assumed equal to the average proportion of plots now stocked with 5 commercial stems over 3 feet and 25 commercial stems total, and the final percentage of preferred species was assumed to be the same as the percentage of plots that now contain them.

Stands showing no potential for improvement in stocking were assigned final stand stocking equal to the proportion of plots stocked with two commercial stems over 5 feet tall, and final percentage of preferred species was assumed to be the same as the percentage of plots that now contain them. No additional delay in establishment was assigned to stands that did not exhibit potential for improvement.

For example, unfenced stand 104 is only 44 percent stocked at age 9, but shows potential for improvement as evidenced by the larger proportion of plots with 5 stems over 3 feet and 25 stems total. So, it is assigned a 10-year delay in establishment on the assumption that stocking will improve during the next 10-year period. Final stand stocking is estimated to be 84 percent—the average proportion of plots now stocked with 5 commercial stems over 3 feet and 25 commercial stems total. Of the 84 percent of plots thus stocked, 78 percent are also stocked with preferred species; so preferred species composition of the final stand is estimated as 78/84 or 93 percent preferred species. Unfenced stand 114 is also only 44 percent stocked at age 21, but shows no potential for improvement. So, final stand stocking is estimated at 44 percent, and final preferred species composition is estimated by the relative proportion of these plots also stocked with preferred species (22/44 or 50 percent). No delay in establishment is assigned this stand. It has not improved in stocking since age 10 and shows no potential for future improvement. It was "established" within the first 10 years after cutting at an unsatisfactory level. Estimates for all stands are shown in Table 6.

Table 6.—Estimated final preferred species composition, stocking, and delay in establishment

	Fenced			Unfenced		
Stand No.	Preferred species	Stand stocking	Delay	Preferred species	Stand stocking	Delay
	Percent		*Years*	*Percent*		*Years*
101	88	89	0	63	89	0
102	100	22	0	0	22	0
103	84	67	0	0	22	0
104	100	100	0	93	84	10
105	86	78	0	0	0	—
106	75	89	0	89	100	0
107	56	100	0	0	100	0
108	89	100	0	14	78	0
109	100	100	0	67	100	0
110	100	100	0	100	100	0
113	100	89	0	100	100	0
114	88	89	0	50	44	0
120	88	89	0	17	46	0

If areas that regenerate with at least 50 percent preferred species, establish without delay, and achieve at least 67 percent stocking are considered satisfactory, then 92 percent of the fenced areas but only 38 percent of the unfenced areas have regenerated successfully. Of the 62 percent of the stands that failed to regenerate outside the fence, 87 percent regenerated successfully inside the fence. Thus, deer browsing was directly responsible for 87 percent of the failures.

Since browsing can damage advanced seedlings before cutting, and the fences in this study were not erected until after cutting, the failure of regeneration in the one fenced area (stand 102) may also be due, at least in part, to deer browsing. On the other hand, we have now learned that the proportions of failures can be greatly reduced by restricting clearcutting to areas that have abundant advance regeneration and by encouraging the establishment of additional advance seedlings through shelterwood cutting (Marquis and others 1975). Such measures require additional expenditures and cannot be applied on some areas, but will reduce the number of failures if applied where appropriate.

Ground cover vegetation

Deer browsing has affected ground cover vegetation as well as tree regeneration. During the first 10 years after cutting, there was considerably more *Rubus* in the fenced areas than the unfenced ones. *Rubus*, like pin cherry, is browsed preferentially by deer, and often nearly eliminated. As the stands aged and canopies closed, the amount of *Rubus* declined in all stands. But in spite of the greater crown closure on the fenced plots, considerably more *Rubus* remains there than in areas subject to browsing (Table 7).

Fern coverage, on the other hand, was not appreciably different between the fenced and unfenced areas in the early years after cutting (1971), but large differences developed. As the crown canopy closed in the fenced areas, the amount of fern there declined. But in the unfenced areas, both fern and grass increased because browsing continued to prevent crown closure and *Rubus* was reduced (Table 7).

Data from other studies, where fences were erected in clearcuts that had previously failed to regenerate, show that protection from browsing even 10 years after cutting quickly results in the reemergence of *Rubus* and suppression of ferns and grass (Marquis and Grisez 1978). Thus, fern and grass appear to expand primarily in areas where browsing or other factors have prevented the development of tree seedlings and *Rubus* that would normally occupy the site. The abundance of fern and grass on the Allegheny Plateau and the difficulties in obtaining seedling regeneration in the presence of these plants (Horsley 1977a, 1977b) may therefore be an indirect effect of deer browsing.

Table 7.—Percentage of plots with more than 30 percent ground cover

Ground cover	1971		1977*	
	Fenced	Unfenced	Fenced	Unfenced
Rubus	57[a]	39	32*	8
Ferns	23	20	21[a]	36
Grass, sedge	6	20	4*	23

*Differences between fenced and unfenced areas statistically significant at 0.05 level.

[a] Differences between fenced and unfenced areas statistically significant at 0.10 level.

Value of Timber Production Lost Due to Deer

In order to make a crude estimate of the effect of deer browsing on timber production, I developed a multiple regression equation to estimate timber value at maturity (assumed to be 80 years) as a function of species composition. Stand table data from 33 Allegheny hardwood stands ranging in age from 55 to 80 years were projected to a common age of 80 years with a computer stand growth simulator at the Forestry Sciences Laboratory, Warren, Pennsylvania. Board-foot and cubic-foot volumes for these stands were calculated from local volume tables. Stand values (stumpage) were estimated from information on average grade distribution (Ernst and Marquis 1979), with stand value computations following the techniques described by Debald and Mendel (1976). Then, multiple regressions were fitted to the data to predict stand value from species composition and other stand variables.

To estimate stand value, I found that both the percentage of black cherry and the percentage of other preferred species had to be included in the regression. Furthermore, the average diameter of these species groups was important, and it varied due to past cutting practices and other factors. Since I had no way to predict these variables from the regeneration data in this study, I fixed these variables as follows: (a) I assumed that two-thirds of the preferred species were black cherry and one-third were other preferred species, and (b) I set the average black cherry diameter at 18 inches and the average diameter of other species at 12 inches. These diameter values are well within the normal range expected at maturity, and the high proportion of black cherry in the preferred species is consistent with the dominance of black cherry in most third-growth regeneration.

e end result was an equation that permitted me to esti-
te mature stand value as a function of the percentage of
ferred species in the regeneration. Although this equation
i gross oversimplification and could be in considerable
or for any individual stand, it does provide a means of
king an educated guess at stand value. Since the same
iation was used for both fenced and unfenced areas, the
ult should at least reflect relative differences.

e curvilinear equation is:

$$= 40.964 - 6.323X + 0.72624X^2 - 0.0037266X^3$$

ere

= stand value in dollars per acre, at age 80, where black
rry average diameter is 18 inches and other species (ex-
ding saplings) average 12 inches in diameter.

= percentage of final basal area in preferred species.
sume that two-thirds of this is black cherry and the
ance is sugar and red maple.

is equation is used to calculate values for each fenced and
fenced stand with the proportion of preferred species
own in Table 6. These values were then reduced in direct
portion to the amount of understocking or delay in estab-
lment, also shown in Table 6. For example, stands with 89
rcent stocking were reduced in value by 11 percent; stands with a delay of 10 years in establishment were reduced in value by 13 percent (10 years of 80-year rotation). All values are shown in Table 8.

On the basis of these estimates, the average stumpage value of the fenced stands is expected to be $2,177 per acre at maturity, while the value of unfenced stands is expected to be only $1,102 per acre. This represents an average loss of $1,075 per acre for all stands clearcut. If you assume that all stands under even-age management will be harvested and regenerated over an 80-year rotation, the value from timber production would average about $27 per acre per year, while losses from deer damage would amount over $13 per acre per year across the entire Allegheny Plateau. These, of course, are stumpage values. Values of sawed lumber, veneer, furniture, or paneling manufactured from this timber would be several times greater.

The reader is again cautioned that these values are only crude estimates. Furthermore, it is not intended that you use these figures to argue the relative value of timber or deer. Both are extremely important resources and both can be obtained from the same forest area if properly managed. But these estimates illustrate that timber losses due to high deer populations in northern Pennsylvania are very large. Much of this loss could be avoided by a reduction in deer population—and that reduction might be achieved with only a minor impact on Pennsylvania's deer hunting resource.

Table 8. Estimated stand values at 80 years of age, in dollars per acre

tand no.	Fenced			Unfenced		
	Fully stocked	Reduced for stocking	Reduced for delay	Fully stocked	Reduced for stocking	Reduced for delay
101	2,569	2,286	2,286	1,593	1,417	1,417
102	2,944	648	648	41	9	9
103	2,425	1,625	1,625	41	9	9
104	2,944	2,944	2,944	2,737	2,299	2,000
105	2,498	1,948	1,948	41	0	0
106	2,080	1,851	1,851	2,604	2,604	2,604
107	1,310	1,310	1,310	41	41	41
108	2,604	2,604	2,604	85	66	66
109	2,944	2,944	2,944	1,757	1,757	1,757
110	2,944	2,944	2,944	2,944	2,944	2,944
113	2,944	2,620	2,620	2,944	2,944	2,944
114	2,569	2,286	2,286	1,075	473	473
120	2,569	2,286	2,286	125	58	58
verage			2,177			1,102

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Scientific Names of Trees Mentioned in This Report

Common name	*Scientific name*
Sugar maple	*Acer saccharum* Marsh
Red maple	*Acer rubrum* L.
Striped maple	*Acer pensylvanicum* L.
Yellow birch	*Betula alleghaniensis* Britton
Black birch	*Betula lenta* L.
Hickory	*Carya* spp.
Beech	*Fagus gradifolia* Ehrh.
White ash	*Fraxinus americana* L.
Yellow-poplar	*Liriodendron tulipifera* L.
Cucumber-tree	*Magnolia acuminata* L.
Aspen	*Populus gradidentata* Michx. or *Populus tremuloides* Michx.
Black cherry	*Prunus serotina* Ehrh.
Pin cherry	*Prunus pensylvanica* L.
Red oak	*Quercus rubra* L.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.

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Marquis, David A.
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10 p. (USDA For. Serv. Res. Pap. NE-475)

Regeneration surveys in fenced and unfenced portions of thirteen 9- to 22-year-old clearcuts on the Allegheny Plateau of Northwestern Pennsylvania show that deer browsing has resulted in (a) inadequate stocking of tree species, (b) delay in establishment, and (c) less valuable species composition. Ninety-two percent of the fenced areas, but only 38 percent of the unfenced areas, are considered satisfactorily stocked. The value of timber production lost as a result of browsing during the regeneration period is estimated to average $1,075 per acre.

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Keywords: regeneration, deer browsing.

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
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Diameters of Clearcut Openings Influence Central Appalachian Hardwood Stem Development—a 10-Year Study

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Abstract

Appalachian hardwood stands in West Virginia were studied to determine how reproduction establishment and development were influenced by circular clearcut openings of different sizes, postlogging herbicide treatments, and site quality. Ten-year results indicate that circular clearcuts should be at least 1/2 acre to gain the silvicultural effects of larger clearcuts. Smaller openings on both fair and good sites produced adequate numbers of trees, but diversity in species composition was lacking. Herbicide treatments reduced stump sprouting. After 10 years, 15 to 20 percent of the good dominant or codominant trees were of stump-sprout origin where the most intensive herbicide treatment has been used. Without the postlogging treatment, about 40 percent of the good dominant-codominant trees were of stump-sprout origin.

ıtroduction

learcutting is a silviculturally acceptable way of harvesting ›ntral Appalachian hardwood stands. The principal ecologi- ıl justification for clearcutting is that it opens up forest ands to admit sufficient light for reestablishing reproduc- on. Within a few years after clearcutting, harvested areas ıay have 10,000 to 20,000 tolerant and intolerant tree ems greater than 1.0 foot tall per acre.

ith reproduction establishment as one measure of the silvi- ıltural success of clearcutting, researchers have recommend- l different minimum sizes for circular clearcut openings ›pending on species and geographical location (Merz and oyce 1958, Marquis 1965, Minckler and Woerheide 1965, ınder and Clark 1971, Trimble 1973). These research data dicate that in most situations if clearcuts are large enough, ›sirable future reproduction will be established. Although tablishment of reproduction is important, development is ore important. Tree development after a 10-year period the main topic in this paper.

›rest managers using cutting practices to encourage repro- ıction should create conditions for desirable species to ›come established, or for existing desirable advance production to respond. In the Appalachians, if intolerant ecies are desired in the future stand clearcutting is silvi- lturally accepted. However, large clearcuts can be thetically undesirable and offensive to the public regardless their silvicultural effectiveness.

ıis paper reports the results of a study to determine how small clearcuts can be and still obtain desirable species composition and insure good stem development comparable to that obtained with large clearcuts. A second objective of the study was to evaluate herbicide treatments applied to saplings and cut stumps after logging to minimize the influence of sprouts.

Study Area

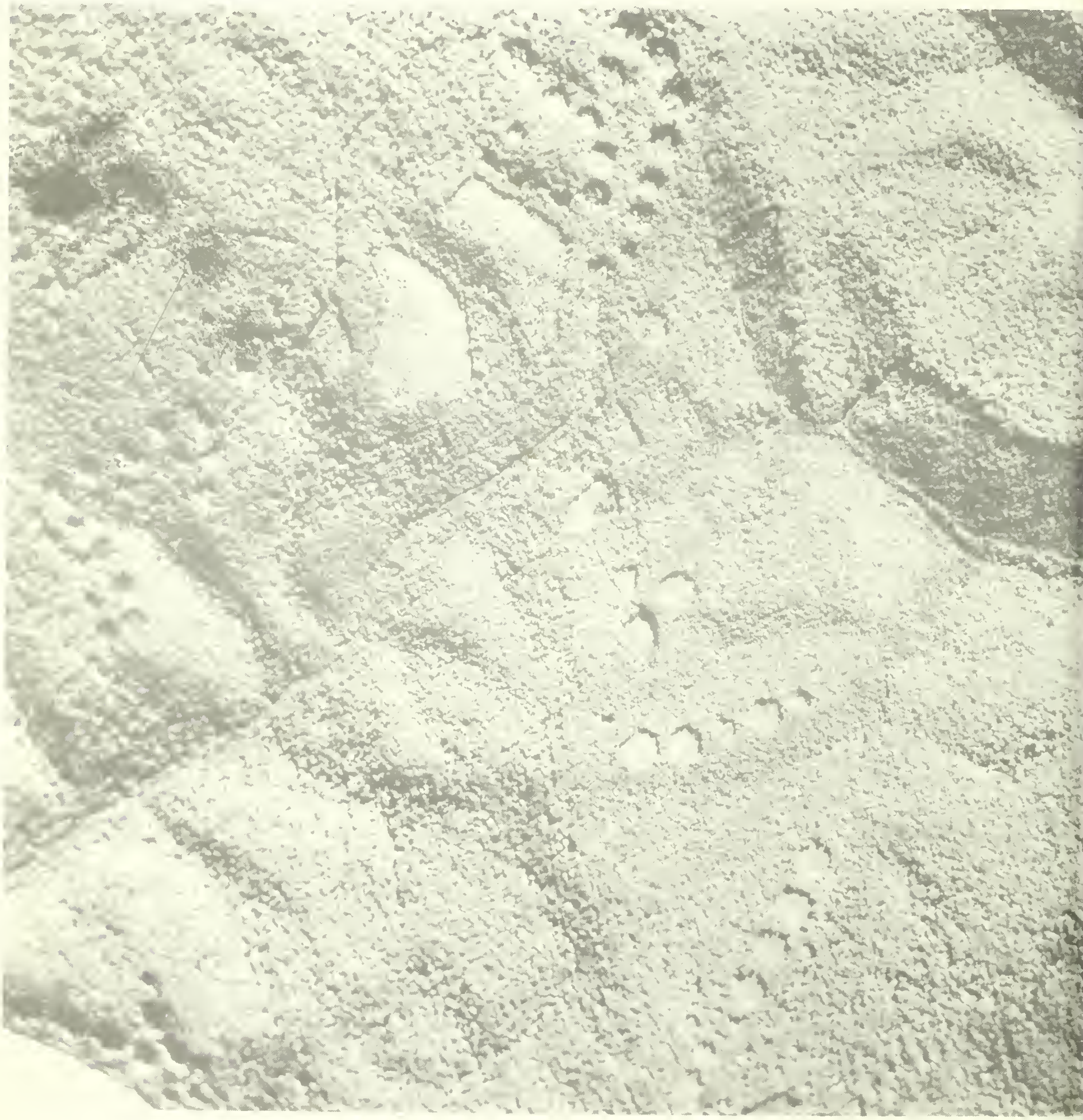
This study was established on the Fernow Experimental Forest near Parsons, West Virginia. Elevation of the study area is 2,300 to 2,500 feet with slopes that vary from flat to very steep (60 percent). Soils were medium textured, well drained, and derived from sandstone and shale. The Experimental Forest has a cool climate with a well distributed annual rainfall of about 60 inches.

From about 1905 to 1910, the study area was logged by highgrading. When the study was installed, the second-growth stands were about 55 years old. The study was done on two oak sites: one with a site index of 75 (good site) and one with a site index of 60 (fair site). The most numerous sawlog-size species on the good sites were sugar maple (*Acer saccharum Marsh.*), yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), black cherry (*Prunus serotina* Ehrh.), basswood (*Tilia americana* L.), hickory (*Carya* spp.), American beech (*Fagus grandifolia* Enrh.), and sweet birch (*Betula lenta* L.). On the fair sites, the main species were chestnut (*Q. prinus* L.), white (*Q. alba* L.) and northern red oak, red maple (*A. rubrum* L.), sweet birch, black gum (*Nyssa sylvatica* Marsh.), sassafras (*Sassafras albidum* (Nutt.) Nees.), and sourwood (*Oxydendrum arboreum* (L.) DC.).

Methods

Circular openings were made in five sizes, 50, 100, 150, 200, and 250 feet in diameter on the good site and 50, 150, and 250 feet in diameter on the fair site (Figure 1). All stems 5.0 inches in diameter at breast height (dbh) and larger were cut and herbicides applied to residual trees 1.0 to 4.9 inches dbh and cut stumps. A total of 72 openings were made; three of each diameter for each of three treatments on both sites, except that no 100- and 200-foot openings were cut on the fair sites (SI 60). This provided three replications of the treatments in each opening size.

Figure 1. Aerial view of some circular clearcut openings. The larger, irregular clearcut areas were not part of this study.



One of three herbicide treatments was applied in each of the three replicated openings:

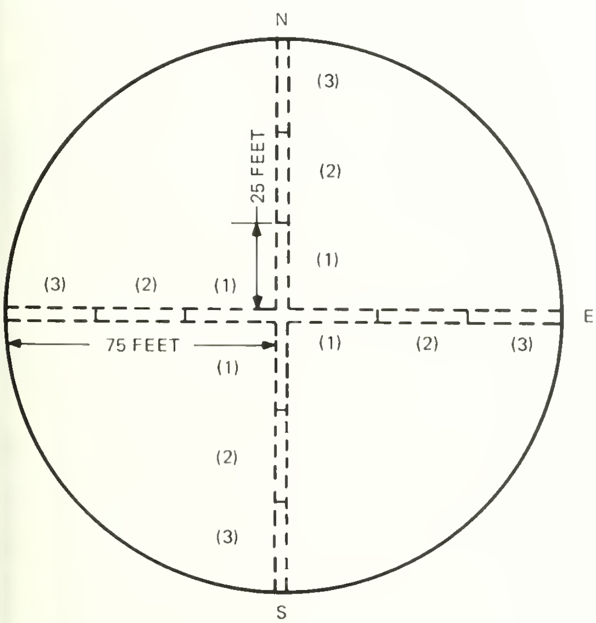
Control	No herbicide treatment.
Moderate	Basal spraying of standing trees.
Intensive	Basal spraying of all cut stumps and standing trees.

The herbicide used for treatment was 2, 4, 5-T[1] in diesel oil mixed at a rate of 16 pounds acid equivalent per 100 gallons.

Ten-year Measurements

Ten years after cutting, all trees 1.0 inch dbh and larger were measured on 25- by 4-foot transects established along radii in the four cardinal directions from the center of each opening. A 50-foot diameter opening had one 25-foot sample strip along each radius or four strips per opening; a 250-foot diameter opening had five 25-foot strips per radius, or 20 strips per opening (Figure 2). Aspect, slope position, and slope percentage were recorded for each opening, but these variables were not evaluated because of the small number of samples in the different categories.

Figure 2. Arrangement of the 25-ft sample strips for a 150-ft diameter opening.



[1] This paper reports research involving herbicides. It does not contain recommendations for their use nor does it imply that the uses discussed here have been registered. All uses of herbicides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Crown class, origin (seedling or sprout—if a tree sprouted from a 2-inch diameter stump or larger, it was considered to be of sprout origin), and stem quality were recorded for each commercial tree species to determine crop tree potential. Tree quality estimates were based on crown vigor, visible bole wounds, and tree form, i.e. straight main stem—no forks, although J-shaped butt origin was allowed. Also trees had to be in a free-to-grow crown class (dominant or codominant). In addition, to be classed as a good sprout, sprout origin had to be less than 6 inches above the groundline at the point of stump attachment.

The number of grapevines originating on a sample transect and the number of trees 1.0 inches or more in dbh with grapevines in their crowns were recorded. No efforts were made to control vine growth during the 10-year study period.

Data were statistically analyzed using multivariant and chi-square analyses. Beacuse the experimental error was impossible to determine and tests were often conducted with nearly a hundred closely related variables, significance was set at the 0.01 probability level.

Results

Immediately after Logging

On the fair sites, the number of 1.0- to 4.9-inch trees averaged about 160 per acre in all control openings (those not treated with herbicides) immediately after logging. The trees were predominantly red maple (95 per acre), oaks (30 per acre), and beech (20 per acre). There were nearly 2,900 stems per acre 1.0 foot tall to 0.9 inch dbh with oaks, sassafras, red maple, and beech accounting for about 85 percent of these stems.

On the good sites, there were about 150 trees 1.0 to 4.9 inches dbh per acre in the control openings. Sugar maple (75 per acre), beech (50 per acre), and red maple (20 per acre) were the predominant species. The average number of stems 1.0 foot to 0.9 inch dbh was 4,220 per acre; sugar maple and beech accounted for 50 percent of these small stems. No data of this type were collected in the herbicide-treated openings because theoretically all of the small trees were killed by the herbicide.

Fair Site (SI 60) After 10 Years

Trees per Acre

Openings of all diameters had 100 or more good quality dominant or codominant trees 1.0 inch or more in dbh per acre. However, the number of stems in each of the three sizes of openings (250-, 150-, and 50-foot) was significantly different from the others. Also, the 150- and 250-foot diameter openings had a greater variety of commercial species. A varied species composition is a major silvicultural objective in management of hardwood stands.

The largest openings had the best stocking of young stems. We found between 250 and 300 good quality dominant or codominant trees per acre in 50-foot openings, 350 to 400 in 150-foot openings, and 450 to 500 in 250-foot openings. The average weighted stand dbh for the good quality dominant or codominant trees for all opening sizes was 2.2 inches dbh, based on an average of 385 trees per acre. The average weighted dbh for each opening size was 1.7 inch (50-foot), 2.6 inches (150-foot), and 2.5 inches (250-foot). However, as expected, the herbicide treatments influenced average dbh. The average weighted dbh values for the good quality dominant or codominant trees on the control openings ranged from 2.2 to 3.2 inches for the 50- to 250-foot openings (Table 1). For the openings treated with moderate herbicide, dbh values ranged from 1.4 to 2.6 inches; and the average dbh of good dominant or codominant trees on the intensively treated openings ranged from 1.5 to 2.0 inches for the 50- to 250-foot openings.

Table 1. Weighted average dbh (in inches) by opening size, herbicide treatment, and site class 10 years after treatment.

Treatment	Opening size				
	50-foot	100-foot	150-foot	200-foot	250-foot
			FAIR SITE (SI 60)		
Control	2.2		3.2		3.0
Moderate	1.4		2.6		2.4
Intensive	1.5		1.9		2.0
			GOOD SITE (SI 75)		
Control	1.6	2.2	2.5	2.8	2.9
Moderate	1.5	1.8	2.0	2.0	2.1
Intensive	1.4	1.8	1.8	1.9	2.2

Regeneration was well distributed throughout the openings. After 10 years, from 50 to 72 percent of the sample transects were stocked with at least one good quality dominant or codominant commercial tree. This percent stocking was consistent for all opening sizes and herbicide treatments. Red maple and sassafras were the most numerous species, averaging about 120 trees per acre per species, and present on about 25 percent of the transects. Red oak, along with some chestnut, white, and scarlet oak (*Q. coccinea* Muenchh.), accounted for about 50 good quality trees per acre; the red and chestnut oaks were found on about 10 percent of the sample transects. About 35 good-quality dominant or codominant beech trees per acre were in the 50-foot openings, but beech was generally absent in 150- and 250-foot openings. Also about 35 black cherry trees per acre were found in the larger 150- and 250-foot herbicide-treated openings. Species variety increased with size of opening. The 50-foot openings contained an average of 6 commerc species per opening, while the 150- and 250-foot openings averaged 10 species per opening.

Postlogging Herbicide Treatment

Herbicide treatments were used to minimize the influence f sprouting. Based on number of good quality dominant or dominant sprouts present 10 years after treatment, the m effective treatment was intensive basal spraying, though d for this treatment were not consistent. For intensive treat ments, the percentage of sprouts differed among the three openings (Table 2); about 15 percent of the good quality dominant or codominant trees in the 50- and 250-foot openings were sprouts, while, for unknown reasons, nearly 50 percent were sprouts in the 150-foot openings. Among the moderate herbicide and control openings, an average of about 35 percent of these trees were of sprout origin. But none of the herbicide treatments consistently resulted in a larger number of good quality dominant or codominant trees for a given opening size, although the moderate and intense herbicide treatments provided more trees than the control.

When considering the total number of sprouts versus seedlings for all trees 1.0 inches and more in dbh, the intensive herb

Table 2. Number per acre of good dominant or co-dominant trees of sprout and seedling origin 1.0 inch or more in dbh, by herbicide treatment, opening, and site class 10 years after treatment.

Opening Size (feet)	Control		Moderate		Intensive	
	Sprouts	All[a]	Sprouts	All	Sprouts	A[illegible]
			FAIR SITE (SI 60)			
50	35	220	110	325	35	2[illegible]
150	170	340	120	375	230	4[illegible]
250	180	460	220	510	80	4[illegible]
			GOOD SITE (SI 75)			
50	35	110	0	180	0	1[illegible]
100	90	345	20	165	55	2[illegible]
150	180	300	75	230	60	3[illegible]
200	255	420	55	410	120	6[illegible]
250	130	405	80	320	60	2[illegible]

[a] All good dominant or codominant trees of seedling and sprout origin.

ide treatment averaged 28 percent sprouting, the moderate reatment 49 percent, and the control had 54 percent trees of prout origin. With the exception of the intensively treated tems on the 150-foot diameter openings, sprouting was ignificantly less after the intensive treatment than after noderate and control treatments. No significant differences vere found between the moderate treatment and the controls. Red maple was the most prolific sprouting species, averaging 3 percent of the total stems sprouting in treated openings, 7 percent for the moderate herbicide treatment, and 36 ercent for the intensive treatment. Also, oak (red, chestnut, nd white) sprouts averaged about 25 percent of the total umber of sprout stems for each of the three cultural reatments.

Good Site (SI 75) After 10 Years

Trees per Acre

tocking on the good sites was similar to that on the fair ites in that all diameter openings had at least 100 good qualy dominant or codominant trees per acre. However, stockng in the 50-foot openings was somewhat marginal in two of he three herbicide treatment categories, averaging only about 10 trees per acre (Table 2).

he 50-foot diameter opening had significantly fewer good ominant or codominant trees than the 100-, 150-, 200-, and 50-foot openings. The numbers of good quality trees in the 00-, 150-, and 250-foot openings were not significantly differnt. The 50- and 100-foot openings averaged 3 to 4 ifferent species per opening, while the 200- and 250-foot penings averaged about 12 different species per opening.

en years after cutting, we found an average of about 125 good uality dominant or codominant trees per acre in the 50-foot penings. Generally, openings 100 feet in diameter or larger ontained from 200 to 400 trees per acre (Figure 3).

he average weighted stand dbh for the good quality domiant or codominant trees for openings of all diameters was 2.0 nches, based on an average of 295 trees per acre. Weighted and dbh values for each opening size were 1.5 (50-foot), 2.0 100-foot), 2.1 (150-foot), 2.2 (200-foot), and 2.5 (250-foot). s expected, trees in the control openings had a higher average bh than those in the openings that had moderate or intensive erbicide treatment. The weighted average dbh values for the ood dominant or codominant trees in the control openings nged from 1.6 to 2.9 inches for the 50- to 250-foot diameter penings (Table 1). Similar dbh values for the openings with oderate herbicide treatment ranged from 1.5 to 2.1 and for ose with intensive herbicide treatment, average dbh ranged om 1.4 to 2.2 for the 50- to 250-foot diameter openings.

or openings of all diameters and herbicide treatments, except e intensive treated 200- and 250-foot openings, sugar maple was consistently the most abundant good quality tree, averaging 100 trees per acre in many instances. Sugar maple was the most abundant species in the 50- to 150-foot openings. Yellow-poplar, sweet birch, and black cherry were numerous, especially in the 200- and 250-foot openings, combining for an average of about 100 good quality dominant or codominant trees per acre. Black locust (*Robinia pseudoacacia* L.) and sassafras were also present in the large openings. Generally, in openings of the same diameter, species composition did not appear to be influenced by herbicide treatment.

From 25 to 33 percent of the sample transects in the 50-foot openings and from 38 to 79 percent of all other openings were stocked with at least one good quality dominant or codominant commercial tree. When all opening sizes and cultural treatments were considered, more than 50 percent of the transects were stocked with at least one good tree. Sugar maple was present in more than 20 percent of the sample transects for all opening sizes and cultural practices—the highest percentage for any species. All other species were in less than 10 percent of the sample plots. Few intolerant species were found in the 50- and 100-foot openings. For the 150-, 200-, and 250-foot openings, good dominant or codominant black cherry occurred in 4 percent and yellow-poplar in 9 percent of the sample strips. Few oak stems were on the good site—few were in the understory to begin with.

Figure 3. Typical stand development 10 years after clearcutting on a good site.

Postlogging Herbicide Treatment

The three herbicide treatments did not have a consistent influence on the number of good quality trees per acre; the control treatment usually resulted in as many good dominant or codominant trees as either of the herbicide treatments, or more. Approximately 20 percent of the good quality dominant or codominant trees in the moderately and intensively treated openings were of sprout origin (Table 2). In the control openings, at least 40 percent of the trees were of sprout origin. The number of good quality sprout-origin trees was most consistent in the intensively treated openings, ranging from 18 to 26 percent, while the control openings were the most variable, ranging from 26 to 61 percent.

To evaluate the effects of herbicide treatments, all sprouts, regardless of stem quality or crown class, were combined. There were significantly fewer sprouts in the intensively treated openings than in the moderately treated or control openings. Also, sprouting was significantly less in the moderately treated than in the control openings. Trees of sprout origin in all sizes of openings totaled 23, 36, and 45 percent respectively for the intensive, moderate, and control treatments.

The most numerous species of sprout origin in the control openings were basswood, red maple, and yellow-poplar, combining for a total of about 60 percent of the good dominant or codominant sprouts in these openings. For openings that had received the intensive treatment, yellow-poplar and sugar maple together averaged about 30 percent of the good dominant or codominant sprouts.

Grapevines

Grapevines severely damage young saplings by deforming the tops, breaking branches, reducing stem quality, and retarding growth (Figure 4); often the trees are killed. Snow or ice storms intensify the grapevine problem.

Grapevines were more of a problem on the better sites and in the larger openings. After 10 years, the major damage was confined to the 150-, 200-, and 250-foot diameter openings on good sites. Grapevines ranged from an estimated 35 to 930 vines per acre in these larger openings, with about 30 percent of the trees 1.0 inch dbh and larger having grapevines in their crowns—occasionally more than 50 percent. In 50- and 100-foot openings, about 6 percent of these trees had grapevines in their crowns. The herbicide treatments did not influence the prevalence of grapevines in the openings. The preference of large grapevine populations in some of the large openings is no doubt partially responsible for differences in number of good quality trees within an opening size class, but the extent of this influence is unknown.

Discussion

In general, for both the fair and good sites, there was an ad quate number of good quality dominant or codominant tre 1.0 inch or more in dbh in all diameter openings and herbici treatments at the 10-year measurement period. However, 1 year-old stands with 100 to 125 good quality dominant or codominant trees per acre may have too few trees for crop tree selection because of species composition and spacing. The major difference among openings occurred in species composition and the variety of species present in the larger 150- to 250-foot openings.

The main purpose of the herbicide 2,4,5-T basal spray on c stumps was to control sprouting. In general, with the exce tion of intensive herbicide treatment in the 150-foot diame openings on SI 60, sprouts were reduced by the intensive herbicide treatment (basal spraying of 1.0- to 4.9-inch dbh stems plus cut stumps) more than by other treatments. Af 10 years, 15 to 20 percent of the good dominant or codom nate trees were of stump-sprout origin in the intensively treated openings; about 40 percent of the stems were of sprout-origin where no herbicide treatments had been used The major sprouting species was red maple, along with bass wood and yellow-poplar. Perhaps a different herbicide wou have been more effective in controlling the sprout vegetati red maple is a difficult species to kill. However, many time sprouts can and do develop into good quality trees (Lamso 1976, Beck 1977, Smith 1979), and the cost of controlling sprouts needs to be considered by forest managers in relati to the results.

As expected, the herbicide cultural treatment did influence average dbh; i.e., the control openings had more good large dominant or codominant trees than the herbicide-treated openings because residual trees in the 1.0- to 4.9-inch dbh class were not cut or herbicided in the control openings.

Predictions based on our study methods and 10-year result indicate that sawtimber-size stands on fair sites will be dom nated by red maple, oaks, and beech in the 50-foot openin The 150- and 250-foot openings will be dominated by red maple, oaks, and sweet birch. Sassafras, though present in large numbers, should rapidly drop out of these stands. On the good sites, sugar maple will probably be the most nume ous tree species in the future sawtimber-size stands in the 5 and 100-foot openings, though there are some good dominan or codominant yellow-poplar, basswood, and beech in the 100-foot openings. In the larger openings, yellow-poplar, black cherry, and sweet birch now dominate, though there are a number of other species. However, in this locale, bircl is questionable as a major component of the sawlog-size stand.

Figure 4. Grapevine damage in young even-aged Appalachian hardwood stands on good site.

Conclusion

Data based on the 10-year results and methods used in this study indicate that openings approximately 150 feet in diameter or larger provide adequate reproduction establishment, variety of species composition, and growth development to resemble large clearcuts. Thus, in this instance, approximately 1/2-acre openings are desirable as the minimum to satisfy silvicultural objectives of even-age management, in Appalachian mixed hardwood stands.

Where controlling stems of sprout origin is the main objective, the most effective study treatment was basal spraying of cut stumps and standing stems with herbicide. Spraying the cut stumps was necessary to reduce sprouting. However, because sprouts often develop into quality stems, the desirability of controlling sprouts in Appalachian hardwood stands can be questioned.

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Appalachian hardwood stands in West Virginia were studied to determine how reproduction establishment and development were influenced by circular clearcut openings of different sizes, postlogging herbicide treatments, and site quality. Ten-year results suggest that circular clearcuts should be at least 1/2 acre to gain the silvicultural effects of larger clearcuts. Smaller openings on both fair and good sites produced adequate numbers of trees, but diversity in species composition was lacking.

232:221.1:181.65:176.1

Keywords: Regeneration, dominant-codominant trees, tree quality, stump sprouts

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Survival, Growth, and Quality of Residual Trees

Following Clearcutting in Allegheny Hardwood Forests

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Abstract

A study of residual saplings and poles left after clearcutting indicates that sugar maple and beech are capable of surviving and growing well after this type of drastic release. Epicormic branches developed on many trees, but those that were free of epicormics before cutting tended to remain free of them after exposure. Residual trees did not interfere with the establishment of intolerant regeneration, but have begun to affect height growth of regeneration 6 years after cutting where the residual density exceeded 10 to 15 square feet (ft^2) of basal area per acre. Good results from residuals are likely only if trees with at least moderately vigorous crowns and clean boles are selected for retention prior to cutting; 30 to 80 such trees per acre should be retained.

merchantable Residuals—Should they be removed?

ost silvicultural guides to clearcutting in eastern hard- oods recommend that all trees down to about 2 inches in ameter at breast height (dbh) be killed or cut following e removal of merchantable stems—no matter how good e unmerchantable trees may look at the time of cutting. eft uncut, it is generally believed that these residuals teriorate in quality and develop into wolf trees that inter- e with the development of desirable regeneration (Leak al. 1969; Roach 1963; Roach and Gingrich 1968).

wever, there is now evidence that this practice—originally escribed for the oak type—is not always advantageous. northern hardwood types that contain valuable tolerant ecies such as sugar maple, it appears that retaining care- ly selected saplings and small poles at the time of final har- t can provide several distinct advantages. Particularly ere tolerants occur in mixture with faster growing intol- nt species, retaining residual trees can allow tolerants to ch mature size at the same time as intolerants. Thus, a w stand is produced that is more nearly even-sized than a ly even-aged one. And this facilitates management.

me Background

e cherry-maple, or Allegheny hardwood, type of northern nnsylvania provides a prime example. Allegheny hard- ods are predominantly second-growth stands that resulted m heavy turn-of-the-century logging in the original beech- ch-maple-hemlock forest. Because the final cuttings were y complete, we usually consider the trees in present stands be all of one age. But this is an oversimplification that con- als some important facts.

e original forests of northwestern Pennsylvania received a ies of partial cuttings during the 1800's that removed white e, hemlock, and the better hardwood sawtimber. These rtial cuts were usually followed by a clearcutting, which moved any remaining sawtimber plus poles and saplings of species for chemical wood (for distillation into charcoal, od alcohol, and other wood chemicals). Although these emical wood cuttings were more nearly complete than ost commercial clearcuts—trees down to 2 or 3 inches dbh re used—they almost always left a number of small sugar ple and beech, many of which had originated from the lier partial cuts. These residuals, plus new regeneration that veloped after cutting, make up the present stands.

reful analyses of present stands reveal that the residuals, ough few in number, have had an important effect on nd development and species composition. Fast-growing generation of intolerant species such as black cherry, white , yellow-poplar, and red maple has caught up with the wer growing tolerant residuals; together they form the in crown canopy. Beneath this main canopy is a second er—almost an understory—of small sugar maple and beech that had been advance seedlings or originated as sprouts at the time of cutting. They were quickly overtopped by the faster growing intolerant regeneration. Almost invariably, sugar maple and beech found in the main crown canopy of cherry-maple stands had a significant head start on the intolerants. If the tolerants started at the same time, they are now relegated to the understory. A more detailed account of the effect of residual saplings left after chemical wood clearcutting is available.[1]

Truly even-aged stands of mixed black cherry and sugar maple are difficult to manage because the cherry matures at about 80 years of age while the maple requires 120 years or more. Clearcutting at age 80 produces a predominance of pulpwood and small logs from the maple; considerable future value that would accrue as the maple grew into large sawtimber size is lost. On the other hand, if the cherry is harvested and the maple retained for an additional 40 years or so, it will be very difficult to regenerate a new stand containing cherry, since the seed source would be gone.

An alternative for future stands is to retain some sapling or small pole-size sugar maple at the time of the regeneration cut; this would provide the maple with a head start over the new black cherry regeneration. This head start would ensure that the residual maples get into the main crown canopy of the next stand where they will grow more rapidly and mature at the same time as the cherry.

Retaining tolerant residuals at the time of the regeneration cut also helps perpetuate these species in the third-growth forest. Because sugar maple is largely confined to the understory in present second-growth Allegheny hardwood stands, seed production and advance regeneration of this species are limited. This, plus preferential deer browsing, tends to eliminate sugar maple and other tolerants from third-growth stands.

Will it work?

The old concerns about residual tree quality and interference with regeneration are still valid. Evidence from present stands suggests that the proportion of cherry is reduced where there were large numbers of residuals after turn-of-the-century chemical wood cuts,[1] but that stand development to commercial size has been more rapid. Most of the residuals left in those early cuttings were 20 to 40 years old, having originated from the prior partial cuts. Similar stems in current second-growth stands are older—usually the same age as the main stand. It is not clear that the older suppressed

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[1] Marquis, David A. Removal of unmerchantable saplings affects the development of regeneration following clearcutting in Allegheny hardwoods. Manuscript submitted to Journal of Forestry, Nov. 18, 1980.

stems in current stands will respond in the same way as the younger stems did.

Further, quality of the residuals left in those early cuttings varies widely. But those trees were not selected for retention; they were left unintentionally or were left because they were too poor to make it worth the effort to cut them. If only good-quality, high-vigor trees were retained, and if their numbers were carefully controlled, it may be possible to grow a good percentage of sawtimber maple and beech without seriously reducing the amount of cherry.

To test this idea, we initiated a study of the survival, growth, and quality of saplings and small pole-size trees retained after final harvest cutting in second-growth Allegheny hardwood stands.

Study Methods

In 1971, a 67-year-old, second-growth cherry-maple stand was clearcut on the Allegheny National Forest as part of its timber management program. The merchantable trees were removed, leaving a variety of unmerchantable residuals. None of these trees had been selected for retention—they were just those small trees that were not knocked down in logging, plus a few larger stems missed or not worth cutting for pulpwood. Because of the wide variety in size, species, and quality, these trees offered an excellent opportunity to study the responses of residuals.

In 1972, sixteen 1/2-acre plots were located within this clearcut. Various treatments representing different residual tree densities were applied to the plots; those that contained more residuals than prescribed were thinned to achieve the desired density and a uniform distribution. Residual stocking levels ranged from 0 to 150 trees per acre and from 0 to 19 square feet (ft^2) of basal area per acre in trees 1 to 9 inches dbh.

All measurements were confined to the central 1/4 acre, leaving the balance as an isolation strip. All residual trees were numbered, and periodic measurements of diameter growth, crown and bole quality, and survival were made over a 5-year period. Regeneration tallies were made on six 0.0026-acre subplots within each plot.

At the beginning of the study, all trees were separated into the following crown and bole condition classes:

Crown condition

A. Crown is average size or larger for tree of that diameter, and foliage is apparently healthy with reasonable density. Tree should survive and grow well.
B. Crown seems adequate for survival and moderate growth, but is small in size with good foliage density, or is average in size with sparse foliage.
C. Crown is definitely small for a tree of that diameter wi foliage so thin and sparse, or so stunted or discolored a to create strong doubt about the tree's survival.

Bole condition

(Disregard minor sweep and small crooks that are not like to affect log grade by the time tree is 16 inches dbh.)

A. Single straight stem for 25 feet or more.
B. Single straight stem for 17 to 24 feet. Strongly forked (two or more apparent leaders) or severe crook betwee 17 and 24 feet from ground.
C. Strong fork or severe crook in first 17 feet, or less than 1 log height.

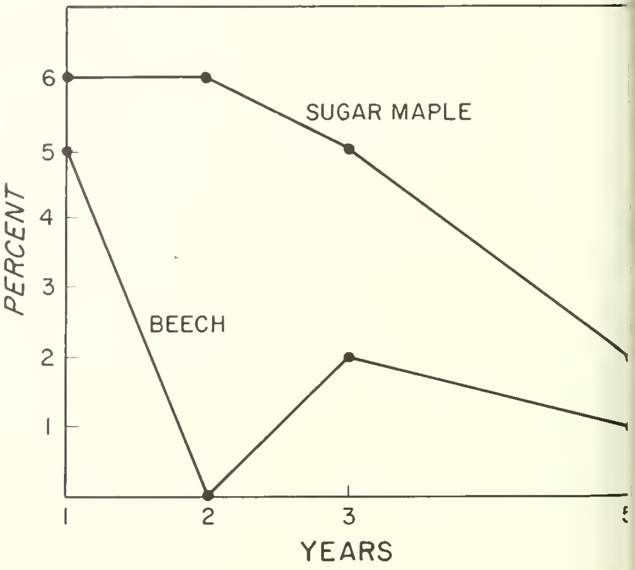
Results and Discussion

Mortality

Over the 5-year period, mortality has amounted to 19 per cent for sugar maple and 8 percent for beech. Mortality was highest during the first few years after cutting, and ha decreased steadily since then (Fig. 1).

Mortality varied significantly by original crown condition class for both species—the larger and more vigorous the crown, the lower the mortality. Mortality did not vary sig nificantly by original dbh, though survival tended to be higher among the larger diameter trees (Table 1). Original diameter and original crown class were interrelated: most the A crown trees were in the larger diameter classes, whil most of the C crown trees were small (1 to 2 inches dbh).

Figure 1.—Mortality of residual trees, in percent.



survival tended to be highest among the larger diameter, ›re vigorous crowned trees. But crown condition is a far ›re important criterion than dbh.

the sugar maples that died, 20 percent were windthrown, percent never releafed after being completely defoliated the saddled prominent *(Heterocampa quitivitta)* the year after cutting, and the balance died from a combination of exposure and defoliation. This maple defoliation was an unusual occurrence that apparently resulted in higher mortality than would otherwise be expected.

Of the beech that died, 55 percent were girdled by porcupine, 33 percent were windthrown, and the balance died from a combination of exposure and logging damage.

All of the mortality that occurred among A crown trees was due to windthrow, porcupine girdling, or insect defoliation—none to exposure. Most (86 percent) of the mortality attributed to exposure was in C crown trees.

Mortality also varied with residual tree density. Mortality was lower in plots with larger numbers of residuals. In plots with less than 5 ft^2 of basal area residual, there was a net loss in basal area and stocking over the 5-year period. In plots with more than 10 ft^2 of residual basal area, growth on surviving trees exceeded losses to mortality, resulting in a net increase in basal area and stocking (Table 2). Apparently, the mutual protection afforded by the larger number of residuals reduced the effects of drastic exposure observed in the completely isolated trees.

The overall average mortality reported here is probably higher than would be obtained in practice, not only because of the insect defoliation on sugar maple, but also because the trees retained in practice would not include those of poor crown vigor such as used in this experiment. I would expect mortality to total less than 10 percent over the first 5 years in actual practice, and decline to less than half that over the next 10 or 15 years, after which it should be nearly zero. Total mortality should average no more than 15 to 25 percent of the trees retained.

able 1.—Mortality of sugar maple and beech ›siduals as affected by original diameter and rown vigor

bh class (ıches)	Crown class A	B	C	All crowns
	Percent			
ıgar maple				
1-3	12	15	29	20
4-6	11	20	44	21
7-9	3	40	33	10
ıl sizes	9	19	36	19
ɜech				
1-3	12	11	17	12
4-6	4	6	0	4
7-9	6	—	—	6
l sizes	6	9	14	8

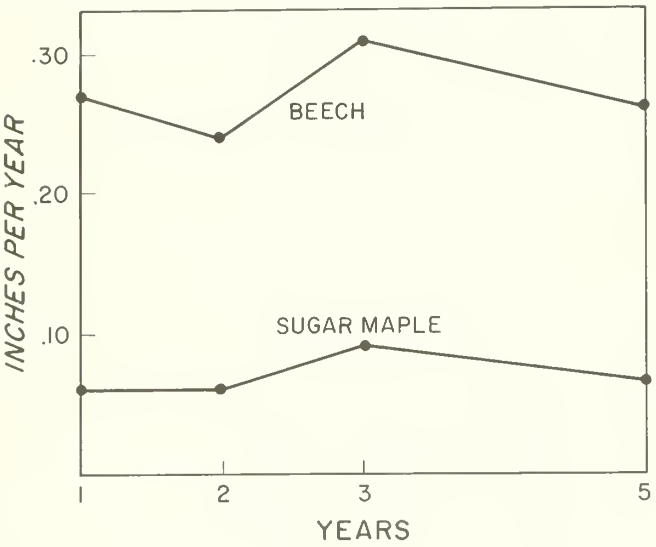
Table 2.—Mortality and stocking as affected by residual density

Original basal area	No. trees per acre		Percent mortality	Basal area			Percent stocking		
	1972	1977		1972	1977	change	1972	1977	change
ft^2/acre				*ft^2/acre*					
0-5	37	29	22	4.4	4.1	-0.3	4	4	-0.4
5-10	78	61	22	8.2	8.6	+0.4	8	8	0
10-15	104	92	12	12.2	14.7	+2.5	12	14	+1.8
15-20	126	113	10	18.1	21.6	+3.5	18	20	+2.6

Growth

Over the 5-year period, diameter growth has amounted to 0.35 inch (0.07 inch per year) for sugar maple and 1.35 inches (0.27 inch per year) for beech. Growth rates have shown no clear trends over time (Fig. 2).

Figure 2.—Diameter growth of survivors, in inches per year.



Growth rates of trees with more vigorous crowns were considerably better than for trees with poor crowns. As in the case of mortality, original crown size or vigor was considerably more important than original dbh, especially for sugar maple (Table 3).

Residual density did not have any consistent effect on the diameter growth of sugar maple, but beech grew somewhat more rapidly at the higher residual densities (Table 4, Fig. 3).

Some trees have grown very rapidly. The fastest growing sugar maple has grown 2.2 inches in 5 years (0.44 inch per year); the fastest growing beech has grown 2.8 inches in that time (0.56 inch per year). These are phenomenal growth rates for previously suppressed trees, most of which are approximately 67 years old—the same age as the previous main stand. Trees 5 inches dbh at the time of clearcutting had averaged only 0.07 inch per year over the previous 67 years; trees 3 inches dbh had averaged only 0.04 inch per year in that time.

Table 3.—Diameter growth of sugar maple and beech residuals as affected by original diameter and crown vigor

Dbh class	Crown class			
(inches)	A	B	C	All crowns
	Inches/5 years			
Sugar maple				
1-3	0.63	0.36	0.26	0.35
4-6	.51	.25	.26	.35
7-9	.39	.11	.10	.35
All sizes	.48	.28	.25	.35
Beech				
1-3	1.41	1.24	.91	1.23
4-6	1.50	1.23	.85	1.37
7-9	1.62	—	—	1.62
All sizes	1.50	1.24	.90	1.35

Table 4.—Diameter growth of residual sugar maple and beech as a function of residual density

Original basal area	Sugar maple	Beech
ft^2/acre	*Inches/5 years*	
0-5	0.30	1.10
5-10	.40	1.10
10-15	.35	1.45
15-20	.30	1.50

Figure 3.—Stand of residual trees 5 years after clearcutting.

Based on the previous 67 years growth rate above, the growth rate of the average beech in this study has quadrupled as a result of release. But the average sugar maple has responded very little. While some of the individual maples have responded quite well (10 percent grew more than 0.20 inch per year), the overall results with maple are puzzling.

Sugar maple has the reputation of responding to release even after some years of suppression. It is usually considered at least equal to beech in this regard. In one report, sugar maple trees 5 to 12 inches dbh left after clearcutting increased in diameter growth from 0.08 to 0.21 inch per year (U.S. Department of Agriculture 1965). Good response has also been reported by Bennett[2] for sugar maple trees left after clearcutting, and understory sugar maple 3 to 6 inches dbh released by early chemical wood clearcuts have grown 0.17 to 0.23 inch per year over a 35-year period since release.[1]

It seems likely that the insect defoliations of maple have influenced their growth in this study, resulting in slow growth that is atypical of maple's usual response. Poor growth and high mortality have been observed in other maple stands throughout the area, apparently a prolonged response to the same defoliations. However, additional experiments will be required to clarify this point.

Extrapolating beyond the data, I have calculated the diameters that residual sugar maple and beech might reach after 80 years—when the cherry regeneration that develops after cutting has matured. If 5-inch diameter trees are left at the time of cutting, they will grow to 11 inches dbh after 80 years if they continue to grow at prerelease rates; or they will grow to 27 inches dbh after 80 years if they grow continuously at the rate shown in this study for beech with A or B vigor crowns at time of release. The actual diameters achieved in 80 years will almost certainly fall between these extremes. Thus, it appears almost certain that residual sugar maple and beech saplings and small poles will grow to sawtimber size in the same time it takes black cherry regeneration to mature.

Tree vigor

Shortly after cutting, many of the residual trees exhibited some dieback in the crowns; this was offset in some trees by the development of new crown and denser foliage. But after 5 years, 30 percent of the surviving residuals still exhibit some important amount of crown dieback. Trees classified in A or B crown classes have decreased from 80 to 58 percent of the total for sugar maple and from 89 to 83 percent for beech.

I expect the surviving trees to eventually develop much larger crowns than they previously possessed, but this has not yet happened and additional time will be required to verify that the residual trees will fully recover from the sudden exposure.

Tree quality

Bole quality was classified both at the beginning of the study, and in 1978, 6 years later. The only major change has been the development of epicormic branches on many trees. Unfortunately, detailed measurements were not made on the numbers of epicormics present at the start of the study. Some notes were made on the field tally sheets of trees that had abundant epicormic branching, but there was no systematic recording of number of epicormics, and many trees that contained small epicormics were not noted.

Observations made in several adjacent uncut areas reveal that small epicormic branches—several inches or less in length and bearing only a few leaves—are common on sugar maple. Well over half the 1- to 8-inch maples in stands such as this study stand often contain such epicormics. When exposed as residual trees, these already present epicormics begin to grow and soon become important sources of future degrade on the bole. In this study, 45 percent of the sugar maple and 27 percent of the beech contained three or more epicormic branches after 6 years.

However, many of these previously suppressed and then fully released trees have few or no epicormic branches after 6 years (Fig. 4, Table 5). Of these epicormic-free trees, none had field notes indicating the presence of epicormics before release. These data, and observations from adjacent thinning studies, suggest that most trees that develop an abundance of epicormics after exposure had small sprouts present before cutting; some—perhaps most—trees that lacked epicormics at the time of cutting remain free of them even after drastic exposure. Unfortunately, verification of this observation will have to await results of other studies now underway where detailed observations were made on epicormics prior to cutting.

Many suppressed beech trees carry small limbs and branches in addition to epicormics on the lower bole, even in tightly closed stands. When these trees are released, the branches survive and grow and the trees look positively hairy. But even in beech, there are exceptions—a few trees are straight and clean, and these seem to remain clean after release. However, our data suggest that the proportion of clean, limb- and epicormic-free beech stems is much lower than the proportion of clean maple stems (Table 5).

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[2] Bennett, A.L. Insurance silviculture for perpetuation of the cherry-hardwood type in Northwestern Pennsylvania. Unpublished talk given at Allegheny Section, Society of American Foresters Winter Meeting, Pittsburgh, Pa., Feb. 7, 1980.

Figure 4.—Single residual sugar maple showing good bole form. This tree had no epicormic branches, and the first live branch was 34 feet above ground at the time of release. Crown size and vigor on this residual is marginal.

Table 5.—Proportion of trees with epicormic branches in first 17 feet and proportion of trees with 8 or 16 feet of clear bole 6 years after cutting

Trees with:	Sugar maple	Beech
	Percent	
0 epicormics	37	56
1-2 epicormics	18	17
3+ epicormics	45	27
8 feet clear bole	24	6
16 feet clear bole	4	1

Perhaps more important than epicormics in determining future quality is the length of bole free of live branches at the time of release. Although too early to tell from this study, it is quite likely that many of the existing live branches will persist after the trees are exposed, so that the length of bole suitable for sawlog material is essentially fixed by the limb-free length at time of release.

Regeneration

There were large initial differences in the amounts of advance regeneration of desirable intolerant species on the 16 study plots, and these initial differences have had a major influence on the amount of regeneration present 5 years later. Therefore, multiple regressions were computed, relating regeneration 6 years after cutting to both residual tree density and number of stems of desirable regeneration present at the start of the study. In this stand, 97 percent of the stems of desirable species were black cherry 6 years after cutting.

Two multiple regression models were run: The independent variable for the first was total number of desirable stems 6 years after cutting, and the independent variable for the second was the percentage of subplots stocked with at least 2 desirable stems over 5 feet tall. The latter criterion is used widely in Allegheny hardwoods as a measure of regeneration stocking—stands with 70 percent of the plots stocked with 2 stems over 5 feet tall after 10 years or so are considered to be satisfactorily established. The r^2 values for the two equations were 0.74 and 0.63, respectively. Both regressions were highly significant.

The resulting regression equations were solved for 0, 5, 10, 15, and 20 ft^2 of residual basal area at an initial regeneration level of 20,000 desirable stems per acre (the average of all plots). This procedure adjusts all plots to the same initial regeneration level, isolating the effect of residual tree density.

A third regression model was run of average regeneration height as a function of residual tree density. No adjustment for initial regeneration level was necessary in the case of height (because height growth was not affected by initial regeneration density). Because of wide variation from plot to plot, the contribution of residual tree density to the equations is often only barely significant, but the results are shown (Table 6) to indicate trends.

There was a tendency to have more stems of regeneration present 6 years after cutting in the plots with heavier residual tree density, but for height growth and stocking (the proportion of subplots with two stems over 5 feet tall) to be less there. Higher residual tree densities are apparently starting to reduce the height of the intolerant regeneration. But shade of these residuals, or perhaps reduced competition among the smaller regeneration, has allowed more stems of regeneration to survive. So it would seem that even the heav[iest] residual density is no handicap—and may be an advantag[e] —in the initial establishment of intolerant species. But after 6 or more years, height growth and stocking of the intolerant regeneration may be affected at the heaviest densities.

Table 6.—Effect of residual tree density on regeneration 6 years after cutting

Basal area	Desirable stems[a]	Plots with two desirables > 5 feet[b]	Height of tallest desirable/plot[c]
ft²/acre	*M/acre*	*Percent*	*Feet*
0	17	50	4.2
5	24	47	3.7
10	30	44	3.2
15	36	41	2.7
20	42	38	2.2

[a]Based on regression Y = 20.126 + 1.2362 BA + 1.8753 OR (r^2 = 0.74, BA term significant at 0.10 level)

[b]Based on regression Y = 18.525 − 0.5761 BA + 1.5856 OR (r^2 = 0.63, BA term not significant)

[c]Based on regression Y = 4.2098 − 0.09878 BA (r^2 = 57, significant at 0.10 level)

In all equations: BA = based area of residual trees in ft^2/ac[re]
OR = original (1972) number desirable stems of regeneration
Y = dependent variable.

Conclusions

Additional time and further experimentation will be needed to provide definitive answers to the questions raised about survival, growth, and quality of residual trees and their effe[ct] on intolerant regeneration. But this study suggests, at least, that the idea may very well prove worthwhile in stands like those of the cherry-maple type.

One conclusion that stands out above all others is that the success of residual trees will depend heavily on the careful selection of trees of good vigor with at least moderately go[od] crowns and with clean, straight boles free of even very smal[l] epicormic branches. Trees of this description in the current study have survived and grown very well, and appear to be maintaining bole quality that will allow their eventual use as sawtimber. It seems imperative that any trees to be retained after clearcutting be selected and clearly marked for retention so that they will not be cut or damaged during logging. The retention of any but the best trees seems clear[ly] undesirable.

Two questions need further examination: a) the growth response of sugar maple that is of the same age and vigor as studied here, but not defoliated or otherwise damaged, and b) the development of epicormic branches on stems that do not have epicormics prior to cutting. Within the past year or two, the Allegheny National Forest began selecting sugar maple and beech for retention in its clearcuts. Detailed observations are now being made on a sample of these trees to provide further experience and data on these questions.

Until better information becomes available, I recommend that those wishing to retain sugar maple and beech residuals select only trees between 3 and 8 inches dbh that have at least a moderately vigorous crown, and a straight bole without low forks, branches, or epicormic branches (not even small ones). Selected trees should have at least 17 feet of limb-free bole, preferably more. Retaining 30 to 80 trees would seem to provide adequate stocking for mutual protection from extreme exposure without affecting early regeneration of intolerant species. Numbers of trees and basal area recommended for retention are shown in the tabulation below for various residual tree average diameters.

Average diameter Inches	*Number of trees No./acre*	*Basal area ft^2/acre*	*Stocking Percent*
3	80	4	5
4	80	7	7
5	65	9	9
6	50	10	9
7	40	11	9
8	30	10	9

In most stands, there will be areas where trees of the size and quality desired are absent. In such areas, it is better to clearcut completely rather than to leave less than desirable residuals. Residual trees should be considered an opportunity where they are present, but one should not become a slave to retention of residuals where stand conditions do not warrant this treatment.

Acknowledgment

Acknowledgment is made to Benjamin A. Roach, who helped set up this study before his death.

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A study of residual saplings and poles left after clearcutting indicates that sugar maple and beech are capable of surviving and growing well after this type of drastic release. Retaining 30 to 80 such trees per acre at the time of clearcutting can provide the head start needed for tolerants to reach mature size at the same time as new intolerant regeneration. This would produce a stand that is more nearly even-sized than a truly even-aged one.

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Keywords: clearcutting, Allegheny hardwood type, regeneration, tree growth, tree quality, age class distribution

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Radial Shakes and "Frost Cracks" in Living Oak Trees

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Abstract

Dissections of hundreds of living, mature oak trees over a 25-year period revealed that radial shakes (or "frost cracks") and ring shakes are associated with a variety of wounds and stubs of branches and basal sprouts. A more intensive study of radial shakes that included dissections of more than 30 oaks confirmed the earlier finds, and provided additional data on radial shakes. Radial shakes were most common in mature oaks that had been wounded, and where basal sprouts died when the dominant tree was less than 20 cm in diameter at 1.4 m aboveground. Radial shakes—frost cracks—are not caused by frost, though frost can be a major factor in their continued development. Radial shakes can be prevented by proper management procedures that minimize basal wounds and by early pruning of branches and basal sprouts.

Auszug

Durch Aufschneiden mehrerer hundert Eichen konnte in Laufe von 25 Jahren festgestellt werden, daß Ring-und Radialrisse im Holz stets mit Wunden verschiedenster A verbunden sind. Die Befunde der nun vorliegenden Unte suchung, die sich auf die Auswertung won über 30 Eich beziehen, bestätigen unde ergänzen die bisherigen Erken tnisse über die Beziehung von Radialrissen zu Wunden. Besonders häufig fanden sich Radialrisse an älteren Bäumen, die vor längerer Zeit eine KambiumVerletzung erlitten hatten, oder die im Jungwuchsalter von absterbenden Stockausschlägen begleitet waren. Durch Verhütung von Rindenschäden sowie durch frühzeitige Beseitigung von überzäligen Stockausschlägen können d Entstehung von Radialrissen und Frostrissen sowie dam verbundene, erhebliche Wertverluste vermieden werden Frost vermag Radialrisse zwar zu intensivieren; er ist jedoch nicht die eigentliche Ursache.

Introduction

Radial shakes are separations along the radical plane in living trees. Some common names are spider heart, ray shakes, and—when they break out to the surface—"frost cracks." Many reports have been published about these defects. Frost or sudden decreases in temperature were given as the cause of frost cracks, hence the term (Caspary 1855; Hartig 1894; Mayer-Wegelin et al. 1962). Yet frost cracks are not caused by frost (Shigo 1972; Phelps et al. 1975; Phelps and McGinnes 1977).

Radial shakes are often associated with ring shakes, which are separations along the circumferential plane of the tree. Ring shakes are often called "wind shakes," implying that they are caused by wind. But ring or wind shakes are not caused by wind.

Ring and radial shakes are associated with a wide variety of wounds—from fire, logging equipment, small and large animals—and with stubs from the basal portion of dead branches and stump sprouts (Shigo 1963; McGinnes et al. 1971; Shigo et al. 1979). The relationship of wounds to "frost cracks" was first observed by Caspary (1855) in Germany. Although his observations were excellent, they have not been accepted, or it may be that they have been overlooked. Research many years later confirmed his observations (Shigo 1963, 1972).

The high value of oaks, *Quercus* spp., for a great number of products necessitates a reevaluation of the causes of internal shakes. A tree with ring and radial shakes cannot be used for veneer. Boards that are cut will fall apart. It is not possible to cut material for turning stock. From an economic standpoint, defects due to shakes can be much more serious than decayed wood. Because decayed wood usually is compartmentalized in trees, high-quality wood can be cut from around the decayed center of a tree. But with radial shakes, the separations, once formed, continue to move outward to the bark. For this reason, radial shakes pose a major problem where high-quality wood is needed.

This paper includes photographs of dissected trees that show the sequence of events that leads to ring and radial shakes. Because much work already has been done that shows the relationship of ring shakes to wounds and stubs (McGinnes et al. 1971; Shigo 1972), this paper will concentrate on radial shakes in several species of oak.

The Problem

The terms used to describe a defect reflect the state of understanding of that defect. Tree pathology is replete with terms that indicate a lack of understanding of many tree defects. Consider the following: mineral stain, wound heartwood, wind shake, red heart, wetwood, brittleheart, spiderheart, frost crack—and the list goes on and on. It is beyond the scope of this paper to elaborate on all the terms and the confusion they cause. Attention here will be given to the term frost crack which implies that frost causes the crack, and that, because frost is a natural phenomenon beyond the regulation of foresters, defects due to frost cracks must be accepted. This type of thinking is a major reason why so little has been done to prevent or minimize the damage caused by many internal defects. When the correct cause of a defect is understood, proper management decisions can be made to deal with the problem. So it is with radial shakes, or frost cracks. They can be prevented—and they are *not* initiated by frost.

The Oaks

The value of the oaks depends on many factors, but one of the most important is the amount of defect-free wood on the stem. The major defects in oaks are knots, decayed wood, and the ring and radial shakes. Radial shakes appear to be more common on oaks than on other tree species (Shigo 1971).

Oaks, like other trees, are highly compartmented plants that compartmentalize or wall off injured and infected wood associated with wounds (McGinnes et al. 1977; Shigo and Marx 1977; Shigo 1979). By this essential and effective process, defects are confined within the diameter of the tree at the time of wounding, or at the time the branch dies. This means that a defect is not so important if it is restricted to a small volume in the center of the tree. Thus, tree managers, buyers, and the wood industry benefit because quality wood can be obtained from trees with some decayed wood.

For example, if a tree is wounded severely when it is 10 cm in diameter, the worst that can happen is that a 10-cm core of defect will develop. The decayed wood caused by fungi will not spread to the growth rings that form after wounding, even in heartwood (Shigo and Shortle 1979), because after wounding the cambium forms a distinctly different tissue called the "barrier zone" (Sharon 1973; Moore 1978; Mulhern et al. 1979; Tippett and Shigo 1980, 1981).

The barrier zone is a very strong protection against further infection, but it is also a plane of structural weakness, because it has a different anatomical and chemical makeup from normal wood. When internal stresses caused by rapid temperature changes or wind occur near the barrier zone, the wood may separate tangentially and longitudinally along the barrier zone, which results in a ring shake (McGinnes et al. 1977). The ring shake could trigger separations along the radial plane, and radial separations may develop from the inside of the stem outward to the bark. When any stress causes the radial separations to break out to the bark, an obvious external seam or crack results. Surface vertical cracks also may develop above and below wounds or stubs when temperatures drop rapidly. The wounds and stubs interrupt the continuous circumferential surface of the trunk; should any stress—such as frost—occur, the bark will crack along the weakest point. Such cracks seldom penetrate deeply into the wood. Again, wounds and stubs serve as the initiating point for such cracks. Radial shakes are especially damaging because the separations can continue for the life of the tree. Once a radial shake is formed, the tree has no system to compartmentalize it.

Dissections of Trees

Twenty-five white oaks, *Quercus alba* L., and red oaks, *Quercus rubra* L., with obvious basal radial shakes or frost cracks were dissected with a chainsaw in southern Maine. Seven chestnut oaks, *Quercus montana* Willd., with similar defects were dissected in Connecticut. The trees ranged in size from 15 to 40 cm and in age from 40 to 150 years. In addition to the tree dissections, sections were cut for study from the stumps of more than 10 larger oak trees recently cut for fuelwood. Three trees with obviously old, dead basal sprouts were dug out and dissected. Information from dissections of hundreds of other oak trees over a 25-year period also is included in this paper (Shigo 1971).

Many dissections of the trunks were made to reveal the wound and to trace the extent of the shakes. Selected samples were smoothed with a power sander to help reveal details of the shakes. The observations were made immediately after the trees were dissected, and before drying complicated the pattern of the shakes. A photographic record was made of selected samples.

Observations

All radial shakes were associated with wounds, branch stubs, or basal sprout stubs, and with ring shakes at some point in the trunk. Most of the shakes in the Maine trees were associated with wounds that occurred during the serious fire of October 1947. Mechanical wounds inflicted during salvage operations several years after the fire were the starting point of some of the shakes. The initial radial shake started above the wounds as the callus closed the wound. Secondary radial shakes started at the points where the first callus tissue formed at the margins of the wound. Additional radial shakes developed outward from the barrier zone that formed after wounding.

Ring and radial shakes associated with dead basal sprouts started at the base of the trunk. In some trunks this point was belowground. The radial shakes appeared as multiple dark radiating lines from the pith when viewed on the cut stump approximately 30 cm aboveground.

Most of the shakes were associated with wounds on small trees less than 20 cm in diameter at 1.4 m aboveground. Wounds on larger trees usually did not develop into shakes.

The triangular shape of fire wounds seemed to enhance the start of radial shakes as the upper pointed tip set the direction for the wood separations. This occurred after the callus began to close the wound.

Wounds with a blunt or rounded upper margin did not serve as the starting point for the radial shakes. The radial shakes were obvious as dark radiating lines in the heartwood. The lines followed the multicellular large rays common to the oaks. When the radial shakes broke out to the bark, the tree responded by forming new callus to close the wound. It was not possible to establish with certainty the factor or factors responsible for the movement of the radial shakes outward to the bark, or the factor or factors responsible for the periodic reopening of the shakes. Stresses due to normal growth processes, to rapid changes in temperatures, to water content, or to movement due to wind all could play a part in the development of a vertical seam.

In some trunks, the closed callus tissues indicated that the shakes stayed closed for several years, only to reopen at a later time. That the trees were in areas where temperatures in winter can decrease overnight from above 0°C to -20°C does make such changes highly suspect as the major cause of the continued development of the cracks after they are formed in the tree from wounds and stubs. In this sense, frost *does* play a role but only as the factor responsible for the *continuation* of the crack. If the radial shake had not first been "preset" in the tree, no crack would have developed no matter how severe the frost.

The observations and patterns of radial shake formation given here are not restricted to North America. Many mature oaks dissected recently in West Germany showed similar patterns.

ummary and Recommendation

'ounds and stubs—not frost—initiate radial shakes. But once arted in the tree, the shakes may persist for the life of the ee because of stresses caused by many factors; in temper-.e regions, frost is a major factor. Radial shakes have been bserved by Shigo in teak, growing in Puerto Rico and in any species of eucalypts growing in Australia. In these eas, frost seldom, if ever, occurs. But in these species, the idial shakes were mostly internal, and did not break out to ie bark until subjected to felling stress or drying. The large rotruding bulges commonly associated with radial cracks on ak were not seen on teak and only on a few eucalypts.

he large vertical bulges or invaginated seams on oak do indi-ite a recurring stress. Because teak and ecualypts are sub-ct to stresses associated with wind and growth, as are oaks, it not to frost, it does appear that frost is the major factor sponsible for the continuation of the vertical crack, and for ie splitting outward of the secondary cracks. In some trees ie secondary cracks may be more obvious and prominent ian the primary crack associated with the wound or stub. 'hen such a tree is dissected, it may be difficult to accept iat the crack started from a wound or stub.

cannot be emphasized enough that if the shakes are not reset due to wounds and stubs, stress factors due to growth, ind, and frost have little or no part in the development of ie crack. Knowing this makes it possible to prevent radial iakes or frost cracks by minimizing wounds, and by proper id early pruning of branches and basal sprouts. The elite ee or dominant tree in a clump should be selected as early ; possible, and all other sprouts should be cut. Even before iis, management procedures should favor single stems from eds, rather than single stems from the sprout clumps. Much eater care must be taken not to wound trees, especially iring logging operations. In the past, the young, rapidly owing tree was thought to be the tree best suited for re-ponding to wounds. This is true where compartmentaliza-on of discolored and decayed wood is concerned, but not hen radial shakes are considered. Thus, greater care must be ven to the young growing stock. They should not be con-dered so tough that nothing will harm them. Yes, they will irvive the wounds and shakes, but survival of a tree with any internal defects is not in the best interest of forestry.

ogging operators must be made aware of the serious damage iat can result from seemingly minor wounds. Special atten-on must be given to young trees that receive many basal ounds, or wounds with pointed tips. Trees with such ounds should be removed as soon as possible. Trees with ovious vertical cracks also should be removed as soon as ossible.

Radial shakes, like many internal defects in trees, can be prevented or minimized, or recognized early so that the trees can be removed. How effectively this is done depends on how well the causes of the defects are understood.

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Acknowledgments

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igure 1.—Small radiating cracks normally form at the ends of oak logs as they dry. This ying pattern is typical of oaks that had no major wounds or preset radial shakes associated with wounds and stubs of basal sprouts. Note the large prominent rays that are pical of oaks. Oaks A and D have central columns of compartmentalized discolored eartwood (arrows), while oaks B and C have clear heartwood except for very small olumns in the center.

b. 1.–Kleine, radial verlaufende Risse auf der Hirnfläche von Stammabschnitten sind typisch d "normal" für holz, das langsam austrocknet. Derartige Trockenrisse entstehen auch an ndholz, das keine schwerwiegenden Wunden oder basale Fäsale Fäulestellen aufzuweisen hat. Die chenabschnitte A und D besitzen ein durch Kompartimentierung hervorgerufenes, verfärbtes rnholz (Pfeile), wogegen die Abschnitte B und C einen nur kleinen Anteil natürlichen Kernlzes aufweisen.

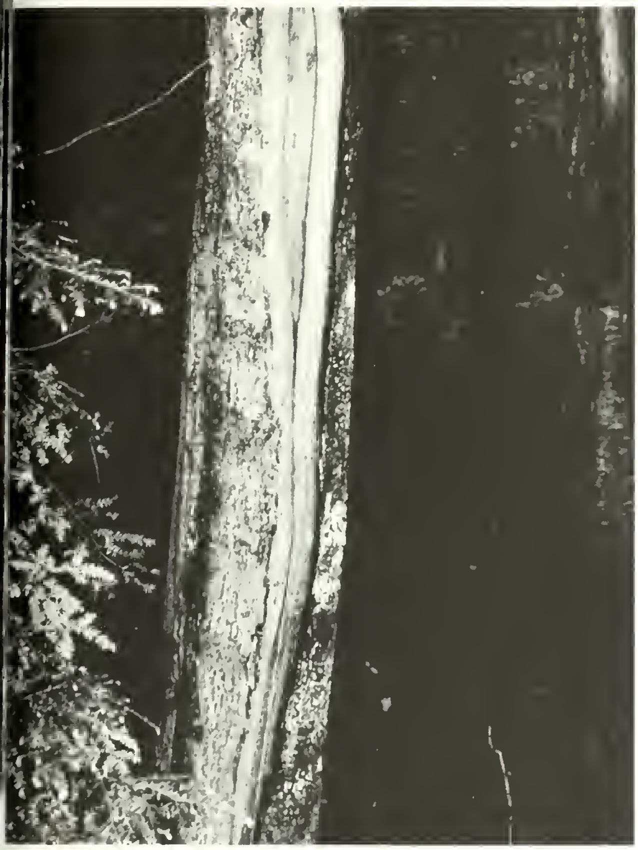
Figure 2.—Basal wounds on oaks are major starting points for radial shakes. Wounds on young, rapidly growing trees are most likley to lead to internal shakes.

Abb. 2. – Langgestreckte Radialfugen am Stamm sind häufig das Ergebnis einer erfolgreichen "Wundheilung". Solche Wundnähte können allerdings nach vollständiger Überwallung wieder aufreißen und dann als "Frostrisse" in Erscheinung treten.

Figure 3.—Wounds on large trees that seldom close during the life of the tree usually do not lead to internal shakes. Wounds with blunt or rounded upper margins seldom lead to internal shakes.

Abb. 3. – Bei einer Verwundung von älteren Bäumen bleibt eine Rißbildung meist aus, besonders dann, wenn die Wunde noch nicht verschlossen ist. Auch Wunden, deren Wundränder stumpf bzw. abgerundet sind, geben selten Anlaß zu Rißbildungen.

ure 4.—Vertical shallow wounds close as
v wood forms at the sides. This closure
cess initiates internal cracks which may
n many years later. A perfect example of
closure process is shown on this white
. The same process occurs on oaks.



ob. 4.–Längs am Stamm verlaufende,
erflächliche Verwundungen werden vom Baum
eist rasch durch Bildung neuen Holzes über-
llt. Bei diesem Prozeß entstehen nicht selten
dialfugen, die später immer wieder aufreißen
nnen. Im vorliegenden Fall handelt es sich um
ne Weiß-Esche; der gleiche Vorgang kann aber
ch bei der Eiche beobachtet werden.

Figure 5.—After the callus closes the wound, frost or other stress factors may cause the internal, preset radial shake to break out to the bark. The tree responds by closing that wound again with more callus. When this sequence is repeated over many years, a ribbed, swollen, vertical bulge will develop. Often, the bulge will form above the primary wound site, which is at the base of this red oak. This is a major defect.

Abb. 5.–Nach vollständiger Überwallung der Wunde können Frost oder andere Streßfaktoren den im Innern noch vorhandenen Spalt dazu veranlassen, wieder aufzureißen. Der Baum antwortet daraufhin mit erneuter Kallusbildung, so daß sich die Wunde wieder schließt. Wenn sich dieses Wechselspiel mehrere Jahre hintereinander wierderholt, kommt es am Stamm zur Ausbildung rippenartiger, vertikal verlaufender Anschwellungen ("Frostleisten").

Figure 6.—Secondary internal shakes often split out to the bark and multiple swollen ribs result when the closure process is repeated for many years.

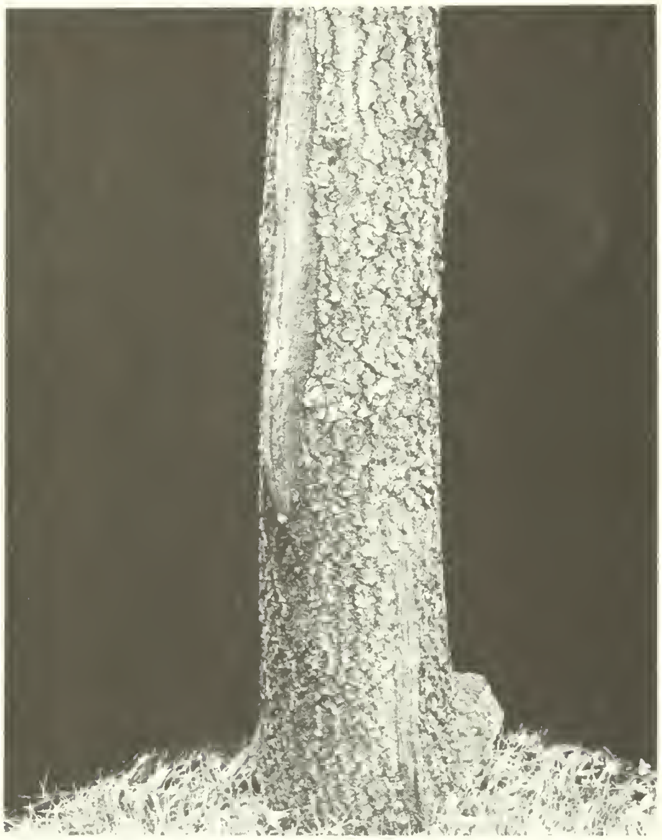


Abb. 6. – Mehrere "Frostleisten" an einem Stamm haben oft den gleichen Ausgangspunkt, auch wenn sie in verschiedener Höhe und auf verschiedenen Seiten des Stammes liegen. Auf dem hier wiedergegebenen Foto erkennt man zwei "Frostleisten", die mit einem faulholzigen Stubben (unten rechts) eines ehemaligen Sproßausschlages in ursächlichem Zusammenhang stehen.

Figure 7.—This chestnut oak shows the relationship of the two "frost cracks" and the basal stub (below right) of an old, decayed sprout.

Abb. 7. – Auch im vorliegenden Fall einer kastanienblättrigen Eiche konnte ein Zusammenhang zwischen den beiden "Frostleisten" bzw. den damit verbundenen Radialrissen im Innern des holzes mit dem Stubben eines Stockausschlages (unten rechts) nachgewiesen werden.

Figure 8.—The swollen rib on this white oak is in a direct line with the primary crack that formed after a 33-year-old fire wound closed.

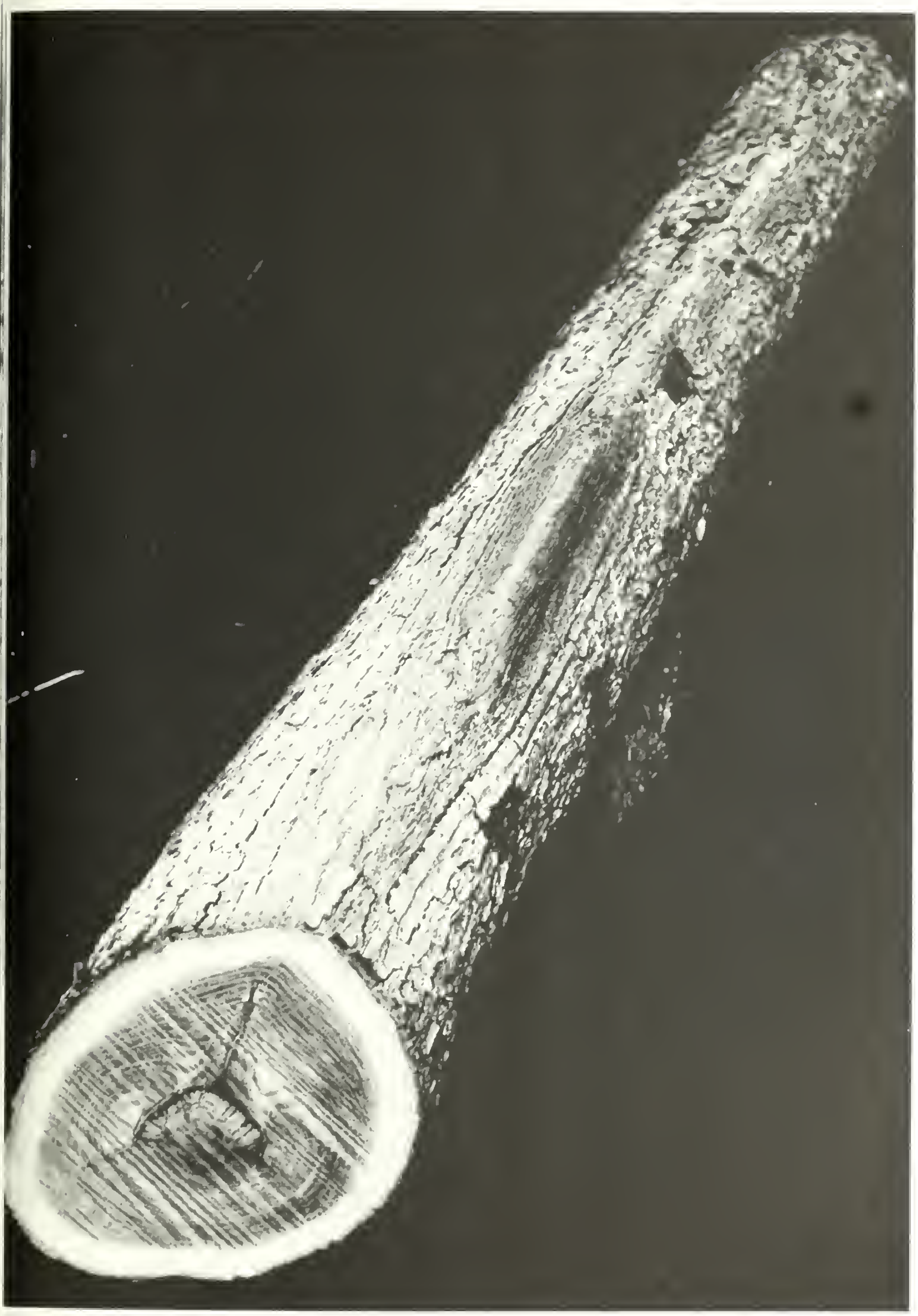


Abb. 8.–Das Bild zeigt deutlich die Verbindung einer beulenartigen Wundleiste mit einer älteren Kambium-Verletzung im Stamminnern bzw. mit dem davon ausgehenden primären Radialriß. Die Wunde entstand vor 33 Jahren durch Einwirkung eines Bodenfeuers.

Figure 9.—The decayed wood in this white oak is well compartmentalized within the wood present at the time of wounding. The primary shake is well established. Two secondary shakes (arrows) have split out to the bark. This tree had multiple cracks or swollen ribs.

Abb. 9.—Auch das Bild dieser Weiß-Eiche zeigt die Verbindung einer vor längerer Zeit entstandenen Wunde mit der Ausbildung eines Radialrisses, der auf der Stammoberfläche als schmale, schwarze Linie erkennbar ist. Weitere kleinere Risse sind auf der gegenüberliegenden Seite der ehemaligen Wunde entstanden, von denen zwei die Rinde bereits erreicht haben (Pfeile). Beachte die zentral gelegene Fäule, die vom Baum erfolgreich kompartimentiert worden ist.

Figure 10.—When small wounds close on trees, a vertical seam forms where the callus tissues meet (arrows). When no additional stress from frost or drying is inflicted on such a tree, the seam will stay closed and constitute only a minor defect. Note the compartmentalized discolored heartwood associated with the wound.

Abb. 10. – Wird eine größere Wunde vom Baum überwallt, so bilden sich meist von beiden Seiten Überwallungswülste, die sich zunächst nur berühren (Pfeile). Die Wunde ist geschlossen, wenn wieder ein völlig durchgehender Jahrring vorhanden ist. Soweit kein Frost oder Trockenstreß auf einen solchen Baum einwirken, bleibt die Wunde geschlossen. Beachte die im Wundbereich aufgetretene Holzverfärbung, die als Anwort (Kompartimentierung) des Baumes auf eine Verwundung aufzufassen ist.

Figure 11.—Small trees wounded at the base are especially vulnerable to radial shakes. On this small white oak, the primary radial shake developed after the callus closed the wound (large arrow). Secondary shakes developed where the callus began to form over the wounds (small arrows). Decayed wood associated with the wound was confined to the wood present at the time of wounding.

Abb. 11.–Jüngere Bäume, die an der Basis verwundet werden, sind für die Entstehung von Radialrissen besonders anfällig. Bei der hier abgebildeten Weiß-Eiche hat sich ein primärer Radialriß gebildet, lange nachdem sich die Wunde schon geschlossen hatte (großer Pfeil). Typisch für größere Wunden sind auch die beiden sekundären Radialrisse (Kleine pfeile), die sich vom ehemaligen Wundrand in das Holz hineinschieben. Die Holzfäule im Stammzentrum (hell) beschränkt sich auf denjeniegen Teil des Holzes, der zur Zeit der Verwundung vorhanden war. Eine weitere Ausdehnung der Fäule auf das neugebildete Holz findet in der Regel nicht statt.

igure 12.—A cross section of a swollen rib in this white oak indicates that the shake ;arted after the wound closed. Note the included bark (large arrow). The shake split pen several years later and the callus began to inroll again (small arrow).

Abb. 12. – Die Entwicklungsgeschichte dieses Stammes läßt zunächst auf einen erheblichen, den ıalben Stamm umfassenden Kambium-Schaden schließen, der vor 33 Jahren durch Feuereinwirkung enstanden ist. Durch starke Kallusbildung hat sich die Wunde bald geschlossen, erkennbar an den ehemals durchgehenden Jahrringen. (Beachte die durch große Pfeile angedeuteten, eingeschlossenen Rindenreste.) Einige Jahre später ist die Wundstelle besonders weit aufgeplatzt, erkennbar an dem dort eingerollten Jahrring. Auch in den darauffolgenden Jahren hat sich die Rißbildung weiter fortgesetzt.

Figure 13.—The primary shake may split again to form bifurcate cracks; or multiple cracks may develop. This tree will only become more defective as it grows older. Such trees should be cut as soon as possible.

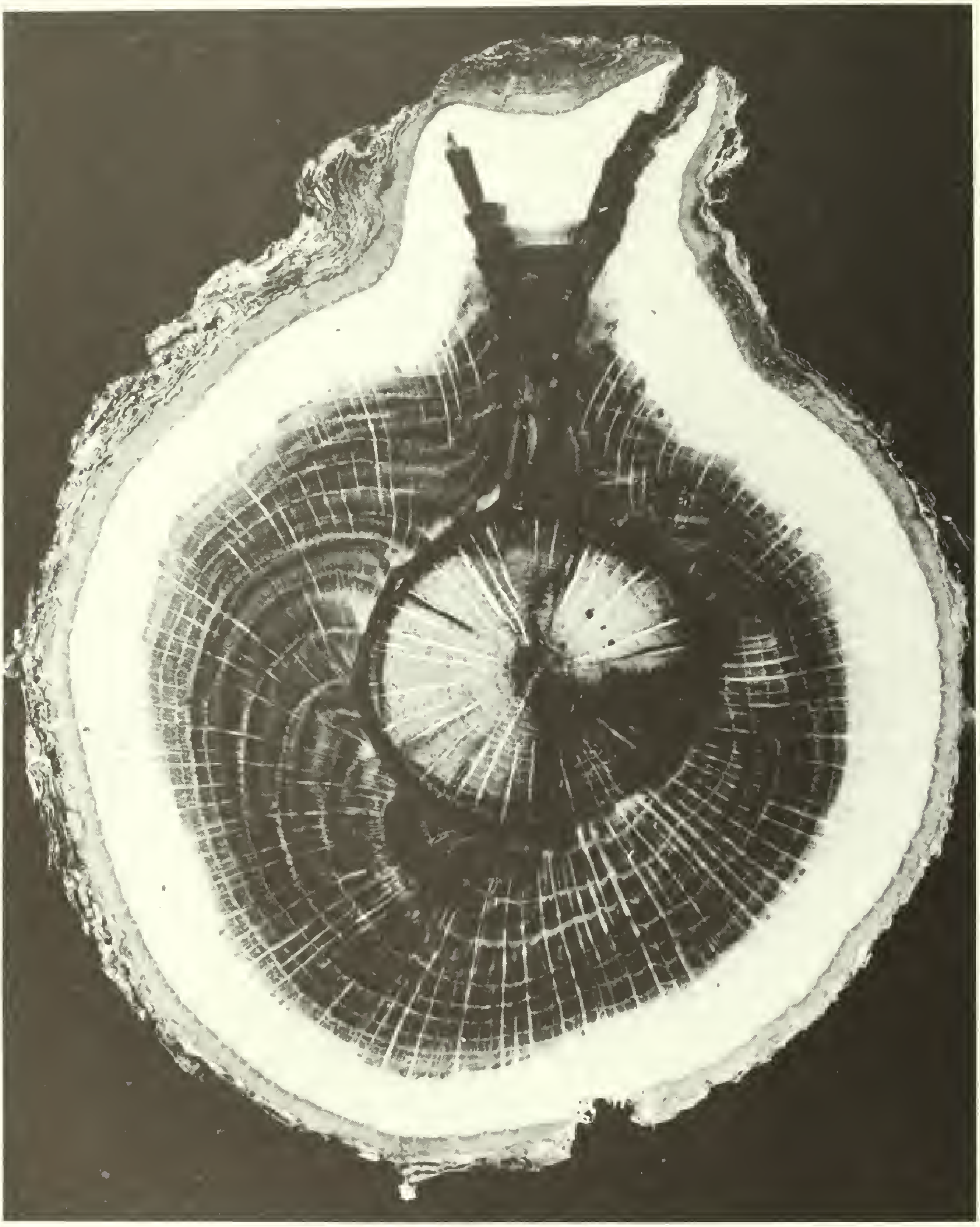


Abb. 13.–Nicht selten verzweigt sich der primäre Riß zu einem gabelförmigen Gebilde. Der hierdurch entstehende Schaden vergrößert sich in dem Maße, wie der Baum an Alter zunimmt. Solche Eichen, die bereits mehrere "Frostleisten" aufweisen, sollten möglichst bald geschlagen werden. Ein Wertzuwachs ist hier kaum mehr zu erwarten.

igure 14.—Many small radial shakes often start from wounds. It is not known why they tart from some wounds and not others. Some of the shakes in this sample have split out o the bark. Note the curved primary shake that opened wide after the sample dried.

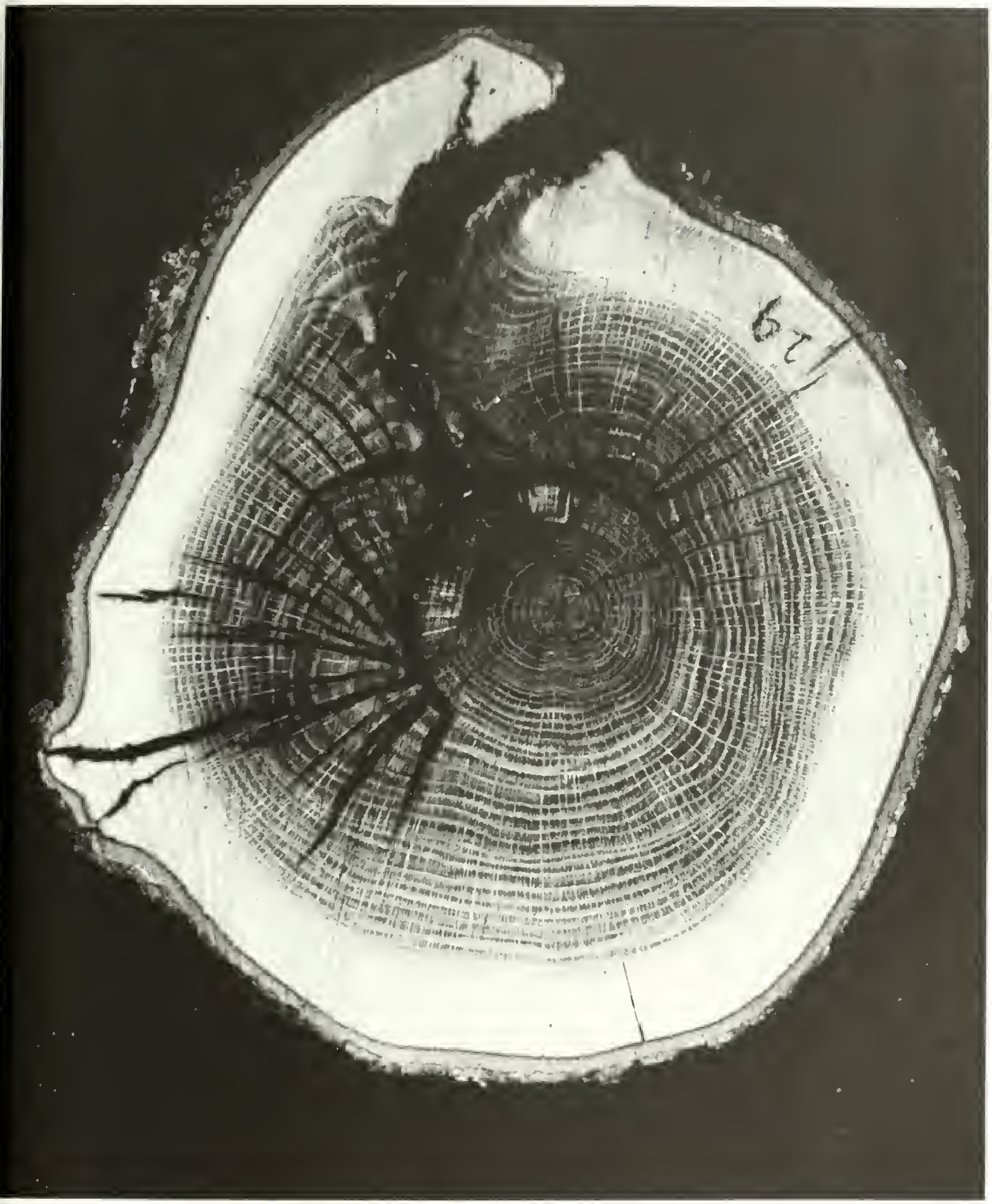


Abb. 14.–Unter bestimmten, bisher unbekannten Voraussetzungen können zahlreiche, kleinere Radialrisse entstehen. Auch diese nehmen ihren Ausgangspunkt stets von ehemaligen Wunden. Aus dem Verlauf der Risse kann man erkennen, daß einige bereits den Rindenmantel durchbrochen haben und damit zu “Frostrissen” geworden sind. Beachte den hier gebogenen, primären Radialriß, der sich durch Austrocknung des Holzes allerdings stark verbreitert hat.

Figure 15.—This white oak had two major wounding periods. The first wounds were inflicted when the tree was less than 4 cm in diameter (small arrows). Many secondary shakes and one obvious primary shake resulted from the injury. Small radial shakes developed later in the life of the tree when several small wounds were inflicted (large arrows).

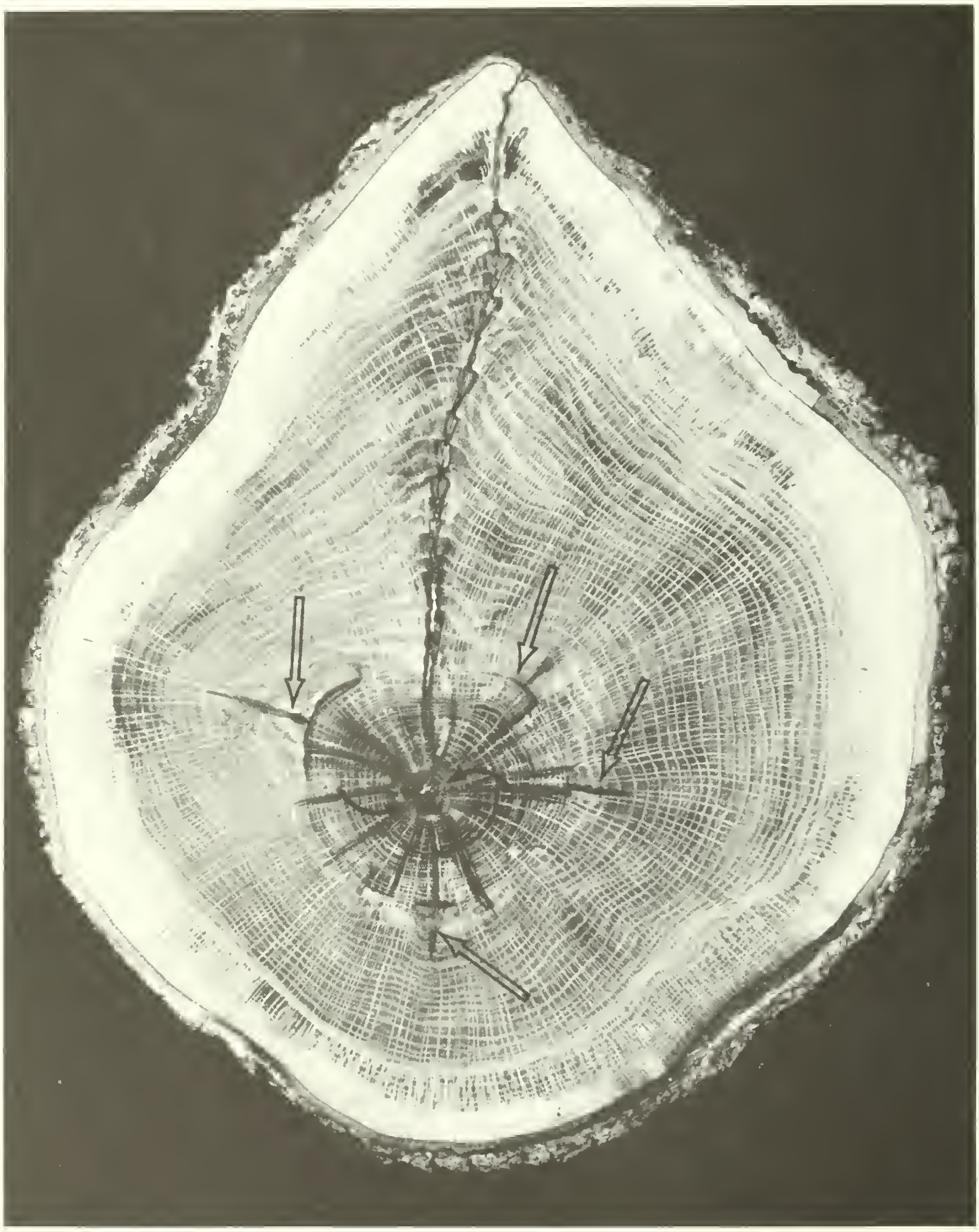


Abb. 15. – Der Querschnitt durch eine ca. 70jährige Weiß-Eiche zeigt zwei bedeutende Verwundungsperioden: Die erste Verletzung erlitt der baum, als er einen Stammdurchmesser von weniger als 4 cm besaß (kleine Pfeile). Die Folgen dieser Verwundungen sind zahlreiche, kleine Spaltén sowie ein großer Primär-Riß, der bereits die Stammoberfläche erreicht hat. Weitere kleinere Radialrisse sind zu einem späteren Zeitpunkt entstanden, als der Baum erneut mehrmals verwundet wurde (große Pfeile).

igure 16.—Radial shakes that appear to start at the pith in this section actually start ightly out from the pith. This section came from a tree with multiple basal stubs.

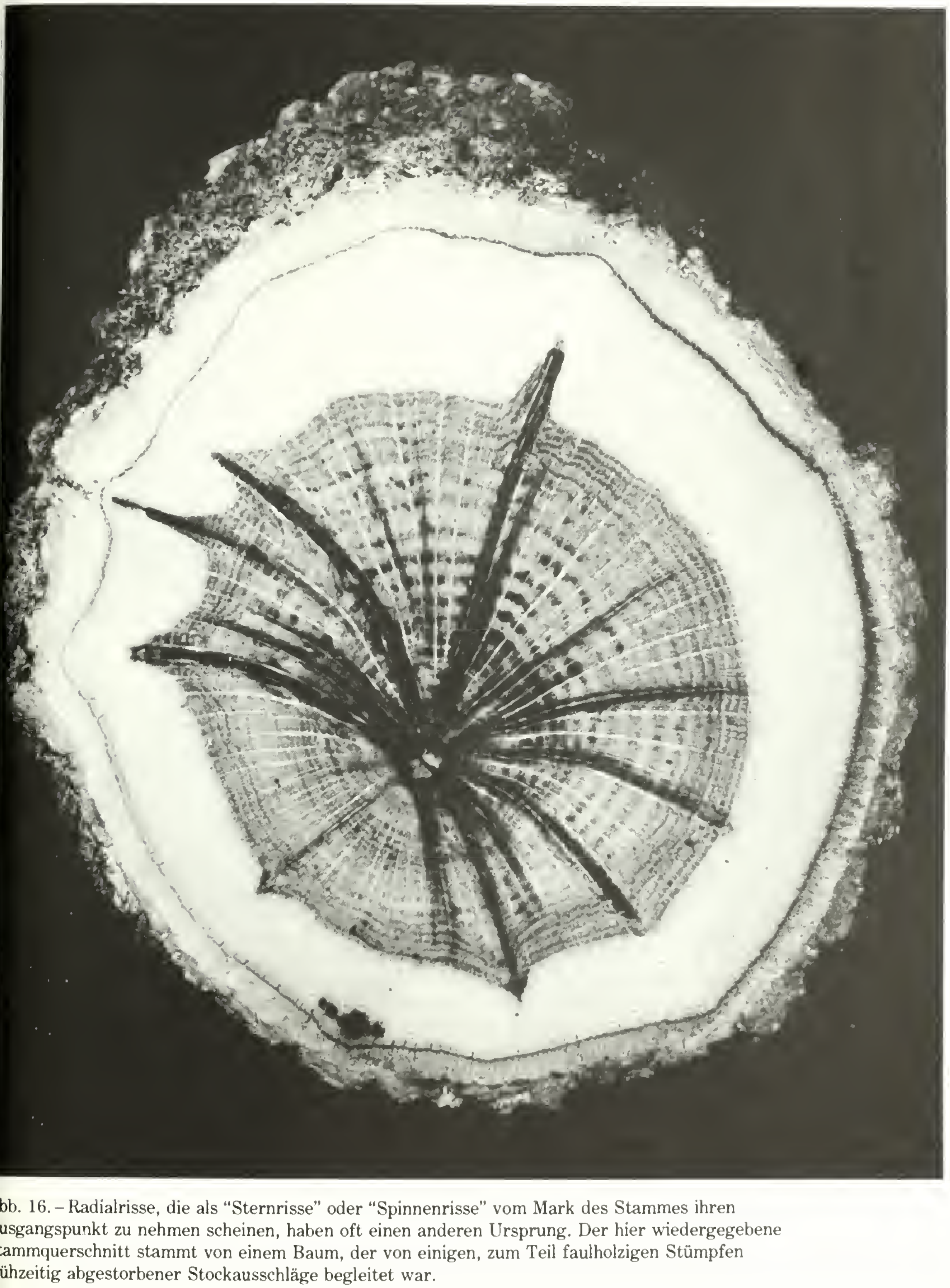


Abb. 16. – Radialrisse, die als "Sternrisse" oder "Spinnenrisse" vom Mark des Stammes ihren Ausgangspunkt zu nehmen scheinen, haben oft einen anderen Ursprung. Der hier wiedergegebene Stammquerschnitt stammt von einem Baum, der von einigen, zum Teil faulholzigen Stümpfen frühzeitig abgestorbener Stockausschläge begleitet war.

Figure 17.—This red oak was cut below ground level to show the multiple radial shakes associated with two basal wounds when the tree was less than 8 cm in diameter. Some of the shakes developed into mulitple ones (arrows).

Abb. 17. – Wird bei sternrissigen Eichen der Sägeschnitt tief genug geführt, so kann auch der eigentliche Ausgangspunkt der Radialrisse erkannt werden. Im vorliegenden Fall gehen die Risse von zwei basalen Wunden aus, die entstanden, als der Baum einen Durchmesser von 8 cm hatte. Einige der Risse zeigen eine Aufspaltung in ein Bündel weiterer Strahlenrisse (Pfeile).

igure 18.—When crosscuts are made at stump height, it often appears that the shakes merge from the pith.

Abb. 18.—Wird der Sägeschnitt zu hoch oder zu tief ausgeführt, verfehlt man oft den eigentlichen Ursprungsort der Radialrisse. So scheinen die Sternrisse im vorliegenden Fall im Mark des Stammes entstanden zu sein (vergl. Abb. 19).

Figure 19.—Dissecting the tree in Figure 11 farther downward revealed that a decayed central core associated with all dead basal stubs was the starting point for the shakes.

Abb. 19.–Ein tief am Wurzelanlauf angesetzter Sägeschnitt zeigt schließlich den eigentlichen Ursprungsort der Radialrisse. Als Ausgangspunkt erkennt man eine zentral gelegene Fäulestelle, die wiederum selbst mit den Resten ehemaliger Stockausschläge in Verbindung steht.

ure 20.—A radial shake associated with an old, dead sprout stub. The radial crack on
inner side occurred after the sample was dried.

Abb. 20.—Radialrisse können ihren Ausgangspunkt auch von eingewachsenen Totästen aus
nehmen. (Der Spalt auf der Innenseite des Astloches entstand nach der Trocknung der
Baumscheibe.)

Butin. Heinz, and Alex L. Shigo.
1981. Radial shakes and "frost cracks" in living oak trees.
Northeast For. Exp. Stn., Broomall, Pa.
21 p., illus. (USDA For. Serv. Res. Pap. NE-478)

Dissections of hundreds of living, mature oak trees over a 25-year period revealed that radial shakes (or "frost cracks") and ring shakes are associated with a variety of wounds and stubs of branches and basal sprouts. A more intensive study of radial shakes that included dissections of more than 30 oaks confirmed earlier findings, and provided additional data on radial shakes. Radial shakes were most common in mature oaks that had been wounded, and where basal sprouts died when the dominant tree was less than 20 cm in diameter at 1.4 m aboveground. Radial shakes—frost cracks—are not caused by frost, though frost can be a major factor in their continued development. Radial shakes can be prevented by proper management procedures that minimize basal wounds and by early pruning of branches and basal sprouts.

416.5

Keywords: Compartmentalization; ring shakes; barrier zones; frost cracks; radial shakes

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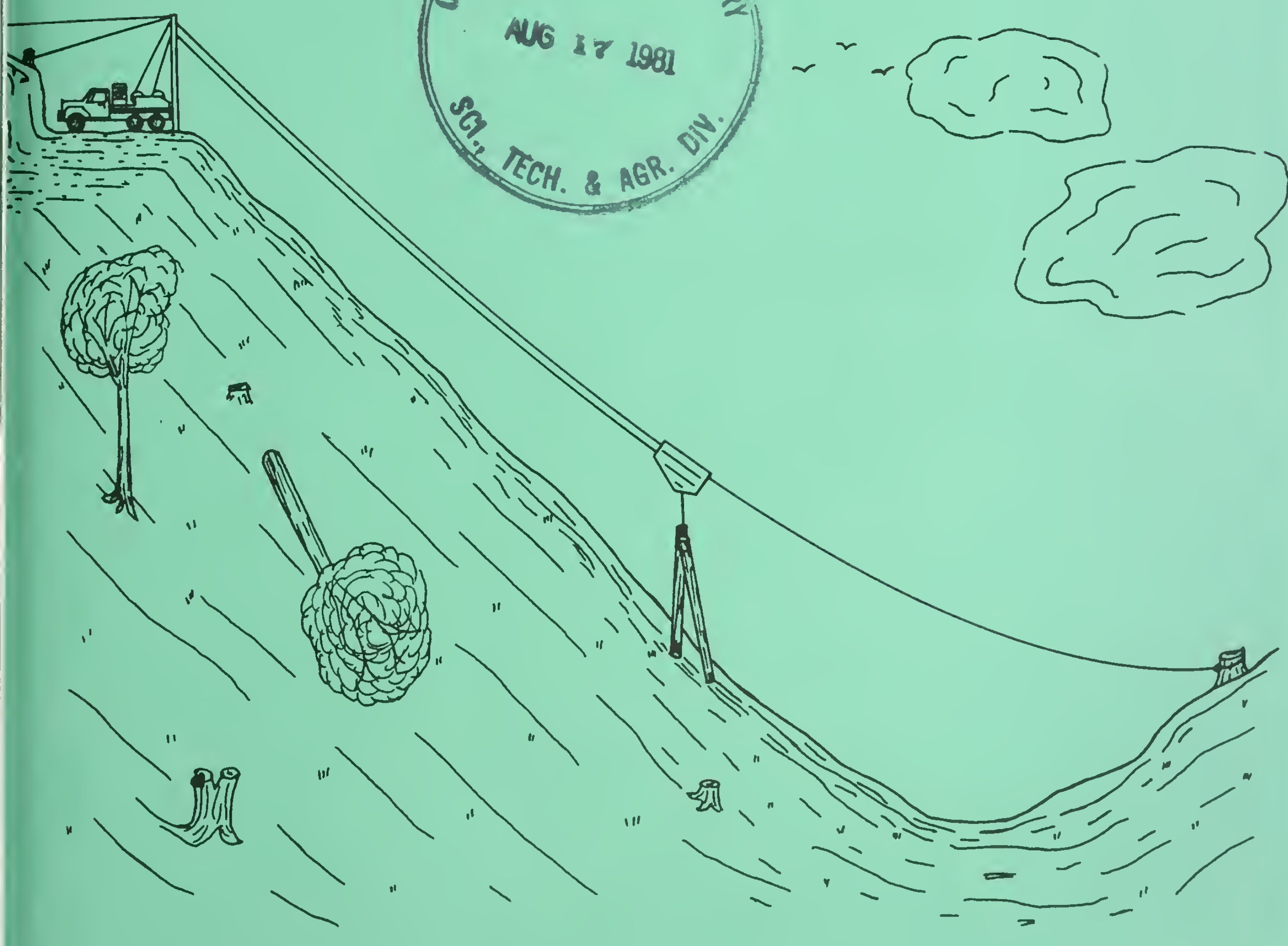
1981

Predicting the Payload Capability of Cable Logging Systems Including the Effect of Partial Suspension

by Gary D. Falk



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Abstract

A systematic procedure for predicting the payload capability of running, live, and standing skylines is presented. Three hand-held calculator programs are used to predict payload capability that includes the effect of partial suspension. The programs allow for predictions for downhill yarding and for yarding away from the yarder. The equations and basic principles involved in analyzing skyline systems for allowable payload are presented.

Predicting the Payload Capability of Cable Logging Systems Including the Effect of Partial Suspension

ontents

Several tools are available for predicting the payload capability of cable logging systems. Hand-held calculator programs (Binkley and Sessions, undated) are among the tools that are capable of yielding the most reliable results with less effort than other hand methods. However, no systematic approach or procedure has been documented for using these programs, which can be followed with relative ease by someone unfamiliar with cable systems mechanics, as there has been for the chain and board method (Lysons and Mann, 1967). Therefore, hand-held calculator programs to determine payload capability are not effectively used by field personnel.

Furthermore, existing programs are based on the assumption that the logs are fully suspended, while actual yarding conditions usually involve partial suspension. The traditional way to account for the effect of partial suspension is to increase the fully suspended payload by a "conservative" 50 percent (Binkley and Sessions, undated). The actual ratio of a partially suspended payload capability to a fully suspended payload capability can range from about 0.5 to 3.5. There are methods to calculate an approximate ratio when the amount of suspension is known, but because the amount of suspension is a function of several variables and not easily determined, these methods of predicting payload capability are not as realistic as they should be, nor are they always conservative.

This paper presents a systematic procedure for predicting the payload capability for the most common skyline yarding systems, by the use of three hand-held calculator programs, that include effect of partial suspension. Because the procedures for predicting the payload capability can be confusing, whether or not partial suspension is considered, the basic principles are also expalined. As a result, the user can better understand the purpose of each step of the procedure and increase the effectiveness of this as well as other methods of predicting payload capability.

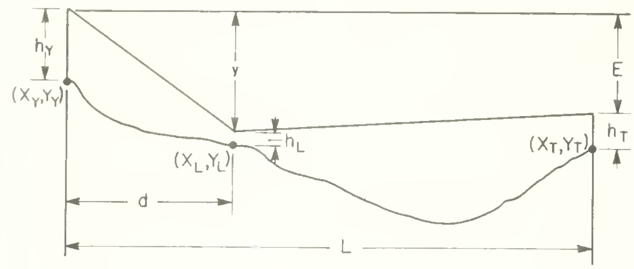
These programs use mathematical formulas based on assumptions that are similar to the so-called "rigid link" (Carson 1976). These formulas have been simplified and extended so that the effects of partial suspension may be included directly. Appendix 4 lists the simplifying assumptions made and the equations used in each of the programs. Because it is not always easy to know when a mainline or haulback is required when partial suspension is considered, the option of a haulback line on live and standing skylines is included. The yarder is assumed to be positioned on the left with stationing increasing toward the right. In addition, the carriage is assumed to be the type in which the mainline is used either to bring the turn to the carriage or to maintain carriage position while the load is brought into position for inhaul.

Description of Variables

The load-carrying capability of a cable logging system depends not only on the size and strength of the cables, but also on the angles at which the cable tensions act at the carriage. These angles depend on the system geometry, which may be thought of as consisting of two parts: the cable geometry which accounts for the deflection, and the log geometry which accounts for the amount of suspension. Regardless of the systems being analyzed, the system geometry must be specified before the payload capability can be determined.

The cable geometry (Fig. 1) is described in two ways. Normally, it is described by the locations of the yarder, tailhold and carriage in terms of X and Y coordinates, and their appropriate heights. These are reduced to the variables L, E, d, and y for the actual calculations. However, when L, E, d, and y are known they may be used directly.

Figure 1.—Cable geometry.

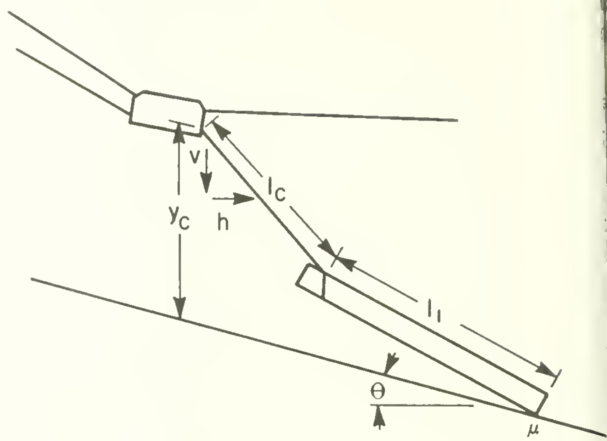


X_Y, Y_Y = X & Y coordinates of yarder spor
X_T, Y_T = X & Y coordinotes of toilhold
X_L, Y_L = X & Y coordinotes of lood point
h_Y, h_T, h_L = Heights of yorder, tailhold, & load clearance
L = Horizontal distonce--yorder to toilhold
E = Verticol distance--yorder to toilhold
d = Horizontol distonce--yorder to lood point
y = Vertical distonce--yorder to load point

The log geometry (Fig. 2) is specified by the friction coefficient, the log and choker lengths, the ground slope, and the carriage clearance. These five variables are used to calculate the partial suspension load factors, v and h, which express the proportion of log weight that is transferred to the carriage as vertical and horizontal force components. For full suspension, v equals 1 and h equals 0.

These diagrams show that as the position of the carriage changes, the cable and the log geometry also change. This results in a different payload capability for each carriage position. In other words, the cable tensions resulting from a given size and weight log will vary as the carriage is moved along the skyline. Generally, the skyline tension is greater when the load is in the middle of the span, and the mainlir or haulback tension is greater when the load is near one en of the span. Because this is a general statement, the payloa capability for each line should be calculated for several car riage positions.

Figure 2.—Log geometry.

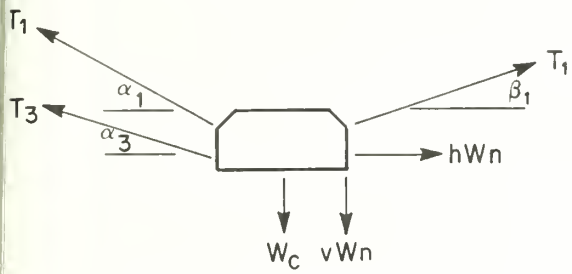


μ = Friction coefficient
l_l = Length of log
l_c = Length of choker
θ = Ground slope
y_c = Carriage clearance
v = Vertical load factor
h = Horizontal load factor

The payload capability for a particular carriage position is determined by the analysis of a free-body diagram of the ca riage. Figure 3 shows a typical free body for a skyline syste with a mainline. The actual forces that act at the carriage d pend on the system being analyzed and whether a mainline or haulback is needed to maintain log stability.

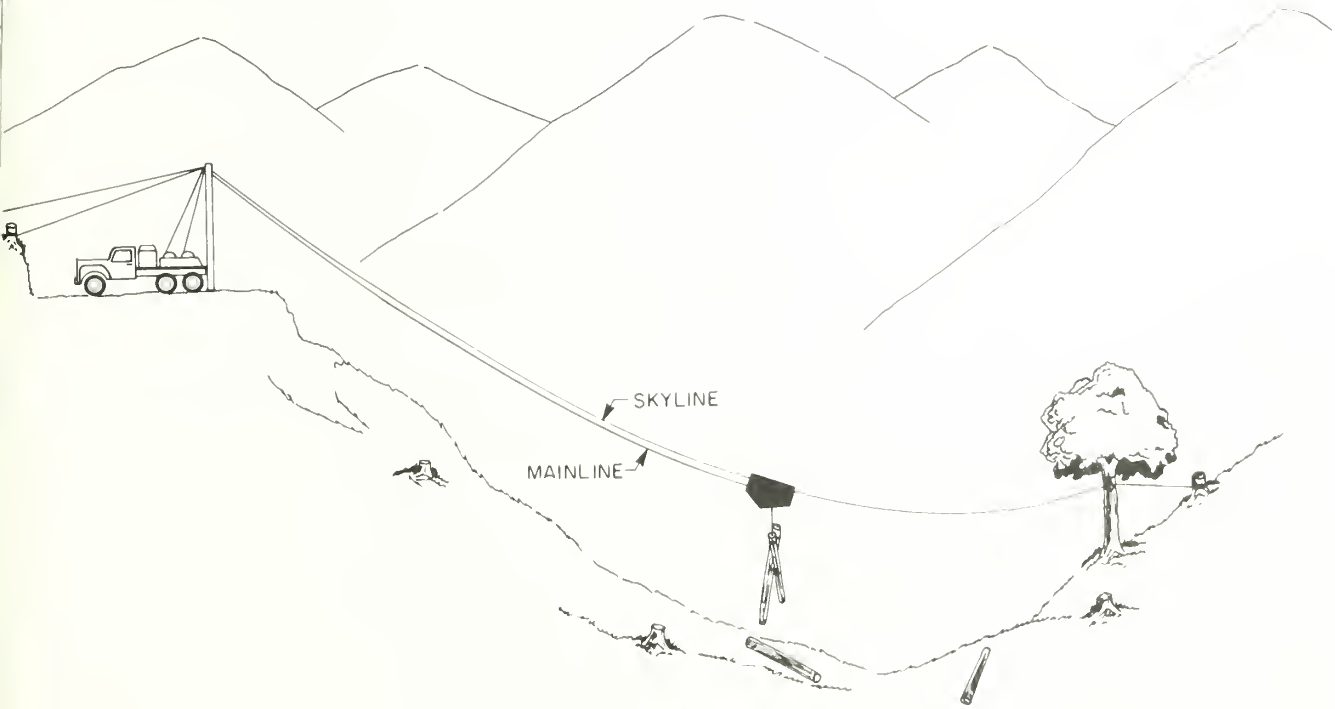
The major difficulty in the analyses and the programs that follow is understanding the geometry. When it is known ho the cable geometry changes for the different systems and how this affects the log geometry and associated load facto the analyses become straightforward. As an aid to understanding this concept, each major skyline system (live, running, and standing) in the text is discussed separately and in order of increasing complexity, even though there are similarities among them. After these systems are discussed and mples are given, methods of using these programs for er yarding configurations are presented.

ure 3.—Free body of carriage.



T_1 = Tension in skyline
T_3 = Tension in mainline
α_1 = Line of action of skyline to left of carriage
α_3 = Line of action of mainline
β_1 = Line of action of skyline to right of carriage
W_c = Carriage weight
vWn = Vertical component due to net payload
hWn = Horizontal component due to net payload

gure 4.—Live skyline configuration.



The reader should become familiar with these concepts by working the example problems in the appendices before proceeding to the example problems for the different systems.

Live Skyline

Figure 4 depicts a typical live skyline. For convenience, the system is shown with only a mainline although a haulback may be required. The program considers either case. As discussed here, a live skyline is one in which the length of the skyline is actually varied as the log turn is brought toward the landing. If the skyline length is not varied, then, even though it is traditionally classified as a live skyline, it should be analyzed as a standing skyline. This distinction is important because it determines the cable geometry.

Cable Geometry

Since the skyline length varies as the load is brought toward the landing, the load clearance (h_L) is considered to be held constant for each carriage position. Figure 5 traces the carriage at each point along the skyline corridor. The geometry is described by specifying the coordinates and heights of the yarder spar and tailhold, and then specifying each load point in terms of its coordinates and the constant load clearance.

Log Geometry

Since the load clearance, h_L, of the cable geometry remains constant, the carriage height, y_c, also remains constant. For most carriages these two clearances can be taken as the same ($h_L = y_c$), and this assumption is made throughout these discussions and in the programs. However, for very large carriages, the more exact relationship given by equation 1 may be used.

$$h_L = y_c + d_s \qquad (1)$$

where d_s = distance separating the skyline and the mainline (or choker) at the carriage. For the live skyline then, the only log geometry parameter that changes significantly from one load point to another is the ground slope.

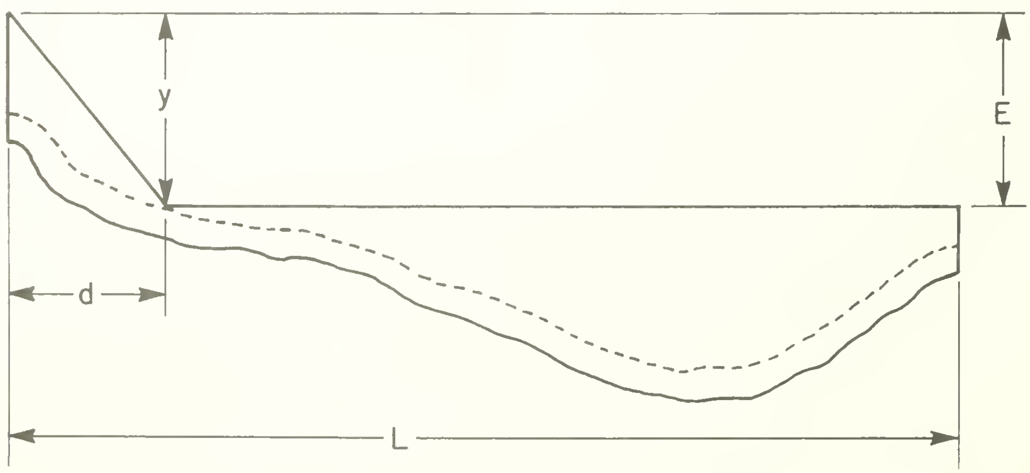
Procedure

The assumption that the carriage clearance is constant makes the procedure for determining payload capability very straightforward. The two main steps are:

1. Use the "Partial Suspension Load Factors" program (Appendix 2) to determine the partial suspension load factors for each load point for which capability is to be determined.

2. Use the "Partial Suspension Payload (III)" program (Appendix 3) to determine the allowable payloads for each lo point for which capability is to be determined.

Figure 5.—Load path of a live or running skyline.



The least of these payloads is the one taken to be the max mum load that the system can carry without exceeding an of the allowable tensions.

Example

The profile data of Figure 6A and the data that follow illu trate the procedure.

ω_1 = 1.85 lb/ft	T_1 = 34500 lb	μ = 0.60
ω_3 = 0.72 lb/ft	T_3 = 13700 lb	1_ℓ = 40 ft
ω_4 = 0.46 lb/ft	T_4 = 8900 lb	1_c = 16 ft
W_c = 750 lb		

Yarder location: Terrain point (T.P.) 3, h_y = 50 ft
Tailhold location: T.P. 10, h_T = 20 ft
Minimum load clearance: $h_L = y_c$ = 12 ft

Step 1. Use the "Partial Suspension Load Factors" progra (Appendix 2) to determine the load factors.

1. Input μ = 0.6 (Key A)
2. Input 1_ℓ = 40 and
   1_c = 16 (Key B)
3. For each load point, enter the ground slope (Key C), an then enter the carriage clearance and compute the value fo v and h (Key D). The results are:

	Input		*Output*	
Terrain point	θ	Y_c	v	
4	0.40	12	0.68	0.
5	0.20	12	0.58	0.
6	0.40	12	0.68	0.
7	0.25	12	0.61	0.
8	0.40	12	0.68	0.

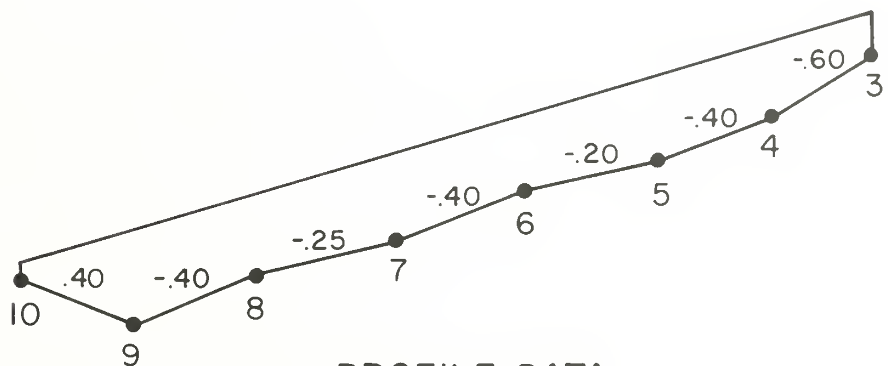
[Fig]ure 6.—Profile data in standard form for yarder above tailhold (A) and below tailhold (B).

A

PROFILE DATA

[T]ERRAIN POINT	SLOPE DISTANCE	% SLOPE	X COORDINATE	Y COORDINATE
3	125	0.60	568.0	4968.2
4	125	0.40	675.2	4903.9
5	150	0.20	791.2	4857.5
6	135	0.40	938.3	4828.0
7	150	0.25	1063.7	4777.9
8	140	0.40	1209.2	4741.5
9	130	-0.40	1339.2	4689.5
10			1459.9	4737.8

B



PROFILE DATA

[T]ERRAIN POINT	SLOPE DISTANCE	% SLOPE	X COORDINATE	Y COORDINATE
10	130	0.40	000.0	5000.0
9	140	-0.40	120.7	4951.7
8	150	-0.25	250.7	5003.7
7	135	-0.40	396.2	5040.1
6	150	-0.20	521.6	5090.2
5	125	-0.40	668.6	5119.6
4	125	-0.60	784.7	5166.1
3			891.9	5230.4

Step 2. Use the "Partial Suspension Payload III" program (Appendix 3) to determine the allowable payload.

1. Input T_3 = 13700
   ω_3 = 0.72
   T_4 = 8900 and
   ω_4 = 0.46 (Key A)
2. Input f = 1
   W_c = 750
   T_1 = 34500 and
   ω_1 = 1.85 (Key B)
3. Input X_Y = 568.0
   Y_Y = 4968.2 and
   h_Y = 50 (Key fA)
4. Input X_T = 1459.9
   Y_T = 4737.8 and
   h_T = 20 (Key fB)

5. For each load point, enter the coordinates and carriage clearance (Key fC), and then ues Key E to enter the load factors and calculate the allowable payloads based on the allowable skyline tension. Use Key fE to calculate the payload based on allowable mainline tension. The results are:

Terrain point	*Input*					*Output*	
	X_L	Y_L	h_L	v	h	$W_n(T_1)$	$W_n(T_3)$
4	675.2	4903.9	12	0.68	0.42	84258.07	18512.13
5	791.2	4857.5	12	0.58	0.38	46123.73	22921.82
6	938.3	4828.0	12	0.68	0.42	19110.31	21875.58
7	1063.7	4777.9	12	0.61	0.39	25702.94	24784.82
8	1209.2	4741.5	12	0.68	0.42	25170.31	24481.35

By these calculations, the system capability is 18512.13 lb, which is 2.03 times the payload that is found by assuming full suspension.

Discussion

The major difference between determining payload capability by this method and traditional methods is the calculation of the load factors. This also is the most time-consuming part of the procedure. The procedure can be simplified significantly by using one or more "average" load factors calculated on the basis of one or more "average" ground slopes. The results will still reflect the effects of partial suspension without much more effort than traditional methods.

Running Skyline

A typical running skyline (Fig. 7) has one line that serves both as a skyline and a haulback line. This line is usually called the haulback line.

Cable Geometry

Since the length of the haulback line varies as the turn is moved toward the landing, the load clearance (h_L) is considered to be constant for determination of payload capability. The path of the carriage under these conditions is shown in Figure 5. The cable geometry is then described first specifying the coordinates and heights of the yarder spar and tailhold, and then specifying each load point in terms of its coordinates and the constant load clearance.

Log Geometry

Since the load clearance remains constant, the carriage clearance, y_c, does too. For running skyline carriages, it is assumed that $y_c = h_L$ without significant error. Therefore, the only log geometry parameter that will change significantly from one load point to another is the ground slope.

Procedure

The assumption that the carriage clearance is constant makes the procedure for determining payload capability for a running skyline essentially the same as for the live skyline. The inputs are only slightly different. Two main steps are:

1. Use the "Partial Suspension Load Factors" program (Appendix 2) to determine the partial suspension load factors for each terrain point for which capability is to be determined.

2. Use the "Partial Suspension Payload (III)" program (Appendix 3) to determine the allowable payloads for each terrain point for which capability is to be determined.

The least of these payloads is the one taken to be the maximum load that the system can carry without exceeding any of the allowable tensions.

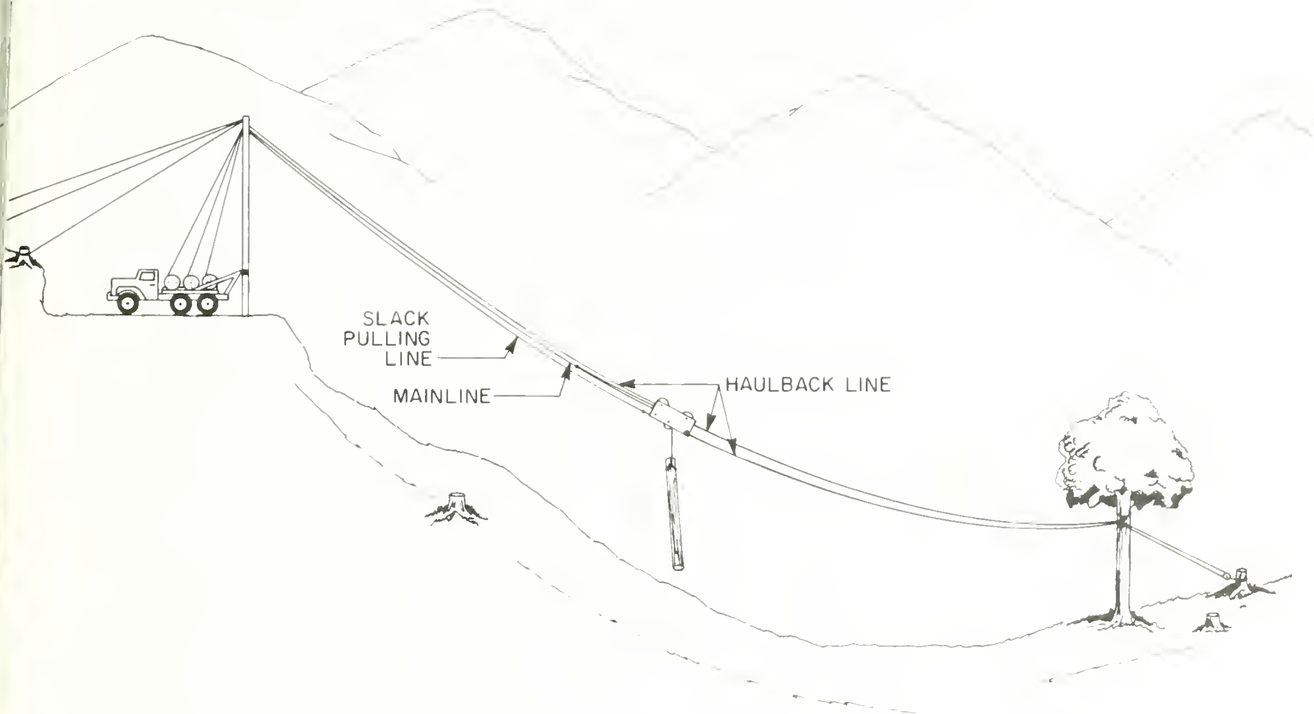
Example

The profile data of Figure 6A and the data that follow illustrate the procedure.

ω_1 = 1.85 lb/ft T_1 = 34500 lb μ = 0.60
ω_3 = 3.70 lb/ft T_3 = 34500 lb l_ℓ = 40′
W_c = 750 lb l_c = 16′

Yarder location: T.P 3, h_y = 50′
Tailhold location: T.P. 10, h_T = 20′
Load clearance: h_L = 12′

ure 7.—Running skyline configuration.



ep 1. Use the "Partial Suspension Load Factor" program Appendix 2) to determine the load factors.

. Input μ = 0.60 (Key A)

. Input 1_{ℓ} = 40 and
1_c = 16 (Key B)

. For each terrain point, enter the ground slope (Key C), nd then enter the carriage clearance (Key D). the values of v nd h will be displayed. The result is:

errain point	*Input*		*Output*	
	θ	Y_c	v	h
4	0.40	12	0.68	0.42
5	0.20	12	0.58	0.38
6	0.40	12	0.68	0.42
7	0.25	12	0.61	0.39
8	0.40	12	0.68	0.42

Step 2. Use the "Partial Suspension Payload (III) program (Appendix 3) to determine the payload capability.

1. Input T_3 = 34500
ω_3 = 3.70
T_4 = 1 and
ω_4 = 1 (Key A)
2. Input f = 2
W_c = 750
T_1 = 34500 and
ω_1 = 1.85 (Key B)
3. Input X_Y = 568.0
Y_Y = 4968.2
h_Y = 50 (Key fA)
4. Input X_T = 1459.9
Y_T = 4737.8
h_T = 20 (Key fB)
5. For each terrain point, enter the load point coordinates and the load clearance (Key fC), and then enter the load factors, v and h, and calculate the payload based on allowable haulback tension (Key E). Use Key fE to calculate the payload based on allowable mainline tension. The results are:

Terrain point	Inputs					Outputs	
	X_L	Y_L	h_L	v	h	$W_n(T_1)$	$W_n(T_3)$
4	675.2	4903.9	12	0.68	0.42	171092.93	36228.59
5	791.2	4857.5	12	0.58	0.38	94372.44	34848.72
6	938.3	4828.0	12	0.68	0.42	39639.30	22110.78
7	1063.7	4777.9	12	0.61	0.39	52884.97	27364.27
8	1209.2	4741.5	12	0.68	0.42	51535.80	26801.60

On the basis of these results, the net allowable system payload is 22110.78 lb and is mainline limited. This payload is 1.40 times the payload determined with a full suspension analysis.

Discussion

There is essentially no difference in procedure for payload determinations for the running skyline and live skyline except for the inputs on one of the programs. Different input is needed because different forces act at the carriage for a running skyline and a live skyline.

The major difference between determining payload capability by this method and traditional methods is the calculation of the load factors. This also is the most time-consuming part of the procedure. The procedure can be simplified significantly by using one or more "average" ground slopes.

The amount of accuracy sacrificed depends on the variat in ground slope. However, the results will still reflect th effects of partial suspension without much more efforts traditional methods.

Note that some running skylines, because they operate o essentially constant haulback tension regardless of load, viate from the conditions described. The constant haulb tension causes a cable geometry with a varying, rather th a constant, load clearance. However, the maximum payl for these conditions can be calculated in the way describ without a significant decrease in accuracy.

Standing Skyline

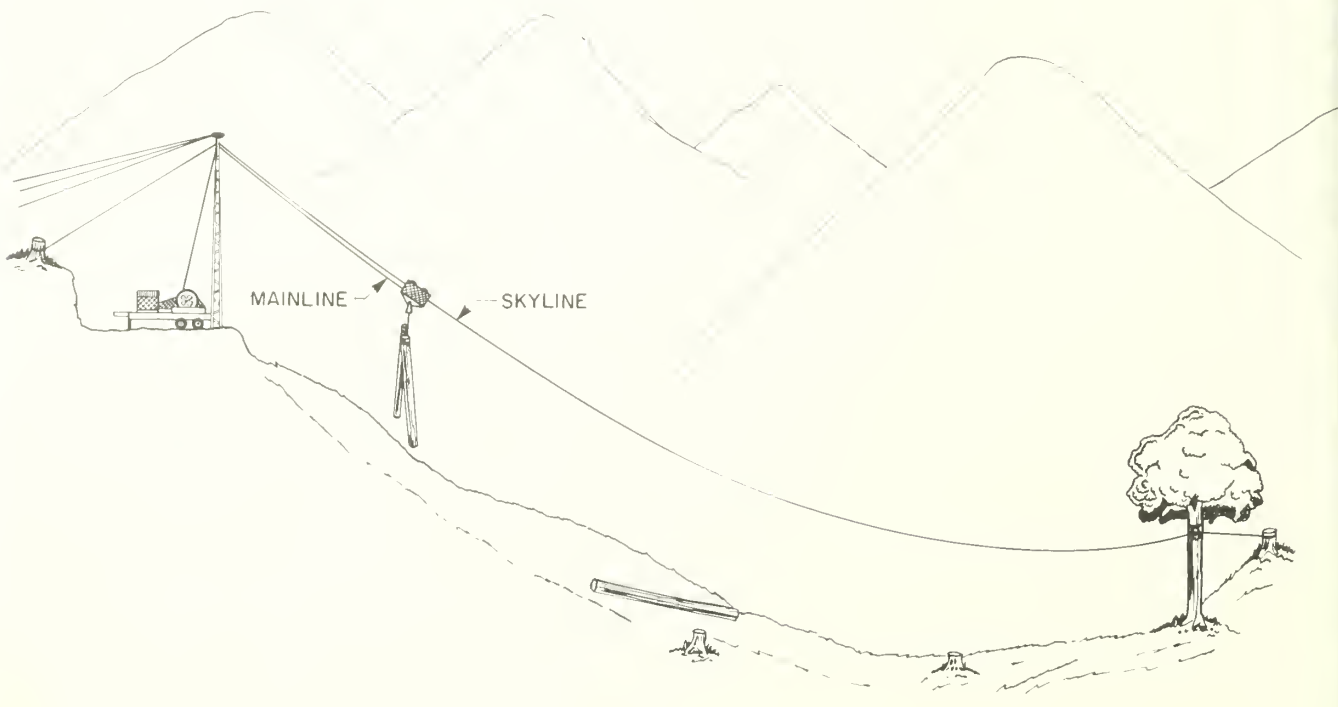
A typical standing skyline configuration is shown in Figu If the skyline length is not varied as the carriage is moved along it, the system is analyzed as a standing skyline. Thi distinction is important because it determines the cable geometry.

Cable Geometry

Since the skyline is essentially constant, the path that the riage takes is elliptical (Fig. 9). This path can be describe mathematically once the skyline length is known. Hence, system geometry can be determined.

Figure 10 illustrates that for each point on a given profile there is an associated skyline length (L_s) that allows passa

Figure 8.—Standing skyline configuration.



he carriage at *exactly* the required clearance. Since these gths vary, as illustrated, there is only one length that will w the carriage to pass each terrain point *within* the wable clearance, which is obviously the shortest of all sible lengths. The shortest skyline length is found by culating the length required to pass the carriage at exactly required clearance for several terrain points until it is tain that a shortest one has been found. By using the rtest skyline length, S_o, the system geometry is specified finding the deflection, y, at any distance, d, with the thematical expression describing the elliptical load path.

g geometry

cause of the elliptical load path, the load clearance, h_L, d the carriage clearance, yc, vary as the carriage moves along the skyline. This means that the amount of suspension can vary considerably for a standing skyline, and the load factors can vary considerably also.

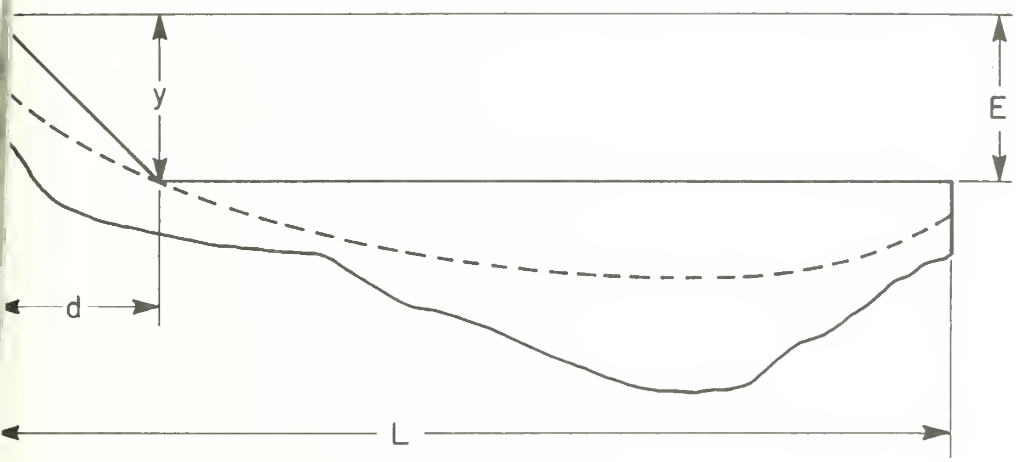
Procedure

Payload capability analysis of the standing skyline is more involved than the live or running skyline systems because of the fixed skyline length. The three primary steps are:

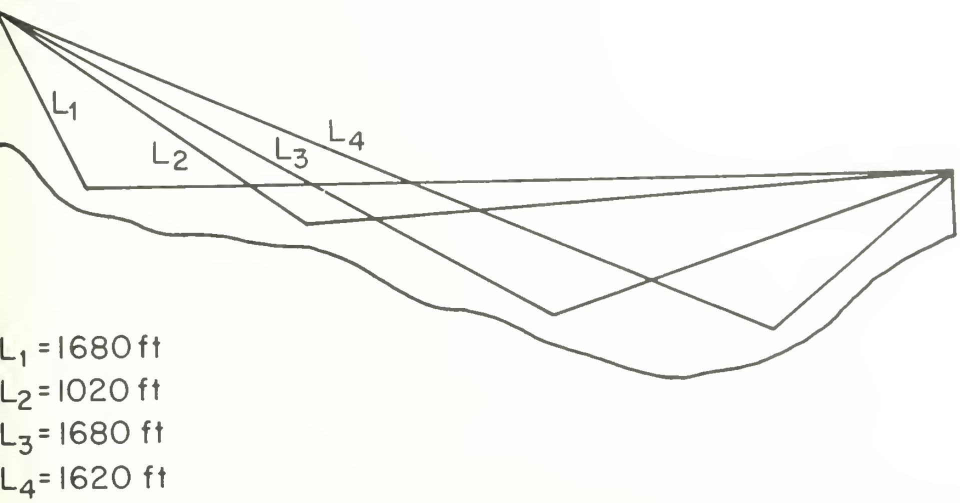
1. Use the "Standing Skyline Length and Load Path" program (Appendix 1) to determine the skyline length, $\overline{S}_o$, then determine the cable geometry parameters, L and E, for the system, and then determine the geometry parameters d, y, and y_c for each load point.

2. Use the "Partial Suspension Load Factors" program (Appendix 2) to determine the partial suspension load factors for each load point.

gure 9.—Elliptical load path of a standing skyline.



igure 10.—Skyline lengths.



3. Use the "Partial Suspension Payload (III)" program (Appendix 3) to determine the allowable payloads.

The least of the payloads is the one taken to be the maximum load the system can support without exceeding any of the allowable tensions.

Example

The profile data of Figure 6A and the data that follow illustrate the procedure.

ω_1 = 1.85 lb/ft	T_1 = 34500 lb	μ = 0.60
ω_3 = 0.72 lb/ft	T_3 = 13700 lb	1_ℓ = 40 ft
ω_4 = 0.46 lb/ft	T_4 = 8900 lb	1_c = 16 ft
W_c = 750 lb		

Yarder location: T.P. 3, h_y = 50 ft
Tailhold location: T.P. 10, h_T = 20 ft
Load clearance: h_L = 12 ft

Step 1. Use the "Standing Skyline—Length and Load Path" program (Appendix 1) to determine the skyline length, $\overline{S}_o$, the cable geometry parameters, L and E, for the system, and then cable geometry parameters, d and y, and the carriage clearance, y_c, for each load point.

1. Input X_Y = 568.0
   X_Y = 4968.2 (Key fA)
2. Input X_T = 1459.9
   Y_T = 4737.8 (Key fB)
3. Input h_Y = 50
   h_T = 0
   h_L = 12 (Key fD)

4. For each terrain point that seems as if it might limit the skyline length, enter the coordinates (Key fC) and then calculate the length, L_s, and the distance, d. The results are:

Terrain point	*Inputs*		*Outputs*	
	X_T	Y_L	L_S	d
5	791.2	4857.5	946.16	223.2
6	938.3	4828.0	938.98	370.3
7	1063.7	4777.9	943.24	495.7
8	1209.2	4741.5	944.43	641.2
9	1339.2	4689.5	966.88	771.2

The limiting skyline length, $\overline{S}_o$, according to these calculations is $\overline{S}_o$ = 938.98

5. Determine the cable geometry parameters, L and E, for the system (Key E).

These are L = 891.9 ft, and E = 260.4 ft.

6. Input $\overline{S}_o$ = 938.98 (Key A) then determine the cable geometry parameters, d and y, and the carriage clearance, y_c, for each load point. The results are:

Terrain point	*Input*	*Output*	*Input*	*Ou*
	d	y	Y_L	
4	107.2	80.13	4903.9	34.
5	223.2	128.00	4857.5	32.
6	370.3	178.18	4828.0	12.
7	495.7	214.54	4777.9	25.
8	641.2	249.54	4741.5	27.
9	771.2	271.91	4689.5	56.

Step 2. Use the "Partial Suspension Load Factors" progra (Appendix 2) to determine the load factors for each load point.

1. Input μ = 0.60 (Key A)
2. Input 1_ℓ = 40 and
   1_c = 16 (Key B)
3. For each load point enter the ground slope (Key C) an then the carriage clearance (Key D). The calculator will di play the load factors. The results are:

Terrain point	*Input*		*Output*	
	θ	Yc	v	
4	0.40	34.17	0.81	0.
5	0.20	32.70	0.71	0.
6	0.40	12.02	0.68	0.
7	0.25	25.76	0.69	0.
8	0.40	27.16	0.77	0.
9	-0.40	56.79	0.57	0.

Step 3. Use the "Partial Suspension Payload (III)" progran (Appendix 3) to determine the payloads based on the appropriate line tensions.

1. Input T_3 = 13700
   ω_3 = 0.72
   T_4 = 8900 and
   ω_4 = 0.46 (Key A)
2. Input f = 1
   W_c = 750
   T_1 = 34500
   ω_1 = 1.85 (Key B)
3. Input L = 891.9 and
   E = 260.4 (Key C)
4. For each load point enter d and y (Key D), and then ent v and h and calculate $W_n(T_1)$ (Key E). Calculate $W_n(T_3)$ (Key fE). The results are:

Terrain point	Inputs				Outputs	
	d	y	v	h	$W_n(T_1)$	$W_n(T_3)$
4	107.2	80.13	0.81	0.25	24998.71	22788.37
5	223.2	128.00	0.71	0.26	19363.69	26596.51
6	370.3	178.18	0.68	0.41	18912.37	22226.53
7	495.7	214.54	0.69	0.31	16039.00	27718.86
8	641.2	249.54	0.77	0.30	15145.13	29472.18
9	771.2	271.91	0.57	0.07	24305.71	98099.36

n the basis of these results, the limiting payload is ›145.13 lb which is 1.70 times the payload determined ith a full suspension analysis.

iscussion

he analysis of a standing skyline is more complex than the ıalysis of the live or running skyline, because Step 1 must e used to determine skyline length and load path. The emaining two steps are identical, as far as the mechanics re concerned.

'raditionally, the only load point that is examined for a tanding skyline analysis is at midspan. However, the deter- nination of the cable geometry and load factors can be ritical because the payload capability at any load point is as ensitive to the amount of suspension as it is to the amount ›f deflection, and because the amount of suspension can vary 'rom full suspension to no suspension quite easily, depending ›n the topography, there is no assurance that the limiting oad will be at midspan. Therefore, the payload for several terrain points should be determined to be certain which one limits the capability of the system. Payload predictions, based on the payload at midspan only, can easily be 50 percent off, and it is not unusual for them to be 80 percent off.

For typical yarders with typical line sizes, a live skyline analysis will nearly always yield a payload capability at least as large as a standing skyline analysis will yield. Therefore, it may be convenient to analyze a profile for a live skyline first. If a satisfactory payload capability is not obtained, there is no point in analyzing the profile for a standing skyline. As experience is gained in using the programs, it will be easier to identify the "critical" terrain points as well as to estimate how much less a standing skyline will carry than that of a live skyline on a given profile.

Variations in Yarding Conditions

The programs used in these analyses are based on the assumption that the yarder is higher in elevation than the tailhold and that the logs moved toward the yarder. However, variations in yarding circumstances can and do occur. For example, it may be desirable to move the log away from the yarder, and some systems are designed with the yarder lower in elevation than the tailhold. The programs can be used to predict payloads for each of these variations if the proper inputs are made.

Yarder Position

If the top of the yarder spar is higher than the top of the tailhold (elevation difference, E>0), then no modifications for yarder position are required. If the reverse is true (E<0), then the allowable tensions should be reduced because the tension in any cable (for a given load at a given location) is maximum at its highest point in the system. The algorithms in the programs use the tensions at the yarder spar because that is assumed to be the highest point. If the yarder is lower than the tailhold, the maximum skyline and haulback tensions are at the tailhold. To account for this, the allowable tensions should be reduced by the product of the line's weight and the elevation difference between the top of the yarder spar and the top of the tailhold. The relationship is expressed by equation 2.

$$T'_{all} = T_{all} + \omega E \qquad (2)$$

where

T'_{all} = allowable tension with yarder lower than tailhold

T_{all} = allowable tension with yarder higher than tailhold

ω = cable weight/foot

E = elevation difference, feet

Since the elevation difference, E, is negative when the yarder is lower than the tailhold, the allowable tensions will be reduced accordingly. The tensions in all lines should be reduced, even though that may yield results that could be slightly conservative if the payload is limited by mainline tension.

Direction of Movement

The direction of log movement, whether toward or away from the yarder, is another variation that may require modification to the inputs. Consider the free body diagram of Figure 3. In particular note that the horizontal component of force due to drag resistance, the "hW_n" force, is toward the right. This is true if the turn is to be moved toward the yarder which is assumed to be on the left. But, if the turn is to be moved away from the yarder, this "hW_n" force would be toward the left. This discrepancy is corrected by simply reversing the sign of the horizontal load factor, h. The load factors are calculated first as they would be normally (give careful attention to which ground slope is specified as well as the sign of the ground slope); then the sign of the horizontal factor, h, is reversed only if the load is to be moved away from the yarder.

The modifications are simple, but because they are sometimes contrary to traditional thinking, they can be confusing.

For this reason, the following chart summarizes the required modifications and the following examples illustrate them:

	Log movement	
Yarder position	*Toward yarder*	*Away from yarder*
Above (Elevation difference E>0)	No modifications	Reverse sign of h
Below (Elevation difference E<0)	Reduce tensions	Reduce tensions Reverse sign of h

Example

To illustrate the modifications for the variations in yarding conditions, consider the profile data of Figure 6A and 6B, both of which are in standard form for having the yarder on the left. These profiles are the same; one is merely the reverse of the other. Note that the beginning coordinates are completely arbitrary. In addition, consider that a live skyline will be used with the same specifications as listed on page 4. It should also be noted that the modifications are the same for running and standing skylines.

Yarder position above. With the yarder at T.P. 3 and the tailhold at T.P. 10, use the profile data of Figure 6A. If the logs were to be moved toward T.P. 3, no modifications would be required to the inputs.

If however, the turns were brought toward T.P. 10 (away from the yarder), the load factors will be different, because a different ground slope is specified. Then the sign of each factor, h, will need to be reversed after it has been calculated. The change in sign of h is the only modification required. The results are:

Terrain Point	*Inputs*			*Outputs*		
	θ	v	h	$W_n(T_1)$	$W_n(T_3)$	$W_n(T_4)$
4	-0.60	0.50	0.00	47049.33	54360.12	
5	-0.40	0.06	-0.15	146881.20		76540.88
6	-0.20	0.21	-0.28	32554.14		43902.03
7	-0.40	0.06	-0.15	140074.39		68191.04
8	-0.25	0.16	-0.25	76634.69		40343.56
9	-0.40	0.06	-0.15	-2616210.54		52915.55

These results show that the system can carry a load of 32554.14 lb without exceeding the allowable tensions. This is 3.56 times the payload determined by full suspension analysis. Note that the system is haulback limited.

Yarder position below. If the yarder is at T.P. 10 and the tailtree at T.P. 3, then the profile would be specified as shown in Figure 6B, to be in standard form. Because the yarder is lower than the tailhold (E<0), the allowable tensions should be reduced by the product of the cable's weig and the elevation difference, E. In this case, E = -200.40 f and the appropriate reductions are:

$T_1 = 34500 - (200.40)\ (1.85) = 34100$ lb

$T_3 = 13700 - (200.40)\ (0.72) = 13600$ lb

$T_4 = 8900 - (200.40)\ (0.46) = 8800$ lb

These reduced tensions are entered as the allowable tension and the payloads are determined as before. If the turns we to be brought toward the yarder, the load factors would be calculated normally and *not* reversed. The results for the load factors and payloads are:

Terrain point	*Load factors*			*Payloads*		
	θ	v	h	$W_n(T_1)$	$W_n(T_3)$	$W_n(T_4)$
8	-0.25	0.16	0.25	115008.09	57190.17	
7	-0.40	0.06	0.15	177866.34	99644.09	
6	-0.20	0.21	0.28	32662.72	61888.79	
5	-0.40	0.06	0.15	135191.48	110001.99	
4	-0.60	0.50	0.00	31247.58		44503.1

These results show that a payload of 31247.58 lb is possible without exceeding the allowable tensions. This is 3.68 times the payload determined with a full suspension analysis.

If the log was moved away from the yarder, then the load factors will be different, because of the difference in specified ground slope. In addition, the sign of the load factor, h, would need to be reversed. The results for both the load factors and payloads are:

Terrain point	*Load factors*			*Payloads*		
	θ	v	h	$W_n(T_1)$	$W_n(T_3)$	$W_n(T_4)$
8	0.40	0.68	-0.42	28886.70		17391.20
7	0.25	0.61	-0.39	25834.83		17077.77
6	0.40	0.68	-0.42	16608.61		15013.76
5	0.20	0.58	-0.38	32395.41		15718.12
4	0.40	0.68	-0.42	39380.92		13002.63

These results indicate that a payload capability of 13002.63 lb. can be expected, which is 1.53 times the payload found with a full suspension analysis.

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Lysons, Hilton H., and Charles N. Mann.
1967. Skyline tension and deflection handbook. USDA For. Serv. Res. Pap. PNW-39. 41 p.

Program Description

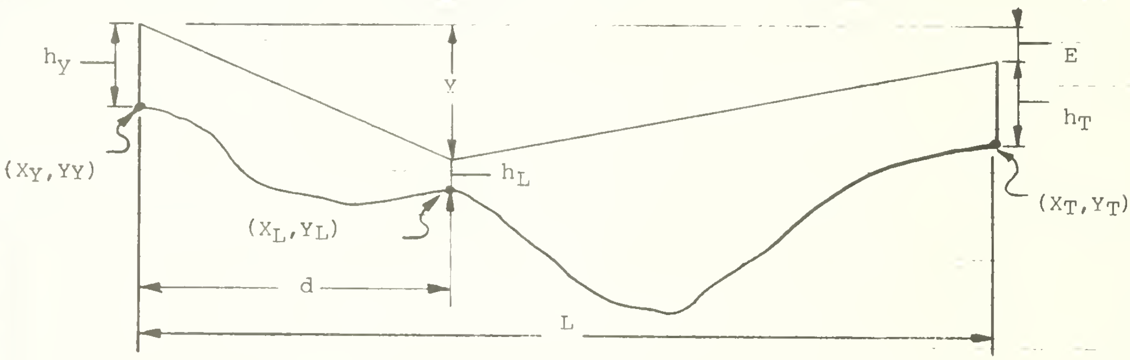
Program Title Standing Skyline--Length and Load Path

Contributor's Name Gary D. Falk **Date:** Sept. 1979

Address Forest Engineering Research, NE

City Morgantown **State** West Virginia **Zip Code** 26505

Program Description, Equations, Variables: This program is used for the determination of the cable geometry parameters necessary for a standing skyline payload analysis. It is basically the elliptical load path program developed by Ward Carson modified to use inputs more consistent with field data, to calculate a skyline length without the use of a secondary program, and to provide outputs that allow for payload analyses that include the effect of partial suspension.



X_Y, Y_Y = X and Y coordinates of yarder (ft)

X_T, Y_T = X and Y coordinates of tailhold (ft)

X_L, Y_L = X and Y coordinates of load point (ft)

h_Y, h_T, h_L = heights of yarder, tailhold, and load clearance at load point (ft)

Operating Limits and Warnings

Program Description

Program Title Standing Skyline--Length and Load Path (Con't)

Contributor's Name

Address

City **State** **Zip Code**

Program Description, Equations, Variables :

L_S = skyline length with h_L as load clearance (ft)

d = horizontal distance, yarder to load point (ft)

$\overline{S_O}$ = critical skyline length (Stretched, shortest of all L_S's) (ft)

y = vertical distance, top of yarder spar to load point (ft)

y_C = load clearance with $\overline{S_O}$ as skyline length (ft)

ω_1 = skyline weight (lb/ft)

T_1 = skyline allowable tension (lb)

S_O = unstretched skyline length (ft)

L = horizontal distance, yarder to tailhold (ft)

E = vertical distance, top of yarder spar to top of tailhold (ft)

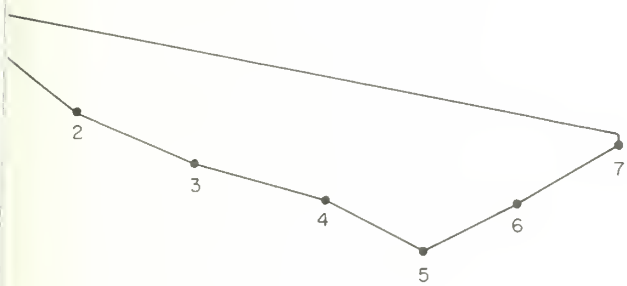
Operating Limits and Warnings

User Instructions

$X_Y \uparrow Y_Y$	$X_T \uparrow Y_T$	$X_L \uparrow Y_L$	$h_Y \uparrow h_T \uparrow h_L$	$\rightarrow L_S, d$
STANDING SKYLINE--LENGTH AND LOAD PATH				
$\bar{S}_o$	$d \rightarrow y$	$Y_L \rightarrow y_c$	$\omega_1 \uparrow T_1 \rightarrow S_o$	$\rightarrow L, E$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Key in and ENTER X_Y	X_Y	↑		
2	Key in Y_Y and store X_Y and Y_Y	Y_Y	f	A	
3	Key in and ENTER X_T	X_T	↑		
4	Key in Y_T and store X_T and Y_T	Y_T	f	B	
5	Key in and ENTER X_L	X_L	↑		
6	Key in Y_L and store X_L and Y_L	Y_L	f	C	
7	Key in and ENTER h_Y	h_Y	↑		
8	Key in and ENTER h_T	h_T	↑		
9	Key in h_L and store h_Y, h_T, and h_L	h_L	f	D	
10	Calculate and display L_S and d		f	E	L_S,d
	Go back to step 5 and 6 and then to				
	step 10 for each "suspected" terrain point				
	until satisfied that the shortest				
	L_S has been found (Each L_S and d calculated				
	should be written down for later use.)				
11	Key in $\bar{S}_o$ (shortest L_S)	$\bar{S}_o$	A		
12	Key in d and calculate y	d	B		y
13	Key in Y_L and calculate y_c	Y_L	C		y_c
	Continue to repeat steps 12 and 13 until				
	y and y_c have been found for each desired				
	terrain point . (Each of these values should				
	also be written down for later use.)				
---	OPTIONAL STEPS---				
14	Key in and ENTER ω_1	ω_1	↑		
15	Key in T_1, and calculate S_o	T_1	D		S_o
	(S_o and $\bar{S}_o$ are for use in "unloaded skyline tension" program).				
16	Calculate and display L,E		E		L,E
	(This option allows for the determination				
	of these parameters, for use in the "Partial				
	Suspension Payload III" program.)				

he program is illustrated by determining the geometry arameters for a standing skyline for the following profile: 55-foot yarder spar at T.P. 1, a 10-foot tailtree at T.P. 7, nd a 12-foot minimum load clearance.



Terrain point	*X Coord*	*Y Coord*
1	0.00	5000.00
2	156.20	4875.10
3	357.40	4774.40
4	587.30	4705.50
5	753.80	4613.90
6	917.90	4687.80
7	1093.20	4784.20

The first step is to determine L_s for each load point that may limit the skyline length. Terrain points 2 to 6, inclusive will be examined to illustrate the procedure.

Key in X_Y = 0.0 and Enter ↑
Key in Y_Y = 5000.0 and fA
Key in X_T = 1093.2 and Enter ↑
Key in Y_T = 4784.2 and fB
Key in X_L = 156.2 and Enter ↑
Key in Y_L = 4875.1 and fC
Key in h_Y = 55 and Enter ↑
Key in h_T = 10 and Enter ↑
Key in h_L = 12 and fD
Key fE. The calculator should flash L_s = 1170.92, and then display d = 156.20. These are the values at T.P. 2 since the input values of X_L and Y_L were for that terrain point.

The values of L_s and d are found for the remaining terrain points by inputting X_L and Y_L for each terrain point (Key fC) and calculating the desired parameters (Key fE) as follows:

Key X_L = 357.4 and Enter ↑
Key Y_L = 4774.4 and fC
Key fE. The calculator should flash L_s = 1182.92, and then display d = 357.40. These are the values for T.P. 3.

The procedure is repeated for each terrain point that may limit the skyline length. The values for the remaining terrain points, along with the appropriate inputs, are:

Terrain point	*Inputs*		*Outputs*	
	X_L	Y_L	L_s	*d*
2	156.20	4875.10	1170.92	156.20
3	357.40	4774.40	1182.92	357.40
4	587.30	4705.50	1189.05	587.30
5	753.80	4613.90	1246.21	753.80
6	917.90	4687.80	1183.33	917.90

Since the shortest L_s is 1170.92, input that value as $\overline{S}_o$. After it is input calculate the cable geometry.
Key in $\overline{S}_o$ = 1170.92 and A.
Key in d = 156.20 and B. The calculator should display y = 167.91.
Key in Y_Y = 4875.10 and C. The calculator should display Y_c = 11.99. These are the values of y and Y_c for T.P. 2 since the input values of d and Y_Y were the values for the terrain point. Note that the actual clearance should have been 12.00. The difference is a result of rounding error.

The values of y and y_c are found for the remaining terrain points by inputting d and calculating y (Key B) and then inputting Y_L and calculating y_c (Key C) as follows:
Key d = 357.40 and B. The calculator should display y = 247.99.
Key Y_L = 4774.40 and C. The calculator should display y_c = 32.61. These are the values for T.P. 3. Note: If the distance parameter, d, was not determined previously, it can be determined manually by d = X_L — X_Y. It will then be in the X register ready to be input (Key B) as above.

The procedure is repeated for each terrain point for which payload capability is to be determined. The values for the remaining terrain points, along with the appropriate inputs, are:

Terrain point	*d*	*Y*	Y_L	Y_c
2	156.20	167.91	4875.10	11.99
3	357.40	247.99	4774.40	32.61
4	587.30	307.39	4705.50	42.11
5	753.80	332.75	4613.90	108.35
6	917.90	339.62	4687.80	27.58

In addition to determining the cable geometry parameters above, the distance and height parameter, L and E, can also be determined any time after the first trial L_s value has been determined. This is done by keying Key E.
Key E. The calculator should first flash L = 1093.20 and then display E = 260.80.

Also, it may be desired to know the unstretched skyline length, S_o, given the allowable tension and line weight. If the allowable tension (T_1) is 34500 lb and the weight (ω_1) is 1.85, then S_o is found as follows:

Key ω_1 = 1.85 and Enter ↑
Key T_1 = 34500 and D. The calculator should display S_o = 1164.76.

Appendix 2
Partial Suspension Load Factors

Program Description

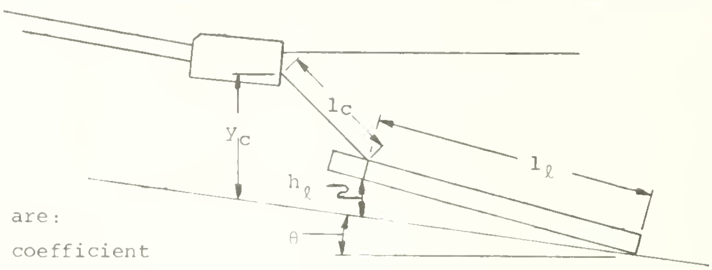
Program Title Partial Suspension Load Factors

Contributor's Name Gary D. Falk Date: Sept. 1979

Address Forest Engineering Research, NE

City Morgantown **State** West Virginia **Zip Code** 26505

Program Description, Equations, Variables : This program is used to determine the amount of log payload that is carried by the carriage as vertical and horizontal force components. Its use is preliminary to skyline payload analyses that consider the effects of partial suspension. It may also be used to determine the required carriage-to-ground clearance for a specified log-to-ground clearance.



The parameters are:

μ = frictional coefficient

l_ℓ = log length (ft) - measured from choker to end of log

l_c = choker length (ft) excluding amount to go around log

θ = ground slope (decimal) - positive if movement is uphill, negative if downhill.

y_c = carriage clearance (ft)

h_ℓ = vertical log-to-ground clearance (ft)

v = ratio of vertical force at carriage to log weight

h = ratio of horizontal force at carriage to log weight

Operating Limits and Warnings

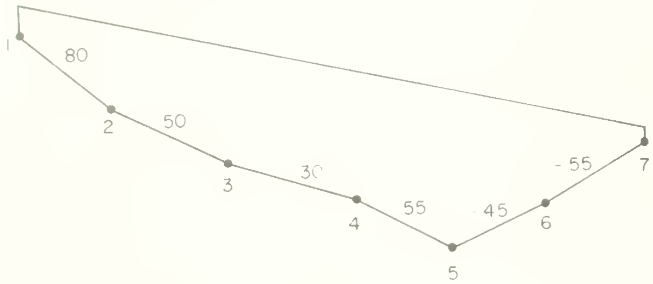
User Instructions

PARTIAL SUSPENSION LOAD FACTORS

					→ v,h
$\mu\uparrow$	$l_\ell \uparrow l_c$	$\Theta\uparrow$	$y_c \to v,h$	$h_\ell \to y_c,v,h$	

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Key in and store μ	μ	A		
2	Key in l_ℓ and ENTER	l_ℓ	↑		
3	Key in l_c and store l_ℓ and l_c	l_c	B		
4	Key in and store Θ	Θ	C		
5	Key in y_c and calculate v and h.	y_c	D		v,h
	v and h are determined by using an iterative routine				
	that is rather lengthy. For this reason,				
	it will take about one minute to get the				
	values v and h.				
	---OPTIONAL---				
	After having performed steps 1-4 above				
6	Key in h_ℓ and calculate y_c, v, h	h_ℓ	E		Y_c,v,n
	If it is desired to redisplay v and h without				
	going through the iterative routine of step 5.				
7	Key fE to display previously calculated v,h		f	E	v,h

The program is illustrated by finding the partial suspension load factors for terrain points 2 to 6, inclusive, of the following profile: friction coefficient, $\mu = 0.60$, log length, $1_{\ell} = 33$ ft, and a choker length, $l_c = 12$ ft.



Terrain point	θ	y_c
2	0.50	11.99
3	0.30	32.61
4	0.55	42.11
5	-0.45	108.35
6	-0.55	27.58

It should be emphasized that the ground slope to be specified for a particular load point is in the direction opposite that in which the log turn is to be moved. Also, the ground slope is positive if it is moved uphill, negative if it is moved downhill. For example, if T.P. 3 is to be examined, a ground slope of +0.30 should be specified if the turn is brought toward T.P. 1. However, a ground slope of -0.50 would be specified if the turn is brought toward T.P. 7.

The first step is to input the parameters that are common to all terrain points as follows:

Key in μ = 0.60 and A

Key in 1_{ℓ} = 33 and Enter ↑

Key in l_c = 12 and B. The calculator is now ready to calculate the load factors.

T.P. 2 is the first to be examined. The inputs which follow are for that terrain point.

Key in θ = 0.50 and C.

Key in y_c = 11.99 and D. The calculator should flash v = 0.75 and then display h = 0.39. The iterative routine used to calculate v and h will normally take about 1 minute to complete. It may be somewhat shorter or longer depending on the inputs.

The load factors for each successive terrain point is calculated by inputting θ (Key C) and then inputting y_c and calculating the load factors (Key D) as follows:

Key in θ = 0.30 and C.

Key in y_c = 32.61 and D. The calculator should flash v 0.81 and then display h = 0.21. These are the factors fo T.P. 3.

The procedure is repeated for each load point for which load factors are to be determined. The load factors for t remaining terrain points, along with the appropriate inpu, are given below:

Terrain point	*Inputs*		*Outputs*	
	θ	y_c	v	h
2	0.50	11.99	0.75	…39
3	0.30	32.61	0.81	…21
4	0.55	42.11	0.97	…06
5	-0.45	108.35	1.00	…00
6	-0.55	27.58	0.50	…02

It is desirable to view the load factors again without spending the time necessary to recalculate them, simply Key fE, an the calculator will redisplay them.

Key fE. The calculator should first flash v = 0.50 and the display h = 0.02. These are the load factors for T.P. 6, wh is the last terrain point examined.

This program also calculates the required carriage clearance for any combination of log and choker lengths, ground slopes, friction coefficients, and log-to-ground clearance. For example, to determine what carriage clearance is required to achieve a log-to-ground clearance of 1.5 ft for a log 40 ft long with a choker 16 ft long on a 25 percent ground slope, with a friction coefficient of 0.60--

Key in μ = 0.60 and A

Key in 1_{ℓ} = 40 and Enter ↑

Key in 1_c = 16 and B

Key in θ = 0.25 and C.

Key in h_l = 1.5 and E. The calculator should flash y_c = 12.87 and then flash v = 0.61 and then display h = 0.39.

For a ground slope of 50 percent

Key in θ = 0.50 and C.

Key in h_l = 1.5 and E. The calculator should flash y_c = 11.32 and then flash v = 0.73 and then display h = 0.42.

It should be emphasized that h_l is the vertical clearance to the ground, and that the sign convention for the ground slope is positive for a log moving uphill and negative for a long moving downhill.

'or negative ground slopes that are larger in magnitude than he friction coefficient, negative values of h will result. If he friction coefficient is equal in magnitude to the negative lope, division by zero will be attempted and an error will result. If the factors for a situation such as this are desired, enter a value of ground slope just slightly larger in magnitude than the friction coefficient and this will allow the load factors to be determined.

\ppendix 3
'artial Suspension Payload III

Program Description

Program Title Partial Suspension Payload III

Contributor's Name Gary D. Falk Date: March 1980

Address Forest Engineering Research, NE

City Morgantown, **State** West Virginia **Zip Code** 26505

Program Description, Equations, Variables This program will analyze running, live, and standing skyline systems for maximum payload capability based on specified allowable line tensions. Also, because it includes the effects of either a mainline or haulback on live and standing skylines, the most commonly used systems can be analyzed with this one program including downhill yarding situations. Although it was primarily developed to include the effects of partial suspension directly, full suspension analyses can be done with it.

The input parameters are described as follows: (See accompanying figure)

T_3 = allowable mainline tension at yarder

ω_3 = mainline weight per unit length
(mainline + slackpulling line weight for running skylines)

T_4 = allowable haulback tension (live and standing skylines)

ω_4 = haulback weight per unit length (live and standing skylines)

f = 1 for live and standing skylines
2 for running skylines

W_c = carriage weight

T_1 = allowable skyline tension at yarder
(haulback tension for running skylines)

ω_1 = skyline weight per unit length
(haulback weight for running skylines)

Operating Limits and Warnings The yarder is assumed to be on the left with increasing stationing to the right whether uphill or downhill yarding. Increased payloads by using both the mainline and haulback simultaneously is not considered. If either a mainline or a haulback is not used on the system being analyzed, "dummy" values should be input for the missing line or erroneous answers will result.

Program Description

Program Title Partial Suspension Payload III cont.

Contributor's Name

Address

City **State** **Zip Code**

Program Description, Equations, Variables

X_Y, Y_Y, h_Y = X and Y coordinates of yarder location and yarder spar height.

X_T, Y_T, h_T = X and Y coordinates of tailhold location and height.

X_L, Y_L, h_L = X and Y coordinates of load point and load clearance.

L = horizontal distance, yarder to tailhold

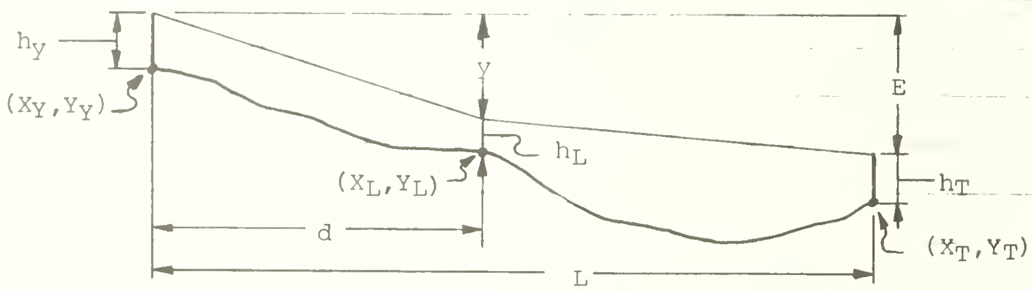
E = vertical distance, top of yarder to top of tailhold

d = horizontal distance, yarder to load point

y = vertical distance, top of yarder to load point

v = vertical partial suspension load factor

h = horizontal partial suspension load factor



$W_n(T_1)$ = allowable payload based on specified tension in skyline.(haulback for running skyline)

$W_n(T_3)$ = allowable payload based on specified tension in mainline.

$W_n(T_4)$ = allowable payload based on specified tension in haulback. (inappropriate for running skyline)

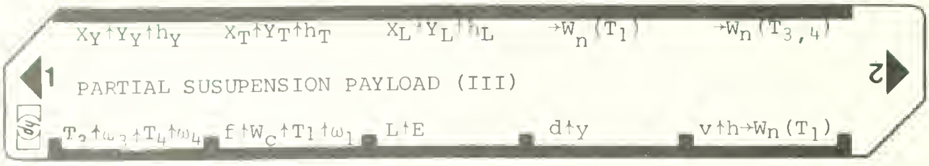
Operating Limits and Warnings

User Instructions

	$X_Y \uparrow Y_Y \uparrow h_Y$	$X_T \uparrow Y_T \uparrow h_T$	$X_L \uparrow Y_L \uparrow h_L$	$\rightarrow W_n(T_1)$	$\rightarrow W_n(T_{3,4})$
1	PARTIAL SUSPENSION PAYLOAD (III)				2
	$T_3 \uparrow \omega_3 \uparrow T_4 \uparrow \omega_4$	$f \uparrow W_C \uparrow T_1 \uparrow \omega_1$	$L \uparrow E$	$d \uparrow y$	$v \uparrow h \rightarrow W_n(T_1)$

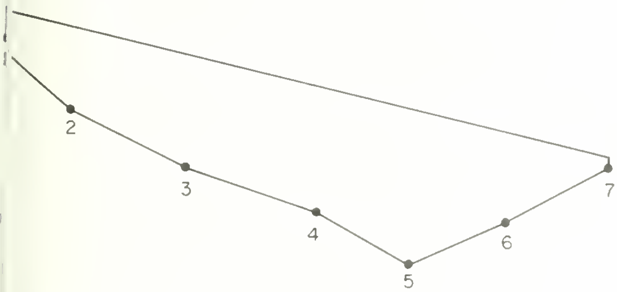
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	OPTION #1 (Straight Entry)				
	Key in T_3 and Enter ↑	T_3	↑		
	Key in ω_3 and Enter ↑	ω_3	↑		
	Key in T_4 and Enter ↑	T_4	↑		
	Key in ω_4 and A	ω_4	A		
	Key in f and Enter ↑	f	↑		
	Key in W_C and Enter ↑	W_C	↑		
	Key in T_1 and Enter ↑	T_1	↑		
8	Key in ω_1 and B	ω_1	B		
9	Key in L and Enter ↑	L	↑		
10	Key in E and C	E	C		
11	Key in d and Enter ↑	d	↑		
12	Key in y and D	y	D		
13	Key in v and Enter ↑	v	↑		
14	Key in h and E. Calculate $W_n(T_1)$, based on having a mainline. If calculator returns "0.00", go to step 15, if not, go to step 16.	h	E		$W_n(T_1)$
15	Key d. Calculate $W_n(T_1)$ based on having a haulback		f	D	$W_n(T_1)$
16	Key 3. Calculate $W_n(T_3)$ or $W_n(T_4)$		f	E	$W_n(T_3)$ or $W_n(T_4)$
	Steps 11-16, as required, are repeated for each terrain point for which capability is to be determined.				
	NOTE: The display of "0.00" of step 14 informs the user that a haulback is required for carriage equilibrium at that load point. $W_n(T_1)$ is then determined by step 15. If "0.00" is not displayed in step 14, the display is $W_n(T_1)$. In this case Step 15 is skipped.				
	The display of step 16 is $W_n(T_3)$ if "0.00" if "0.00" was not displayed at step 14. It is $W_n(T_4)$ if "0.00" was displayed at step 14.				

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
	OPTION #2 (Coordinate entry)				
1	Key in T_3 and Enter ↑	T_3	↑		
2	Key in ω_3 and Enter ↑	ω_3	↑		
3	Key in T_4 and Enter ↑	T_4	↑		
4	Key in ω_4 and A.	ω_4	A		
5	Key in f and Enter ↑	f	↑		
6	Key in W_C and Enter ↑	W_C	↑		
7	Key in T_1 and Enter ↑	T_1	↑		
8	Key in ω_1 and B.	ω_1	B		
9	Key in X_Y and Enter ↑	X_Y	↑		
10	Key in Y_Y and Enter ↑	Y_Y	↑		
11	Key in h_Y and a	h_Y	f	A	
12	Key in X_T and Enter ↑	X_T	↑		
13	Key in Y_T and Enter ↑	Y_T	↑		
14	Key in h_T and b	h_T	f	B	
15	Key in X_L and Enter ↑	X_L	↑		
16	Key in Y_L and Enter ↑	Y_L	↑		
17	Key in h_L and c	h_L	f	C	
18	Key in v and Enter ↑	v	↑		
19	Key in h and E. Calculate $W_n(T_1)$ based on having a mainline. If the display is "0.00" go to step 20, if not go to step 21.	h	E		$W_n(T_1)$
20	Key d. Calculate $W_n(T_1)$ based on having a haulback.		f	D	$W_n(T_1)$
21.	Key e. Calculate $W_n(T_3)$ or $W_n(T_4)$		f	E	$W_n(T_3)$ or $W_n(T_4)$
	Steps 15-21 are repeated, as required for each load point for which capability is to be determined.				
	NOTE: The note on the preceeding page is appropriate for this option where steps 19, 20, and 21, are substituted for 14,15, and 16.				

'e program is illustrated by calculating the payload capabil- i for terrain points 2 to 6, inclusive, of the following pro- for a running, live, and standing skyline. It should be ntioned that in order to illustrate the use of the program a short example, the profile data used result in values that somewhat atypical.



rrain oint	X Coord	Y Coord	v	h
1	0.00	5000.00		
2	156.20	4875.10	0.75	0.39
3	357.40	4774.40	0.66	0.38
4	587.30	4705.50	0.77	0.39
5	753.80	4613.90	0.09	0.11
6	917.90	4687.80	0.02	0.04
7	1093.20	4784.20		

ve Skyline

he following yarder specifications are given.

$_3$	= 13700 lb	f	= 1
$_3$	= 0.72 lb/ft	W_c	= 700 lb
$_4$	= None	T_1	= 34500 lb
$_4$	= None	ω_1	= 1.85 lb/ft

arder location: T.P. 1, h_y = 55 ft
ailhold location: T.P. 7, h_T = 10 ft
inimum load clearance: h_L = 12 ft

ption 2 is normally the more efficient option to use for oth the live and running skyline because it uses the reduced rofile data directly. The first step is to input the yarder ecifications, and use "dummy" values for the missing aulback line.

ey in T_3 = 13700 and Enter ↑
ey in ω_3 = 0.72 and Enter ↑
ey in T_4 = 1 and Enter ↑
ey in ω_4 = 1 and A
ey in f = 1 and Enter ↑
ey in W_c = 700 and Enter ↑
ey in T_1 = 34500 and Enter ↑
ey in ω_1 = 1.85 and B.

he yarder and tailhold locations and heights are input after e yarder specifications.

Key in X_Y = 0.0 and Enter ↑
Key in Y_Y = 5000.0 and Enter ↑
Key in h_Y = 55 and fA
Key in X_T = 1093.2 and Enter ↑
Key in Y_T = 4784.2 and Enter ↑
Key in h_T = 10 and fB. The cable geometry parameters, L and E, are calculated and stored in the correct registers. They can be recalled from storage registers 1 and 2, respectively.

The calculator is now ready to begin to calculate the allowable payloads for each desired terrain point. T.P. 2 will be examined first. The inputs which follow are the values for that terrain point.

Key in X_L = 156.2 and Enter ↑
Key in Y_L = 4875.1 and Enter ↑
Key in h_L = 12 and fC
Key in v = 0.75 and Enter ↑
Key in h = 0.39 and E. The calculator should display $W_n(T_1)$ = 94433.08

Key fE. The calculator should display $W_n(T_3)$ = 18108.71. These are the maximum payloads at this point based on the allowable tensions in the respective cables.

The payloads for the remaining terrain points are calculated by inputting the X and Y coordinates of the load point and the load clearance (Key fC), then inputting the load factors and calculating $W_n(T_1)$ (Key E) (or Key fD, as illustrated later), and then calculating $W_n(T_3)$, (or $W_n(T_4)$, as shown later) (Key fE). This is shown for T.P. 3 as follows:

Key in X_L = 357.4 and Enter ↑
Key in Y_L = 4774.4 and Enter ↑
Key in h_L = 12 and fC
Key in v = 0.66 and Enter ↑
Key in h = 0.38 and E. The calculator should display $W_n(T_1)$ = 63994.12.

Key fE. The calculator should display $W_n(T_3)$ = 22180.32.

The procedure is repeated for each load point for which capability is to be determined. The values for the remaining terrain points, along with the appropriate inputs are shown as follows:

Terrain point	Inputs					Outputs	
	X_L	Y_L	h_L	v	h	$W_n(T_1)$	$W_n(T_3)$
2	156.20	4875.10	12	0.75	0.39	94433.08	18108.71
3	357.40	4774.40	12	0.66	0.38	63994.12	22180.32
4	587.30	4705.50	12	0.77	0.39	40912.28	24091.97
5	753.80	4613.80	12	0.09	0.11	1101109.95	106181.56
6	917.90	4687.80	12	0.02	0.04	5640766.73	321004.75

Running Skyline

The running skyline procedure is essentially the same as the live skyline procedure. The differences are in the yarder specification inputs and, of course, the outputs. The following yarder specifications are given:

T_3	= 34500 lb	f	= 2
ω_3	= 3.70 lb/ft	W_c	= 700 lb
T_4	= None	T_1	= 34500 lb
ω_4	= None	ω_1	= 1.85 lb/ft

Yarder location: T.P. 1, h_Y = 55 ft
Tailhold location: T.P. 7, h_T = 10 ft
Minimum load clearance: h_L = 12 ft

As stated before, option 2 is the more efficient option to use for the running skyline. The first step is to input the yarder specifications, and be certain to input "dummy" values for the missing line.

Key in T_3 = 34500 and Enter ↑
Key in ω_3 = 3.70 and Enter ↑
Key in T_4 = 1 and Enter ↑
Key in ω_4 = 1 and A
Key in f = 2 and Enter ↑
Key in W_c = 700 and Enter ↑
Key in T_1 = 34500 and Enter ↑
Key in ω_1 = 1.85 and B.

The yarder and tailhold locations and heights are input after the yarder specifications.

Key in X_Y = 0.0 and Enter ↑
Key in Y_Y = 5000.0 and Enter ↑
Key in h_Y = 55 and fA
Key in X_T = 1093.2 and Enter ↑
Key in Y_T = 4784.2 and Enter ↑
Key in h_T = 10 and fB. The cable geometry parameters, L and E, are calculated and stored in the correct registers. They may be viewed by recalling them from registers 1 and 2, respectively.

The calculator is now ready to begin to calculate the allowable payloads for each desired terrain point. T.P. 2 will be examined first. The inputs which follow are for that terrain point.

Key in X_L = 156.2 and Enter ↑

Key in Y_L = 4875.1 and Enter ↑

Key in h_L = 12 and fC.

Key in v = 0.75 and Enter ↑

Key and h = 0.39 and E. The calculator should display $W_n(T_1)$ = 190838.75.

Key fE. The calculator should display $W_n(T_3)$ = 363[illegible] These are the maximum payloads at T.P.2 based on the allowable tensions in the respective cables.

The payloads for the remaining terrain points are calcu[illegible]ted by inputting the X and Y coordinates of the load point [illegible]nd the load clearance (fC), then inputting the load factors [illegible]d calculating $W_n(T_1)$ (Key E), and then calculating $W_n(T$[illegible] (Key fE). This is shown for T.P. 3 as follows:

Key in X_L = 357.4 and Enter ↑

Key in Y_L = 4774.4 and Enter ↑

Key in h_L = 12 and fC.

Key in v = 0.66 and Enter ↑

Key in h = 0.38 and E. The calculator should displa[illegible] $W_n(T_1)$ = 129609.04.

Key in fE. The calculator should display $W_n(T_3)$ = 379[illegible]

The procedure is repeated for each load point for which [illegible] capability is to be determined. The values for the remai[illegible]ng terrain points, along with the appropriate inputs are sho[illegible] as follows:

Terrain point	*Inputs*					*Outputs*	
	X_L	Y_L	h_L	v	h	$W_n(T_1)$	$W_n(T$[illegible]
2	156.20	4875.10	12	0.75	0.39	190838.75	3637[illegible]6
3	357.40	4774.40	12	0.66	0.38	129609.04	3793[illegible]7
4	587.30	4705.50	12	0.77	0.39	82847.26	3376[illegible]9
5	753.80	4613.90	12	0.09	0.11	2221119.44	227881[illegible]3
6	917.90	4687.80	12	0.02	0.04	11390764.75	71394[illegible]1

Standing Skyline

The same yarder specifications as those used for the live s[illegible] line example will be used for this example. In addition, a[illegible] haulback line will be specified.

T_3	= 13700 lb	W_c	= 700 lb
ω_3	= 0.72 lb/ft	T_1	= 34500 lb
T_4	= 8900 lb	ω_1	= 1.85 lb/ft
ω_4	= 0.46 lb/ft		

Yarder location: T.P. 1, h_Y = 55 ft
Tailhold location: T.P. 7, h_T = 10 ft

In addition to the above data, the following inputs will be used because they have been previously determined with the "Standing Skyline—Length and Load Path" and "Parti[illegible] Suspension Load Factors" programs.

L = 1093.20 E = 260.80

rrain oint	d	y	v	h
2	156.20	167.91	0.75	0.39
3	357.40	247.99	0.81	0.21
4	587.30	307.39	0.97	0.06
5	753.80	332.75	1.00	0.00
6	917.90	339.62	0.50	0.02

ecause the cable geometry parameters L, E, d, and y have een previously determined, option 1 is the more convenient otion to use for the standing skyline. The first step is to put the yarder specifications.

ey in T_3 = 13700 and Enter ↑
ey in ω_3 = 0.72 and Enter ↑
ey in T_4 = 8900 and Enter ↑
ey in ω_4 = 0.46 and A
ey in f = 1 and Enter ↑
ey in W_c = 700 and Enter ↑
ey in T_1 = 34500 and Enter ↑
ey in ω_1 = 1.85 and B.

he cable geometry parameters L and E are input next.

ey in L = 1093.20 and Enter ↑

ey in E = 260.80 and C. The calculator is now ready to egin calculating payloads.

he payload at T.P. 6 is calculated first because it illustrates hat happens when a haulback is required. The inputs which ollow are the values for that terrain point.

ey in d = 917.90 and Enter ↑

ey in y = 339.62 and D.

ey in v = 0.50 and Enter ↑

ey in h = 0.02 and E. The calculator should display $W_n(T_1)$ = 0.00. This means that a haulback is required t this load point to maintain carriage stability. To calculate $W_n(T_1)$:

ey fD. The calculator should display $W_n(T_1)$ = 48028.95.

ey fE. The calculator should display $W_n(T_4)$ = 3866150.98. t should be emphasized that the only time it is necessary to ey fD to determine $W_n(T_1)$ is when the display from Key E s 0.00. The display from Key fE is $W_n(T_4)$ when the 0.00 is isplayed.

he basis for using this procedure is that it is often difficult o determine whether a mainline or haulback is necessary, specially for "downhill" yarding under partial-suspension onditions. Payloads calculated by assuming that a mainline s used when a haulback is required are not valid and vice ersa. This way the user not only has valid payloads, but lso knows whether a mainline or haulback, or both, are equired on a particular profile.

The payload for each load point for which capability is to be determined is found by inputting d and y (Key D), then inputting the load factors and calculating $W_n(T_1)$ (Key E) (or Key fd, as appropriate), and then calculating $W_n(T_3)$ or $W_n(T_4)$ (Key fE). This is shown for T.P. 5 as follows:

Key in d = 753.80 and Enter ↑

Key in y = 332.75 and D.

Key in v = 1.00 and Enter ↑

Key in h = 0.00 and E. The calculator should display $W_n(T_1)$ = 19625.06.

Key in fE. The calculator should display $W_n(T_3)$ = 131099.13.

The procedure is repeated for each load point for which capability is to be determined. The values for the remaining terrain points are shown below:

Terrain point	$W_n(T_1)$	$W_n(T_3)$ or $W_n(T_4)$
2	94447.92	18108.43
3	31722.79	28258.11
4	20031.90	52228.31
5	19625.06	131099.13
6	48028.95	3866150.98

In the previous examples it was assumed that the user started out without having previously input any of the parameters. If previous correct values were input, it is not necessary to re-enter them. This is particularly useful when going on to analyze another profile or changing the position of the yarder or tailhold or heights without changing yarder specifications. However, when at least one value, which is input with a particular key, is to be changed, all the values input with that key must be entered whether they change or not. For example, to increase the tailtree height to 20 feet without changing the location, it would be necessary to re-enter the location along with the changed height. If they aren't re-entered, erroneous values will be entered for its location. After changing any values, the load point (Key D or fC, whichever is appropriate) must be re-entered as well, even if it does not change. The load factors must always be input before Key E is used to calculate $W_n(T_1)$.

Note, also, that the inputs with Keys A and B can be made after the inputs with Keys fA and fB. This is so that E can be determined and adjustments made to the allowable tensions of the yarder when it is below the tailhold. All other inputs should be made in the specified order or erroneous answers will result.

Appendix 4
Equations

Cable Geometry

Live and running skyline. Given the coordinates and heights of the yarder, tailtree, and load point (Fig. 1) the cable geometry parameters L, E, d, and y are determined by the following equations:

$$L = (X_T - X_Y) \qquad (1.1.0)$$

$$E = (Y_Y + h_Y) - (Y_T + h_T) \qquad (1.2.0)$$

$$d = (X_T - X_L) \qquad (1.3.0)$$

$$y = (Y_Y + h_Y) - (Y_L + h_L) \qquad (1.4.0)$$

Standing skyline. The skyline length that allows passage of the carriage at exactly the required clearance at any trial load point is:

$$L_s = [(d)^2 + (y_t)^2]^{1/2} + [(L-d)^2 + (y_t - E)^2]^{1/2} \qquad (1.5.0)$$

where L, E, d, and y_t are given by equation 1.1.0 through 1.4.0, respectively. The difference between y and y_t, which are both given by equation 1.4.0, is that y_t is only a "trial" value for a standing skyline. The actual value of y is determined after the limiting skyline length ($\overline{S}_o$) is determined.

The skyline length given by equation 1.5.0 is the sum of two straight line cable segments. The difference between this length and the more accurate catenary length is insignificant for cables tensioned to about one-third of their breaking strength. As a result of this simplifying assumption, the error is less than the error that is introduced as a result of temperature differentials.

The limiting skyline length, $\overline{S}_o$, is determined by using equation 1.5.0 to calculate L_s for several points, and the shortest of these is $\overline{S}_o$. After the limiting skyline length is determined the following system of equations is used to solve for the cable geometry parameter, y.

$$y = \tfrac{1}{2}\left[E(1+\xi\eta) + L[(\xi^2-1)(1-\eta^2)]^{1/2}\right] \qquad (1.6.0)$$

where

$$\xi = \frac{\overline{S}_o}{(L^2 + E^2)^{1/2}} \qquad (1.6.1)$$

$$\eta = \frac{-b \pm \sqrt{b^2 - ac}}{a} \qquad (1.6.2)$$

$$a = \xi^2 + \frac{E^2}{L^2}(\xi^2 - 1) \qquad (1.6.3)$$

$$b = \xi\left(1 - \frac{2d}{L}\right) \qquad 1.6.4)$$

$$c = \left(1 - \frac{2d}{L}\right)^2 - \frac{E^2}{L^2}(\xi^2 - 1) \qquad (1.6.5)$$

The sign of the radical in equation 1.6.2 is the same as the sign of the elevation difference, E.

Log Geometry

The log geometry is specified for the sole purpose of determining the partial suspension load factors, which are given by the following equations:

$$v = \frac{\tan\alpha\,(\sin\theta + \mu\cos\theta)}{(\cos\theta - \mu\sin\theta) + \tan\alpha\,(\sin\theta + \mu\cos\theta)} \qquad (2.1$$

$$h = \frac{\sin\theta + \mu\cos\theta}{(\cos\theta - \mu\sin\theta) + \tan\alpha\,(\sin\theta + \mu\cos\theta)} \qquad (2.2$$

Before equations 2.1.0 and 2.2.0 can be solved the angle from the horizontal to the choker, α, must be known. This is done with an iterative procedure for the simultaneous solution of equations 2.3.0 and 2.4.0.

$$\alpha = \tan^{-1}\left[2\tan(\theta+\beta) + \frac{\cos\theta - \mu\sin\theta}{\sin\theta + \mu\cos\theta}\right] \qquad (2.$$

$$\beta = \sin^{-1}\left[\frac{y_c\cos\theta - l_c\sin(\alpha-\theta)}{l_\ell}\right] \qquad (2.$$

Equation 2.3.0 is valid only if the ground-to-log angle, β, i greater than zero (Carson 1975). For yarding situations where this angle is zero, the choker angle can be determin directly from equation 2.5.0.

$$\alpha = \sin^{-1}\left(\frac{yc}{l_c}\cos\theta\right) + \theta \qquad (2.5$$

The carriage clearance, y_c, used in equations 2.4.0 and 2.5. for the live and running skyline is the same as the minimum required load clearance, h_L. For the standing skyline, y_c is taken to be equal to the variable load clearance, h_L, given b equation 2.6.0.

$$h_L{}' = (Y_y + h_y) - (Y_L + y) \qquad (2.6.$$

where y is from equation 1.6.0.

The equations giving the load factors, v and h, were generated by assuming a homogenous, cylindrical column of negligible diameter to length ratio. The error introduced is minimal compared to the uncertainty of the log's weight distribution, the leading end, the choker placement, and scale allowance for log length.

...load Calculations

...e payloads that will cause the tensions to reach the allow... e limit are given by the following systems of equations for ...ning skylines and for live and standing skylines when a ...inline is needed for carriage control.

$$(T_1) = \frac{(V_1 + fV_2) - \frac{y}{d}(H_1 - fH_2) - W_c - \frac{W_3}{2}}{[v - (\frac{y}{d})h]} \qquad (3.1.0)$$

$$= \frac{2T_1{}^c\omega_1 y + \omega_1{}^2 y^2 - W_1{}^2}{2W_1} \qquad (3.1.1)$$

$$= [(T_1{}^c)^2 - (V_1)^2]^{1/2} \qquad (3.1.2)$$

$$= \frac{2T_1{}^c\omega_1 (y-E) + \omega_1{}^2 (y-E)^2 - W_2{}^2}{2W_2} \qquad (3.1.3)$$

$$= [(T_1{}^c)^2 - (V_2)^2]^{1/2} \qquad (3.1.4)$$

$$_1 = \omega_1 [(y)^2 + (d)^2]^{1/2} \qquad (3.1.5)$$

$$_2 = \omega_1 [(y-E)^2 + (L-d)^2]^{1/2} \qquad (3.1.6)$$

$$_3 = \omega_3 [(y)^2 + (d)^2]^{1/2} \qquad (3.1.7)$$

$$_1{}^c = T_1 - \omega_1 y \qquad (3.1.8)$$

$$_n(T_3) = \frac{V_3 - \left(\frac{V_1 + fV_2}{H_1 - fH_2}\right)H_3 - W_c}{[v - \left(\frac{V_1 + fV_2}{H_1 - fH_2}\right)h]} \qquad (3.2.0)$$

$$_3 = \frac{2T_3{}^c\omega_3 y + \omega_3{}^2 y^2 - W_3{}^2}{2W_3} \qquad (3.2.1)$$

$$_3 = [(T_3{}^c)^2 - (V_3)^2]^{1/2} \qquad (3.2.2)$$

$$T_3{}^c = T_3 - \omega_3 y \qquad (3.2.3)$$

The following expressions yield the payloads when a haulback is needed on live and standing skylines.

$$W_n(T_1) = \frac{(V_1 + V_2) + \left(\frac{y - E}{L - d}\right)(H_1 - H_2) - \frac{W_4}{2} - W_c}{[v + \left(\frac{y - E}{L - d}\right)h]} \qquad (3.3.0)$$

$$W_n(T_4) = \frac{V_4 + \left(\frac{V_1 + V_2}{H_1 - H_2}\right)H_4 - W_c}{v - \left(\frac{V_1 + V_2}{H_1 - H_2}\right)h} \qquad (3.4.0)$$

$$V_4 = \frac{2T_4{}^c\omega_4 (y-E) + \omega_4{}^2 (y-E)^2 - W_4{}^2}{2W_4} \qquad (3.4.1)$$

$$H_4 = [(T_4{}^c)^2 - (V_4)^2]^{1/2} \qquad (3.4.2)$$

$$W_4 = \omega_4 [(y-E)^2 + (L-d)^2]^{1/2} \qquad (3.4.3)$$

$$T_4{}^c = T_4 - \omega_4 y \qquad (3.4.4)$$

The value for the variable f is 1 for live and standing skylines, 2 for running skylines. Some of these equations are based on certain simplifying assumptions similar to the "rigid link" analyses (Carson 1976). However, the errors involved for the vertical and horizontal forces are considerably less and the expressions are much easier to work with. The greatest error is introduced by equations 3.2.0 and 3.4.0 because they assume that the supporting line tension is at the specified allowable tension, but the supporting line tension may be considerably more or less. However, because only the angles at which they act are involved, the error is usually less than about 2 percent.

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Falk, Gary D.
1981. Predicting the payload capability of cable logging systems including the effect of partial suspension. Northeast. For. Exp. Stn., Broomall, Pa.
29 p. (USDA For. Serv. Res. Pap. NE-479)

A systematic procedure for predicting the payload capability of running, live, and standing skylines is presented. Three hand-held calculator programs are used to predict payload capability that includes the effect of partial suspension. The programs allow for predictions for downhill yarding and for yarding away from the yarder. Equations and the basis principles involved in analyzing skyline systems for allowable payload are presented.

375.1

Keywords: cable logging systems, yarding

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

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Cavities in Trees Around Spring Seeps in the Maple-beech-birch Forest Type

Andrew B. Carey
and William M. Healy

The Authors

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Abstract

We examined 913 trees of 15 species in the vicinity of eight spring seeps in a second-growth maple-beech-birch forest. We found that 18 percent of the trees had large dead limbs that indicated top rot. We found 37 cavities in 27 trees (3.0 percent). However, only seven cavities were being used by wildlife in September and mice (*Peromyscus* sp.) used these as dens. The low density of cavities was not sufficient to maintain "fair" populations of cavity-nesting birds, and cutting trees to improve the seeps for wildlife would have little overall effect on cavity-using wildlife.

roduction

ities and Wildlife

ities in trees provide shelter for 60 species of central palachian birds and mammals. Animals such as pileated odpeckers (*Dryocopus pileatus*), raccoons (*Procyon or*), great-creasted flycatchers (*Myiarchus crinitus*), and thern flying squirrels (*Glaucomys volans*) use tree cavities roosts, nests, dens, or food caches.

mation of a tree cavity begins with an injury or the ural pruning of a branch. Infections by fungi and other croorganisms follow, and eventually an animal excavates decayed wood to produce the cavity (Baumgartner 1939 l Hansen 1966). Despite the importance of tree cavities to dlife, little is known about the distribution and abundance trees that contain cavities or the decayed wood substrate cavity-excavating wildlife.

ore information is available on cavities and decay in the k-hickory forest type (Hepting et al. 1940, Dalke 1948, lig 1956, Gysel 1961, Trimble 1963, Hansen 1966, Berry 69, Berry and Beaton 1972, Sanderson et al. 1975, and rry and Lombard 1978) than for maple-beech-birch forests hlig 1956), which comprise 14 percent of the forests in ntral Appalachia. The available information on cavities and cay was not collected for quantifying a feature of wildlife bitat, and thus, it is inadequate.

ata on cavities and decay as elements of wildlife habitat are ow being collected by the USDA Forest Service, North-stern Forest Experiment Station's forest survey teams Barnes 1979). But specific information is still needed for tes with exceptionally high value for wildlife.

pring Seeps

pring seeps are important components of the winter habitat f wild turkeys (*Meleagris gallopavo*) and to a lesser extent enefit many other species of wildlife in the maple-beech-irch forest. Yet, there are few guidelines for managing this nportant resource. The major value of seeps is that they in-rease snowmelt, thereby providing snow-free areas to turkeys and many other ground feeders when other areas are inaccessible. They also provide abundant food because their bowl shape serves as a seedtrap (Healy 1977). We have hypothesized that removing or reducing tree cover can enhance snowmelt, and thereby increase the value of seeps for many wildlife species.

Problem and Objectives

The age of a forest stand, distribution of tree diameters, amount of decaying wood, and prevalence of tree cavities are directly related. It takes from 30 to 60 years to produce dead limbs that are large enough to start the cavity-forming process (Baumgartner 1939). The presence of large dead limbs is a good external indicator of top rot (Baumgartner 1939 and Hepting et al. 1940) and, therefore, of substrate for cavity excavators and potential for cavity formation. However, rot is not always present when large dead limbs are present. Tree removal to enhance snowmelt could decrease the actual and potential number of cavities in the vicinity of the seep. Our objectives were to describe the distribution and abundance of potential cavity trees in second-growth maple-beech-birch forests and to determine if the removal of tree cover to enhance snowmelt would eliminate substantial numbers of cavities.

Study Area and Methods

A broad area of maple-beech-birch forest southeast of Elkins, West Virginia, was searched for seeps. A 25 x 40 m (0.1 ha) rectangular plot was surveyed around the head of each of eight randomly selected seeps. The seeps were located near the base of a major slope, aspect was generally southwest, and slope ranged from 9 to 28 percent. The stands were from 55 to 69 years old. Tree species, crown position, stem decay class, diameter breast height, and number of cavities visible from the ground were recorded for all trees over 5 cm dbh. Decay classes (indexes of potential for cavity formation) were: (1) no dead limbs 5 cm in diameter or greater, (2) one or two dead limbs 5 cm in diameter or greater, (3) three or more dead limbs 5 cm in diameter or greater, (4) portion of the tree trunk dead, and (5) tree dead. All trees were felled and examined for cavities. Interior dimensions, location, origin, and use by vertebrates was recorded for each cavity.

Results

Tree Species Abundance

We examined a total of 913 trees of 15 species (Table 1). In descending order, the abundant species were: sugar maple, red maple, black cherry, American beech, yellow birch, red spruce, and serviceberry. Although the forest has been under even-age management, the distribution of tree dbh was J-shaped (Leak 1964, 1965). The J-shaped distribution was due to the relative abundances of tree species with different silvical characteristics, particularly shade tolerance and growth rates. Shade tolerant, slow-growth species (sugar maple, red maple, American beech) (Trimble 1975) were more abundant than the faster growing species of intermediate (yellow birch) and low (black cherry) shade tole ance, in addition, serviceberry is not only intermediate i shade tolerance, but also does not grow as large as the ot species. The tolerant species tended to follow the J distri tion; most of these trees had dbh's of less than 10 cm (fc example, 60 percent of the American beech). Black cher diameters followed a symmetrical distribution with a me dbh of 23.3 ±8.2 (SD) cm. The resulting joint distributio was J-shaped (Fig. 1).

Table 1.—Numbers and diameters of tree species examined around spring seeps in West Virginia in 1979

Species	Number of trees >5 cm dbh	dbh (cm)		
		$\overline{X}$	SD	Maximum
Sugar maple *Acer saccharum*	233	11.3	5.7	47.5
Red maple *Acer rubrum*	173	13.4	5.9	40.0
Black cherry *Prunus serotina*	116	23.3	8.2	47.3
American beech *Fagus grandifolia*	111	13.1	10.3	51.9
Yellow birch *Betula alleghaniensis*	98	16.3	11.2	87.5
Red spruce *Picea rubens*	54	26.1	12.4	54.6
Serviceberry *Amelanchier* spp.	48	10.5	3.9	19.1
White ash *Fraxinus americana*	21	15.7	7.4	34.2
Eastern hemlock *Tsuga canadensis*	16	13.9	9.3	38.4
Sweet birch *Betula lenta*	16	16.8	6.5	30.0
Pin cherry *Prunus pensylvanica*	8	9.7	3.8	15.8
Cucumbertree *Magnolia acuminata*	8	21.8	9.1	35.5
Witch-hazel *Hamamelis virginiana*	6	5.5	0.4	6.1
Striped maple *Acer pensylvanicum*	3	8.2	3.1	11.8
Fraser magnolia *Magnolia fraseri*	2	11.2	0.4	11.4

Variability Among Seeps

Among the seeps, mean dbh ranged from 11.2 to 20.4 cn the number of trees greater than 5 cm dbh ranged from 8 to 1700 per ha; and the relative abundance of the tree sp differed (Table 2). The seeps selected for study were ran ly chosen from a large number of known seeps that were generally found in a characteristic topographic position. feel that the variability observed among the study seeps v characteristic of the maple-beech-birch forest in central Appalachia and was not a result of selecting particular se

Decay Class dbh Distributions

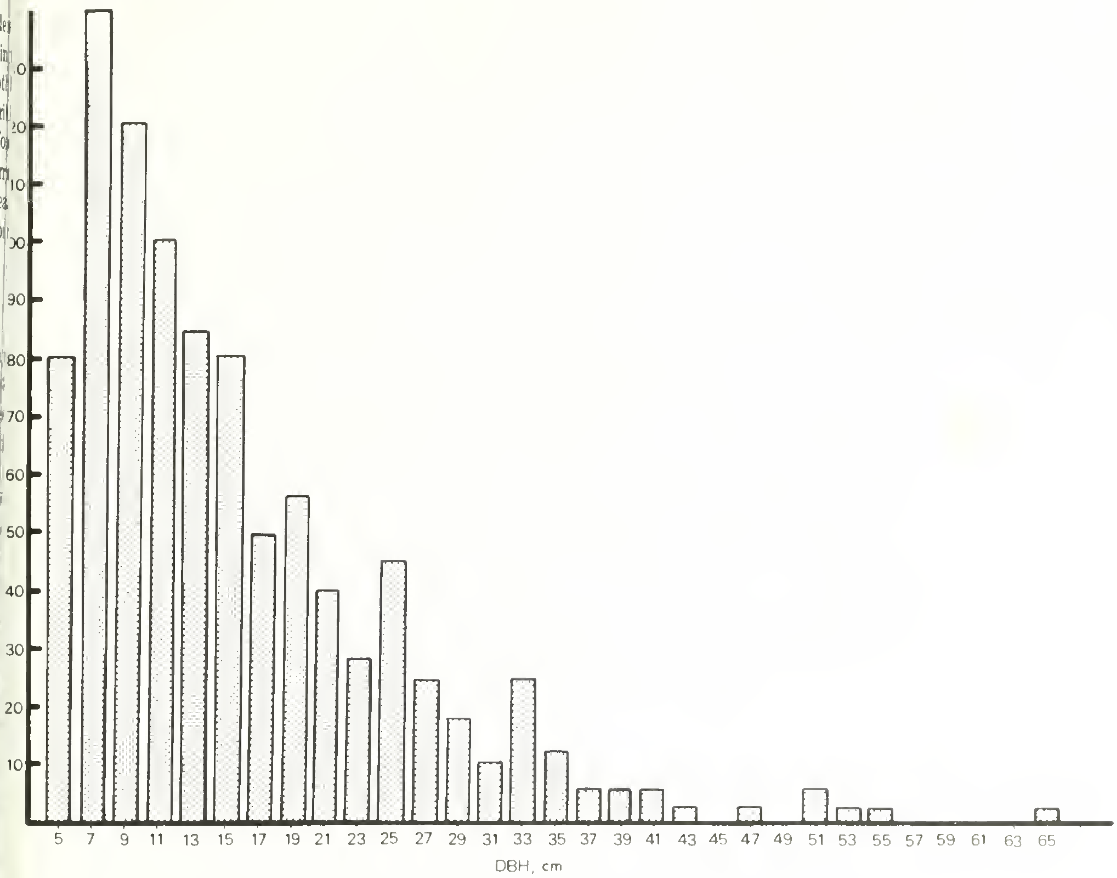
The distribution of the dbh of trees without large dead li (Fig. 2A) was J-shaped and similar to the overall dbh dist bution (Fig. 1). Sugar maple (195 trees), red maple (140 trees), and American beech (90 trees), all shade-tolerant species, were the most abundant species in this class. Tree with one or two large dead limbs were fewer, roughly distributed by dbh (Fig. 2B), and most were black cherry (5 of the 133 trees in the class). Trees with three or more lar dead limbs were few (32 trees) (Fig. 2C), and most were black cherry; a few large American beech and yellow bircl left after the regeneration cut, were also in this class. Onl six trees had portions of their trunks dead; these trees we all suppressed and less than 12 cm dbh. The dbh of dead trees (105 trees) followed a J-shaped distribution; most (9) were less than 15 cm dbh.

Trees with Cavities

We found 37 tree cavities: 23 trees had 1 cavity, 2 had 2 cavities, 1 had 4 cavities, and 1 had 6 cavities (some in lar branches). Twenty-four cavities were due to natural pruni of branches, five were due to mechanical damage, one to fire, and seven to heart rot of unknown etiology. Twenty- e cavities were too small to be used by vertebrates, three we useful as refuges, two had been used as dens, and seven we being used as dens by white-footed mice. When one large American beech (50.6 cm dbh) with four cavities was felle at least five white-footed mice fled the tree. Twenty-five trees with cavity entrances less than 8 cm in diameter had mean dbh of 22.4 cm; one tree (American beech) with a

(Text con't on pg. 6

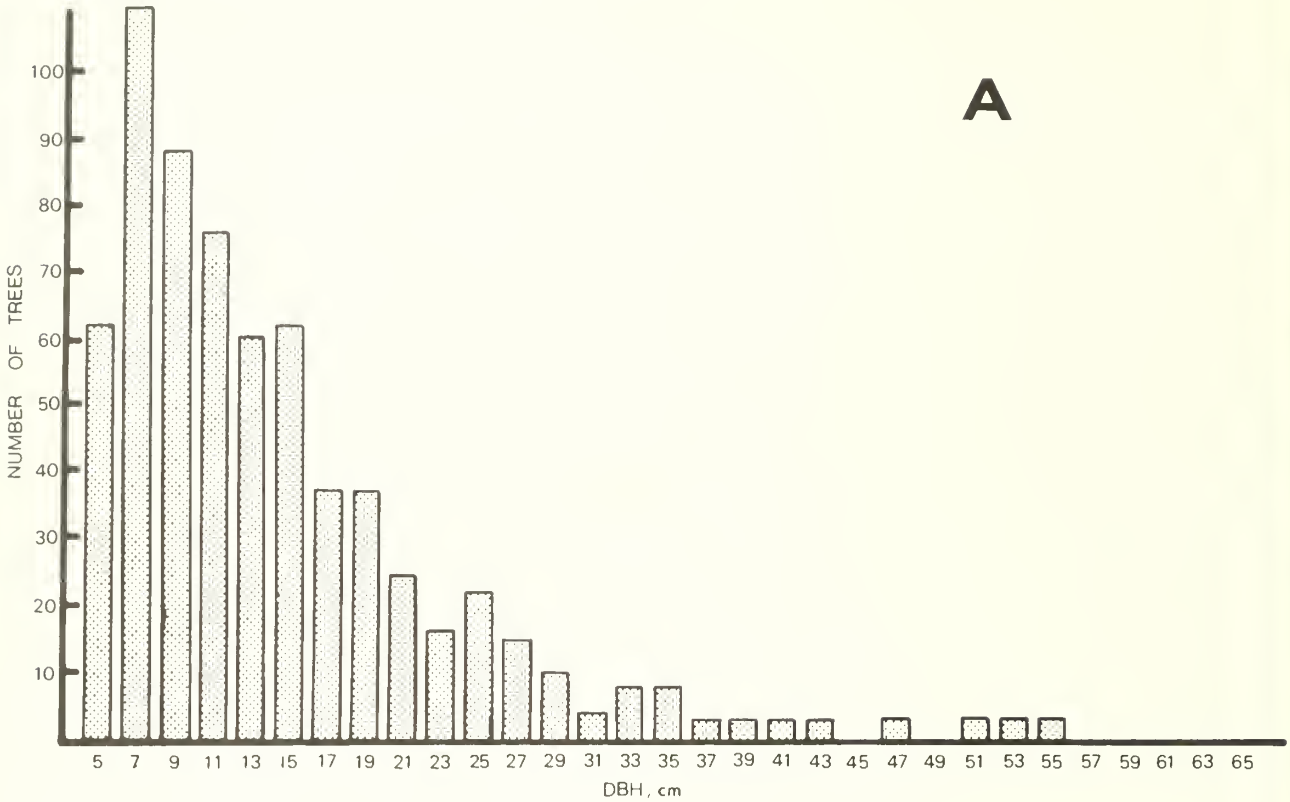
ure 1.—Distribution of dbh for 913 trees examined around eight seeps in a 55 to 70- -old maple-beech-birch forest.

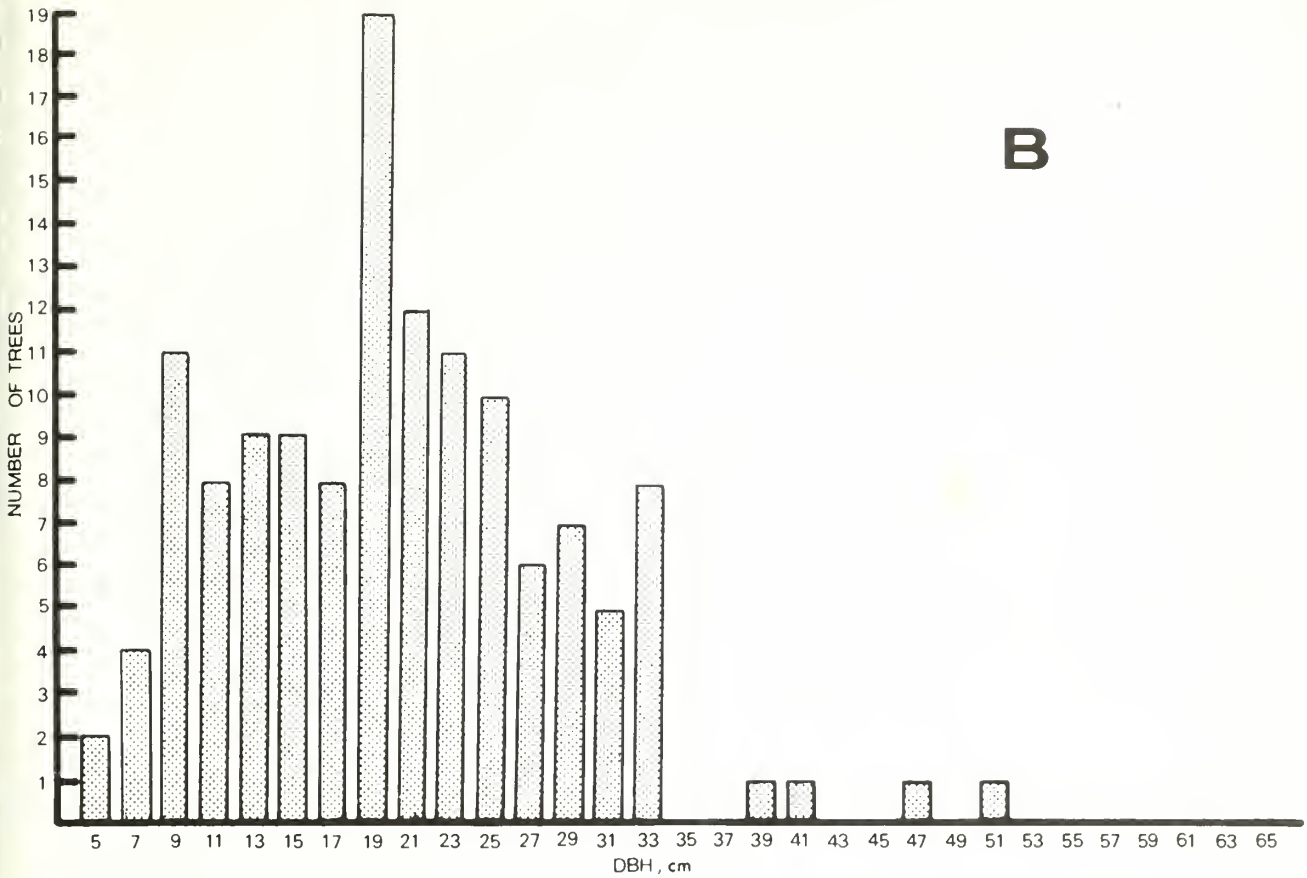


able 2.—Characteristics of eight seeps (0.8 ha) in a 55-to-70-year-old maple-beech-birch forest

Seep	Trees >5 cm dbh, per 0.1 ha plot	dbh (cm)			Aspect (% slope)	The three most abundant species
		$\overline{X}$	SD	Maximum		
52	102	11.2	5.3	33.6	SW (9)	serviceberry, yellow birch, red maple
55	126	15.9	8.6	47.3	SW (12)	sugar maple, black cherry, yellow birch
58	137	12.1	6.3	31.8	SW (10)	sugar maple, red maple, American beech
60	119	15.2	11.4	87.5	SSE (11)	sugar maple, yellow birch, red maple
81	84	18.2	10.5	41.1	WSW (18)	American beech, red spruce, black cherry
86	91	17.1	11.4	50.5	WSW (12)	American beech, red spruce, black cherry
94	84	20.4	11.7	54.6	SSE (28)	red spruce, red maple, American beech
97	170	13.9	6.7	38.4	S (20)	red maple, black cherry, sugar maple
Overall	913	15.1	9.3	87.5	SW (15)	sugar maple, red maple, black cherry

Figure 2.—Dbh distribution for three decay classes: A—No dead limbs >5 cm. B—One or two dead limbs >5 cm. C—Three or more dead limbs >5 cm.





B
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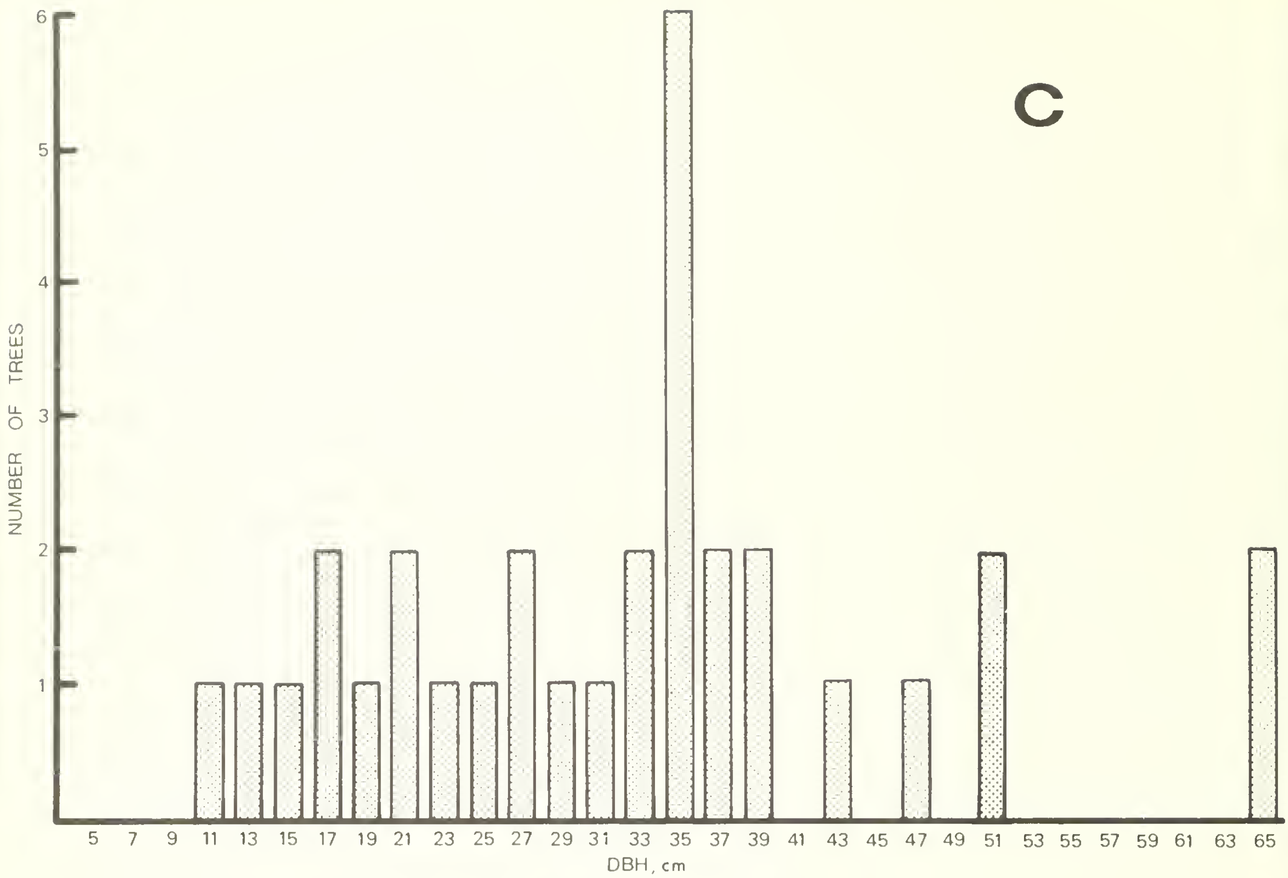
DBH, cm



cavity entrance between 8 and 15 cm in diameter was 28.6 cm dbh; and three trees (two yellow birch, one American beech) with cavity entrances larger than 15 cm in diameter averaged 69.5 cm dbh and had at least three dead limbs.

Conclusions

Cavities and Wildlife

Cavities and potential cavities were rare around seeps in the 55- to 70-year-old maple-beech-birch forest. The density of cavities was 46/ha, but only 15/ha were large enough to be used by vertebrates. Only 3 percent of the trees had three or more large dead limbs, and only 29 of the 913 trees contained useful or potentially useful cavities. If trees had not been left standing in the last regeneration cut, there would have been even fewer cavities. In addition, most of the standing dead trees were small, providing feeding, but not nesting, substrate for the insectivorous cavity-using birds. If we assume that seeps represent the general forest, there exists little opportunity for cavity-dependent wildlife in this forest. Our limited samples suggest that seeps comprise less than 1 percent of the general forest area, but occur at a frequency of 6 to 20 seeps per km^2. The density of trees with cavities or with decayed wood substrate suitable for cavity excavation is far below the 50 snags larger than 15 cm dbh per hectare required to maintain "fair" populations of cavity-using bird Around 70 snags per ha are required for "good" population (Evans and Conner 1979). We found no cavities suitable as dens for squirrel-sized or larger mammals. Seep managemen therefore, would have little immediate effect on cavity-usin wildlife, especially if the scattered residual trees were left.

Potential for Cavities

The distribution of dbh by decay class (Fig. 2) suggests that the 30 to 60 years suggested by Baumgartner (1939) as necessary for trees to produce rotten limbs that are large enoug to initiate the cavity formation process may be too short a time for the maple-beech-birch forest type. After 55 to 70 years of growth, the fastest growing species, black cherry, had an average diameter of 23.3 cm, and 95 percent had a dbh less than 34 cm—the median size of trees with three or more large dead limbs. Baumgartner (1939) estimated that between 8 and 30 years are required from the death of a large limb to the final hollowing of the tree trunk. Thus, it would appear that another two decades of growth would be necessary before populations of cavity-using wildlife would be fair to good.

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Keywords: Cavities; seeps

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Soil Temperatures under Urban Trees and Asphalt

by Howard G. Halverson
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Abstract

Summer temperatures under trees planted in holes cut through an asphalt cover in a parking lot and in soil beneath the surrounding asphalt were higher than soil temperatures under trees at a control site. Winter minimums were not different, but maximum summer temperature exceeded the control by 3°C beneath the parking lot trees and up to 10°C beneath the asphalt cover at a depth of 15 cm below the surface. Horizontal and vertical soil temperatures varied little at a given time within each type of site. Asphalt covering the soil not only increased maximum temperatures through a 60-cm profile, but apparently increased the rate of heat exchange since temperatures in the covered soil rose and fell more rapidly than control soil temperatures. The soil, even when covered, could be a sink or source of excess heat exchange in the urban energy balance.

oduction

soil temperature, as well as the rate and direction of heat sfer, is important to those managing urban forest vegeta- or concerned with trends and modeling of urban cli- e. Heat and moisture are transferred simultaneously in soil, especially near the soil surface. This can affect tree er stress by changing the distribution of soil water and water demand of trees. Sap velocities in an urban honey- ıst were shown to be 10 percent greater than sap veloc- ; in a suburban tree (Christensen and Miller 1979), indi- ng greater water use by the urban tree. Evapotranspira- ı from urban grass was shown to exceed potential rates by ›ut 30 percent (Oke 1979). These authors attributed ex- s water demand to advected sensible heat in the atmo- ıere over impervious surfaces. However, soil can be a major k or source of energy during the different seasons and may o act to modify the urban climate. Extreme soil temper- ıres can be lethal to vegetation. Consequently, urban soil nperatures have significant impacts both on the urban en- onment and on urban forests.

›rest soil temperatures are responsive to many environ- ental factors. Soil temperatures are known to be changed moisture conditions (Leonard et al. 1971, Willis et al. ›77). Bocock and his coworkers (1977) derived good pre- ctive equations for forest soil temperatures from air temp- ature, wind, solar radiation, and precipitation data. How- /er, the impact of an asphalt cover on forest soil temper- ures has not been investigated.

arking lots are a significant portion of urban areas. Shop- ing centers, for example, require three to four times as uch parking space as retail space (Lull and Sopper 1969). he urban lots have little aesthetic appeal, and trees are often lanted to improve their appearance and thermal comfort. lowever, urbanization may create a difficult environment or forest vegetation. Himelick (1976) lists insufficient soil ıoisture, nutrient deficiencies, and pollution, as well as ısect and disease problems, as urban stress factors. Both oil moisture and soil temperature stresses could be in- reased by development.

he purpose of this study was to examine soil temperature t an urban forest site and determine whether soil temper- tures were strongly influenced by one form of development, n asphalt cover. The temporal distribution of temperature important, as well as the maximum and minimum temp- ratures and the rate of temperature change in the soil. In this study, we measured temperatures in the soil beneath 8 newly-established trees at a control site, beneath 32 similarly established trees in an adjacent parking lot, and at three points in the soil beneath the asphalt cover of the lot. The composite of trees on the lot could be considered to be an urban forest or a portion thereof.

Study Site and Procedures

The study site was on and near a university parking lot at New Brunswick, New Jersey (lat. 40°29′N, long. 74°26′W). The lot was 192 m by 50 m, only slightly less than a hectare. The lot slopes slightly eastward, across the narrow dimension, to promote drainage.

Three years after its construction, the lot underwent a major modification to improve its aesthetic value. In April of 1976, 32 gaps spaced about 18 m apart, each approximately 2.5 m square, were cut through the surface of the asphalt, and 32 trees were planted on the site. The aggregate of these 32 trees was our urban forest for soil temperature measurements. The control site consisted of 8 additional trees planted in an undisturbed area about 4 m from the lot. Planting material consisted of 5-year-old red maple (*Acer rubrum* L.) and green ash (*Fraxinus pennsylvanicum* L.) saplings, half bare root and half with a soil ball around the roots. Each parking lot and control planting location was curbed with railroad ties and backfilled to a level 10 to 15 cm above the surrounding surface. The fill gradually settled, and a thin layer of wood chips was added to control weeds.

The Soil

The soil exposed for planting beneath the lot cannot be described in the usual manner, because it had been disturbed by development activities. The parent soil is a somewhat poorly drained variant of the Nixon series in Middlesex County, NJ (U.S. Soil Conservation Service 1976). The topsoil in the series is usually about 30 cm deep and is classified as a silt loam. The subsoil, from about 30 to 84 cm deep, is higher in clay and is a silty clay loam. Depth to the water table was about 60 cm, so lower soil levels were frequently saturated.

During construction of the parking lot, roughly 50 cm of soil was removed from the site. There was some deeper disturbance to install utilities in parts of the area. The soil was not replaced; rather, a layer of coarse sand was spread over the remaining subsoil. The sand was capped with a 15-cm layer of asphalt.

The soil was completely changed during development of the lot. As shown in Table 1, the original horizons were destroyed, texture was changed, and pH was altered. The sand layer, although spread between 20 and 50 cm below the original surface, affected all layers in the soil, probably by mixing during construction activities. A new soil profile was created, almost a meter deep, that was unlike the parent profile.

The control trees were planted off the edge of the lot, sufficiently separated so that the Nixon soil was not disturbed by construction.

Table 1.—Physical properties of the undisturbed and disturbed soils

Property	Undisturbed soil adjacent to the lot depth, cm		Disturbed soil beneath lot approximate depth, cm		
	0-30	30-84	0-20	20-50	50-84
Percent sand	35	6	40	85	65
Percent silt	50	59	32	10	10
Percent clay	16	35	28	5	25
pH	6.8	5.0	5.4	5.9	5.4

Instrumentation

During and after tree planting in 1976, instruments were added to measure both soil moisture and soil temperature. The basic instrument chosen was the double-junction thermocouple psychrometer. One junction was used for soil water potential determinations and the second for soil temperature measurement.

The surface above the sensors was shaded by the tree crown, but the shadows were small and probably had little, if any, significant effect on soil temperatures at the depths of our measurements. Also, all temperatures we measured would have been influenced about equally by shade.

Eight of the openings that had been created in the lot surface were selected randomly for intensive instrumentation. At these points, a series of three psychrometers was installed at 15, 30, and 60 cm below the bottom of the railroad ties. We did not use the existing fill surface as a depth reference because settling caused changes in the surface elevation. These psychrometers were in the tree root zone but offset approximately 38 cm from the tree bole; in fill material around the trees that were planted as bare root stock and on a vertical line tangent to the soil ball on trees planted as balled stock. At three of the eight locations, psychrometers were also installed laterally beneath the asphalt, 30 cm behind the edge of the covering. At each of these locations, three psychrometers were installed at the same depths below the surface of the asphalt as the sensors in the root zone.

Four of the eight control locations were also instrumented with a series of three psychrometers extending through the root zone at 15, 30, and 60 cm below the bottom of the railroad ties, depths equivalent to those used on the experimental site.

Each of the other tree locations on the parking lot and the control area was instrumented with a thermocouple psychrometer in the root zone 30 cm below the surface. During the summer, soil moisture tensiometers were installed at five parking lot tree locations when soil water potential was above the range where psychrometers are reliable (-1 bar). Three locations on the lot and one control location were also instrumented with ground water observation wells to follow changes in water table elevation.

Because of changes in the soil surface caused by fill added after planting and settling around the trees, the psychrometers in the root zone were not exactly the same distance below the surface as the psychrometers below the asphalt. The depth discrepancy was not considered a major shortcoming since the study objective was to determine the impact of the asphalt, rather than to document the vertical temperature profile.

Temporal Sampling

All of the instrumentation (except the tensiometers) was installed and had equilibrated by mid-November 1976. Sampling began in mid-November and continued until January 1, 1978. Temperature and moisture determinations were scheduled weekly, although adjustments had to be made on some occasions. Readings were taken during a one-hour period near midday.

Of the 73 psychrometers installed, one failed shortly after installation, and a second was vandalized in May 1977. The remaining sensors were operative during the entire 58-week period. Soil water potential and soil temperature values were read from the psychrometer junctions with a Wescor HR-33 microvoltmeter.[1] Accuracy of the equipment for temperature measurement was ±0.5°C.

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

ults

Water Regime

water table below the lot remained relatively stable, ough there was some fluctuation with precipitation ble 2). The five wells that were installed varied in absolute ation by about a meter, owing to fluctuations in lot sur- elevation. Only one well, the lowest, reached the water le during the entire growing season; it was monitored to ermine the depth to the water table. The other wells, slightly higher in elevation, reached the water table only ermittently and data from them were not included in ble 2. The water table fluctuated at a depth of about 50 below the surface at the lowest well. Depth to the water le before and after the 1977 growing season was about ual to the depths recorded during the growing season.

able 2.—Depth to the water table, precipitation since the preceding measurement date, and average soil water potential beneath parking lot trees measured with tension-meters at five different locations and at 30 and 60 cm below the surface during 1977

)ate	Depth to water table	Precipi-tation	Average soil water potential at:	
			30 cm	60 cm
	- - - - - - - - - *cm* - - - - - - - - -		- - *negative bars* - - -	
-27	50			
'-11	50	2.82	0.06	0.04
'-15	45	5.46	0.04	
'-18	51		0.12	0.07
'-25	58	0.36	0.05	0.09
-26	37		0.04	
-28	46	4.47	0.06	
-1	46	0.15	0.08	0.06
-3	43		0.07	0.05
-5	43		0.06	0.05
-8	49	0.33	0.13	0.06
-12	58	1.47	0.10	0.07
-15	44	5.46	0.05	0.05
-16	46		0.06	0.14
-19	52	0.03	0.10	0.14
-23	54	0.33	0.09	0.14
-29	52	4.47	0.06	0.10
-19	50	2.67	0.07	
-26	35	9.30		
0-3	42	0.66		
0-17	44	6.10		
0-31	78	3.20		
1-21	60	14.66		
1-28	45	3.76		

Soil water potential at the parking lot tree site also remained high. On only one date, 11 July 1977, and then at only one of 32 locations, was a water potential less than -1 bar recorded. Otherwise, soil water potential varied between -0.03 and -0.37 bars (Table 2). Soil water potentials at the control site and beneath the asphalt never indicated a water potential less than -1 bar. We therefore assumed that the soil moisture regime was the same at all sites, although there were small differences among the planting locations on the parking lot.

Soil Temperature

The mean soil temperatures for the soil below the parking lot trees and the asphalt were compared with those under the control trees by linear regression for each depth. Soil temperature was significantly higher under the parking lot trees than in the control site, as illustrated by the regression coefficients (Table 3). All slopes were different from unity. The comparisons for each depth showed a definite relationship among the temperatures at the site, with correlation coefficients greater than .99. Under the asphalt, temperatures rose more quickly and to higher maximums, as shown by the greater slopes. Correlations between control and asphalt-covered sites were between .94 and .98.

The correlation coefficients showed a temperature relationship between the control and the other sites, but an analysis of covariance showed that the individual regressions were not significantly different.

Table 3.—Linear regression statistics relating mean urban soil temperatures for a given depth to soil temperatures at a control site based on the model $y = a_0 + b_1x$, where x is the mean soil temperature at the control site at the same depth.

Depth (cm)	Sample size	Intercept a	Slope b	Standard error	Correla-tion r
		PARKING LOT TREE SITE			
15	43	0.23(.09)[a]	1.09(.01)[a]	0.34	0.996
30	43	0.11(.13)	1.12(.01)	0.46	0.998
60	43	0.02(.12)	1.15(.01)	0.38	0.999
		ASPHALT-COVERED SITE			
15	42	0.83(1.05)	1.29(.07)	3.91	0.940
30	42	-0.13(.63)	1.25(.04)	2.13	0.976
60	42	-0.02(.50)	1.24(.04)	1.62	0.984

[a]standard error of coefficient in parenthesis

Although the regressions are not statistically different, some trends in the data are as might be expected: Temperatures beneath the asphalt rise faster, and to higher maximums, than soil temperatures at the control or parking lot sites. The parking lot tree site showed an intermediate response, with soil temperatures above those at the control site but below those under the asphalt cover.

There was little variation in temperature among locations within each type of site. As shown in Table 4, soil temperatures at the control points rarely differed by more than 1°C at a given depth, regardless of season. The differences between parking lot tree locations at a given time or depth were almost always less than 2°C during all seasons. Although soil temperatures beneath the asphalt were more variable, the different sites responded in the same fashion, with measured temperature at only one time and depth differing by more than 2°C from the temperatures measured at the other asphalt-covered sites. Among the asphalt-covered sample points, there was also no seasonal trend.

Vertical temperature profiles were also quite uniform, with the majority of mean temperature differences between the upper and lower measurement depth less than 2°C (Table 5). The temperature distribution beneath the asphalt was more variable than at the control and parking lot tree sites, with vertical gradients as high as 8°C.

The information about horizontal and vertical temperature gradients was not examined statistically, because most temperature gradients are within the ±0.5°C range of the thermocouple and reference junction accuracy. However, the results showed that an asphalt cover tends to make soil temperatures more erratic as well as higher during midday.

The impact of covering the soil with asphalt can be seen in data from a period of fluctuating temperatures (Table 6). In mid-April, the soils began to warm rapidly. Control site soil temperatures rose 3 to 4°C in one week and about an additional degree the following week. Vertical temperature differences never exceeded 1°C. The parking lot tree site showed the same pattern, but the increases were about a degree greater. Again, the vertical temperature differences never exceeded 1°C. The asphalt-covered soil showed a 5.5 to 8°C increase the first week, followed by decreases in temperature in the upper levels the second week. By the end of the second week, a uniform vertical temperature pattern had been established. The presence of an asphalt cover apparently accelerated heat exchange.

Although an asphalt cover affected the rate of heat exchange between the underlying soil and the atmosphere, it did not affect the timing of minimum and maximum temperature by

Table 4.—Number of occurrences of soil hori[z] temperature differences between repl at the control, parking-lot-tree, and asphalt-covered sites between 15 November 1976 and 9 January 1978

Depth (cm)	Number of measurement points	Temperature rang	
		<1	1-2
	CONTROL SITE		
15	4	41	2
30	8	43	0
60	4	43	0
	PARKING LOT TREE SITE		
15	8	34	9
30	32	21	20
60	8	35	7
	ASPHALT COVERED SITE		
15	3	30	12
30	3	37	5
60	3	38	3

Table 5.—Number of occurrences of mean soil temperature differences vertically thro[ug] the soil profile from 15 to 60 cm at the control, parking-lot-tree, and asphalt-covered sites between 15 November 1[9]6 and 9 January 1978.

Site	Temperature range, °C						
	<1	1-2	2-3	3-4	4-5	5-6	6-7
Control	22	14	6	1	0	0	0
Parking-lot tree site	20	10	8	5	0	0	0
Asphalt-covered site	12	10	7	3	6	2	0

…le 6.—Average soil temperatures at three sites during a period of temperature fluctuation, in °C

…th (…)	Date		
	4-11-77	4-18-77	4-25-77
	CONTROL SITE		
[illegible]	6.2	10.2	11.1
[illegible]	6.1	9.9	11.1
[illegible]	6.5	9.5	10.8
	PARKING-LOT TREE SITE		
5	7.1	12.2	12.9
0	7.2	11.9	13.4
0	7.6	11.6	13.1
	ASPHALT-COVERED SITE		
5	12.2	20.0	14.2
0	9.7	16.5	14.5
0	9.2	14.7	15.3

Table 7.—Maximum and minimum mean soil temperatures and the date the temperature was recorded

Depth (cm)	Minimum temperature	Date	Maximum temperature	Date
	°C		°C	
		CONTROL SITE		
15	0.8	2-14-77	24.4	7-18-77
30	1.2	2-14-77	23.2	7-18-77
60	2.1	2-14-77	22.5	7-25-77
		PARKING-LOT TREE SITE		
15	0.8	2-14-77	27.1	7-18-77
30	1.2	2-14-77	26.4	7-18-77
60	2.1	2-14-77	25.9	8-15-77
		ASPHALT-COVERED SITE		
15	0.5	2-14-77	34.2	7-18-77
30	1.2	2-14-77	30.7	7-18-77
60	2.0	2-14-77	28.8	7-18-77

ore than a week (Table 7). Minimum temperatures at all tes and all depths were recorded on the same day, 14 February. The temperatures at a given depth did not differ signif- antly among sites, although temperatures at the lowest easurement level were warmer than temperatures near the ırface. Minimum temperatures had been less than 1°C above ıe tabular values for the preceding 4 weeks. Maximum mperatures increased from control to parking-lot-tree to sphalt-covered sites, but most maximums occurred in mid- ıly, regardless of site. At the parking-lot-tree and asphalt- overed sites, the maximum temperature at the lowest depth aried by less than 1°C between mid-July and mid-August, ıd that difference was within the resolution of the thermo- ouples. Increasing urbanization, as represented by increasing mounts of asphalt cover, increased the amplitude of the mperature wave in the soil but did not alter its timing ithin the 15 to 60 cm zone.

onclusions

onstruction activities changed the upper soil horizons in our tudy lot by mixing the soil and adding sand. These activities nd the consequent changes in the soil limited the value of existing soil surveys for describing the soil. Structure, pH, texture, and soil horizons were all altered in the upper level of the soil, which is the most important for vegetation. In this lot, soil moisture remained high in the gaps cut for the trees, probably because of the high water table.

Soil temperatures were altered, both in the parking-lot tree site and under the surrounding asphalt cover. Temperature differences we observed can be categorized into changes in trend, horizontal and vertical distribution, timing of maximum and minimum temperatures, and magnitude of maximum and minimum temperatures. These temperature changes could affect vegetation directly through thermal effects or indirectly by modifying local energy balances in urban forests.

The trend of soil temperatures was clear. If we consider the series from soil beneath off-lot trees, to soil beneath on-lot trees, to soil beneath asphalt, as representing increasing degrees of urbanization, then urbanization results in higher soil temperatures. During winter, at the lowest temperatures, this effect was negligible, but it increased with increasing soil temperatures.

Increased soil temperatures at the parking-lot tree site and under asphalt were well distributed in the soils, both horizontally and vertically. The even temperature distribution is consistent with the conclusion of others that mean soil temperatures do not vary a great deal below 2 inches (Toy et al. 1978).

These results suggest the magnitude of the effect of an asphalt cover on the urban surface energy balance. The properties of asphalt are not well defined, because the composition of the material can vary. However, most thermal properties of asphalt are not greatly different from those of moist soil.

Since temperature fluctuations occur more rapidly under asphalt than in adjacent soil, we conclude that covered urban soil acts as a responsive sink or source of heat in urban environments. The contribution of soils to urban thermal extremes needs additional study.

The thermal responsiveness of the soil resulted in two other effects: Maximum temperatures occurred on all sites in the same week; so did minimum temperatures. Neither the highest nor the lowest temperatures at any site would preclude plant growth, since most plant limits are below freezing or in the 50 to 60°C range (Kramer and Kozlowski 1960). These extremes were never reached, even under the asphalt cover.

The study results and conclusions can be summarized as follows:

1. The urban energy balance is changed by an asphalt covering. Not only the paving, but the underlying soil contributes to increased storage and release of heat.

2. Direct thermal effects on trees were not severe.

3. Asphalt covering increased summer maximum soil temperatures but had no effect on winter minimums.

4. The timing of the annual soil temperature wave was not altered significantly by an asphalt cover, but the amplitude was increased.

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6 p. (USDA For. Serv. Res. Pap, NE-481)

An asphalt cover increased summer soil temperatures throughout a 60 cm profile but did not affect winter soil temperatures. Horizontal and vertical temperatures were consistent within a site type. The rate of heat transfer between the atmosphere and the soil apparently was increased.

114.16

Keywords: thermocouple psychrometer, water potential

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Yield of pallet cants and lumber from hardwood poletimber thinnings

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Abstract

Woods-run bolts in 4- and 6-foot lengths from poletimber stand thinnings were classified into five quality classes, and the absolute sweep was measured for each bolt. Cants 4 by 4 and 4 by 6 inches were sawn from these bolts. The cants were classified by an interim classification system for the production of pallet parts.

In contrast to straight bolts, sweep from 0.6 to 1.0 inches in bolts from 6 to 10 inches in diameter reduces the yield of pallet cants approximately 5 percent; 1.1 to 1.5 inches of sweep reduces the yield approximately 10 percent. The quality mix of pallet cants produced from woods-run bolts is sufficient for commercial pallet production when unsound bolts and those with sweep in excess of 1-1/2 inches are eliminated. No need for a more detailed pallet bolt classification system was indicated.

Cover Photo

Sawable boltwood from thinning Allegheny hardwood stands. The bolts yield a grade mix of parts suitable for commercial pallet production.

RODUCTION

:ribed thinnings in hardwood poletimber stands yield) 70 green tons of wood per acre (Craft and Baumgras }, 1979). Recently 40- to 60-year-old stands in three or hardwood types were thinned on medium to good . Product yields in the following three categories were uated: sawable wood—which includes standard sawlogs boltwood 6 inches or larger in diameter by 4 feet or er and straight enough to produce at least a 4-inch by ch by 4-foot cant of Sound Square Edge (National dwood Lumber Association 1978) or better grade; nd pulpwood from 4 to 6 inches small end diameter; chippable wood (tops and bolewood less than 4 inches iameter). Each product category comprised about one-d of green weight yield in each of the areas thinned.

able wood yields by weight ranged from 25 to 50 per-t of trees removed in the thinnings. This amounted to 00 to 4,500 board feet per acre, Int. 1/4″ log/bolt scale is, or 2,500 to 5,300 board feet per acre of sawed cants l lumber. About two-thirds of the sawable volume was pieces less than 8 feet long; a similar percentage of the able volume was in pieces 10 inches or less in scaling meter.

cause of the prevalence of short lengths and small di-eters, we evaluated the sawable boltwood for use as let parts. This report summarizes the distribution of vbolt quality and the yield and quality of pallet cants at can be expected from thinnings.

TUDY AREAS

wbolts processed in the study were taken from sample ots located in Allegheny hardwood type stands on the onongahela National Forest, in oak-hickory type stands n the Monongahela National Forest and the Jefferson ational Forest, and in oak-hickory and cove types on amp Creek State Forest in West Virginia. A total of 36 udy plots were located to include a variety of site and and conditions.

ROCEDURE

olt Selection

udy plots were marked according to the appropriate anagement guides to improve crop-tree spacing and reduce and density. Trees at least 5.6 inches dbh (diameter breast gh) that were designated for removal were felled and cut to 4-inch diameter top. The full-length stems were skidded to landing and bucked to obtain the highest yield of sawable undwood. The minimum acceptable piece was 6 inches in scaling diameter and straight enough to yield at least a 4- by 4-inch Sound Square Edge cant with a minimum length of 4 feet. The resulting 4- and 6-foot long sawbolts with scaling diameters of 6 to 10 inches were analyzed for this study. Sample bolts were measured for both end diameters (inside bark), total length (including trim allowance), and absolute sweep to the nearest 1/2-inch. Cubic foot volume was determined for each sample bolt.

Bolt Quality Classification

Each bolt was assigned to a quality class, based on the number of "good" faces. For our purpose, a "good" face was defined as one free of defects. Sound knots or limb scars not exceeding one-third of the face width were not considered defects. Bolts with unsound ends (except those with defects within 1 inch of the periphery or within the trim allowance) were considered unusable for pallet stock and tallied separately. Five bolt quality classes were as follows:

Class 4 — bolts with all good faces
Class 3 — bolts with only three good faces
Class 2 — bolts with only two good faces
Class 1 — bolts with only one good face
Class 0 — bolts with no good faces

Bolt Conversion

Each sample bolt was sawn into either a 4- by 4-inch or 4- by 6-inch cant and side lumber. The larger cant was produced whenever possible without exceeding wane limitations. Side lumber was edged to the nearest 1 inch width with wane limited to 1/4 inch on a maximum of two corners. Cant volume was measured by NHLA (National Hardwood Lumber Association) rules. Since 4- and 6-inch widths are the predominant widths used in pallet production, only 4-inch and wider side lumber was tallied as usable for pallets. All 5-inch side lumber was tallied as 4-inch widths and all side lumber over 6 inches as 6-inch widths.

Cant Quality Classification

Since no pallet cant grading system has been published, interim quality classes were devised for use in the study. The minimum specifications for three classes of cants were:

Class 1 cants

Sound knots:

Maximum dimension one-third face width. Clustered knot dimensions are additive. No knots over 1/2-inch diameter in edges or end 3 inches of the piece.

Unsound knots and holes:

Unsound or loose knots or holes may not exceed one-sixth width of cant face.

Cross grain:

Cannot exceed 1:10 except in vicinity of knots and burls.

Splits, checks, shake:

Singly or in combination may not exceed one-third cant length, except that those 3 inches or shorter are ignored.

Wane:

May not exceed 1/2-inch width on any edge of the cant.

Manufacture:

75 percent of pieces must be at least specified dimensions and may not exceed specified thickness by more than 1/4 inch; 25 percent may be within -1/8 to +1/4 inch of specified dimension.

Class 2 cants

Sound knots:

Maximum dimension is one-half face width. Dimensions of clustered knots within 3 inches of each other are additive. No knots over 1 inch in diameter in edges or end 3 inches.

Unsound knots or holes:

Unsound knots, loose knots, or holes may not exceed one-fourth width of cant face.

Cross grain:

Not greater than 1:6 except in vicinity of knots and burls.

Splits, checks, shake:

Singly or in combination, may not exceed one-half of cant length. Those less than 3 inches long are ignored.

Wane:

May not exceed 5/8-inch width on any edge of the cant.

Manufacture:

66-2/3 percent of pieces must be at least specified dimensions and may not exceed specified thickness by more than 1/4 inch; 33-1/3 percent of pieces may be within -1/8 to +1/4 inch of specified dimension.

Class 3 cants

Sound knots:

No size limitation.

Unsound knots and holes:

Unsound knots, loose knots, or holes may not exceed one-half width of cant face.

Cross grain:

No limitation.

Splits, checks, shake:

Singly or in combination, may not exceed three-fourths of cant length, except that those less than 3 inches long are ignored.

Wane:

May not exceed 3/4-inch width on any edge of the cant.

Manufacture:

All pieces must be within -1/8 to +1/4 inch of specified dimension.

RESULTS

Pallet Bolt Classification and Cant Yields

The quality class distribution of 1,628 woods-run bolts was as follows:

Bolt class	*4-foot bolts*	*6-foot bolts*
	- - - - *percent* - - - -	
4	29	15
3	18	16
2	13	13
1	15	15
0	25	31

The cant class yield from the 1,628 bolts was:

Cant class	*4-foot cants*	*6-foot cants*
	- - - - *percent* - - - -	
1	47	47
2	32	33
3	21	20

Bolt class distribution and cant class yields by species and bolt class are shown in Table 1. Less than 1/2 of 1 percent of all bolts harvested were unusable because of unsound

ble 1—Pallet bolt and cant class distribution for woods-run oak-hickory and Allegheny hardwood pole-timber thinnings (Interim bolt and cant classification system)

lt ss	No. samples	% of samples	Cant class 1	Cant class 2	Cant class 3
			percent		
		OAK			
4	94	34	85	13	2
3	54	19	69	22	9
2	32	12	47	37	16
1	35	13	69	14	17
0	61	22	38	32	30
All	276		65	22	13
		YELLOW-POPLAR			
4	184	42	57	34	9
3	81	19	40	48	12
2	43	10	40	44	16
1	39	9	36	49	15
0	85	20	21	56	23
All	432		43	43	14
		CHERRY			
4	114	26	70	20	10
3	77	18	35	35	30
2	61	14	28	44	28
1	70	16	29	31	40
0	113	26	23	40	37
All	435		39	33	28
		BEECH, BIRCH, MAPLE			
4	56	11	75	23	2
3	71	15	60	28	12
2	76	16	50	34	16
1	108	22	37	36	27
0	174	36	37	24	39
All	485		47	29	24

defects. Ninety-eight percent of all cants produced (both 4- and 6-foot lengths) were of Sound-Square-Edge or better grade. Table 2 shows cant quality yield by the different bolt classes for all species of woods-run bolts.

Table 2—Cant quality yield by bolt quality classes

Bolt class	Percent of bolts in cant class: 1	2	3
	4-FOOT BOLTS		
0	36	30	34
1	34	36	30
2	40	38	21
3	52	30	18
4	75	18	7
	6-FOOT BOLTS		
0	26	47	27
1	35	42	23
2	48	33	19
3	53	31	16
4	76	22	2

Average yields per bolt of cants and side lumber were:

Diameter class (inches)	*Average yield per bolt (all species combined)* *4-foot bolts*	*6-foot bolts*
	- - - - *board feet* - - - -	
6	5.3	8.1
7	6.4	9.6
8	9.0	14.4
9	11.8	18.0
10	14.9	22.7

Pallet Stock Yields by Sweep Classes

Because of the range of cross-sectional dimensions within a single bolt diameter class, an appropriate way to express the effect of sweep on product yield is to compare product yield in cubic feet with cubic-foot volume of sample bolts. The following tabulation shows average yield of pallet cants and side lumber by sweep classes from the sample bolts:

Sweep class (inches)	*Yield from 4-foot bolts*	*Yield fr[om] 6-foot b[olts]*
	- - - - *percent of volume* - - - -	
0 – 0.5	56	58
0.6 – 1.0	53	55
1.1 – 1.5	49	47

In some pallet-producing areas, degrade problems occur in shipping and storage of green pallet parts, especially those 4/4 inches or less in thickness; thus some processors recov[er] only pallet cants from boltwood. (Exceptions are where t[he] primary bolt conversion facility is adjacent to or near the pallet assembly plant). The yield of pallet cants only from the sample bolts was:

Sweep class (inches)	*Yield from 4-foot bolts*	*Yield fro[m] 6-foot b[olts]*
	- - - - *percent of volume* - - - -	
0 – 0.5	48	47
0.6 – 1.0	44	42
1.1 – 1.5	39	36

Tables 3 and 4 show the effect of sweep on pallet stock yield by bolt diameter class.

DISCUSSION

The interim cant quality classes used in this study are base[d] on an unpublished industry grading system for pallet parts, and on observations at several pallet plants that process boltwood and/or cants. Studies are now being conducted to determine the extent to which the interim cant quality classes can be used to estimate actual pallet part yields by grade. Recent field tests by cooperating pallet manufacturers indicate that woods-run bolts do yield a grade mix of parts suitable for commercial pallet production.

Two sample lots of bolts from Allegheny hardwood species (cherry, maples, birch, and beech) and one sample lot of bolts from cove hardwoods (oak, yellow-poplar, hickory, and maples) were processed through a pallet parts mill. All parts recovered from the bolts were measured and grade[d] as to their suitability for (a) permanent pallets (high-grade parts) or (b) expendable pallets (low-grade parts). Results were as follows:

Table 3—Pallet cant and lumber yields from 4-foot woods-run bolts by diameter and sweep class

Sweep class	Bolt volume	Product yield	Product yield	Cant yield 4x4	Cant yield 4x6	Side lumber yield 1x4	Side lumber yield 1x6	Cants only
- inches - - - -	- - - - - - - - ft³ - - - - - - - -		- -	- - - - - - percent of bolt volume	- - - - - - - - - - - - - - - - -			
0-0.5	283.9	160.3	53	53	0	0	0	53
0.6-1.0	124.0	68.6	48	48	0	0	0	48
1.1-1.5	29.6	16.0	43	42	0	1	0	42
0-0.5	200.1	103.1	52	31	16	5	0	47
0.6-1.0	101.6	47.8	47	40	2	5	0	42
1.1-1.5	32.1	14.7	45	39	2	4	0	41
0-0.5	127.4	72.7	57	3	44	7	3	47
0.6-1.0	88.2	47.6	54	7	37	7	3	43
1.1-1.5	12.6	5.8	46	13	26	6	1	40
0-0.5	88.5	50.5	57	4	36	7	10	40
0.6-1.0	44.2	24.9	56	0	39	7	10	39
1.1-1.5	12.4	6.6	53	0	38	7	8	38
0-0.5	58.9	36.2	61	2	41	5	13	43
0.6-1.0	28.3	16.9	60	5	38	8	9	42
1.1-1.5	10.9	5.1	47	4	25	7	11	28

Table 4—Pallet cant and lumber yields from 6-foot woods-run bolts by diameter and sweep class

Sweep class	Bolt volume	Product yield	Product yield	Cant yield 4x4	Cant yield 4x6	Side lumber yield 1x4	Side lumber yield 1x6	Cants only
- - - inches - - - - -	- - - - - - - - ft³ - - - - - - - -		- -	- - - - - - percent of bolt volume	- - - - - - - - - - - - - - - -			
0-0.5	188.8	110.4	54	50	1	3	0	51
0.6-1.0	107.4	59.2	46	45	0	1	0	45
1.1-1.5	22.4	11.7	39	39	0	0	0	39
0-0.5	211.2	116.0	55	36	9	10	0	45
0.6-1.0	163.2	86.2	50	34	7	9	0	41
1.1-1.5	28.8	11.2	39	31	3	5	0	34
0-0.5	53.2	31.2	60	1	46	11	2	47
0.6-1.0	46.0	26.2	57	8	37	10	2	45
1.1-1.5	14.6	7.8	53	14	27	9	3	41
0-0.5	45.1	27.5	61	6	35	13	10	35
0.6-1.0	21.2	11.7	55	3	33	8	11	36
1.1-1.5	8.0	4.1	51	0	37	8	6	37
0-0.5	36.0	22.2	62	2	43	10	7	45
0.6-1.0	19.6	11.7	60	0	40	9	11	40
1.1-1.5	3.3	1.2	36	21	0	15	0	21

Sample lot	Total parts yield	Distribution of parts yield	
		Permanent	Expendable
	board feet	*percent of total yield*	
Allegheny hardwoods 1	8,268	77.6	22.4
Allegheny hardwoods 2	3,761	87.4	12.6
Cove hardwoods	6,220	86.6	13.4

Three sample lots of cants from woods-run bolts totaling 10,000 board feet (cant measure) were processed at a plant making medium-size expandable pallets. The species mix included approximately equal amounts of oaks, beech-maple-cherry, and yellow-poplar. Less than 3 percent of the parts produced were unusable.

Both cooperating firms concluded that the quality yield from the sample wood was equal to or better than that from the wood raw material they normally process.

CONCLUSIONS

Woods-run bolts produced from hardwood poletimber thinnings are well suited for commercial pallet production. Bolts containing unsound heart defects and those contai absolute sweep that exceeds 1-1/2 inches should be elim nated. Otherwise, there is no need for segregating bolts. ' resulting bolts yield approximately 55 percent of cubic-f volume in acceptable pallet cants and boards. When only 4- by 4- and 4- by 6-inch cants are produced (no side lun ber), product yield is approximately 45 percent of the cubic-foot bolt volume. The quality mix of cants produc from sound woods-run bolts is adequate for the producti of permanent or returnable warehouse pallets.

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6 p. (USDA For. Serv. Res. Pap. NE-482)

Four- and six-foot long bolts from poletimber thinnings were classified into five quality classes and three sweep classes. Cants and lumber for pallet parts were sawn. The effects of sweep and sound defects in the bolts on pallet part quality are described.

525.1:333.014

Keywords: Product quality yields, hardwood thinnings

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White-pine Weevil Attack

Susceptibility of Western White Pine in the Northeast

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Abstract

Heights were measured and white-pine weevil *(Pissodes strobi* (Peck)) attacks were recorded on 668 western white pines *(Pinus monticola* Douglas) interplanted among 109 eastern white pines *(Pinus strobus* L.) in a 10-year-old plantation in southern Maine. Less than 13 percent of the western white pines were successfully attacked (leader killed) by the weevil. Weevils killed the leader on 63 percent of the eastern white pines. Eastern white pine was the taller of the two species, but 3 open-pollinated families of western white pine from New York-grown parents and 1 of 12 familes from Idaho-Montana parents were nearly equal to or surpassed eastern white pine in height. Selection and seed collections from the proper seed sources or parent trees of western white pine could produce trees that grow rapidly and are low or moderate in susceptibility to weevil attack. These could be planted instead of eastern white pine in areas of the Northeast with high weevil populations.

Cover Photo: Fast growing unweeviled western white pine progeny from New York State parents on the left and much slower growing western white pine progeny from Idaho-Montana parents on the right.

Eastern white pine *(Pinus strobus* L.) has lost prominence as a lumber producing species in the Northeast because of its extreme susceptibility to damage by the white-pine weevil *(Pissodes strobi* (Peck)). Attempts to locate resistant races or individuals have been unsuccessful but are continuing. For the present, the best possibility of producing a weevil-resistant white pine may be to use another species or hybrids.

Resistance to white-pine weevil attack has been reported in the closely related but geographically distant western white pine *(Pinus monticola* Douglas). This was first noted by Wright and Gabriel (1959). They examined plantations of western white pine in New York that were surrounded by heavily weeviled eastern white pines, but the western white pines were almost free of attack. Garrett (1970) and Soles and others (1970) reported examples in New England and New York where the attack rate was only 10 to 35 percent as heavy on western as it was on eastern white pine. In western North America, where the preferred hosts of *Pissodes strobi* are Engelmann spruce *(Picea engelmannii* Parry) and Sitka spruce *(Picea sitchensis* (Bong) Carr), western white pine is apparently not susceptible to attack (Vandersar 1978).

In spite of these promising reports, western white pine has not been widely tested for susceptibility to weevil attack or adaptability to growing conditions in the northeastern United States. In this study I have evaluated weevil damage and height growth rate of western and eastern white pines and possible hybrids located in a 10-year-old plantation in southern Maine. The western white pines were attacked infrequently by the weevil despite the presence of high weevil populations in the area. Also, some of the western white pine families and numerous individual trees grew as rapidly as eastern white pine.

Materials and Methods

The trees tested were: (a) 10 full-sib familes of western white pine — grown from seed supplied by Richard T. Bingham, Intermountain Forest Experiment Station, Moscow, Idaho — from matings among selections that were free of blister rust *(Cronartium ribicola* J.C. Fisch. ex Rabenh) in natural stands in Idaho and Montana, and 2 open-pollinated controls from the same area; (b) 7 open-pollinated familes from planted western white pine located near Maryland, New York, in Otsego County; some of which may contain hybrids with eastern white pines; and (c) eastern white pines of unknown origin obtained from the New Hampshire State Nursery at Boscawen.

The trees were planted as 3-0 stock on the Massabesic Experimental Forest near Alfred, Maine, in 1971. There was no replication in the experiment. Instead, each family was planted in 1 to 3 adjacent rows in a 31-row plantation. There were 25 to 39 trees in each row. Eastern white pines were planted in every fifth row, including the first and the last. Spacing was 6 x 6 feet. Surrounding stands of eastern white pine of various ages assured that a substantial population of weevils was present at the planting site.

In 1976, and again in 1980 when the plantation was 10 years old (13 years from seed), height, survival, and incidence of weevil attack were measured. Weevil damage sustained by each species and western white pine family, as well as their growth rates, were compared to determine the potential for planting western white pine in the Northeast.

Results and Discussion

Height growth and weevil attacks on both species are summarized in Table 1. Average survival in the plantation was higher for western white pine (88 percent) than for eastern white pine (62 percent). Through the sixth year after planting, all of the western white pines were comparatively slow growing, which upholds their reputation for slow early growth in other experiments. Only 11 percent of the western white pines were as tall as the average white pine. By the 10th year, however, 1 of the 12 families grown from Idaho-Montana parents and 3 of the 7 families grown from New York parents were nearly equal to or surpassed eastern white pine in height.

The first successful weevil attack (leader death) was in 1974 on an eastern white pine. From then through the summer of 1980, there were 183 successful weevil attacks on 153 different trees in the plantation. The proportions of trees attacked were 63 percent for eastern white pine, 6 percent for Idaho-Montana western white pine, and 20 percent for the western white pines grown from N[illegible] York parents. No western white pine was successfully attacked more than once. Five eastern white pines ha[illegible] their leaders killed in three different years, and 20 tre[illegible] were successfully attacked twice. The low incidence o[illegible] weevil attack on young western white pines compares favorably with the low incidence of weeviling on older trees reported by Soles and others (1970) and Wright a[illegible] Gabriel (1959).

Tree height is one factor involved in the likelihood of attack on individual trees of eastern white pine. In general, taller trees with stout leaders are attacked mor[illegible] frequently than shorter trees of the same age. In this study, the mean height of eastern white pine was great[illegible] than that of western white pine. To determine whethe[illegible] stature was a major factor in the relative numbers of attacks on the two species, I made two analyses. First, t[illegible] mean height of the 69 weeviled eastern white pine trees was 232 cm in 1980, and 130 of the 668 western white pine were taller than 232 cm, but only 16 (12 percent) of those tall trees were weeviled. Second, in the five western white pine families with mean heights ranging from 202 to 234 cm (versus 233 cm for eastern white pine), only 46 of 221 trees (21 percent) were weeviled. Thus, both analyses indicate that the low susceptibility of western white pine to weevil attack is due to factors other than growth rate alone.

No other basis for the disproportionate susceptibility of the two pine species to weevil attack was readily appare[illegible]. After conducting feeding-preference tests with caged weevils on eastern and western white pines, Soles and others (1970) suggested that the resistance mechanisms o[illegible] western white pine, under natural conditions, must eithe[illegible] inhibit the weevils from traveling to the trees, or induce them to leave after landing. Forced-feeding experiments by Vandersar (1978) demonstrated that western white

Table 1.—Heights of eastern and western white pines and weevil attacks in a 10-year-old plantation i[illegible] southern Maine

Species	Number of trees	Height: Mean	Height: Range	Height: Range of family means	Number of weevil attacks	Number of weeviled trees	Perce[illegible] of trees weevil[illegible]
		cm	cm	cm			
Eastern white pine	109	233	130-347	—	99	69	63
Western white pine from:							
Idaho and Montana	368	166	53-342	66-213	23	23	6
New York	300	211	55-421	126-234	61	61	20

is an acceptable host species for weevil feeding, but a separate releasing stimulus for oviposition, necessary uccessful attack, is absent from western white pine. lata could support the existence of each mechanism estern white pine. The ratios of total attack incidence iccessful attack were 2:1 for western white pine and 1 for eastern white pine. Weevil attacks on the former ies, therefore, are less likely to be successful. Since 22 percent of western white pines were attacked e 77 percent of eastern white pines were attacked, it ear that the latter species is also the preferred host initial attack, whether or not that attack is successful.

iough tree height does not appear to be the principal or in differential susceptibility to weevil attack be- en species, the low incidence of successful weevil ick on families of western white pine from Idaho- ntana may be due, in part, to their slow rate of growth. much taller progeny from New York parents were acked more than three times as often.

milies of the Otsego County western white pine may tain hybrids between eastern and western white pines. ch hybrids are easily made and the plantation of parent es is adjacent to a plantation of eastern white pine; a tential pollen source. Hybridity may at least partially plain the more rapid early growth and greater suscepti- ity to weevil attack of the offspring of New York rents. However, selection of the fastest growing indi- luals when seed collections were made from a prove- ince (Kaniksu National Forest, Idaho) that is apparently ell adapted to soil and climatic conditions in the north- stern United States — western white pines in the tsego County plantation were as tall as eastern white ne in 1967 when the plantations were 30 years old — uld also account for the 27 percent difference in height owth between New York and Idaho-Montana progeny.

he susceptibility of western white pine to diseases and sect pests other than the white-pine weevil in the North- ist will require further study. Western white pine within s natural range is very susceptible to white pine blister st, but none of the trees in the 10-year-old plantation ive been infected. Blister rust is currently uncommon southern Maine, and nothing is known about how the sted trees would fare in areas where rust is prevalent. t present, necrotic lesions on branches, resembling the mptoms of infection by the ascomycetous fungi *liciopis* (Funk 1963), of several western white pines the test plantation may represent a potentially more rious problem. Soles and others (1970) reported in- stations of *Caliciopsis pinea* Peck on western white ne in New York state. Attempts to culture *Calici- psis* from infected western white pines in two different years were unsuccessful; only the usually saprophytic but sometimes pathogenic fungus *Pullularia pullulans* was isolated and identified. *Pullularia* may be the cause of the branch damage, but *Caliciopsis* cannot be ruled out.

On the basis of the data presented here and in earlier reports, it is evident that western white pine or hybrids with eastern white pine would be a worthwhile alternative species to eastern white pine if planted in areas of the Northeast with a history of producing low quality eastern white pine due to heavy weevil attack. Less severe weeviling than would normally occur on eastern white pine is almost guaranteed, and depending upon the source of seed, growth rates also look promising.

Planting of western white pine provenance tests on various sites in the Northeast to increase our knowledge of the geographic ecotypes and soil adaptability of this species before it is more widely introduced has long been recommended. Steps have been taken recently to establish at least one such test with replicates in Vermont and New Hampshire. The results from provenance tests, however, require considerable time to become useful. In the meantime, the Ostego County, New York, plantation, which furnished part of the seed for this experiment, and several other existing northeastern plantations of western white pine could be considered the nuclei of a series of seed orchards or seed production areas that could produce trees almost as fast-growing as eastern white pine and a great deal less susceptible to white-pine weevil attack.

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White-pine weevils killed the leaders of western white pines only 13 percent as frequently as they killed the leaders of eastern white pine in the same 10-year-old test plantation. Eastern white pine was the taller of the two species, but four families of western white pine of low to moderate susceptibility to weevil attack were almost as tall or taller than eastern white pine.

232.1:174.7 *Pinus monticola* Douglas: 453—145.719 *Pissodes strobi* Peck

Keywords: Height growth.

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Satisfaction Monitoring for Quality Control in Campground Management

by Wilbur F. LaPage
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Abstract

A 4-year study of camper satisfaction indicates that satisfaction monitoring is a useful tool for campground managers to assess their performance and achieve a high level of quality control in their service to the public. An indication of camper satisfaction with campground management is gained from a report card on which a small sample of visitors rates 14 elements of their camping experience. Changes from year to year in element scores correlated in many cases with actual changes in management practices. Differences in composite scores between parks and park systems were consistent from year to year. On the average, no differences were found between public and private campgrounds in the composite satisfaction ratings.

"The only way you can measure the value of a leisure activity is by the amount of pleasure it gives."

Introduction

While use of forested recreation areas has increased dramatically over the past 20 years, it is generally conceded that neither management expertise nor budgets have kept pace. As a consequence, there is a growing concern among professionals that the quality of outdoor recreation experiences is slipping (Feuchter 1980). For years we have assumed that increasing use of our parks, forests, and wilderness areas indicates that the public is enjoying satisfactory experiences. And yet we know that because of the long waiting lines at ski lifts, large numbers of skiers have shifted their interests to cross-country skiing. And despite a steady growth of the camping market, there are many more former campers today than there are actively participating campers (LaPage and Cole 1979). To what extent such trends reflect declining satisfaction—and management failure—is of increasing concern.

Several studies have examined factors associated with visitor motivations and satisfactions at developed campgrounds (Bultena and Klessig 1969; Burch 1965; Foster and Jackson 1979; Hollender 1977; James and Cordell 1970; LaPage 1968; Munson and Schweitzer 1964; Stille 1970). Most researchers have concluded that camper satisfaction results from the interaction of camper expectations and the campground environment. While it is desirable to know more than we currently do about campers' social and psychological needs, it is more immediately useful to know how well campground management is performing in providing an environment conducive to satisfying those needs. The former is not a prerequisite to the latter: People dine out for many reasons, but the extent to which the restaurant provides good food, quality service, and a pleasant atmosphere can still be assessed. Not only does satisfaction offer the distinct prospect of a highly useful measure of management performance, its relationship to the basic business goals of longer visits, more repeat visitation, and more intentions to return has been documented by at least two studies (Foster and Jackson 1979; LaPage 1968).

Providing quality recreation experiences is the goal of all outdoor recreation agencies. It requires that management understands quality, visitor expectations, and the extent to which those expectations are satisfied. The goal of providing quality experiences also implies a commitment to manage for quality. Unfortunately, there are few guidelines to tell the recreation resource manager whether he is producing generally satisfying experiences for his visitors and whether the level of overall satisfaction is responsive to increased management efforts.

The Study

In an attempt to meet this need, a camping satisfaction monitoring system was established in 1977 as a cooperative effort of the New Hampshire Division of State Parks and the Northeastern Forest Experiment Station. Using a simple 2-to-3-minute report card, distributed to a small sample of visitors throughout the camping season, a composite measure of camper "satisfaction" is generated from 14 elements of a campground visit (Fig. 1). Each element is ranked from "A" (for excellent) to "E" (for poor). Converting letter "grades" to numeric scores produces a sensitive 0-to-8 point scale that monitors the slightest change in the average satisfaction of campers visiting a given campground or all campgrounds in the park system. With 8 points representing a completely satisfying experience (A=8, C=4, E=0), the composite ranking among more than 3,300 campers sampled at New Hampshire state park campgrounds over the past 4 years shows remarkable consistency:

Year	*System-wide Satisfaction*
1977	6.6
1978	6.7
1979	6.7
1980	6.7

Despite system-wide consistency, from year to year, considerable variation was found among individual satisfaction elements at specific campgrounds, thereby pinpointing areas needing management attention. For example, camper satisfaction declined at a number of campgrounds, between 1979 and 1980, with the "availability of firewood". A follow-up check with campground managers disclosed that indeed availability had declined as a result of changes in park policy or vendor practices.

Assessment of recreational satisfaction will usually involve more variables than the "quality of service—quality of food" evaluation cards used by many restaurants. The methodology for monitoring camper satisfaction was developed in an extensive study of camper and campground variability at 16 state parks in Massachusetts, Vermont, and New Hampshire in 1977. The following year, through the cooperation of the National Campground Owners Association, the report cards were used by more than 100 commercial campgrounds nationwide. Despite enormous differences in the kinds and quality of camping experiences being evaluated, the average camping satisfaction scores at public and private campgrounds were surprisingly similar (Table 1). Campgrounds in both sectors rated a 6.5 (B+) average satisfaction score, but public sector campgrounds seemed to have slightly more

Table 1.—Average satisfaction scores on 14 eleme[...] of a camping experience, reported in 1[...] by visitors to public and private ca[...] grounds.

Factor	Public	Priv[...]
Your first impression	6.9	6.
Cleanliness of campsites	7.0	7.
Cleanliness of restrooms	6.0	6.
Privacy of campsites	6.4	5.
Good size of campsites	7.1	6.
Good choice of campsites	6.5	6.
Availability of firewood	5.7	5.
Availability of supplies	5.3	6.
Recreation opportunities	5.9	6.
Ease of check-in	6.8	7.
Safety and security	6.8	6.
Good rules & regulations	6.8	6.
Helpfulness of employees	7.1	7.
Your recommendation of us	7.1	6.
Mean score	6.5	6.
Number of campers	774	304
Number of campgrounds	16	10

satisfying campsites (in size and privacy) while private cam[...]ing enterprises provided better services (recreation opportunities and availability of supplies).

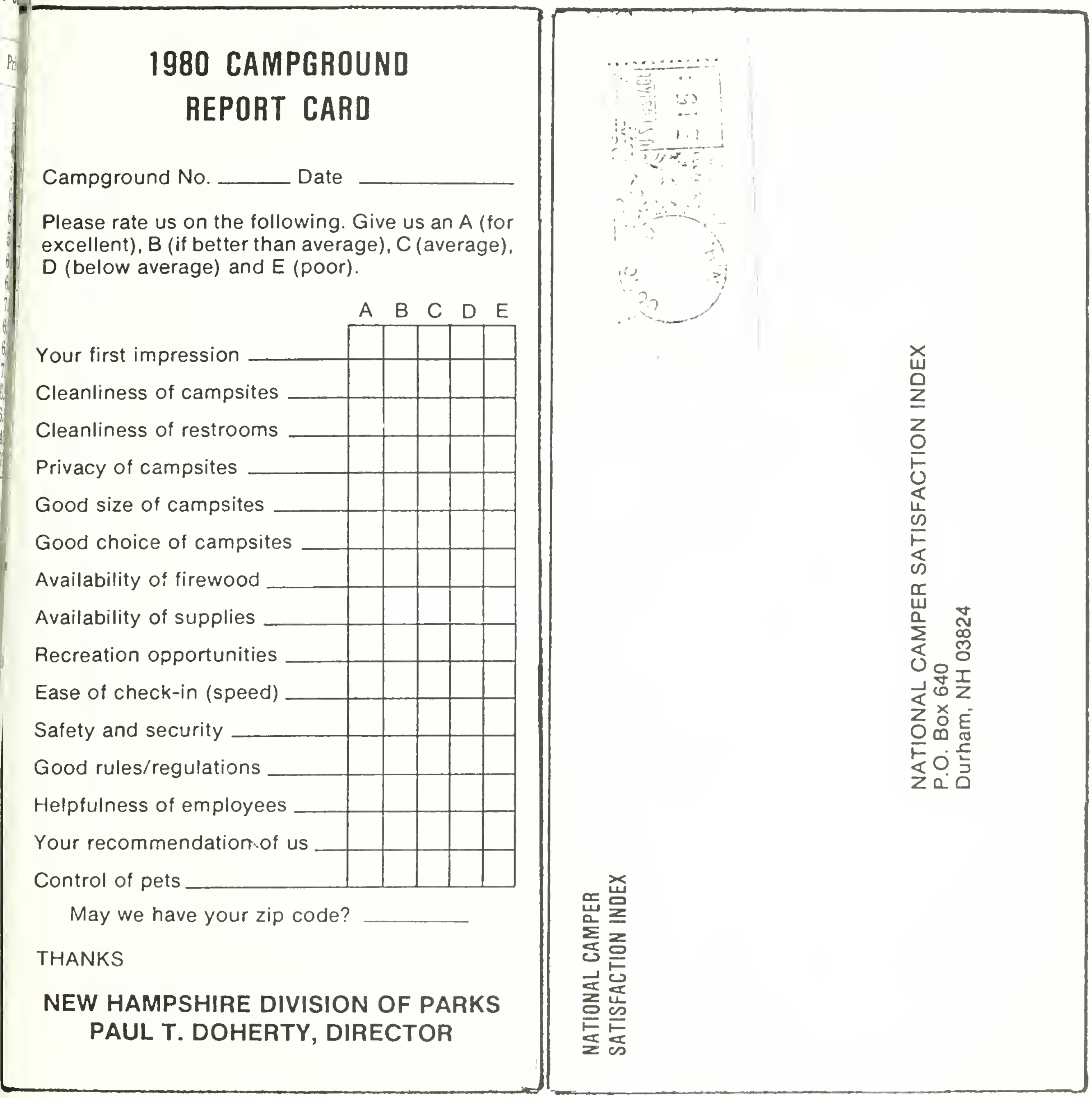
During the initial test of the system, an additional seven el[...]ments were included on the report card:

- Maintenance of campsites
- Maintenance of restrooms
- Availability of information
- Convenience of check-out time
- Attitude of employees
- General attractiveness
- Campground worth revisiting

While all of these elements were found to be adequately me[...]sured by other elements, they provided a useful test of the internal consistency of the report card. That is, essentially identical campground scores for each of the above were generated by:

- Cleanliness of campsites
- Cleanliness of restrooms
- Helpfulness of employees
- Ease of check-in and Good rules and regulations
- Your first impression
- Your recommendation of us

Figure 1.—Sample report card used to assess camper satisfaction at New Hampshire state parks, 1977—1980.



1980 CAMPGROUND REPORT CARD

Campground No. ______ Date ______________

Please rate us on the following. Give us an A (for excellent), B (if better than average), C (average), D (below average) and E (poor).

	A	B	C	D	E
Your first impression					
Cleanliness of campsites					
Cleanliness of restrooms					
Privacy of campsites					
Good size of campsites					
Good choice of campsites					
Availability of firewood					
Availability of supplies					
Recreation opportunities					
Ease of check-in (speed)					
Safety and security					
Good rules/regulations					
Helpfulness of employees					
Your recommendation of us					
Control of pets					

May we have your zip code? __________

THANKS

NEW HAMPSHIRE DIVISION OF PARKS
PAUL T. DOHERTY, DIRECTOR

NATIONAL CAMPER SATISFACTION INDEX
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NATIONAL CAMPER
SATISFACTION INDEX

Additional first-year consistency tests were provided by asking campers what they liked least and most about the area and what services, programs, facilities, and improvements they would like to see added. The aggregate response to those questions was found to follow the same response patterns as the report cards alone. For example "solitude" was a more frequent response to "What did you like most" at those campgrounds receiving a high rating for "privacy of campsites" on the report cards. A 15th element, "control of pets" was added to the report card in 1980, but was not used in computing total satisfaction scores.

A wide range in average satisfaction scores was reported by visitors (Table 2) and the scores appear to be, at least in part, a function of the campground or its management. For example, significantly different average scores were reported by visitors to campgrounds in Vermont, Massachusetts, and New Hampshire. And differences between parks in New Hampshire tended to be consistent over 4 years of study, with the same parks generally producing below-average or above-average satisfaction scores. Further evidence that the scores reflect actual changes in camping conditions was offered by several New Hampshire campground managers who confirmed changes in safety and security (improved through the addition of a night attendant on duty), in availability of firewood (declined as the result of a policy change), and in restroom cleanliness (improved through more frequent spot checks) (Table 3). Also, those items t[hat] would only be expected to change from year to year with changes in clientele, such as first impressions, size of sites and recommendations, did not change. On the other hand campground managers occasionally did report a change in their operations which failed to show up in the ratings, such as a cutback in frequency of cleaning campsites to reduce fuel consumption.

Table 2.—Range in satisfaction scores (mean ±1 standard deviation) at 17 state park campgrounds in New Hampshire, Massachusetts, and Vermont, during the years 1977-1980.

Campground	Satisfaction range	Letter grade	Years
Greenfield (NH)	6.33 – 7.83	B to A	4
Moose Brook (NH)	6.17 – 7.90	B to A	4
Coleman (NH)	6.16 – 7.82	B to A	4
Milan (NH)	6.13 – 7.80	B to A	4
Pillsbury (NH)	5.92 – 7.86	B to A	4
Monadnock (NH)	5.89 – 7.67	B- to A-	4
Pawtuckaway (NH)	5.75 – 7.64	B- to A-	4
Brighton (VT)	5.50 – 7.48	B- to A-	1
Lafayette (NH)	5.48 – 7.51	B- to A-	4
Bear Brook (NH)	5.40 – 7.61	B- to A-	4
Tolland (MA)	5.32 – 7.38	B- to A-	2
Dry River (NH)	5.26 – 7.50	B- to A-	4
St. Catherine (VT)	5.26 – 7.42	B- to A-	1
White Lake (NH)	5.11 – 7.33	B- to A-	4
Nickerson (MA)	4.60 – 7.28	C+ to A-	1
Myles Standish (MA)	3.98 – 6.73	C to B+	2
Salisbury (MA)	3.05 – 5.99	C- to B	2

No within-season differences in satisfaction scores were found at any of the 16 campgrounds studied during the first year of testing the system (1977). In each of the following years, a much smaller sample of campers was, therefore, used to assess satisfaction. Report cards were distributed to all incoming campers on 9 days during the summer camping season. The 9 days were selected to include a weekend period, a mid-week period, and a holiday period. Returned questionnaires averaged 32 percent of those distributed.

Discussion

In their study of *Social Indicators of Well-Being*, Andrews and Withey (1976) measured "satisfaction with life as a whole" on a 7-point scale in a national sample of 1,072 people. Minimal variation in scores was reported between the sexes, eight age classes, and seven socioeconomic status classes. The greatest variation (0.7 point) was found among eight family-life-cycle classes, and (0.6 point) between races. Using these differences as a guideline, we assumed that a difference of at least 1.0 point would be a reasonably reliable indicator of year-to-year change within individual satisfaction elements at state park campgrounds.

Table 3.—Summary of satisfaction changes noted at nine New Hampshire state park campgrounds 1977-1980, and frequency of manager's recollection of a change.

Change of at least 1.0 point	No. Parks +	No. Parks –	Manager agreement
Cleanliness of sites	1	0	1
Cleanliness of restrooms	3	1	3
Availability of supplies	5	3	1
Availability of firewood	4	4	3
Privacy of campsites	1	0	
Recreation opportunities	2	0	
Rules and regulations	0	1	
Safety and security	1	0	1
Ease of check-in	1	1	
Totals	18	10	9

Table 4.—Annual summary ratings of "satisfaction scores" by visitors to New Hampshire state park campgrounds, 1977-1980.[a]

Factor	1977	1978	1979	1980
Your first impression	7.0	7.0	7.2	7.1
Cleanliness of campsites	7.2	7.3	7.3	7.3
Cleanliness of restrooms	6.5	6.6	6.5	6.6
Privacy of campsites	6.6	6.6	6.7	6.4
Good size of campsites	7.1	7.2	7.2	7.1
Good choice of campsites	6.5	6.8	6.9	6.6
Availablity of firewood	5.4	5.8	5.4	5.3
Availability of supplies	5.0	5.5	5.4	5.3
Recreation opportunities	5.8	6.0	6.0	6.1
Ease of check-in (speed)	7.0	7.1	7.1	7.3
Safety and security	6.8	7.0	6.9	7.1
Good rules/regulations	—	7.0	7.0	7.1
Helpfulness of employees	7.4	7.3	7.3	7.5
Your recommendation of us	7.4	7.3	7.4	7.4
Mean Score	6.6	6.7	6.7	6.7
Number of respondents	1532	617	491	705
Number of campgrounds	11	11	11	11

[a]Based on ratings of: A—Excellent—8 points; B—Better than average—6 points; C—Average—4 points; D—Below average—2 points; E—Poor—0 points.

ıe striking finding about average camper satisfaction ores, like "satisfaction with life" scores, is their apparent nsistency. No clear annual trend was apparent at any of e campgrounds studied—suggesting that professional con- rns about declining experience quality may be unfounded. fact, seven of the nine parks in New Hampshire showed nall increases in satisfaction (much less than 1.0 point) ver the 4-year study period. At nine New Hampshire state arks[1], (during 4 years of study, and among 14 satisfaction ements, only 28 changes of at least 1.0 point were noted out of a possible 367) (Table 3). In all 28 cases the change f 1.0 point or more in average satisfaction scores should e interpreted not as a *measure* of real change in services, ut as an *indicator* of perceived change. The indicator may e a valid expression of physical change, changes in percep- on, changes in clientele and their expectations, or all three combination. Therefore, changes in satisfaction scores an only be realistically used as clues that some element of ampground management may need more (or less) man- gement attention.

Eleven state park campgrounds were studied, however, the ample size at two campgrounds was consistently too small o provide reliable comparisons. The coefficients of variation total satisfaction indicated a minimum sample of 27 re- ponses per campground would be essential for assessing aver- ge satisfaction at the 2-standard-error level.

While the 14 elements of a campground visit analyzed in this study may not reflect all, or even the most critical concerns of the average camper, they were selected from a number of surveys documentating camper needs for cleanliness, variety, service, privacy, and security (Alden 1967; Burch 1965; Cordell and James 1972; Hancock 1973; Hollender 1977; Kerr and Kerr 1972; LaPage 1968; Lucas 1970; Stille 1970). Additionally, the first and last elements of the report card are designed to provide a composite image of the campground at two different points in time during the visit ("your first impression" and "your recommendation of us"). A decline in the average rating for a campground between these two scores should immediately suggest that campers are dissatisfied, or at least that the campground fails to live up to its first impression. In only 5 of the 53 cases studied (all public parks and all years) was the average recommendation score lower than the average first impression score. At New Hampshire state parks, recommendation scores were consistently higher than first impressions (Table 4) suggesting that overall experience quality is satisfying to most campers and is not declining, at least at these campgrounds.

Measurement of visitor satisfaction, for research purposes, has usually considered only aggregate satisfaction and has generally involved the use of a Likert-type scaling system, e.g. "Highly Satisfied to Highly Dissatisfied." For management purposes, this approach presents a number of difficulties in both administration and interpretation. The use of letter grades in a report card format was readily understood, producing 100-percent useable data over the four years of this study without the confusion that sometimes accompanies numeric scales. More important, gross satisfaction measures cannot be disaggregated to pinpoint those areas of management that need further attention or those areas where employees should receive a commendation for their performance. Because of this lack of focus on management, gross satisfaction measures will invariably be contaminated by factors beyond the control of management such as the friendliness or unfriendliness of one's camping neighbors.

The evidence is strong that recreational satisfaction, among campers at least, is responsive to changes in management, and that improved management, in turn, produces quantifiable gains to management in the form of longer and more frequent visits. Given these relationships, it would seem that the monitoring of camper satisfaction might well become a basic management tool. Satisfaction monitoring offers a means of quality assurance for the visitor, an approach to performance measurement for administration, and a rational basis for decisions about use limits and the delivery of recreation services.

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A 4-year study of camper satisfaction indicates that satisfaction monitoring is a useful tool for campground managers to assess their performance and achieve a high level of quality control in their service to the public. An indication of camper satisfaction with campground management is gained from a report card on which a small sample of visitors rates 14 elements of their camping experience. Changes from year to year in element scores correlated in many cases with actual changes in management practices. Differences in composite scores between parks and park systems were consistent from year to year. On the average, no differences were found between public and private campgrounds in the composite satisfaction ratings.

ODC: 907.2

Keywords: Campground management, recreation quality, visitor satisfaction

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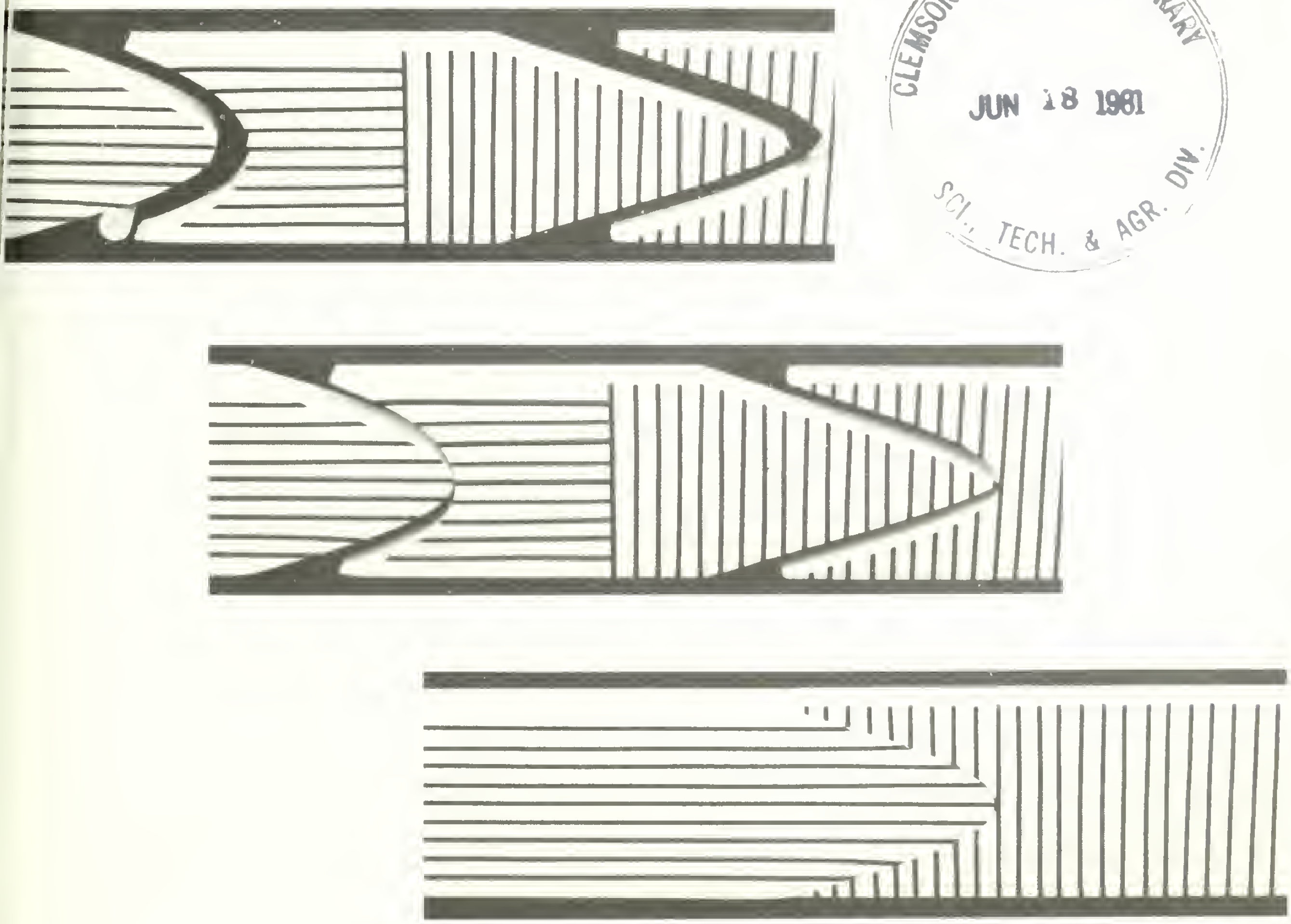
The Serpentine End-Matched Joint: Evaluating Strength and Stability

Charles J. Gatchell and Curtis C. Peters



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Abstract

The Serpentine end-matched (Sem) joint is a precisely machined butt joint with a sine wave shape. The joint is not readily visible to the eye and performs well in panels made of sugar maple, red oak, black walnut, and black cherry. The Sem joint is unaffected by changes in equilibrium moisture content from 6 to 12 to 18 to 6 percent. Panels containing Sem joints have about the same stiffness as panels without Sem joints. When tested to failure in bending, panels with Sem joints were weaker than control panels. However, the panels had to bend much farther than nonstructural applications would dictate before failure occurred. When making the joint, some side pressure and end pressures of 60 to 240 psi are needed.

duction

erpentine end-matched (Sem) joint (Fig. 1) has created derable interest among furniture manufacturers because ›ws them to end join short lengths of high-value hard- ls into aesthetically pleasing long lengths. Finger joint- considered unacceptable for most exposed furniture because it produces a clearly visible straight line at right s to the length of the strip. But the Sem joint is difficult, ›ften impossible, to detect because of its sine wave pat- and the precision with which it is machined (Hansen Gatchell 1978).

joints are made with a numerically controlled router that uces glue line thicknesses of about 0.001 inch (Gatchell . 1977). The proposed uses for the Sem joint are in non- ctural applications where two or more strips are edge d together. Panels of widely varying grain and color that tain Sem joints have been found acceptable by manu- urers who have used them to build demonstration pieces urniture.

pite this acceptance, questions often are asked about the ngth or performance of the Sem joint because it is es- tially a curved butt joint. This limited study of strength l dimensional stability was conducted to provide potential rs with answers to these questions. In Part I, we looked inly at the performance of the joint under changes in uilibrium moisture content (EMC) and at the bending ength of panels containing Sem joints. In Part II, we eval- ted the manufacturing variables of end and edge pressure the strength of the Sem joints in tension.

ırt I:
imensional Stability and Strength in Bending

ıe sine wave shape of a Sem joint is defined by its ampli- de and period (Fig. 2). We used 2-1/2, 5 and 1-1/2, 5 Sem ints in this study. A 2-1/2, 5 Sem joint has an amplitude of -1/2 inches and a period of 5 inches. A 1-1/2, 5 Sem joint flatter in appearance because the amplitude is decreased. umerical control tapes for Sem joints of different ampli- ıdes and periods are easy to generate with Coleman's 1977) SEMTAP program. All that is required for input is he amplitude and period of the sine wave and the radius of he router bit.

n making the joints, a cold-setting aliphatic resin adhesive, btained commercially, was applied by brush to one of the oint surfaces. All joints were made by applying an unknown ut heavy end pressure with screw-type pipe clamps. Side ressure at the outer edge of each joint was applied by ightening a C-clamp.

Effect of Changes in Moisture Content on Panel Surface Smoothness

When used in the construction of a panel for fine furniture, how will the Sem joint perform with changes in moisture content? Will the joint maintain its integrity when subjected to variations in EMC? To find out, we made two unfinished panels each of northern red oak, black walnut, and black cherry according to the design shown in Figure 3. The 2-1/2, 5 Sem joint was used. The panels were equilibrated at 80°F-30 percent relative humidity (RH); then at 80°F-65 percent RH; then at 80°F-80 percent RH; and again to 80°F-30 percent RH. This EMC cycle of 6 to 12 to 18 to 6 percent is far more severe than any cycles that could be expected in normal use.

The technique used for measuring panel surface smoothness was described by Peters and Mergen (1971). It is a precise technique that uses a stylus tracing head that was designed specifically for wood. The apparatus was sensitive enough so that the wood anatomy and raised or sunken joints would show clearly. Surface smoothness was measured for each moisture content.

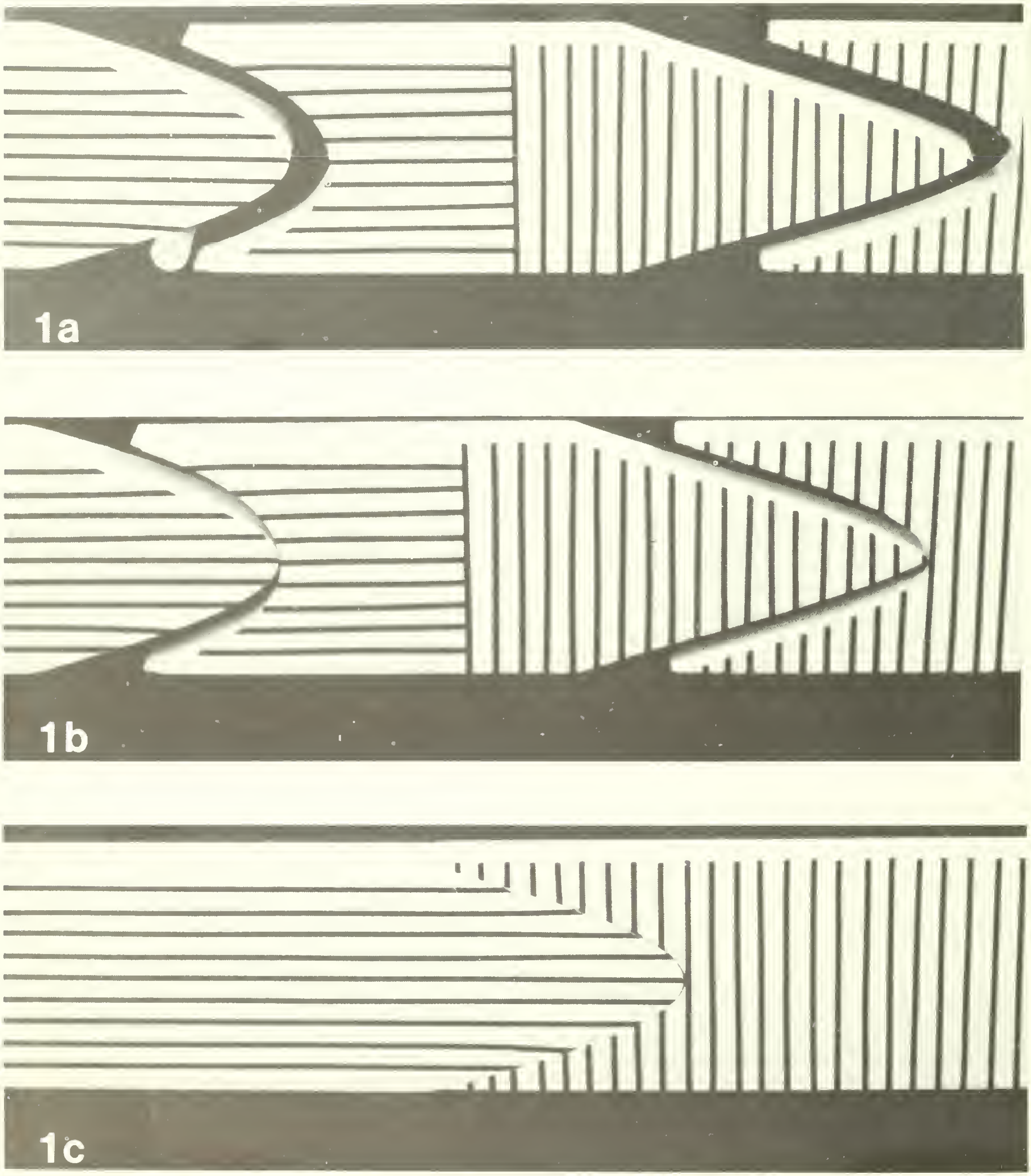
The results of these tests were most pleasing. The Sem joints could not be identified on any panel at any moisture content. It made no difference whether the stylus went along or across the grain; whether the panels were flat or edge grained; or whether the panels were made from black walnut, black cherry, or northern red oak.

Strength in Bending of Panels With and Without Sem Joints

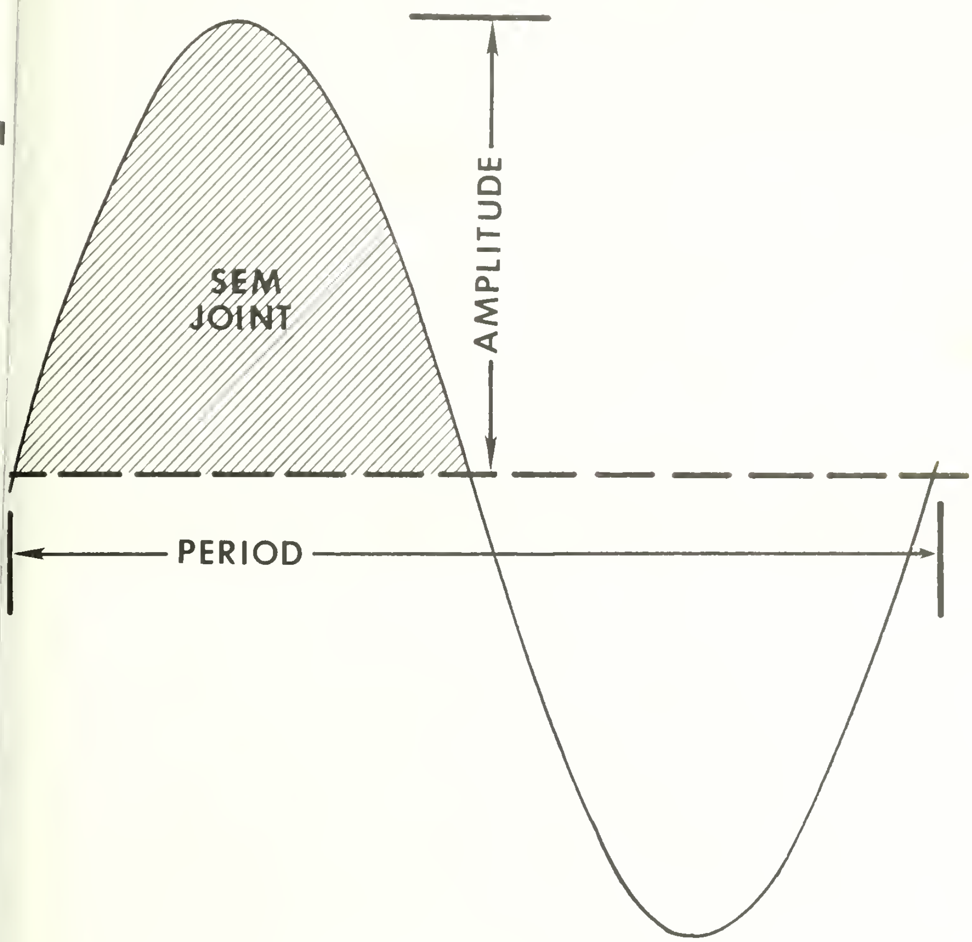
To evaluate bending strength, black cherry panels were made as shown in Figure 4. The 40-inch-long panels were made of strips of wood that had been selected for straightness of grain. The panels were surfaced to 0.7 inch in thickness and crosscut to two panels 20 inches long — one with a Sem joint and one without. Because the wood, the gluing procedures, and the processing were essentially the same for each half, differences in bending strength between each half of the 40-inch panel were attributed to the Sem joint. For destructive bending tests, we made four 40-inch panels. A panel contained either a 1-1/2, 5 or a 2-1/2, 5 Sem joint that was either centered or located at one edge. The panels were placed on supports spaced 18 inches apart and the load was applied at the peak of the Sem joint.

We also conducted nondestructive bending tests so that the Sem joint itself could be later tested in tension Using only centered joints (layup 1), we made two panels containing 1-1/2, 5 and two panels containing 2-1/2, 5 joints. Following the nondestructive tests of the modulus of elasticity (MOE), the Sem joints were carefully sawed from the panels and tested in tension.

Figure 1.—Sem joints are machined precisely with a numerical control router. When a router bit passes through a piece of wood on a curved path (A), the resulting pieces cannot be pushed together (B) because the path of one side of the bit is different from that of the opposite side. However, with a numerical control router, one side of a glue line can be machined on one piece of wood (vertical lines) and the other side on another piece (horizontal lines). When the waste is removed, the pieces fit together (C).



re 2.—The Sem joint resembles one-half of a full sine wave.



gure 3.—Panel design for dimensional stability tests.

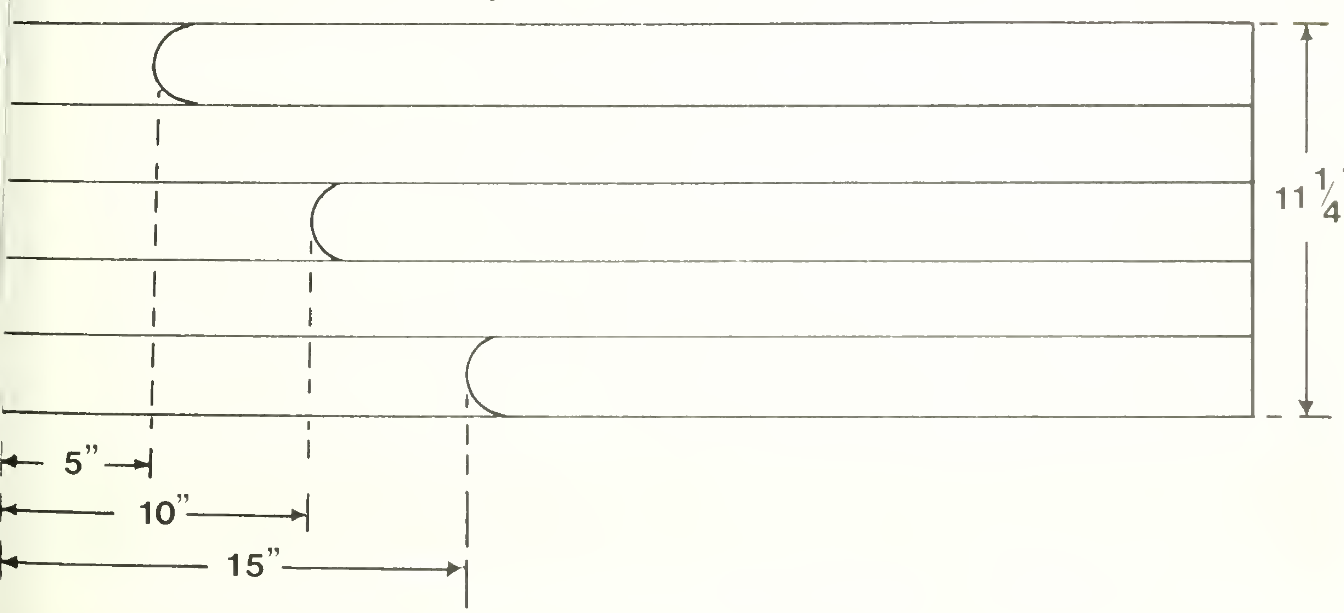


Figure 4.—Panel design for static bending tests.

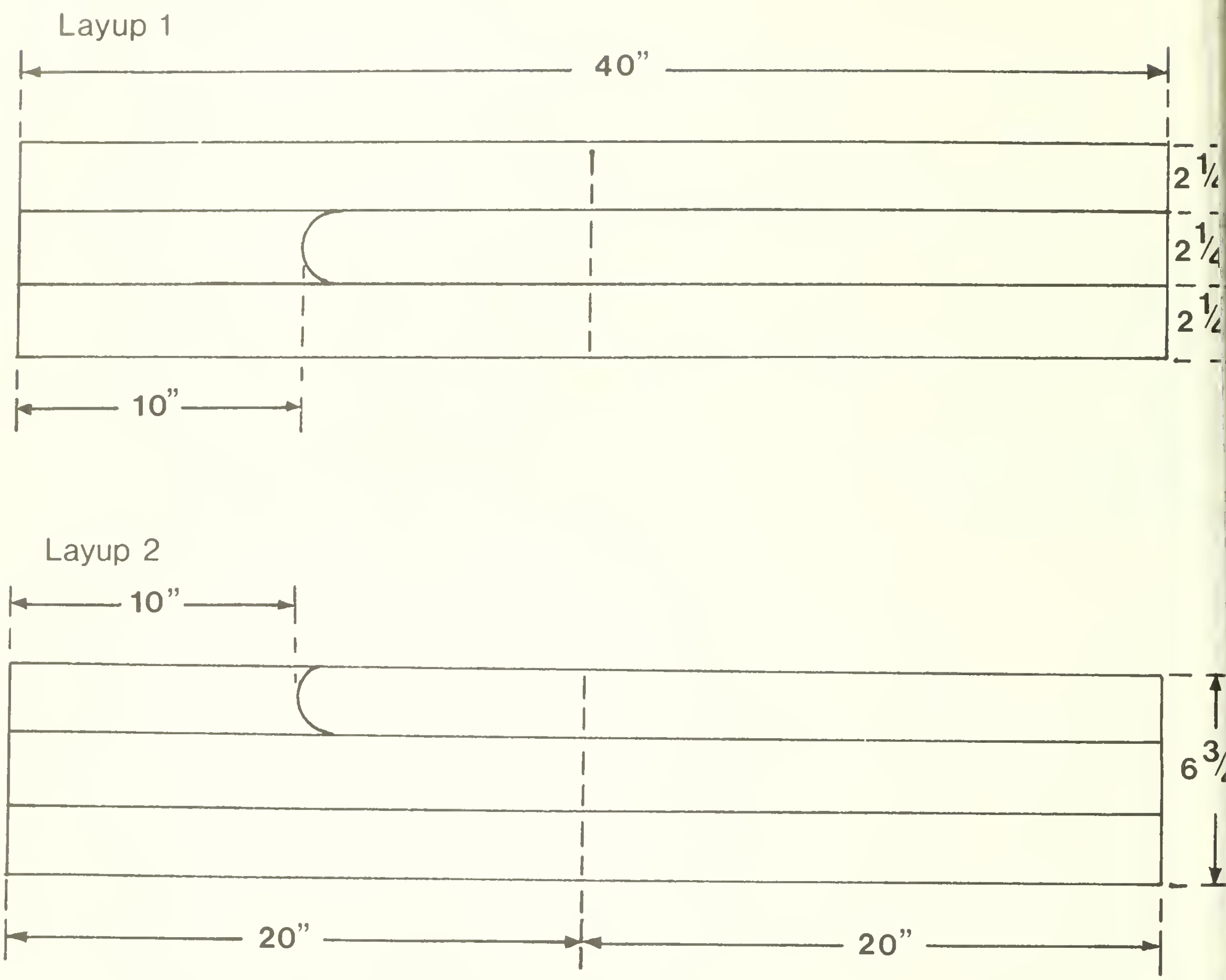


Table 1. Results of tests of panel failure in bending and of tensile strength of Sem joints

Test variable	Panels with Sem joints		Control panels		Tensile strength of Sem joints
	Maximum load	Modulus of elasticity (psi)	Maximum load	Modulus of elasticity (psi)	
	lb	*(thousands)*	*lb*	*(thousands)*	*psi*
ructive test					
-1/2, 5 centered joint)	1,815	1,800	2,585	1,830	—
-1/2, 5 edge joint)	1,625	1,830	2,640	1,925	—
-1/2, 5 centered joint)	1,610	1,425	2,190	1,670	—
-1/2, 5 edge joint)	1,340	1,775	2,410	1,790	—
ndestructive test					
2-1/2, 5 centered joint)	—	1,580	—	1,475	1,827
2-1/2, 5 (centered joint)	—	1,460	—	1,525	2,224
1-1/2, 5 (centered joint)	—	1,580	—	1,630	1,505
1-1/2, 5 (centered joint)	—	1,615	—	1,615	1,619

he results of the nondestructive and destructive tests are ven in Table 1. The most important factor in the application of nonstructural Sem panels is panel stiffness that is ndicated by the MOE. Comparing the MOE's of panels conaining Sem joints with the controls, we conclude that the em joints had no effect on stiffness. In six of the eight panls containing Sem joints, MOE values were slightly lower han in their controls, but these differences were not conidered of practical significance.

n the destructive tests, the maximum load was affected both y the presence of Sem joints and the position of the Sem oints relative to the edge of the panels. In panels with Sem oints, two-thirds of the width was free of end joints. These anels were about two-thirds as strong as the controls (the ange of values was 55 to 73 percent of controls).

Panels with joints in the center were about 15 percent stronger relative to the controls than panels containing joints in the outer strips. The difference in amplitude between the 1-1/2, 5 and the 2-1/2, 5 joint was not considered important. The four tests of joints in tension suggest that joint amplitude may be important to individual joint tensile strength. Even so, all four joints were surprisingly strong.

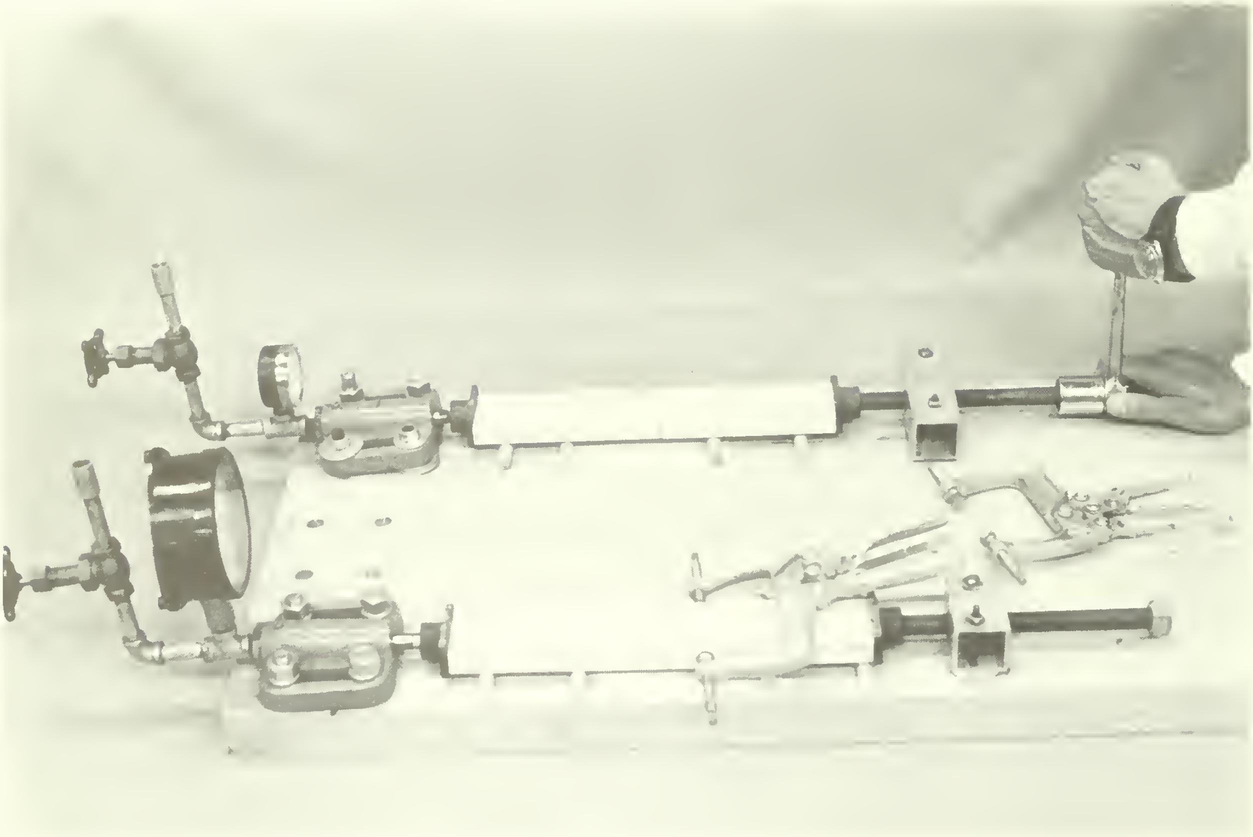
In discussions of panel bending strength, a most significant factor overrides the tabular values. The 0.7-inch-thick panels were placed on supports spaced 18 inches apart. A deflection of at least 0.6 inch was required over an 18-inch span before "catastrophic" failure took place. A load of at least two-thirds of a ton was needed to produce this deflection. We know of no furniture or other nonstructural applications where such a deflection or the support of such a load is required. Thus, discussions of maximum load are of limited value, at best.

Part II: End and Side Gluing Pressures

The precision with which the Sem joint can be machined suggests that relatively small end pressures are needed for satisfactory bonding. But, how much is enough? Is side pressure necessary? Answers to such questions are needed before a commercial Sem gluing technique can be designed. To evaluate gluing procedures, we used the tension test. Results from these tests tell us, relatively, whether we are doing a good job of gluing.

In Part II there were significant changes in pressure application procedures and adhesives. A special device was built so

Figure 5.—This special gluing device allows the recording of end pressure used in the manufacture of Sem joints.



that end pressure could be recorded (Fig. 5) and two different commercial adhesives (A and B) were used. Each was defined as a modified polyvinyl acetate emulsion adhesive that is crosslinked (thermoset) by the addition of the appropriate catalyst. A filler was used with adhesive A. Some of the properties of the adhesives were:

Item	*Adhesive A*	*Adhesive B*
Solids (percent)	50 to 56	50 to 56
Adhesives pH	4.0 to 5.0	4.5 to 5.5
Adhesive and catalyst pH	2.5 to 3.5	2.5 to 3.5
Adhesive and catalyst viscosity (centipoises)	1,200 to 2,000	2,000 to 3,000

The shape of the concave side of the Sem joint presents a minor gluing problem. The interaction of the moisture in the adhesive and the feather edges of the concave side of the Sem joints can cause wide or open joints at the outer edges. This opening can be easily closed by hand pressure. Side pressures, applied by spring-releasing hand clamps, included none, restraint, and heavy. For restraint, the closed hand clamp was adjusted until it fit snugly above the concave side of the joint. The clamp was then released and applied again at the feather edges of the joint. Heavy side pressure was achieved by closing an adjustable pressure foot about 0.06 inch beyond the restraint side pressure opening.

In addition to using side pressure, we used a force-fitting joint in Part II. This was done by simply specifying a slightly larger period for the convex side of the joint and leaving the 2-1/2-inch amplitude the same for both sides. For these tests the width of the base of the convex side was 2.505 inches; the concave side was 2.500 inches.

Each joint was placed in the end-pressure device about 1 minute after glue was applied by brush to each face. The gage pressure plate moved as pressure was applied; thus, the sample was supported on each side of the joint by two dowels so that it was free to move. After end pressures of 60, 120, 240, or 400 pounds per square inch (psi) were applied, the side pressure was introduced. The assembled joint was left in the clamps for 30 minutes. Tests in tension were conducted several days later.

he very peak of the joint, end grain is glued to end grain; is, the glue line is at an angle of 90° to the grain of the d. From the peak and through a distance of about 1/2 along the glue line, the glue line angle changes rapidly to ıt 30°. Then, the angle of the joint face changes slowly bout 20° from parallel to the grain at the outer edge. le these are hardly optimum grain angles for gluing, the ı joints perform well in tension tests.

samples failed in tension at the glue line. Often, there some wood failure in the weaker wood elements. In oak, example, wood failure often occurred along all of the line except at the peak of the joint. Failure was mainly he wood rays and springwood vessel areas. Careful obser- on was needed to note this wood failure, however, and st joint failures appeared fairly clean to the naked eye.

Sem joints were surprisingly strong. Samples of the ce-fitting 2-1/2, 5 Sem joints were ripped into 1/4-inch ps and tested in tension by the adhesive manufacturer. the 1/2 inch of glue line at the peak, 27 cherry samples lded an average strength in tension of 3,170 psi and 15 d maple samples had an average strength of 3,480 psi.

hesive A

hesive A, with 5 percent catalyst and 5 percent filler was d to evaluate the effects of end pressure on matched nples of cherry and oak. All samples for each species were m one board. "Restraint" side pressure was used on all nts at the 5 percent filler level. For both cherry and oak, ength in tension decreased as end pressure increased from to 240 psi (Table 2).

e effect of side pressure on oak joints was evaluated at an d pressure of 120 psi with adhesive A, with 5 percent cata- st and 10 percent filler (Table 2). There was not a great fference in the tension values. The use of restraint side essure produced values about 150 psi higher than no or avy side pressure. This difference was not considered im- ortant.

dhesive B

dhesive B, with 5 percent catalyst and no filler, had a gher initial viscosity than adhesive A. It was easier to apply. ithin 3 hours, the viscosity had increased to that of a very ick latex paint. The adhesive could be easily spread over 8-hour period.

he results obtained from the end pressure tests with adhe- ve B (Table 3) did not show trends as distinct as those with dhesive A. For cherry at all side pressures and for oak under straint side pressure, an end pressure of 120 psi resulted slightly higher values than 60 psi, though the differences ere not considered important. With restraint side pressure, 240 psi had about the same effect as 120 psi in cherry, oak, and maple.

An end pressure of 400 psi produced highly variable results in black cherry joints. We believe that adhesive viscosity and the shape of the joint contributed to this variability. When adhesive B was freshly mixed and the viscosity was low, the resulting joints had a starved appearance. While the joints appeared excellent to the naked eye, under magnified view- ing (to 80X), problems were encountered when no side pres- sure was used. These joints were open at the outer edges and along the sides. We visualize that the joints were seated properly with enough glue at some end pressure less than 400 psi. As end pressure continued to be applied, there was ex- cessive squeeze out and stress near the peak caused the outer edges to open out. Squeeze out was not excessive when the viscosity increased. The 400 psi joints bonded with heavy side pressure were made when the adhesive viscosity was similar to thick latex paint. The heavy side pressure closed the open outer edges and high strength resulted.

Table 2.—Effect of end and side pressure on tensile strength of Sem joints glued with adhesive A (in psi)[a]

Species	Percent filler	Side pressure	End pressure (psi)		
			60	120	240
Cherry	5	Restraint	2,280	1,940	1,540
Oak	5	Restraint	2,840	2,590	2,380
Oak	10	None	—	2,530	—
Oak	10	Restraint	—	2,710	—
Oak	10	Heavy	—	2,550	—

[a] All values are an average from three tension tests.

Table 3.—Effect of end and side pressure on tensile strength of Sem joints glued with adhesive B (in psi)[a]

Species	Side pressure	End pressure (psi)			
		60	120	240	400
Cherry	None	2,380	2,950	—	510
Cherry	Restraint	3,035	3,250	3,180	—
Cherry	Heavy	1,650	1,800	—	3,730
Oak	Restraint	2,340	2,780	2,760	—
Maple	Restraint	—	3,380	3,340	3,360

[a] All values are an average from at least three tension tests.

In black cherry, restraint side pressure produced higher strength values at end pressures of 60 and 120 psi than did no or heavy side pressure.

Sugar maple and black cherry occasionally suffered slightly from torn or chipped grain on the infeed side of the concave side of the joint. While clearly noticeable under the microscope, this minor problem did not prevent high tension values for these species. Router bits with a different rake angle might not tear the grain at all. Torn grain was not observed in oak or walnut.

Conclusions

The performance of Serpentine end-matched joints and of panels with Sem joints was excellent. Manufacturers need not be concerned that the Sem joint will create problems in panels as a result of changes in moisture content before or after a finish is applied. The stiffness of panels containing a Sem joint is about the same as panels without Sem joints. While the maximum load, as determined by static bending tests, is reduced by Sem joints, it is doubtful that these factors are important in nonstructural applications. Our 0.7-inch-thick panels had to deflect at least 0.6 inch over an 18-inch span before "catastrophic" failure took place.

The precise manner in which the Sem joint is machined allows the use of relatively low assembly end and edge pressures. End pressures should be great enough to bring the t sides of the joint together but not so great as to cause exc sive squeeze out or to force open the concave side of the joint. When the two sides of the joint are free to move, en pressures between 60 and 240 psi are effective. Some side pressure is desirable to prevent the feather edges from ope ing, but only restraint side pressure is needed. Under these conditions, a strength in tension of more than 2,000 psi c be achieved.

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The Serpentine end-matched (Sem) joint is a precisely machined but joint with a sine wave shape. The joint is not readily visible to the eye and performs well in panels made of sugar maple, red oak, black walnut, and black cherry. The Sem joint is unaffected by changes in equilibrium moisture content from 6 to 12 to 18 to 6 percent. Panels containing Sem joints have about the same stiffness as panels without Sem joints. When tested to failure in bending, panels with Sem joints were weaker than control panels. However, the panels had to bend much farther than nonstructural applications would dictate before failure occurred. When making the joint, some side pressure and end pressures of 60 to 240 psi are needed.

824

Keywords: Panels; end gluing; edge gluing; numerical control routers

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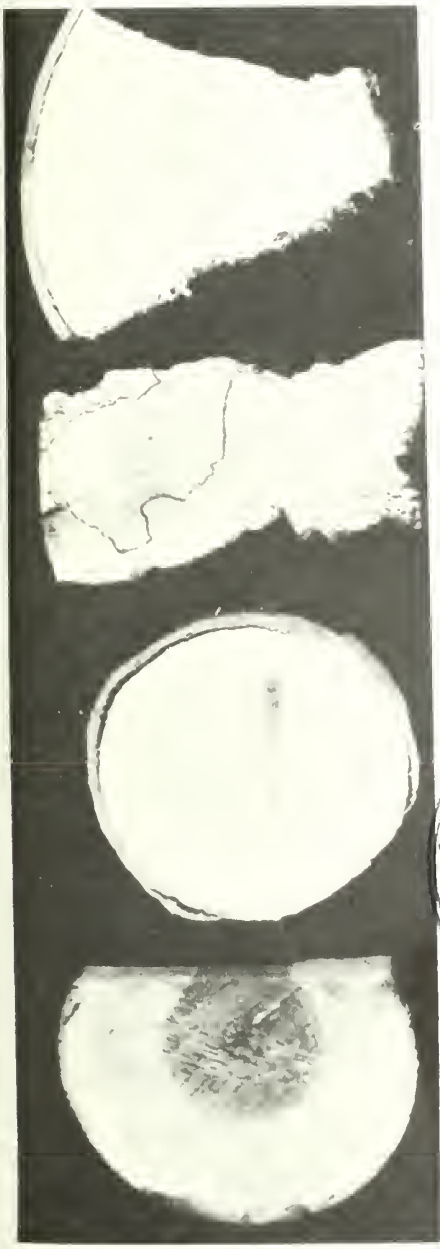
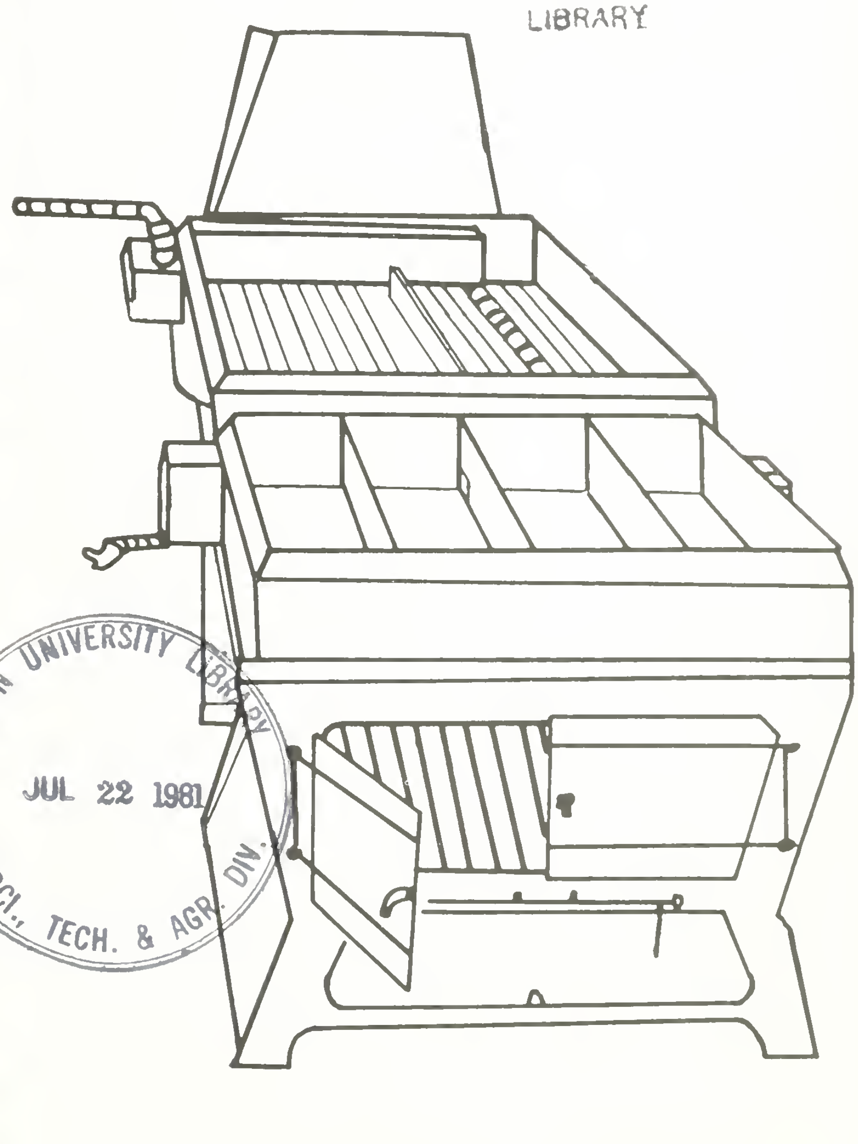
Efficiency of Using Solid Wood Fuels
in Maple Syrup Evaporators

by Lawrence D. Garrett





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Abstract

A study of commercial, wood-fired evaporators revealed that normal expected thermal efficiencies are between 35 and 50 percent. The moisture content and quality of wood fuels used and the design and method of firing the evaporator are critical in determining evaporator efficiency and the economic implications of using wood.

Introduction

In the United States and Canada, it is estimated that approximately 15,000 maple syrup producers process 3 million gallons of pure maple syrup annually. There are insufficient data on the percentage of total production that is processed by solid wood-fired evaporators. However, regional studies indicate that a significant number of producers are using wood (Kearl 1970, Acker et al. 1970). Oil also is used extensively and generally in larger and more modern maple processing plants.

Number 2 fuel oil is the most common fuel purchased by maple producers operating with oil. It also is the evaporator fuel that has experienced the most rapid rise in price. From a price of $0.12 to $0.14/gal in 1970, No. 2 fuel oil rose in one decade to the price of $0.95/gal in 1980. At $0.95/gal, $3.32 in oil alone is required to process 1 gallon of pure maple syrup. Possibly more critical than its price is the possible restricted availability of No. 2 fuel oil over the next 5 years.

This combination of restricted availability and rising price of fuel oil prompted research to determine the thermal efficiency of commercial, open-pan evaporators that use solid wood fuels, and to characterize the economic implications of these fuels as an alternative to oil and gas. There has never been a study of this type, though manufacturers have estimated the efficiency of open-pan evaporators using wood fuels, and have recommended appropriate species and evaluated the probable effects of using wet and deteriorated wood (Morrow 1959).

Procedure

To meet the study objective in a manner most beneficial to the industry, actual case studies were analyzed. Three commercial maple syrup operations (A, B, and C) in which solid wood fuels are used were selected as best representing actual production conditions. The evaporators had to be of commercial size (5 x 16 feet or 6 x 16 feet), in a good state of repair, installed to manufacturer's specifications, and have no modifications.

Four types of wood fuel were tested in each evaporator. Each fuel type had at least 80 percent of its total weight in beech, birch, and maple.

1. *Split or round hardwood*—Selected fuels were used by the operator at his plant during the study. The average moisture content (MC) was less than 25 percent.
2. *Split or round hardwood*—The average MC was less than 30 percent.
3. *Split or round hardwood*—Rot accounted for at least 50 percent of total volume. The average MC was less than 35 percent.

4. *Split or round hardwood*—The average MC was greater than 35 percent.

A total of 12 tests were conducted with the three evaporators; and each test consumed approximately 7,000 pounds of wood fuel and lasted approximately 5 hours.

Syrup quality was determined by taking samples coming off the evaporator at 1/2-hour intervals during each test. Analysis of the samples was made to ensure that the test procedures produced a quality product for marketing.

All factors affecting each evaporator's thermal efficiency and operating effectiveness were studied. These included: sap and syrup temperature; sap and syrup Brix; sap and syrup flow rates; stack, firebox, and air temperature; weight of fuel consumed; wood moisture; barometric pressure; stack-gas composition; and time intervals for opening and closing firebox doors.

For each of the four wood fuels, wafers were sawed at random from the center of solid fuel sticks during each test to provide an accurate assessment of MC (Fig. 1). Wood moisture was determined on the wet basis by the formula:

$$\text{MC (percent)} = \left(\frac{\text{wt. wet wood - wt. dry wood}}{\text{wt. wet wood}}\right) \quad (100).$$

Factors Affecting Efficiency

The efficiency of the wood-fired evaporator is affected the design and operability of the evaporator itself and b the type and condition of fuel used. In combination, the effects, defined as "equipment effect" and "fuel effect, produced evaporator efficiencies ranging from 20 to 60 percent.

Equipment effect

The open-pan evaporator was originally designed to use solid wood fuels (Willits 1965). The design requires a lo firebox to accommodate 4-foot lengths of split or roun wood fuel set on a grate (Fig. 2). The sap and syrup pa are heated by convection and radiant energy. The desig the firebox is such that the cold-air draft creates a long ball extending under the back pan. The rise in the arch the firebox region actually forces the hot gases into the dropped flues of the back pan (sap pan). The cold draf reduces the overall temperature of the hot gas mixture, thereby reducing the effective heat transfer to the unde surface.

The oil-fired evaporator's firebox is shorter and deeper a has less grade in the arch (Fig. 3). The placement of the the angle of the jet spray, and the angle of the rise in th

Figure 1.—Wood samples taken during each evaporator test to determine wood moisture and Btu value.

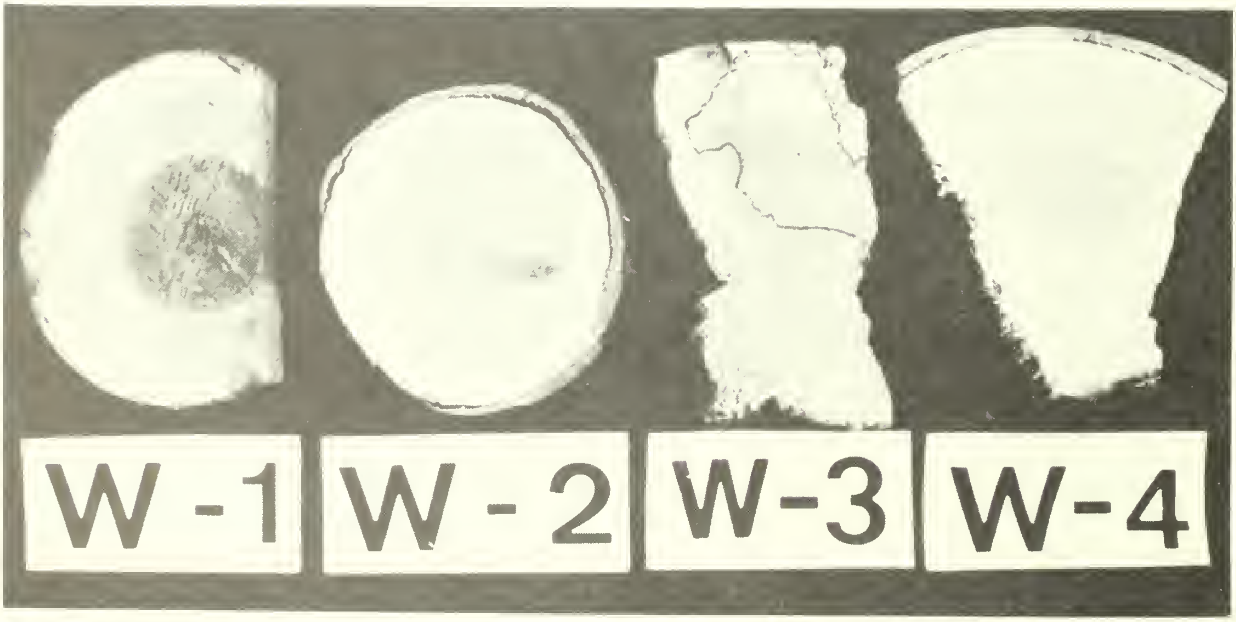


Figure 2.—Schematic of conventional, wood-fired, open-pan evaporator.

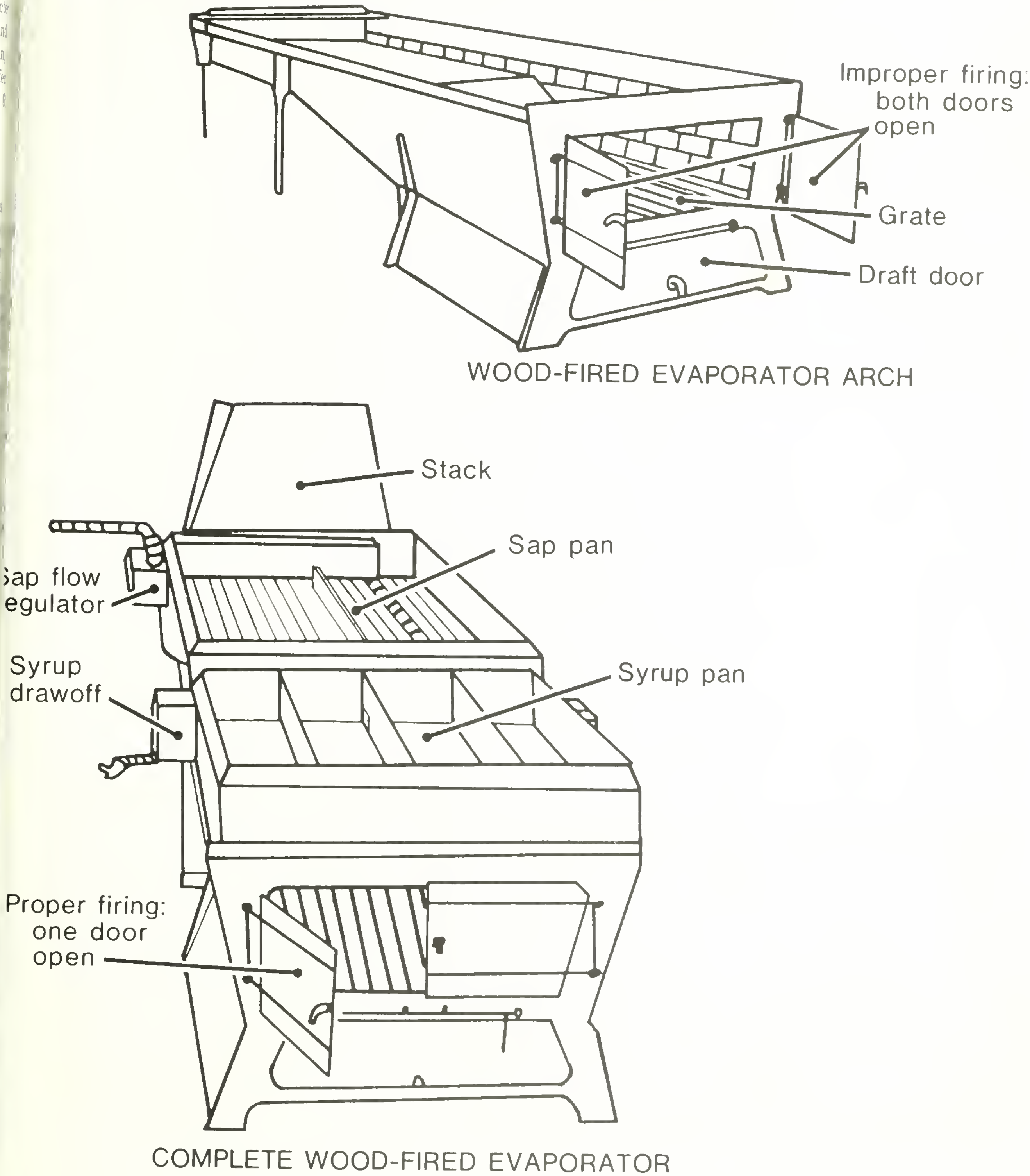
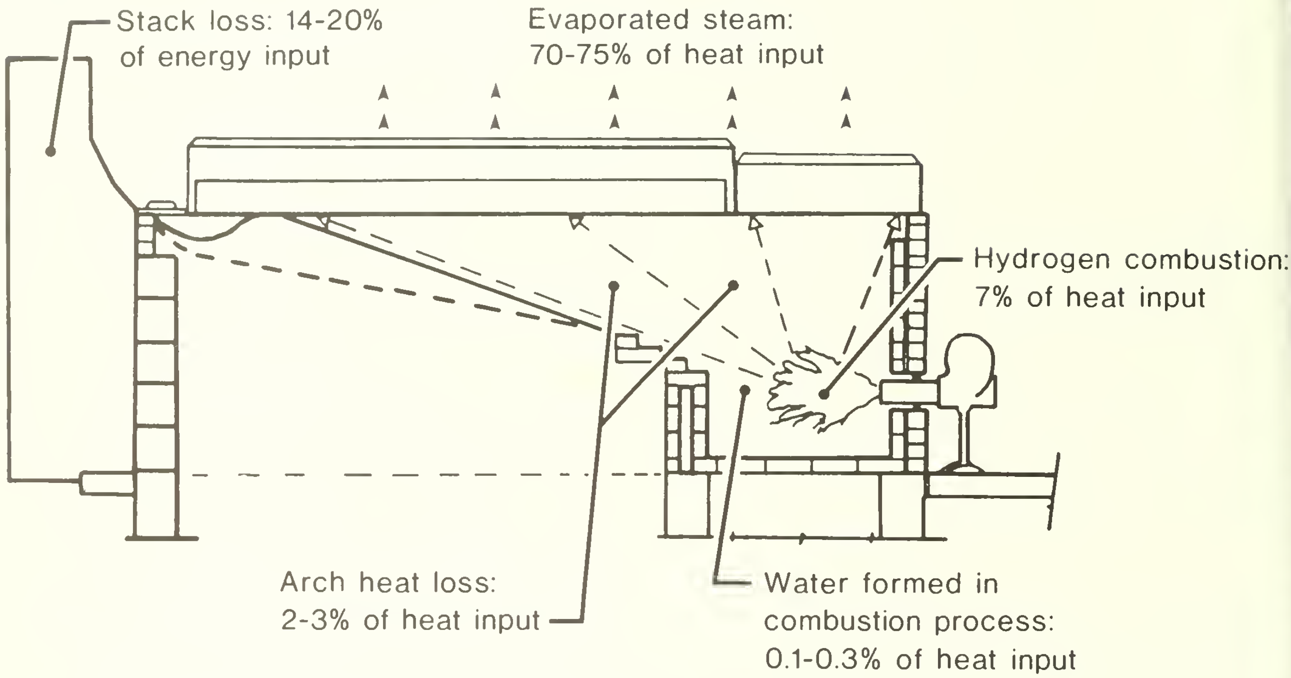


Figure 3.—Schematic of conventional, oil-fired, open-pan evaporator showing efficiency losses.



$$
\begin{aligned}
\text{Evaporator efficiency} &= 100 - [16 + 2.5 + 7.0 + 0.2] \\
&= 100 - 25.7 \\
&= 74.3
\end{aligned}
$$

arch are important in ensuring maximum heat transfer to the underpan surfaces (Strolle et al. 1956). The front pan on many wood evaporators that have been converted to oil has been damaged because the oil fireball is too close to the pan.

Evaluation of evaporators operating on fuel oil showed that 14 to 20 percent of the direct input of heat units or Btu is lost to gases exiting through the stack (Fig. 3). An additional loss of 7 percent results from poor hydrogen combustion in the firebox (Garrett et al. 1977). It is realistic to assume that similar evaporators that use solid wood fuels would have lower efficiencies. Since the fire doors must be opened continually to fire the evaporator, cold-air drafts are created over the fuel bed, cooling down the hot gases and reducing heat transfer to the evaporator pans.

The fuel effect

The amount of heat energy produced from a fuel depends on the combustion process, wood moisture, and type of fuel consumed. The greatest heat is generated by atomizing a fuel so that a rapid, complete burn is obtained. This efficient combustion process is more nearly attained with liquid or gas fuels and obviously cannot be obtained with split or solid wood fuels.

The combustion process. The combustion of wood occurs in three stages (Koch 1972). Although the stages are not always distinct, it is important to define the general character of wood in each stage. In the first stage, heat is absorbed by the wood to evaporate water. The wood temperature generally does not exceed 212°F until the moisture content approaches zero. The length of time wood remains in the first stage depends on the total amount of heat available, the rate at which it is applied, and the MC of the wood.

The second stage of the combustion process includes driving off and burning gas volatiles other than water. The rate at which this takes place also depends on the rate at which heat is applied. Most volatiles ignite and burn at temperatures above 1,000°F. This is where 65 to 80 percent of energy from wood burning is derived.

The third stage of combustion is the actual burning of recal charcoal matter. The surface of the charcoal reaches owing temperature and burns as external oxygen is ight into contact with it.

d moisture. Fuel moisture does not reduce the total e produced during combustion. However, its presence in flue gases, together with the water formed as the hydro-e in the fuel is burned, reduces recoverable heat. Heat is uired to raise the water in the wood from an ambient perature (65°F, for example) to 212°F. In addition, poration of the water (212°F) to steam (at 212°F) requires ge heat input (970 Btu per pound). The steam tempera- is then raised from 212°F to a flue temperature of ut 400°F, and the steam is released through the stack. otal, each pound of steam carries up the flue approxi-ely 1,210 Btu.

ically, green sapwood (50 percent MC, wet basis) of thern hardwoods contains approximately 1 pound of er for each pound of wood. One pound of dry wood con-s approximately 8,600 Btu. Since there is 1/2 pound of wood and 1/2 pound of water in each pound of freshly wood, the heat value is only 4,300 Btu (8,600/2). So ounds of wet wood would be required to obtain 8,600 ilable Btu.

roximately 0.55 pound of water is formed during the nbustion process. This causes an additional loss of about 6 Btu. Also, for each 1 pound of wood burned, an addi-nal 690 Btu may be lost through the stack in other hot gases (carbon dioxide, nitrogen, and excess air).

erefore, the net heat value normally recovered from 2 unds of green sapwood (1 pound wood and 1 pound water) is

at of combustion of 2 pounds of wet wood	8,600
ss	
at loss associated with water content	-1,210
at loss associated with hydrogen combustion	-726
at loss in other flue gases	-690
Net usable heat	5,974

e recoverable heat from 1 pound of wet fuel would be ly 2,987 Btu (5,974/2), i.e., about 70 percent of the 4,300 u (8,600/2) input.

e recoverable heat value from air-dried wood (20 percent C wet basis) is significantly larger. Using 1 pound of air-ed wood at 20 percent MC gives 0.8 pound of wood or 880 Btu (8,600 x 0.8). Only 1,300 Btu are lost to moisture, ter vapor formed, and dry flue gas, leaving a net for evap-ation of approximately 5,580 Btu.

Type of wood. For practical purposes, 1 pound of oven-dried wood of any species has the same energy component —approximately 8,600 Btu per pound. However, ignition and burning characteristics and the weight of a given volume of wood can confuse the user of wood fuels as to the efficiency of one wood versus another.

Certain woods have greater concentrations of lignin than others. Some of these include sassafras, wood from fruit trees, white oak, and locusts. These concentrations increase the Btu yield slightly above the normal yield from species with little or no lignin deposits. Also, certain pines have greater resin levels which increases the Btu yield per pound. Resins have a higher Btu yield per unit weight than cellulose fiber. Yet, Btu yield per pound is fairly consistent among the species normally used (Table 1).

The confusion concerning heat yield from different species relates to wood being sold on a unit volume or cord basis rather than on a weight basis. The dimensions of a cord of wood (4 x 4 x 8 feet) produce a volume of 128 cubic feet (ft^3). In reality, a cord contains between 80 and 100 ft^3 of solid wood with approximately 30 to 50 ft^3 taken up in air space. The amount of energy that the maple producer obtains from a cord will depend on the species used, since equal volumes (1 cord) have different densities and/or weights.

A producer would need almost 2 cords of white pine, balsam fir, hemlock, or basswood (12.1 MM Btu/cord) to equal the Btu yield from 1 cord of locust, red oak, white oak, or hard maple (22.5 MM Btu/cord). Table 1 shows the specific gravity (density) and Btu heat yields per cord for typical Northeastern and North Central woods.

Results

This study documents the major cause of wood-fired evaporator efficiency to be related to characteristics of the wood fuel and secondly, to evaporator design. Further, it characterizes expected evaporator efficiency to fall between 35 percent and 50 percent. These findings support research by Huyler and Garrett (1979).

Wood fuel effect

In this study, no attempt was made to define the effect of different wood species used most often—beech, birch, and maple. Lower density hardwoods and softwoods made up 20 percent of the weight of the test fuelwood. Test fuels composed of deteriorated wood were used to represent wood that normally is recovered from sugarbush improvement and used in evaporators.

Wood moisture was identified as the primary wood fuel variable for evaluation. The average MC (wet basis) of wood

Table 1.—Greater heat values of wood and heat equivalents in coal, fuel oil, and natural gas

Species (1 standard cord)[a]	Specific gravity	Available heat of 1 cord wood (Btu)[b]	Anthracite coal (tons)[c]	No. 2 fuel oil (gallons)[d]	Natural (100 ft^3
Shagback hickory	0.72	24,600,000	1.12	251	308
Black locust	.69	24,600,000	1.12	251	307
Rock elm	.63	23,488,000	1.07	240	294
White oak	.68	22,700,000	1.04	232	284
American beech	.64	21,800,000	.99	222	273
Yellow birch	.62	21,300,000	.97	217	286
Sugar maple	.63	21,300,000	.97	217	286
Red oak	.63	21,300,000	.97	217	286
White ash	.60	20,000,000	.91	204	250
Black walnut	.55	19,500,000	.89	198	244
White birch	.55	18,900,000	.86	193	236
Black cherry	.50	18,770,000	.85	191	235
Tamarack (eastern larch)	.53	18,650,000	.85	190	233
Red maple	.54	18,600,000	.84	190	232
Green ash	.56	18,360,000	.83	187	229
Pitch pine	.52	17,970,000	.82	183	225
American sycamore	.49	17,950,000	.82	183	224
Black ash	.49	17,300,000	.79	177	216
American elm	.50	17,200,000	.78	176	215
Silver maple	.47	17,000,000	.77	173	213
Red spruce	.41	13,632,000	.62	139	170
Hemlock	.40	13,500,000	.61	138	169
Black willow	.39	13,206,000	.60	135	165
Red pine	.46	12,765,000	.58	130	160
Aspen (poplar)	.38	12,500,000	.57	128	156
White pine	.35	12,022,000	.55	123	150
Basswood	.37	11,700,000	.53	119	146
Balsam fir	.36	11,282,000	.51	115	141

[a] 1 standard cord = 128 ft^3 of wood and air; 80 ft^3 solid wood; 20% MC; 1 lb of this wood contains approximately 5,580
[b] It is assumed that available heat of wood is oven-dry, or calorific value, minus loss due to moisture, minus loss due to wat vapor formed, minus loss due to heat carried away in dry chimney gas. Stack temperature 450° F. No excess air. Efficiency f burning unit = 50 to 60 percent.
[c] Contains 28 million Btu per ton, but available heat is only 22 million Btu per ton; 1 lb of coal contains 11,000 available Btu. Coal burned under similar conditions to wood.
[d] 1 gallon contains 140,000 Btu, but is burned at 70 percent efficiency, providing 98,000 available Btu.
[e] 100 ft^3 = 1 therm = 100,000 Btu, but is burned at 80 percent efficiency, providing 80,000 available Btu.

fuels used in the 12 tests ranged from 19.3 to 41.8 percent. The average MC for the three tests run with fuel type 1 was 21.9 percent. The average for wood fuel type 4 was 40.3 (Table 2).

The number of pounds of wet fuel used per hour ranged from 551 to 685 for the four fuel types. Actual dry fuel consumed for the four fuels ranged from 409 to 466 pounds per hour (Table 2).

The average amount of water evaporated per hour from the various woods for the three operators was greatest (1,844.8 pounds) with relatively dry wood (21.9 percent MC) and lowest (1,194.8 pounds) with wet woods (40.3 percent M (Table 2).

Wood moisture was critical in reducing evaporator efficie For each operator, efficiency dropped significantly when wood fuel used was changed from a relatively dry to a ve wet one (Table 3). For the three operators, the average ciency was 52.8 percent when wood fuels with an averag MC of 21.9 percent were used. As the MC of the wood f increased to 40.3 percent, evaporator efficiency dropped to 27.7 percent.

type 3 was used in the study because producers remove
orated wood from their sugarbushes for use in evapor-
. It can be concluded from the results of this study that
IC of the deteriorated wood was much more critical
ermining evaporator efficiency than the deteriorated
of the wood. On a comparative dry-pound basis, fuel
3 performed as effectively as the nondeteriorated woods.

le 2.—Relationship of wood moisture content to wood use and water evaporated per hour

Item	Wood fuel			
	1	2	3	4
age wood C(%) wet basis	21.9	26.1	32.6	40.3
ds of wood our				
C	430.6	466.4	447.5	409.4
t	551.2	631.5	664.1	685.3
ds of water orated	1844.8	1630.4	1431.8	1194.8

A word of caution is important concerning this analysis. Efficiency evaluations are computed on pounds of dry fuel consumed. As such, deteriorated wood is evaluated purely on the weight of the remaining tissue, which naturally would be less than an equal volume of solid wood. Stated another way, the deteriorated condition of the wood results in lower specific gravity or weight per unit volume and also in a reduction in some energy chemicals. Its Btu yield per pound is only slightly less than that of oak, pine, or balsa wood. But the number of pounds of wood remaining per unit volume or cord has been reduced by rot. The primary objective was to see if the deteriorated wood produced an efficient flame for effective evaporation. The conclusion is that it did.

Evaluating equipment effect

In addition to the obvious fuel effect of higher MC on evaporator efficiency, an equipment effect was also important. The continual opening of the evaporator doors produced high infusions of cold draft air, which created a buffer of cold air that reduced the coefficient of heat exchange to the underside pan surfaces. Also, the cold air mixed with the hot gases to produce a lower average gas temperature, which further reduced net heat transfer.

Operators of wood-fueled evaporators can control the efficiency of their evaporator through an effective firing method. The best method for firing a solid wood-fueled, open-pan evaporator is to open one fire door at a time, as illustrated in Figure 2. By firing one-half of the burning surface at a time, the operator can maintain an effective fire in the evaporator with minimal door opening time.

Table 3.—Relative efficiencies using solid wood fuels in maple syrup evaporators, in percent

rator	Evaporator efficiency using:				
	Dry hardwood <25% H_2O	Partially dry hardwood <30% H_2O	Deteriorated wet hardwood <35% H_2O	Green hardwood >35% H_2O	Average efficiency
A	66.3	45.4	38.2	30.4	45.1
B	49.5	43.6	32.5	28.4	38.5
C	42.7	33.2	32.1	24.4	33.1
rage ciency	52.8	40.7	34.3	27.7	38.9

Table 4 shows the relationship of required fueling time to evaporator efficiency. For the most efficient operator (A), the average time in which one of the fire doors was open was 16.6 minutes per hour. The average efficiency of operator A's evaporator was 45.1 percent. For the next most efficient operator (B), the average fire door opening time was 19.9 minutes per hour, and the average evaporator efficiency was 38.5 percent.

Wood Fuel Economics

The type of wood burned by maple producers has little alternate use except as pulpwood. It consists of stems and tops of cull, small-diameter, rough and rotten, and dead standing timber, and upper stems and tops of sawtimber. It usually represents cleanings from the producer's sugarbush and tops and culls from logging operations and timber stand improvement.

Generally, fuelwood is cut by the maple producer from his woodlot (Acker et al. 1970, Kearl 1970, Morrow 1959). As such, the producer must assign costs to his procurement activities to derive a real cost of the wood fuel. These costs will include:

1. $5 to $10 per cord for standing or down wood resources.
2. $3 to $5 per cord for chainsaw, splitting mall, axe, wedges, and accessories used in cutting and splitting operations.
3. $2 to $3 per cord annual maintenance cost for worn and damaged equipment.
4. $4 to $6 per cord annual operating cost for gloves, gas, plugs, and oil products.
5. $2 to $4 per cord for transportation associated with moving the wood to the sugarhouse.

A purchaser will incur out-of-pocket costs between $20 and $30 for each cord obtained (Frick 1978). If labor is included, the cost would be between $3 and $5 per hour and 3 to 5 hours per cord would be required. In our example, the total price of a cord would be $34. If the producer buys wood from other producers or on the open market in maple-producing regions, he will incur a cost of $60 to $80 per cord for air-dried wood.

The price of $34 to $80 per cord does not necessarily reflect the value of energy received. If the maple producer ignores the effect of wood volume, species differences, and MC on realized net heat yield from wood, he could be paying a much higher price for fuel than he realizes.

Nominal fuel volume

When wood is obtained by the cord in a 4-foot or longer length, one can expect significantly less than the actual cub foot measure of the truck body in which it is hauled. Anything that causes cordwood sticks to vary from perfect cylinders, such as limbs, knots, crook, and sweep, will increas the air space in a stacked cord. In general, the smaller, longer, and more crooked the material, the lower the cubic foot yield and the higher the real energy cost (Tables 5-6).

Fuel type

As noted, 1 pound of oven-dried wood of any species has the same energy component, approximately 8,600 Btu per pound. However, Btu content varies greatly for a given volume of wood such as a cord (Table 1). The variable heat yield relates to specific gravity or weight per unit volume o the wood.

Table 7 relates the effect of specific gravity or wood densit to the true cost of energy received from purchased wood fis. If beech and fir each cost $60 a cord, the real cost of fir becomes $102.60, because 1.7 cords of fir are required to equal the heat yield of 1 cord of beech.

Fuel moisture content

A third factor directly affecting the energy cost of wood fuels is fuel moisture content. Typically, green sapwood of northern hardwoods contains approximately 0.5 to 0.7 of a pound of water for each pound of wood, or is said to hav 30 to 40 percent MC measured on a wet basis. As related earlier, maple producers using low moisture fuels (20 to 30 percent) obtained evaporator efficiencies above 50 percent As MC increased to 40 percent, efficiency dropped to 30 percent.

The primary economic question posed by wet fuels is: how many pounds of water can be evaporated per dollar of fuel input? In the food processing industry, this is expressed as a fuel cost per 1,000 pounds of water removed, and it is th guiding factor in determining an evaporator's economic effectiveness.

A conventional 5 x 16 foot evaporator using seasoned woo of 20 to 30 percent MC (dry basis) can evaporate 208 pour or 25 gallons of water with about 72 pounds of wood. Seventy-two pounds of wood is .025 of the weight of 1 co of medium density hardwood at 25 percent moisture (72 lb/2,900 lb = .025).

Table 4.—Relationship of fire door opening time to evaporator efficiency for three commercial operators

Operator	Time fire door open				Average	Evaporator efficiency
	Fuel type 1	Fuel type 2	Fuel type 3	Fuel type 4		
	Minutes/hour					*Percent*
A	15.9	16.1	13.7	20.9	16.6	45.1
B	16.1	19.1	21.7	22.6	19.9	38.5
C	21.9	29.9	24.9	19.6	24.0	33.1
Average	17.9	21.7	20.1	21.0	20.2	

Table 5.—Solid content[a] of stacked roundwood cord[b], by dimension and type of wood, in ft³

Wood type	6-inch or less diameter		6- to 12-inch diameter		12-inch diameter	
	4 feet	8 feet	4 feet	8 feet	4 feet	8 feet
Softwood						
Straight	87	84	92	90	98	96
Crooked	75	71	84	79	88	86
Tops and branches	67	60	—	—	—	—
Hardwood						
Straight	79	78	88	85	95	92
Crooked	70	65	78	74	84	81
Tops and branches	58	50	—	—	—	—

[a]Source: USDA Forest Service, Lake States For. Exp. Stn., For. Res. Dig., May 1935.
[b]Stacked cord dimension 4 x 4 x 8 feet.

Table 6.—Cost of obtaining less than 1 cord of wood (80 ft³) in a purchase agreement

Purchase price (dollars/cord)	Amount of wood paid for	Wood actually received	Conversion value (cords)	Actual cost of wood purchased
	ft³			*Dollars*
60	80	75	1.07	64.20
60	80	70	1.14	68.40
60	80	65	1.23	73.80
60	80	60	1.33	79.80
60	80	55	1.45	87.00

Table 7.—Relationship of wood density to cost per Btu when buying on volume basis

Species class	Specific gravity	Purchase price	Conversion value (cords)	Real cost · equivale heat valu
		Dollars/cord[a]		*Dollars*
Red and white oak, hard maple, pecan, beech	0.60—0.65	60.00	1.00	60.00
Soft maple, cherry	.50—.55	60.00	1.20	72.00
Cottonwood, aspen	.40—.45	60.00	1.50	90.00
Pines, true firs, spruce	.35—.40	60.00	1.71	102.60

[a] Assumes 80 ft^3 of solid wood.
[b] Assumes oak and maple heat yield as base or equal 100 percent.

For the operators studied, $1.25 worth of wood (at $50 per cord) would be required to produce 1 gallon of syrup (.025 x 50). At $70, $100, and $130 per cord, the cost of wood fuel per gallon of syrup produced would be $1.75, $2.50 and $3.25, respectively. By contrast, 3.5 gallons of oil are required to produce the same gallon of syrup. Thus, at $0.50 per gallon of oil, $1.75 worth of oil would be needed to yield 1 gallon of syrup (3.5 x 50). At $0.90, $1.20, and $1.50 per gallon, the cost of oil per gallon of syrup produced would be $3.15, $4.20 and $5.25, respectively.

Even at $90 per cord, wood will be much more competitive than oil if the price per gallon of oil ranges from $0.90 to $1.20. At $90 per cord versus $1.20 per gallon of oil, an operator using wood would achieve a fuel cost advantage of $1.95 for each gallon of syrup produced.

Summary

The operator who chooses wood over oil or gas must deal with several factors that contribute to the efficiency and economics of using wood in a conventional evaporator. First, he must remember that when buying on a volume basis, such as cord measure, less of a denser wood is required for the same heat value. Second, if the operator keeps his evaporator in good repair and uses good firing techniques, he still must be concerned with the MC of the wood that he is using. For any given wood, the evaporator efficiency can drop from a level of about 50 percent to less than 30 percent when the MC of wood is increased from 20 to 40 percent on a wet basis. His fuel cost will increase significantly, diminishing the cost advantage of wood over oil or gas.

The use of dry dense hardwoods with proper operating procedures can ensure significant reductions in fuel costs over oil and gas. Further, wood is expected to maintain its economic advantage over alternate fuels such as oil and gas over an investment period of 5 to 10 years.

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10 p., illus. (USDA For. Serv. Res. Pap. NE-486)

A study of commercial, wood-fired evaporators revealed that normal expected thermal efficiencies are between 35 to 50 percent. The moisture content and quality of wood fuels used and the design and method of firing the evaporator are critical in determining evaporator efficiency and the economic implications of using wood.

ODC: 892.68

Keywords: Maple syrup production, processing; economics of processing; costs of processing

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Water Requirements of Honeylocust *(Gleditsia triacanthos* f. *inermis)* in the Urban Forest

by Howard G. Halverson
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Abstract

Water use by an urban tree was measured lysimetrically while water use by the same tree at a non-urban site was estimated by a model. Comparison of the measured and estimated water use showed that the urban honeylocust (*Gleditsia triacanthos* f. *inermis*) required an average of 155 percent of the water needed by the same tree surrounded on a homogeneous vegetated surface. Measured water use ranged from 60 to 303 percent of estimated water use. Advected energy from surrounding urban sites was the apparent cause of the excess transpiration. A water requirement this much greater in the city would place the trees under water stress during the growing season.

I:roduction

Evironmental stresses on urban forests are often caused by c natic or edaphic factors. Among the stress factors, avail- a e soil moisture has a great impact on vigor and growth. Misture stress may interact with other stress factors, such as n chanical damage or insect infestation, to retard growth or i rease mortality in urban forests (Himelick 1976), but noisture stress is probably the most important.

Iidence of water stress can be found in many cities. Pre- nture senescence, general decline, and early mortality in uan honeylocust (*Gleditsia triacanthos* f. *inermis*) can be i luced by water stress (Potts and Herrington 1979). Iought damage is often attributed to a simple lack of soil noisture. Soil moisture deficit can result when compacted s ls and other impervious surfaces route precipitation away fom forest sites before the water can infiltrate the soil. Iowever, an excessive evaporative demand, even when soil noisture is available, can result in stress damage to urban frests. This study was an attempt to quantify the evapora- ti e demands on the urban forest. Although evaporative de- nands in urban vegetation are thought to be excessive, only few studies, such as Oke's (1979) comparisons of water mand by grasses between rural and urban areas, are avail- ble.

ethods

ie urban site and tree

ie study site was a grassy knoll adjacent to large structures d paved areas. The site had conditions similar to urban nenity spaces common in large northeastern cities, with ructures and paved areas completely surrounding it. It is in /racuse, N.Y. at 43°02'N latitude and 76°06'W longitude.

or a study species, we chose honeylocust (*Gleditsia tri- anthos* f. *inermis*) because it is one of the most popular ban trees (Gerhold et al. 1975). It is also the most com- only used tree species in Syracuse amenity spaces.

he urban forest tree

'e measured actual water use with a weighing lysimeter. ne-m^3 lysimeters were constructed of marine grade ply- ood, thoroughly sealed on the interior surface to prevent oisture leakage. The exterior surface was coated with a re- ective paint to prevent excessive heat transfer into the lysi- eter. Two lysimeter tanks were filled with soil. We installed x Wescor[1] psychrometers to monitor soil water potential the lysimeter.

A tree was established in one lysimeter tank in the summer of 1976, and the soil surface was covered with plastic to prevent evaporation. No measurements were taken until 1977 to allow tree roots to occupy the soil volume in the lysimeter. Throughout the study we maintained soil moisture at a water potential between -1 and -4 bars. In 1977, the tree was 3 m tall, 4 cm in diameter, and had a leaf area index of 3.72. Leaf orientation was predominantly horizontal, and leaves were oriented evenly in all quadrants.

In the summer of 1977 the tanks were placed on a platform about 30 cm above the ground. Each tank, with a mass of about 1000 kg, was supported on a coiled tube containing degassed water. The two coiled tubes were connected to the inlet ports of a differential pressure transducer. The lysimeter without a tree was capped to prevent changes in water content, had a constant mass, and was used on the reference side of the transducer. The active side of the transducer was connected to the coiled tube supporting the lysimeter with the test tree. The lysimeter and transducer system was capable of determining mass changes of ±100 g in the 1000 kg lysimeter. However, because the lysimeters were above ground level, we experienced some temperature instability and some low frequency pressure oscillation due to wind.

At the lysimeter site, we recorded meteorological variables at hourly intervals during August 1977. We recorded net radiation just above the tree crown with Micromet instruments[1]. Direct and diffuse photosynthetically active radiation (Lambda sensor), and beam and diffuse shortwave radiation (Kipp and Zonen radiometer) were measured at a point adjacent to the crown. Atmospheric humidity was measured with a condensation hygrometer (Cambridge) at the site. Air temperatures were measured with a shielded, ventilated mercury thermometer while leaf and soil temperatures were measured with an infrared thermometer (Barnes Engineering Co.). Wind was measured at crown height with sensitive sup anemometers (Casella anemometers). A complete 24-hour record was obtained on 7 days. Other days were excluded from the analysis because of extended storm periods or other unfavorable conditions.

The evapotranspiration model

We estimated tree water demand at a non-urban site with a model employing the micrometeorological data taken at the lysimeter site. The model selected to estimate water requirements was a single leaf energy budget form of the modified Penman equation (Monteith 1964). The equation had the form:

$$\lambda E = \frac{sQ_{nl} + \rho C_p \ (e_s - e_a)\ k_h}{s + \gamma\ (2 + k_h / k_s)}$$

where Q_{nl} = average net radiation absorbed per unit of leaf area, taken as crown net radiation divided by 2 when radiation was less than 300 wm^{-2} and 4 when radiation exceeded

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300 wm^{-2}. Correction factors were computed from data presented by Landsberg and others (1975) and Butler (1976).

ρ	=	air density
C_p	=	specific heat of air at constant pressure
e_s	=	saturation vapor pressure of air
e_a	=	actual vapor pressure
k_h	=	boundary layer heat conductance
γ	=	psychometric constant
k_s	=	mean stomatal conductance
s	=	slope of the saturation vapor pressure curve
λ	=	heat of vaporization of water
E	=	evaporation

Although providing a framework for discussing forest evapotranspiration (Federer 1975), the modified Penman equation makes certain assumptions about energy transfers between vegetation and the environment. The most critical assumption is that there is no advection of energy or water vapor from surrounding areas. In this experiment, the lysimeter and study tree were on a site that did not meet the assumptions of the model. Thus, any discrepancy between measured and estimated water use is probably due to advection in the urban location (Miller 1980). Further, the difference is a good measure of the excess evaporation demand placed on urban vegetation.

The meteorological variables measured near the lysimeter provided the data necessary to solve the modified Penman equation except for k_s and k_h. We measured stomatal resistances on the lysimeter tree (under varying soil water potentials, leaf water potentials and visible light flux densities) with a diffusion porometer (Lambda) and computed k_s as the reciprocal of stomatal resistance. The boundary layer conductance for heat, k_h, was assumed to approximate the conductance for water vapor (k_p) (Monteith 1964). The value of k_h in a mixed convection regime was derived from the relationship derived by Campbell (1977) and corrected for hypostomatous leaves:

$$\frac{1}{k_h} = 180\sqrt{\frac{d}{u}}$$

where d = a characteristic leaflet dimension
u - wind velocity over the leaf

The values used for leaf conductances in the model estimations were liberal; any errors would be in the direction of overestimation.

On the study tree, there was an actual count of 2121 compound leaves. There was an average of 24 leaflets per compound leaf, and each leaflet had an average area of 0.55 cm^2 in our sample. The characteristic dimension of the leaflet was equated to the square root of the area, assuming random orientation of leaflets. The characteristic dimension was 0.74 cm.

We selected several honeylocust growing near the site an measured stomatal resistance on these trees to be sure ou lysimeter tree was reacting normally. We also measured petiole water potential on these trees by the pressure cha ber technique (Scholander et al. 1965). We did not meas water potential in the lysimeter tree because sampling w ld have been destructive.

Results and Discussion

The volume of water transpired by a plant is determined plant as well as environmental factors. The plant reacts t water strees by closing stomata and thus reduces its wate requirements. However, in our study, honeylocust stoma were not active in controlling water loss. The stomata oped at any solar radiation level greater than 10 percent of ful sunlight, as they do in most other tree species. In most tr stomata abruptly close when plant water potential drops a species-dependent threshold level, usually some value between -11 and -25 bars (Hinckley et al. 1978). Honeylocu stomata did not close, even when measured plant potenti dropped to -25 bars on trees near the lysimeter. Consequently, transpiration at near potential rates occurred fro shortly after sunrise almost until sunset. Stomatal resista on the lysimeter tree and nearby trees were the same, so lysimeter was not causing our test tree to react abnormal Similar stomatal behavior has been observed in some othe pioneer species (Toblessen and Kana 1974).

The urban tree required substantially more water than wa estimated by the Penman-Monteith equation. As shown in Table 1, actual water use exceeded model predictions on almost every day that was suitable for data acquisition. In general, the greater the demand, as indexed by lysimetric water loss, the larger was the discrepancy between actual d predicted honeylocust behavior. On the day with the great demand, the urban tree used 3.03 times the predicted wat requirement. On days of lesser demand, the ratio droppec to less than unity. On the average, the urban tree requirec 1.55 times the water estimated to be needed by a tree on non-urban site.

Increased water use by urban trees has been attributed to advected energy in the form of sensible heat produced in ban surroundings (Miller 1980). Solar radiation, wind, anc vapor pressure deficit are important factors because radiat is the energy source, wind is required for advection, and t atmosphere must accept transpired water. Boundary layer theory suggests that high wind velocities thoroughly mix t varying air properties and dissipate boundary layers over leaves. At low wind velocities, a boundary layer over the s faces allows local extremes in the various air properties, su as temperature and humidity. However, a boundary layer

Table 1.—Actual and simulated water use by urban honeylocust and the percentage of simulated evapotranspiration that would occur under urban conditions

Parameter	Date						
	8/09	8/15	8/16	8/18	8/23	8/25	8/31
Urban evapotranspiration (g)	8200	3600	900	10000	1800	5700	4500
Estimated evapotranspiration (g)	5579	2674	1485	3300	2190	2548	3329
Ratio (percent)	147	135	60	303	82	223	135

Table 2.—Average meteorological conditions on days when data were collected

Parameter	Date						
	8/09	8/15	8/16	8/18	8/23	8/25	8/31
Net radiation per unit leaf area (W/m^2 between 0900 & 1500 hrs)	135.9	142.7	79.2	170.9	64.9	138.6	120.2
Vapor Pressure Deficit, mb	10.66	9.82	7.23	7.55	6.90	7.11	8.77
Wind, cm/sec	71.9	69.4	18.2	132.8	55.8	79.6	21.9
Leaf to air Temp. gradient, °C	-2.2	-2.3	-3.4	-1.1	-1.3	-1.6	-3.4

tends to restrict the movement of water vapor away from the leaf so increased windspeed tends to increase boundary layer conductance and total water use.

In Table 2, the average daily radiation flux, vapor pressure gradient between the leaf and the air, and wind are presented. Tree water use tends to increase with wind speed until it's limited by radiation fluxes or vapor pressure gradients. On August 18, wind, solar radiation, and vapor pressure gradient were all high, and the greatest measured evapotranspiration, August 16 and 23, were days when one or more of the meteorological variables was low. Radiation was low on both days and vapor pressure gradient and wind were both also low on August 16. Thus, the advection of energy from surrounding areas appears to increase evapotranspiration from urban forest vegetation.

Conclusions

This study showed that honeylocust in an urban forest does require more water than the same tree at a non-urban site. However, the amount of additional water needed was not constant, but varied with environmental factors.

Other authors have also considered advection from surrounding areas to be the energy source increasing water demands by urban vegetation. Grassed surfaces showed an increase in transpiration to 130 percent of potential evapotranspiration (Oke 1979). Urban trees have been less intensively studied, although heat pulse velocities in the transpiration stream were about 10 percent higher in an urban than in a rural honeylocust (Christensen and Miller 1979), and Miller (1980) computed a transpiration increase of about 1.5 times due to energy entering an urban forest edge. Excessive water requirements mean that the tree is under water stress most of the growing season. And, as Potts and Herrington (1979) concluded, drought damage is a common result with urban honeylocust.

Trees in the urban forest are valued for amenity purposes and have high replacement costs, so great efforts may be expended to save them (Jackson 1979). Because of their value, special techniques such as providing supplemental water can be justified. Evidence from this study suggests that honeylocust in the urban forest can benefit from supplemental water to reduce water stress during the growing season.

Water is available in urban areas; in fact, excessive surface runoff is often a problem. At least some of the runoff is suitable for tree irrigation (Pham et al. 1978). If this water could be redirected to urban forests, water stress in the vegetation could be reduced and a more vigorous urban forest may result.

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Honeylocust in the urban forest requires more water than the same tree growing on a homogeneous site. Water requirements averaged 1.55 times rural water requirements in the urban environment. Additional water demand was apparently due to advected energy.

ODC: 273:181.31

Keywords: Urban climate, advection, plant water relations

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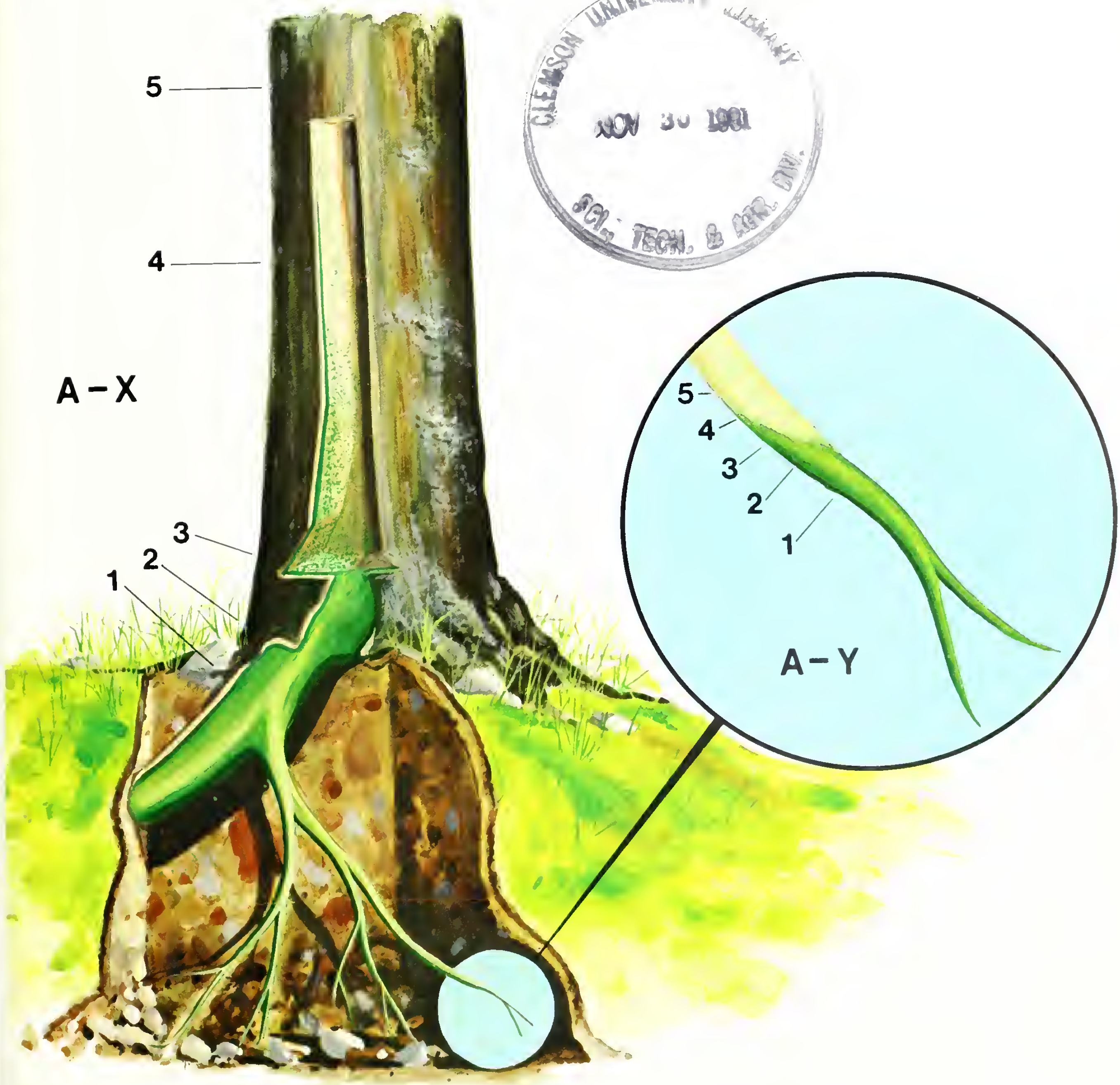
Compartmentalization of Decayed Wood

Associated with *Armillaria mellea* in Several Tree Species

by Alex L. Shigo and Joanna T. Tippett



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Abstract

Decayed wood associated with *Armillaria mellea* was compartmentalized according to the CODIT (Compartmentalization Of Decay In Trees) model. Compartmentalization in the sapwood began after the tree walled off the area of dead cambium associated with the inflection of the fungus. The fungus spread into dying sapwood beneath and beyond the area of killed cambium, but the fungus did not spread radially outward into new wood that formed.

Armillaria mellea (Vahl. ex Fr.) Kummer and other fungi cause root and butt rot of many species of woody plants. Some trees tolerate infections; others do not and they die quickly after infection (Rykowski 1975). Between these extremes are all gradations of injury caused by the fungus. There is an abundance of information and literature on *A. mellea* (Dimitri 1980; Shaw and Roth 1978).

The disease has four parts: (1) infection ; (2) spread into bark, cambium, and wood followed by walling off in those tissues by some trees; (3) compartmentalization in wood; and (4) decay of wood.

Armillaria mellea can infect and kill the bark, cambium, and wood when conditions for the fungus are favorable, or when conditions for tree health are unfavorable (Wargo and Houston 1974). Some trees of a species can stop the spread of the fungus; these trees continue to live after many infections. It is not fully known why other trees of the same species do not stop the spread of the fungus; these trees usually die after few infections.

From the walled-off dead bark, *A. mellea* can continue to grow deep into the sapwood beneath and beyond the limits of the dead area. It causes a white rot.

In this paper, bark killing refers to death of inner bark, cambium, and in some instances the most recently formed growth rings or rings of xylem. The tissues killed are called dead bark.

To clarify the points in this paper, it is also essential to understand the following terms: Sapwood has four major functions—storage, transport, protection, and support; heartwood has a protection and support function, but no storage or transport function; discolored wood does not have a storage and transport function, but has a support function, and a protective function that may be more or less than that of sapwood.

In CODIT, which is a model for compartmentalization of decay in trees, walls 1, 2, and 3 are movable, and wall 4 is stationary. Wall 1 resists vertical spread, wall 2 resists inward spread, and wall 3 resists lateral spread of microorganisms. Wall 4 separates the xylem present at the time of injury and infection from the xylem that forms later. Once formed, wall 4 remains in place, but walls 1, 2, and 3 may recede or give way to the pressure of the spreading microorganisms. Thus, discolored and decayed wood may increase in volume within the boundaries set by wall 4. A thorough understanding of CODIT is essential to understand the patterns of discolored and decayed wood associated with multiple infections of *A. mellea* over a period of many years.

The infection process, the factors affecting the spread of the fungus, and the walling off of the dead areas in the bark are beyond the scope of this paper. This paper focuses on the patterns of decayed wood associated with *A. mellea.*

The Study

Root systems of 30 trees were dug carefully by hand. The roots were washed, dissected, and studied. The trees ranged from 10 to 30 cm diameter at 1.4 m aboveground and were from 30 to 100 years old. In visual appearance, the trees ranged from suppressed dying to dominant healthy. The trees were in natural forests in southern Maine and central New Hampshire. The species were *Abies balsamea* (L.) Mill, *Picea rubens* Sarg., *Tsuga canadensis* (L.) Carr., *Populus tremuloides* Michx., *Fagus grandifolia* Ehrh., *Betula papyrifera* Marsh., *Betula alleghaniensis* Britt., *Acer rubrum* L., *Quercus rubra* L., and *Quercus alba* L.

Most of the trees had sporophores of *A. mellea* on roots and butts. Isolations from decayed wood confirmed the presence of *A. mellea* in roots that had no sporophores. More than 150 wood chips were taken from four *F. grandifolia* trees from dead basal trunk areas above large dead roots that had no sporophores. These wood chips were isolated. The small chips of wood were removed in an orderly pattern from base to top of the dead areas to determine the location of microorganisms. The isolation method and the malt-yeast medium were the same as those used in a previous study (Shigo 1977).

Dissections of roots and trunks were done by power and hand saws, knives, and razor blades. Selected wood samples with barrier zones were sectioned on a microtome. All large samples selected for examination were sanded smooth.

Results

The patterns of decayed wood associated with *A. mellea* in roots and butts can be explained by CODIT (Shigo and Marx 1977; Shigo 1979a).

When the bark killing associated with spread of *A. mellea* stopped before it circled a root or butt, the living cambium beyond the lateral and vertical limits of the dead bark area formed cells in the xylem that developed into a barrier zone (wall 4 of the CODIT model) (Figs. 1 and 2). The barrier zones formed in the early portion of the growth ring (Fig. 3). The position of the barrier zones indicated that the area of killed cambium associated with spread of *A. mellea* occurred during the dormant period, or soon after the onset of growth. The position of the barrier zones between two growth rings indicated that the area of dead bark was set in a short time, at least within one growing season.

In most instances, barrier zones form in response to injury and infection. The barrier zone was anatomically distinct from normal wood (Fig. 3). Anatomical details on barrier zones associated with *A. mellea* and other root-infecting fungi have been described (Tippett and Shigo 1980). After the barrier zone formed, normal xylem began to form again (Figs. 3 and 4). *Armillaria mellea* and other microorganisms spread deeper into the xylem beneath and beyond the area of dead bark, but they did not spread from the xylem present at the time of infection radially outward into the new xylem that formed after completion of the barrier zone (Fig. 5).

This boundary of barrier-zone tissue walled off decay even after many years (Fig. 2). In some roots, it was difficult to see an anatomically distinct barrier zone, but the new wood that formed after the bark stopped dying was free of *A. mellea* and other microorganisms.

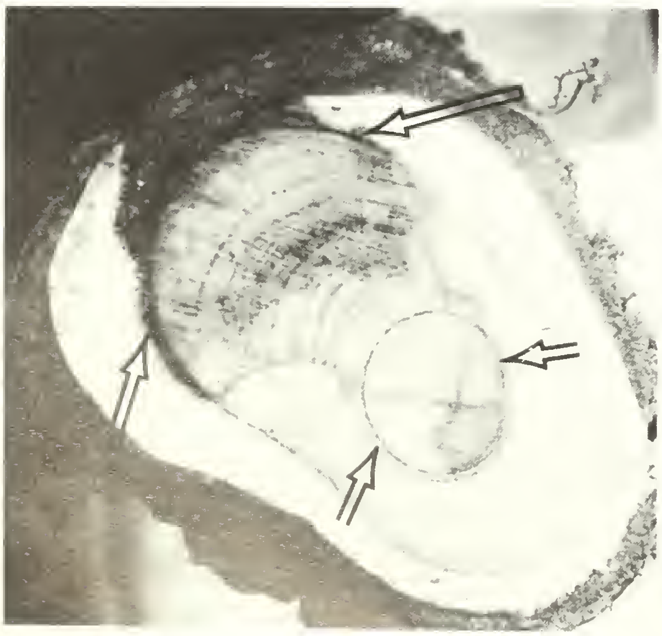

Figure 1.—Discolored and decayed wood associated with two infections in roots of *A. balsamea*. The root was infected when it was 8 years old (small arrows) and when it was 23 years old (large arrows). The arrows also point to the barrier zones. The distance between the two small arrows is 1 cm.

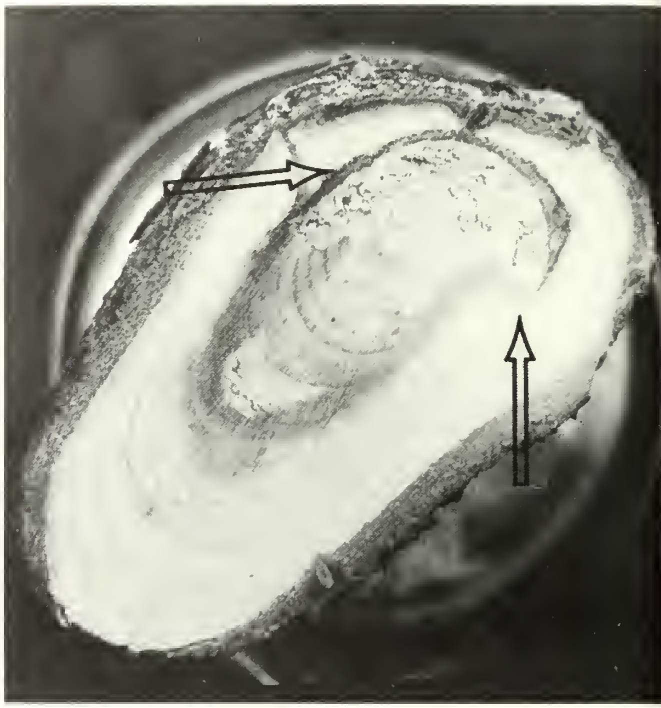

Figure 2.—Decayed wood associated with *A. mellea* was walled off by a barrier zone. Distance between the arrow points is 1.5 cm. The wood decayed to the center of the root.

When the wood in the center of roots and butts was healthy sapwood at the time of infection, *A. mellea* spread to the center (Figs. 6 and 7). When the wood in the center of butts was heartwood or discolored wood at the time of infection, *A. mellea* spread inward only to the outer margins of the heartwood or discolored wood (Figs. 8, 9, and 10). Heartwood extended downward from the butt into the transition zone between butt and root in the trees that have heartwood. Roots below this transition zone did not contain heartwood. Discolored wood associated with wounds and dead root stubs in roots looked similar to heartwood. Many wounds were found on the roots. When *A. mellea* spread upward from the roots into the root-butt transition zone that contained discolored wood or heartwood, the decayed wood was restricted to sapwood (Figs. 8, 9, 10, and 11). In species of *Fagus*, *Betula*, and *Acer* that had no heartwood, *A. mellea* spread to the center of the butt except when the butt contained discolored wood (Figs. 12 and 13).

The areas of dead bark were from very small, where a few small roots were killed, to very large, where many large roots and a portion of the trunk was killed (Figs. 12 and 13). Areas of dead bark associated with many small roots often

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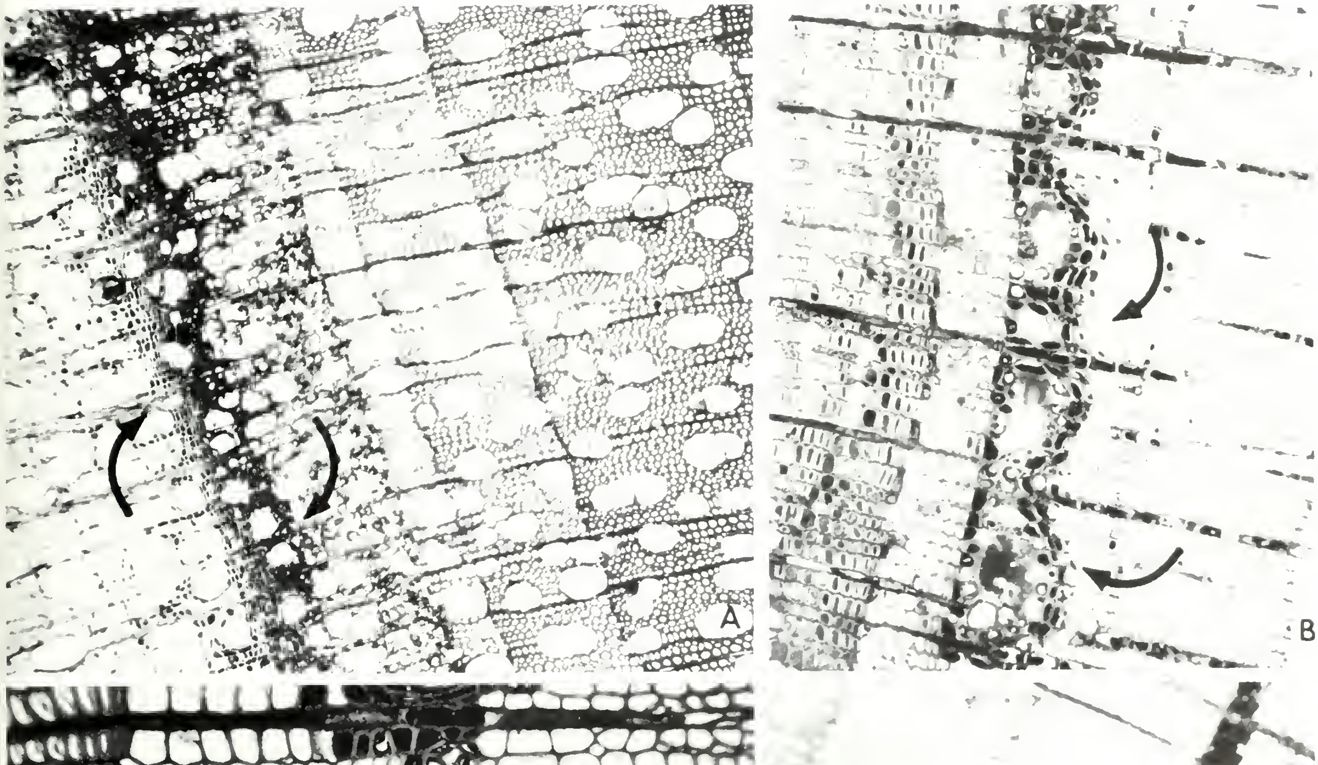


Figure 3.—Barrier zones (arrows) in *P. tremuloides* (A), *T. canadensis* (B), *A. balsamea* (C), and *P. rubens* (D).

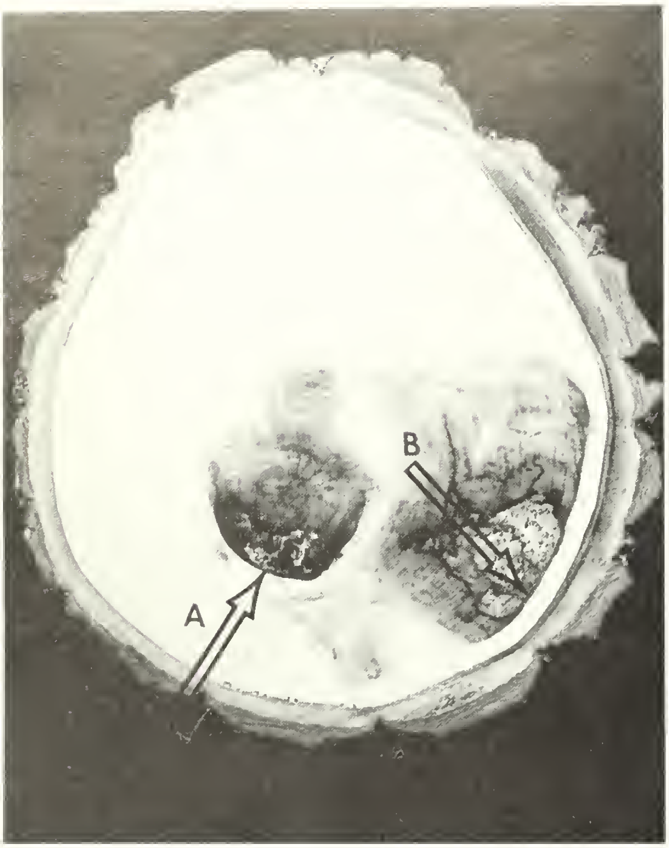


Figure 4.—Two columns of compartmentalized decayed wood in a butt of *P. tremuloides*. The section was cut 5 cm above the top of an approximately 10-year-old dead bark area, similar to that shown in figure 9. Arrow A shows the walled-off decayed wood associated with an early infection, and arrow B shows the same pattern for a later infection.

Figure 5.—Multiple columns of decayed wood associated with several infections in an *A. balsamea* tree. The butt section shown here was 15 cm in diameter. The arrows point to the barrier zones. The central hollow was associated with early infections. This tree had a green, suppressed crown.

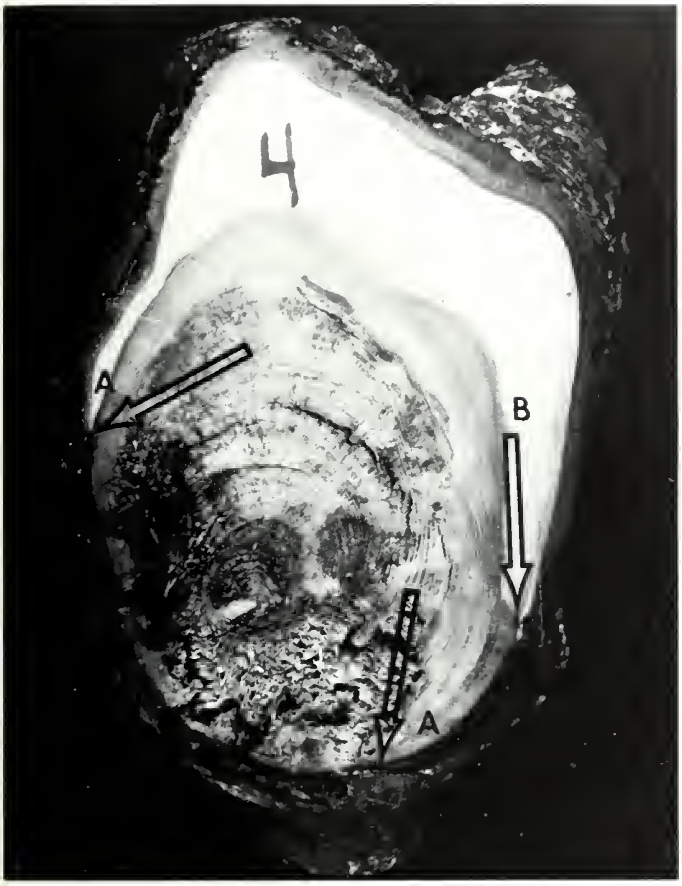


Figure 6.—Wood decayed in the center of this *P. rubens* butt which indicates that the central wood was healthy sapwood, not heartwood or discolored wood, at the time of infection. Arrows A show the lateral limits, or widths, of the early infection. Arrow B shows the extended limits of the second infection that occurred approximately 12 years later. The second infection was approximately 7 years before the tree was cut. Note the wide growth rings associated with the roots that remained alive after the first infection, and the very narrow growth rings that formed after the last infection.

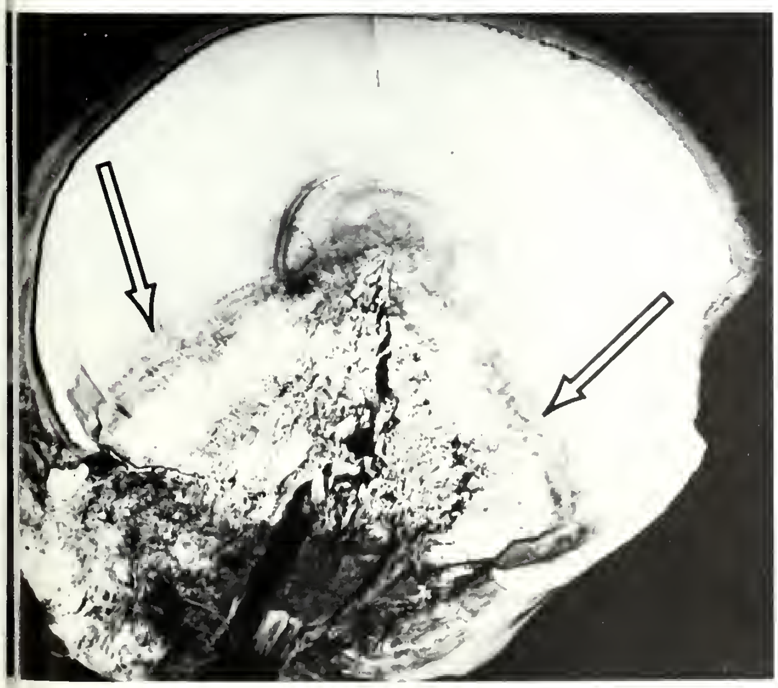


Figure 7.—Wood decayed to the center of this *P. tremuloides* butt which indicates that the central wood was healthy sapwood at the time of infection approximately 12 years ago. The arrows show the discolored wood that borders the decayed wood. The arrows indicate wall 3 of CODIT. The pressure of the developing decayed wood over the 12-year period pushed the lateral boundaries—wall 3—slightly beyond (arrows) the original width of the killed bark area.

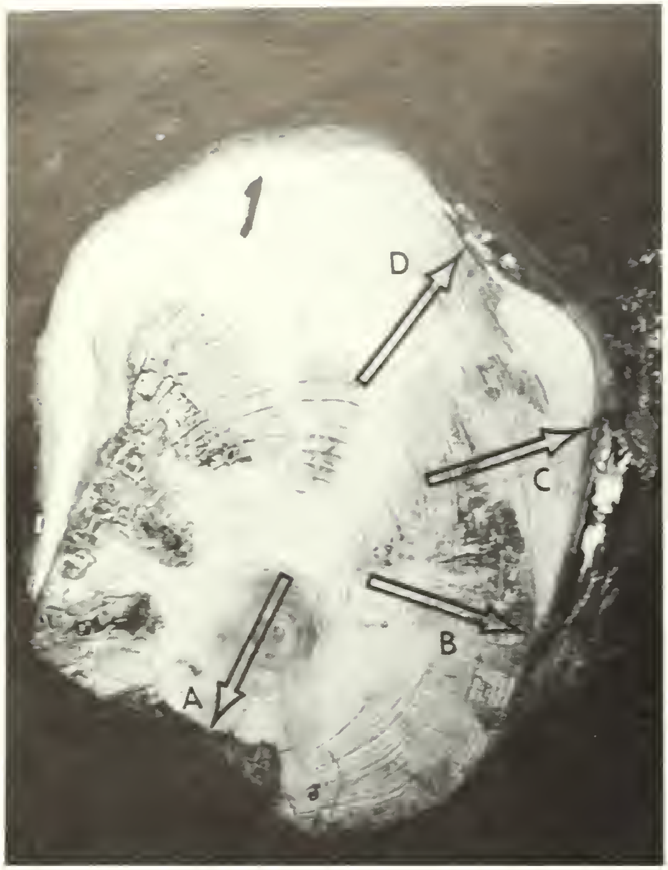


Figure 8.—Wood did not decay to the center of this *P. rubens* butt which indicates that the central wood was discolored wood or heartwood at the time of infection. Note the abrupt limit of decayed wood at arrow A. Arrow B shows the point where the lateral spread of the first infection stopped. Arrow C shows where an infection 15 years later extended the circumferential killing. The infection at arrow C was 1 year old. Also, note the heavy resin deposits in the bark at arrow C. Arrow D shows a cut through the top of a 1-year-old dead bark area. Again, there is heavy white resin deposit in the bark. This is typical for recent infections in bark.

Figure 9.—The infection in this *P. tremuloides* was 21 years old. Note the triangular shape of the dead area as it developed up the butt from the large dead root. The advanced decay associated with *A. mellea* was primarily in sapwood at the time of infection. The fungi have slowly spread into the center of the butt, but it is difficult to see in this photograph. Over time, walls 1, 2, and 3 will slowly recede, but wall 4 will remain in position. This was occurring in the large dissected root, where walls 2 and 3 were moving after 21 years of infection, but wall 4 remained in position.

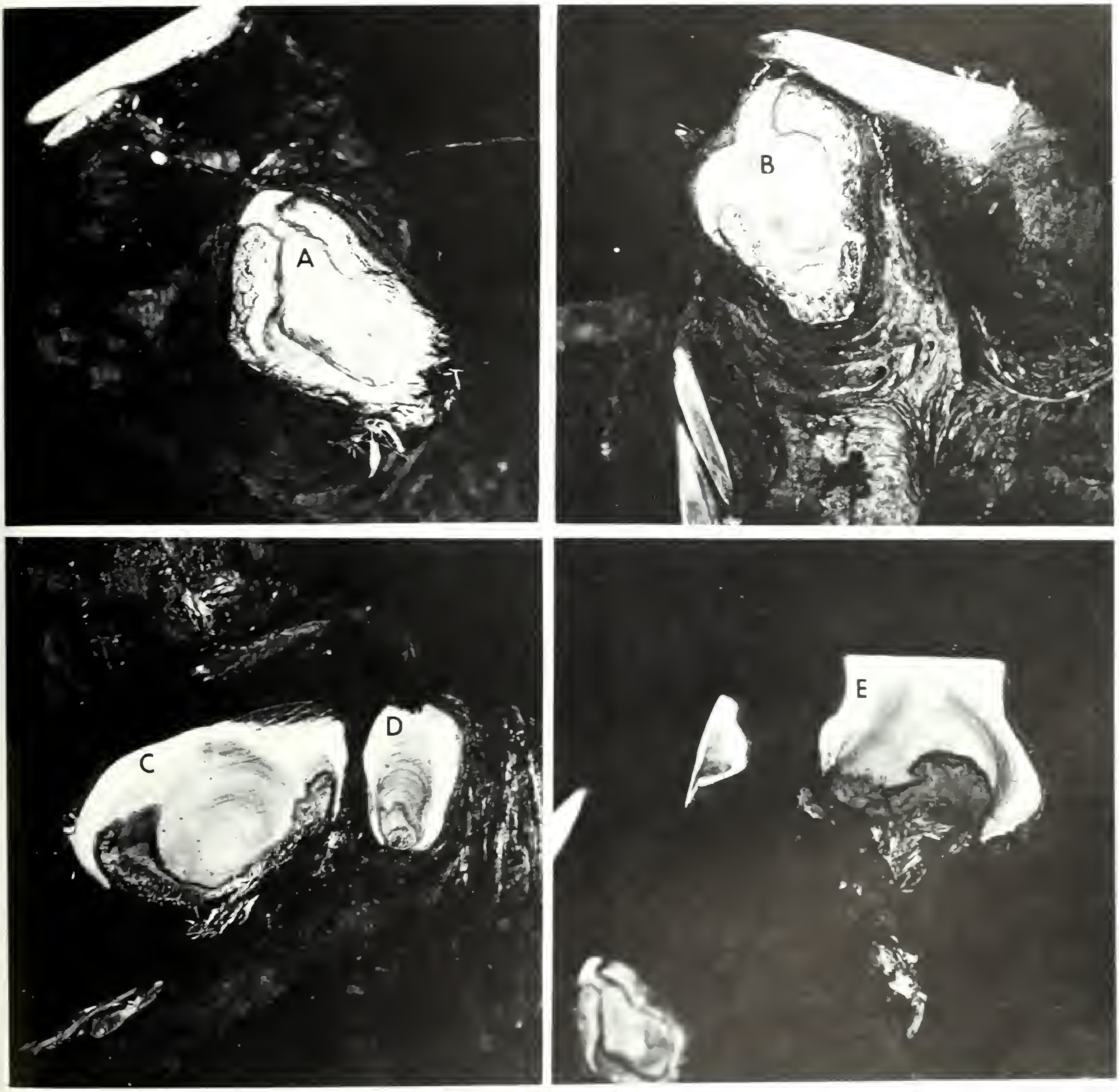


Figure 10.—Decayed wood associated with five roots of *A. balsamea* on the same stump. Roots A and B were almost completely girdled, roots C and E were about 50 percent girdled, and root D had only a small portion killed. The wood did not decay into the central column of discolored wood of roots A, B, and C, or outward into the wood that formed after infection in all roots. Wood did decay into the centers of roots D and E. Roots D and E apparently did not have central discolored wood at the time of infection. If the central wood in all roots was heartwood, and if *A. mellea* was able to infect heartwood, then all roots should have been decayed to the center.

Figure 11.—Wood in the butt of *A. balsamea* did not decay into the central discolored wood or outward into the wood that formed after the infection. A ring shake (arrow A) was associated with a barrier zone from an old wound. Arrow B shows the radial shake associated with the old wound. Note that the decay associated with *A. mellea* did not develop in the discolored wood around the radial shake. The faint discolored areas in this sample were associated with the tops of other columns of decayed wood associated with root infections.

Figure 12.—Half of the butt of this *F. grandifolia* was decayed. The infection force of *A. mellea* was as strong as the compartmentalizing force of the tree. When the infection force is stronger than the compartmentalizing force, the tree declines and may die. The wood decayed to the center of the butt which indicates that the central wood was not discolored wood at the time of infection. The infection into the butt was at least 15 years old. The large roots on this tree were in contact with large roots on an old dead tree.

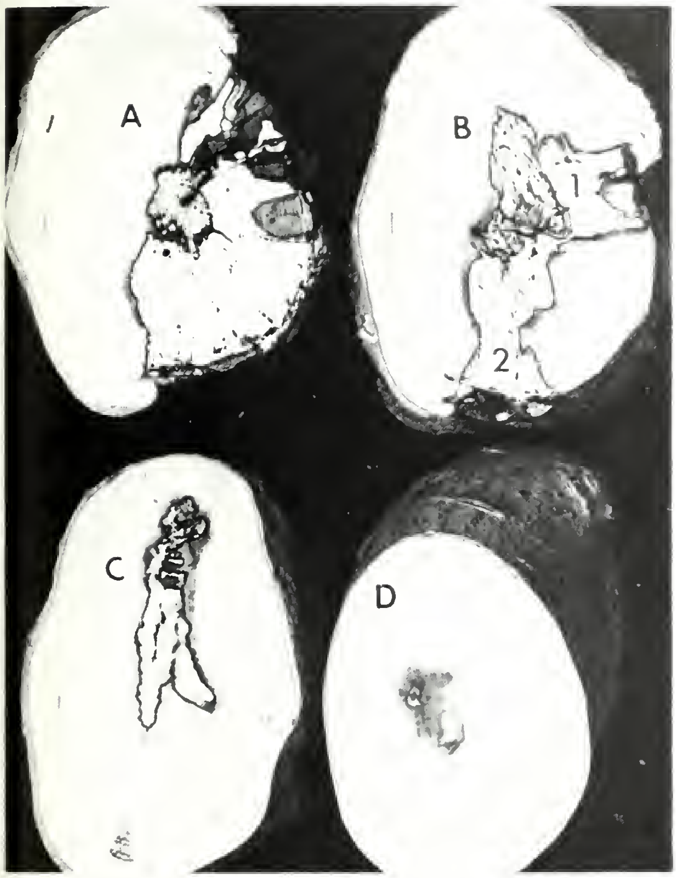


Figure 13.—Trunk sections, each 10 cm long, from above the *F. grandifolia* butt shown in figure 12. Section A, 10 cm above the butt, shows wood decayed to the center. Section B shows that two infection sites, 1 and 2, had coalesced in the butt. Section C, 30 cm above the butt, and section D, 40 cm above the butt, showed that the discolored and decayed wood was only in the center of the trunk. At the time of the infection, 50 percent of the butt was killed.

Figure 14.—The fungus-infected outer bark was walled off in this *P. tremuloides*. This sample is 10 cm above that shown in figure 7. The cambial killing attenuated as the dead bark area moved upward. The arrow shows where the cambial killing stopped.

coalesced to form one large dead area. The upward vertical extension of this dead area into the trunk was greatest when a large root or several roots were girdled.

The width of the areas of the dead bark was larger than the width of the decayed wood beneath the dead area (Fig. 14). It appeared that the fungus was also walled-off in the bark by necrophylactic periderm as described by Mullick (1977). The fungus in the bark appeared as wedges (Fig. 14). In the conifers, the wedges also contained great amounts of resin (Fig. 8).

Isolations from the dying and dead wood beneath the dead bark of the upper portions of the trunks in *F. grandifolia* yielded many bacteria, yeasts, and a variety of fungi, but not *A. mellea*. Yet, *A. mellea* was isolated with a high frequency from the wood beneath the bark of the lower portions of the trunk (Fig. 15). After several years, the limits of the dead bark area of the butt were bordered by callus (Fig. 16).

Bark killing was most extensive along the under sides of roots. When such dead areas extended upward to the trunk, it was the bark between the roots that was killed first (Fig. 17). On some species, long vertical basal cracks formed at this position. Figures 18 to 23 are diagrams of the points discussed and shown in the photographs.

Figure 15.—Current year dead bark area on a *F. grandifolia*. The sunken dead area on the butt was between two large infected roots. The arrows show the limits of the dead area. Isolations were made from wood chips taken from the base to the top of this dead area. *Armillaria mellea* was only isolated from the base of the dead area. The limits of the dead area are set in a very short time—a few weeks to a month—but the development of *A. mellea* into the dead area may take a much longer time.

Text continues on page 19

Figure 16.—Large ridges of callus mark the boundary of this old dead bark area on a *F. grandifolia*.

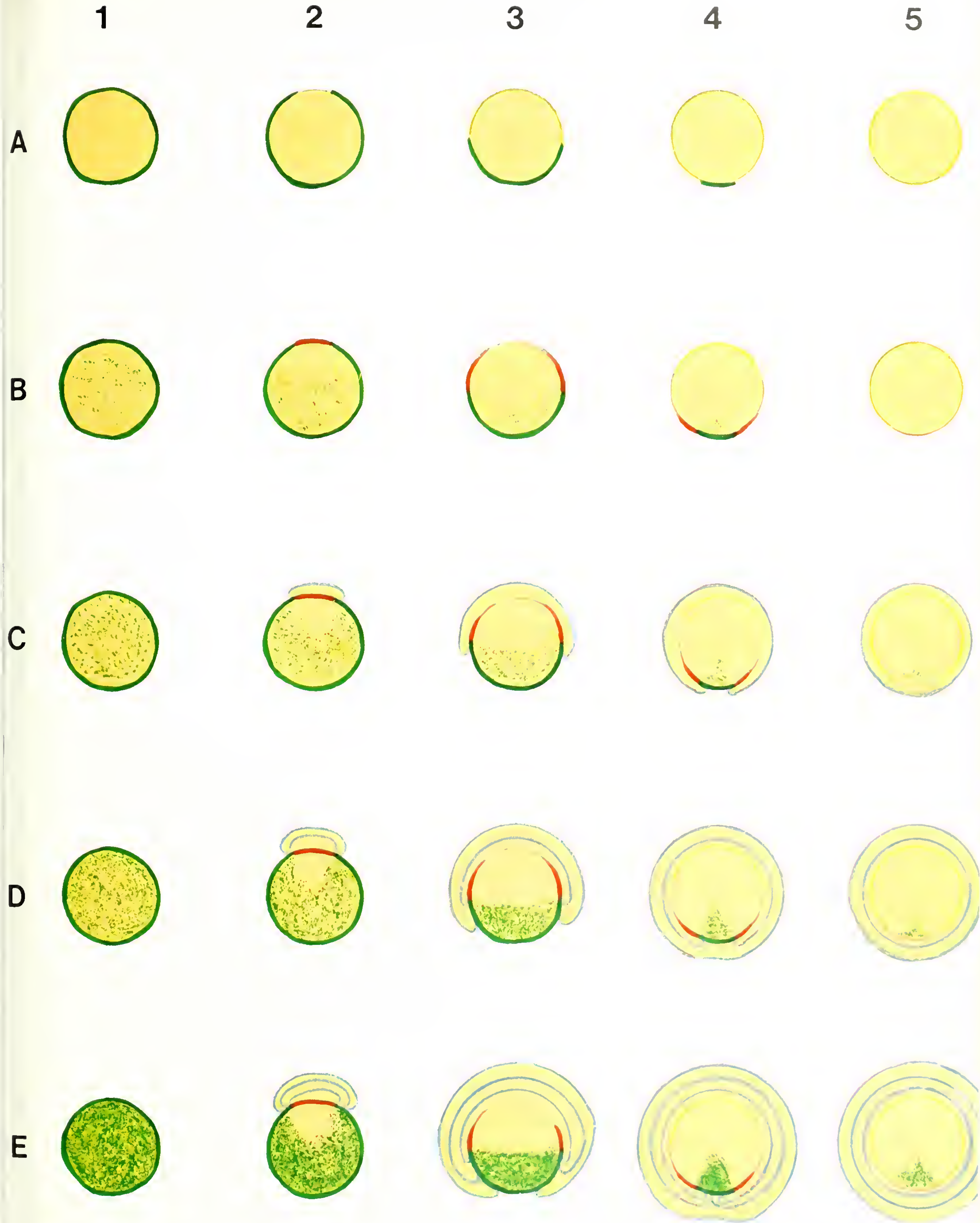
Figure 17.—Dissection of this *A. Balsamea* root base and butt shows the limits of the 7-year-old dead area. The wood decayed from the bottom of the roots upward on the butt between the infected roots. Note the fully-formed growth rings before and after the limits of the dead area (arrows). This indicates that the limits of the dead area were within a single growth period. The top section shows discolored wood associated with other infections.

Diagramatic Representations of Patterns of Compartmentalization Associated with *Armillaria mellea* in Roots and Butts.

Color Key

Green: killed cambium and decaying wood
Red: barrier zone
Blue: growth rings

Figure 18.—Summary of general patterns associated with a single infection. Horizontal row A shows cross sections of one dead bark area from complete circumferential killing of a root tip, A-1, to healthy wood, A-5, directly above the vertical limit of the dead area. Row B shows the response of the living cambium after the bark killing has stopped. Rows C, D, and E show events after 1, 2 and 3 years, respectively. The vertical rows 1 to 5, show changes occurring over 3 years as viewed at the same cross-sectional plane of the root. (Letters, A-E, and numbers, 1-5, in the following figures refer to those given in this figure).


1
2
3
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A
B
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D
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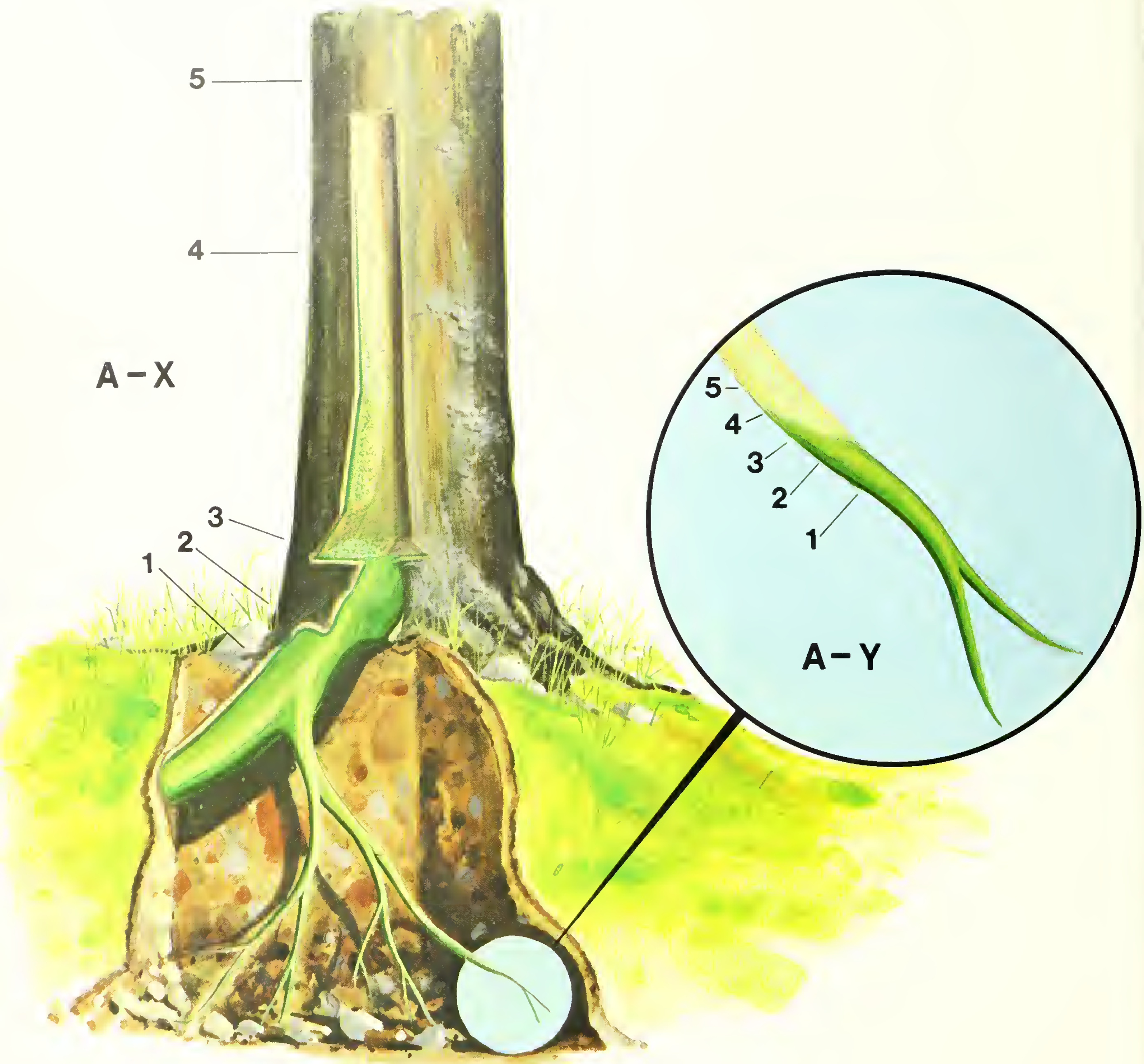

Figure 19.—The area of dead bark depicted as cross sections in row A. Dead area may be many meters long, A-X, or only a few centimeters long, A-Y. But, regardless of size there will always be an A-1 and an A-5. When A-1 is present on many roots, or at the butt, the tree dies. Many dying bark areas may coalesce to form one large dead area.

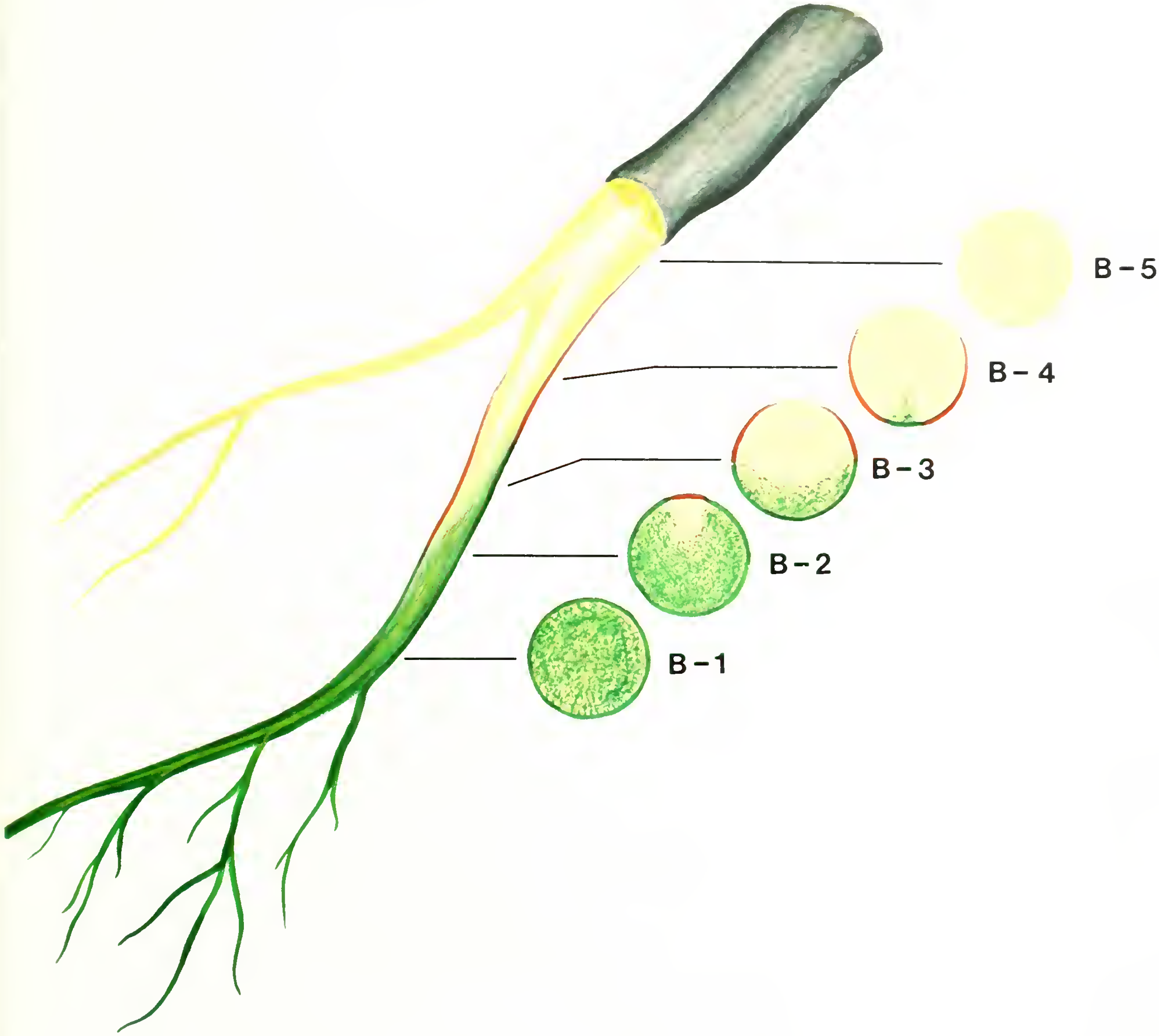

Figure 20.—Compartmentalization in wood present at the time of infection starts after bark killing stops. It is the living cambium beyond the limits of the dead bark area that produces xylem cells that develop into the barrier zone.

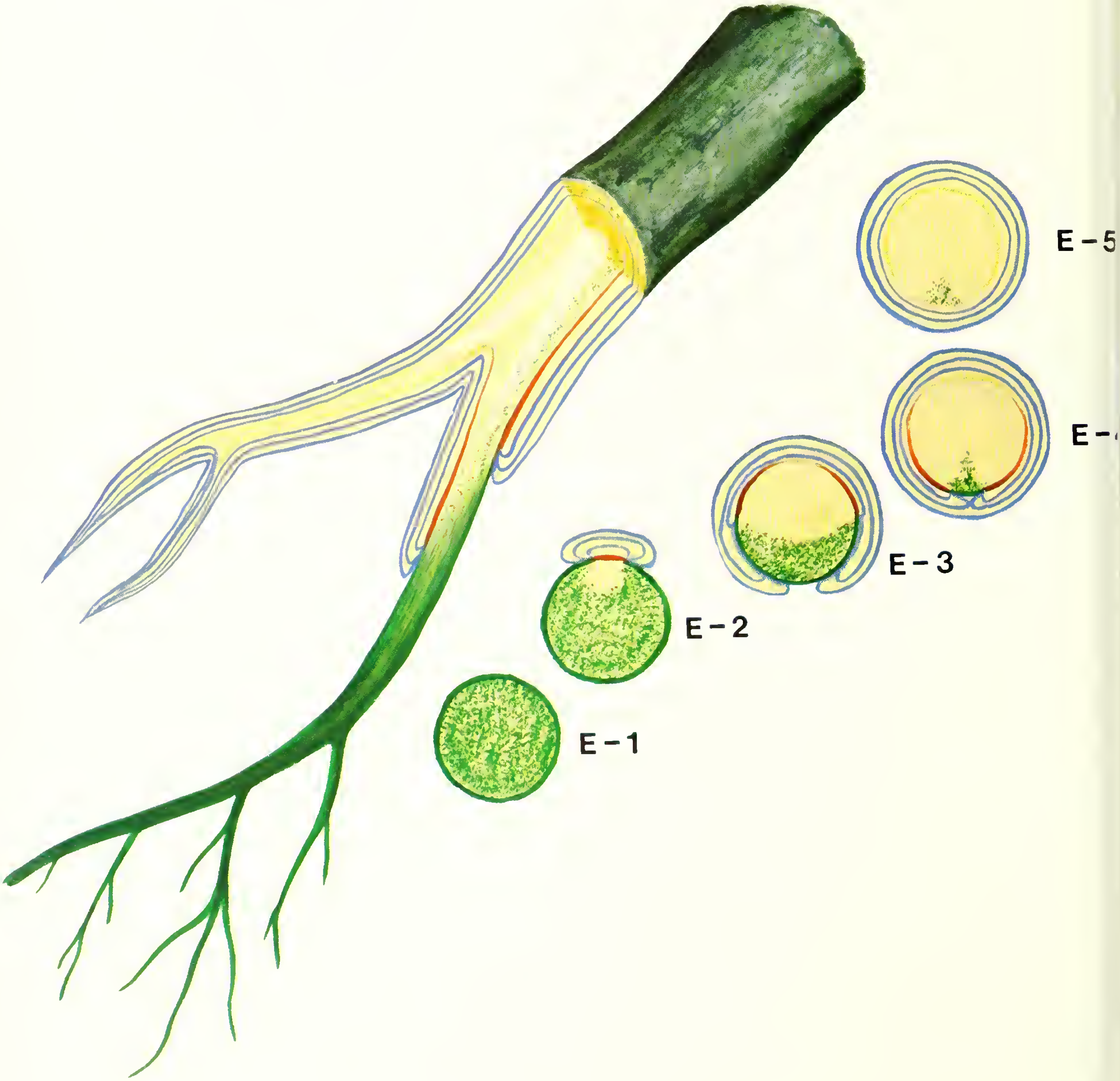

Figure 21.—*Armillaria mellea* may continue to spread within the wood present at the time the bark killing stopped. The fungus does not spread radially outward into xylem that forms after the bark killing stops.

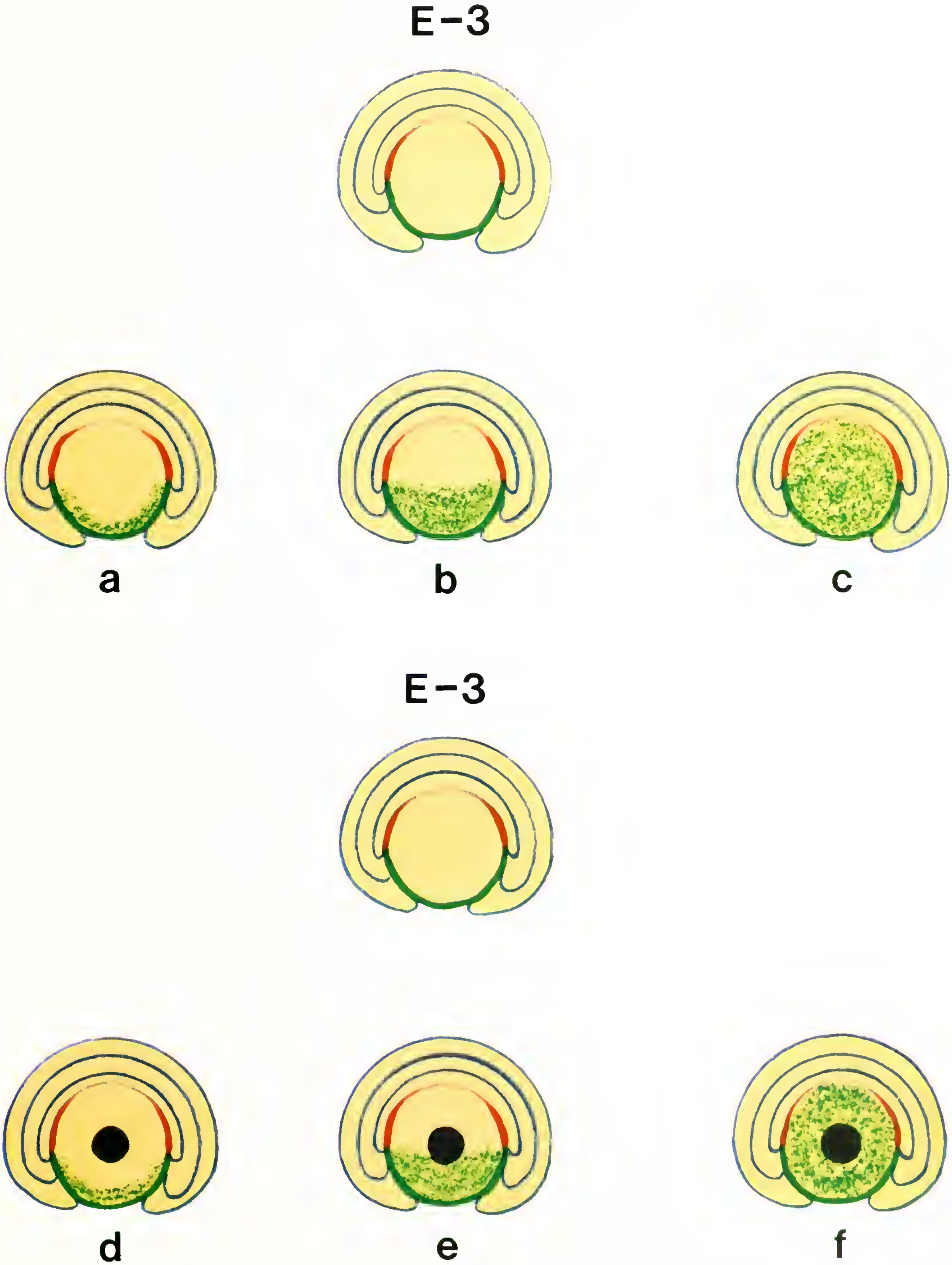

Figure 22.—How rapidly *A. mellea* spreads within xylem present at the time bark killing stopped depends on many factors. Some trees in a species and some different tree species can limit the spread of the fungus to small volumes, E-3-a; others have a moderate response, E-3-b; and others have a weak response, E-3-c. Some *A. rubrum* and *Quercus* spp. trees had patterns similar to E-3-a and E-3-b, and *A. balsamea* trees had patterns similar to E-3-c. The patterns, E-3-a, b, and c, occur in wood that has no heartwood or injured wood. When heartwood or injured wood is present, the patterns are similar to those shown in E-3-d, e, and f.

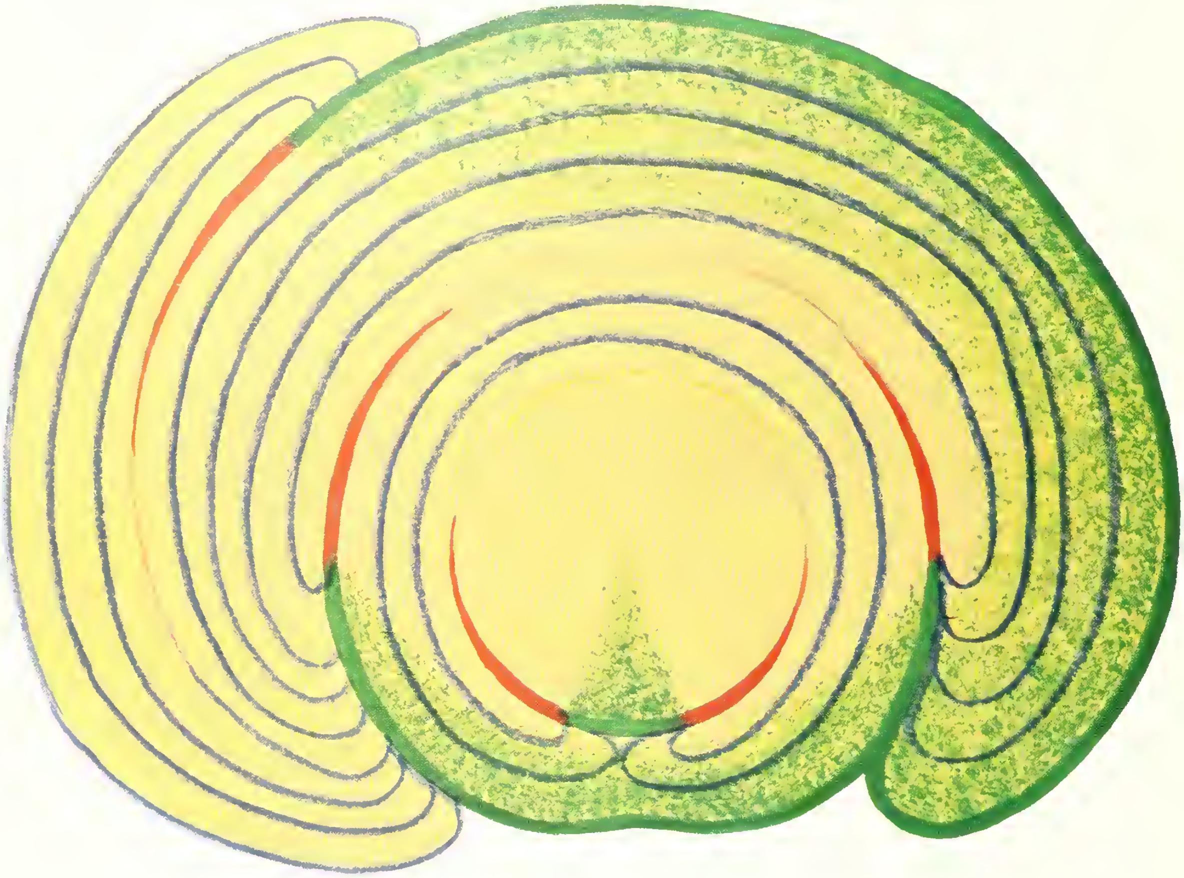

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Figure 23.—Multiple infections over time result in an endless array of patterns. As long as some cambium remains alive, the root or butt responds to wall off the spread of the fungus. As the living circumference of a root or butt decreases, additional infection leads to death. The ability to compartmentalize xylem to small volumes decreased as total volume of living wood decreased.

Discussion

Trees have many roots, but only one butt; when the butt is girdled, the tree dies. *Pinus resinosa* Sol. infected with *Heterobasidion annosum* (Fr.) Bref. is such an example (Shigo 1975; 1979b). Compartmentalization of decayed wood associated with *H. annosum* was similar to that reported here for *A. mellea.*

The long, narrow, triangular shape of the dead basal areas suggests that the walling-off force is more from the sides than downward from the top. Many microorganisms other than *A. mellea* were isolated from wood in the upper portions of the dead basal areas on *F. grandifolia.* After the tree sets the limits for the dead areas in the bark, cambium, and outer xylem. *A. mellea* may continue to spread deeper into the wood beneath and beyond the dead area.

After the dead bark is walled off, compartmentalization in the wood begins. The living cambium beyond the margin of the dead bark area forms cells that develop into a barrier zone (Tippett and Shigo 1981).

Armillaria mellea and many other wood-inhabiting microorganisms have an opportunity to spread into the wood beneath the dead bark area. This wood has limited biochemical mechanisms for defense. It is dying wood; no longer covered by living bark and a cambium. Such dying wood is quickly invaded by *A. mellea.* The wood beyond the limits of the dead bark area contains an abundance of living cells that can respond chemically to stop the spread of the fungus. The microorganisms may spread within the entire cylinder of wood present at the time of infection, or they may make only slight penetration into the wood. Once the parenchyma cells in the wood die, further deterioration of the wood depends on the types of microorganisms in the succession. The wood may discolor slightly or decay.

Two ways that the area of walled-off dead bark may increase in size are (1) new infections on roots can cause new areas of dead bark, and (2) the fungus in the dead bark at the margins of the dead area may break out of its wedge-shaped confinement and spread again into the new layer of living bark. This reinfection from wedges of fungus material at the margin of dead bark areas is the way that canker rot fungi, such as *Poria obliqua* and *Polyporus glomeratus*, continue to spread (Shigo 1969).

There is a walling-off process in bark which is similar in some ways to the walling-off process in wood as described in CODIT. The walling off is not similar in anatomy and biochemistry because of the many differences between bark and wood.

The information given here also appears to be similar for species of *Eucalyptus* (Kile 1980, Fig. 2).

Our studies of *A. mellea* and many other tree diseases indicate a basic design for survival of host and parasite. To survive, a parasite must infect when the defense systems of the host are at the lowest point and spread as far as possible before recognition and walling-off by the host. The parasite must then reproduce. For the host to survive, it must recognize the parasite as soon as possible, and wall it off to a small volume of bark and wood as rapidly as possible. The host must then generate new tissues, bark, and wood.

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Decayed wood associated with *Armillaria mellea* was compartmentalized according to the CODIT (Compartmentalization Of Decay In Trees) model. Compartmentalization in the sapwood began after the tree walled off the area of dead cambium associated with the infection of the fungus. The fungus spread into dying sapwood beneath and beyond the area of killed cambium, but the fungus did not spread radially outward into new wood that formed later.

443

Keywords: Root and butt rot

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Trends in New Hampshire Private Campgrounds During the Seventies

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and Peggy S. Nystrom

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Abstract

The findings of a 1980 census of commercial camping enterprises in New Hampshire are presented, including the growth of commercial camping enterprises during the period 1964 to 1980, campground characteristics, services and facilities, and the average costs and returns of operating a campground. This report represents the third census of the New Hampshire campground industry. The data presented reflect the 1979 calendar year and are based on a survey of 138 campgrounds conducted by the U.S. Forest Service in cooperation with the campground owners of New Hampshire.

ıtroduction

he Survey

ıcluded in this analysis is information about the character-tics of New Hampshire private campgrounds, such as aver-ȩe length of season, years in business, years of ownership, ıpacity, recreation facilities, campsite fees, operations, em-oyment, revenue, expenses, and profitability.

he results presented here are summarized from 1979 oper-ing data provided by a sample of 138 campgrounds. The ıestionnaire was mailed to 189 campgrounds listed in the 980 New Hampshire Camping Guide, Wheelers RV Resort & ampground Guide (1980 edition), Rand McNally Camp-ound & Trailer Park Guide (1980 edition), and the 1980 embership list provided by the New Hampshire Camp-ound Owners Association. Responses were obtained from 38 campgrounds or 73 percent of those receiving the sur-y. Fifty-one percent (70) of the respondents provided com-ete information about their income, fees charged, and costs operation.

he Growth of Commercial ampgrounds in New Hampshire

uring the summers of 1964, 1971, and 1980, attempts were ade to conduct complete censuses of commercial camp-ounds in New Hampshire. In 1964, 108 campgrounds were cated. In the 1971 census we found 189 camping enter-ises in business and 25 under construction. In 1980, 189 ımpgrounds were located.

ıe New Hampshire campground industry doubled in size ery 3 years from 1955 to 1964; by 1971 it had doubled ain, and reached its peak of 237 enterprises in 1973. Camp-ounds that have ceased operation since 1955 number 106, failure rate of 36 percent.

ıe regional distribution of commercial campgrounds re-als heavy concentration of enterprises in the lakes region ıd White Mountain region (Table 1).

1971, the size structure of the industry revealed a strong ıbalance toward smaller and less economic units (Table 2). ımpgrounds with fewer than 50 tent or trailer units de-eased from 53 percent of the total to 31 percent in 1980. ıe percentage of campgrounds with 50 to 99 campsites in-eased from 28 to 33. And campgrounds with more than 99 es increased from 19 to 36 percent. In 1971 an average mpground had 62 sites; by 1980 the average had increased 89 sites.

latively few owners provided a complete accounting of the sts of operating a campground. However, enough data were llected on major cost items to produce a partial compari-n picture of operating costs (Table 3).

Campgrounds in 1970 had an average gross income of $9,000 or approximately $145 per site. Campgrounds in 1979 had an average gross income of $34,000 or approximately $382 per site.

The most common daily rates charged at New Hampshire campgrounds are shown in Table 4. The seasonal camping rate in 1970 averaged $176; in 1979 it was $385.

The 189 campgrounds in 1980 had a projected developed capacity of 16,821 campsites, not including overflow capacity and undeveloped campsites. This was an increase of 51 percent over the 11,123 developed sites reported in the 1971 census.

A comparison of facilities and services offered at reporting campgrounds between 1971 and 1980 reveals substantial investments in modernization (Table 5).

All but two (1 percent) of the 138 campgrounds had some campsites with utility connections for electricity or water and sewage; in 1971, 6 percent of the campgrounds lacked utility connections. Seventy-six percent of the 12,285 campsites at the responding campgrounds had at least an electrical connection, up from 70 percent in the last census. The average campground of 89 sites had 28 tent sites (no hook-ups) and 61 sites with some combination of utility connections (Table 6). In 1971, the average commercial campground in New Hampshire had 62 sites (19 tent sites and 43 sites with some utility). And in 1964, the average campground had about 40 campsites evenly divided between tents and trailers.

Campground Characteristics

Enterprise Size and Competition

Campgrounds responding to the survey reported a total of 12,285 developed sites; an additional 422 sites were under construction, reflecting a 3 percent rate of expansion.

Ninety-three percent of the surveyed campgrounds were located wholly on their own land. Another 5 percent had part of their operation on leased land, and the remaining 1 percent were located entirely on leased land (Table 7).

Of the 119 campgrounds that reported competitor campgrounds within 10 miles, 36 percent reported at least six campgrounds within 10 miles. The median number of competitors was 4.1 (Table 8).

Volume and Trend of Business

The maximum overnight capacity of a campground is equal to total developed sites plus overflow capacity multiplied by average number of persons in a camping party. The average maximum capacity for all campgrounds was 409 persons (Table 9). The average "comfortable capacity," a subjective assessment by each campground owner, was 293 persons (or approximately 3.25 persons per developed site).

The average campground attendance decreased by 2 percent in 1979, while income remained the same (Table 10). Forty percent of the campgrounds reported declines in business, while 36 percent had increases in 1979. While an overall decline is apparent, volume of business ranges from minus 80 percent to plus 99 percent. The primary factor affecting attendance mentioned by 59 campground owners (60 percent) was the gasoline situation.

Of the 124 campgrounds responding to the question, "What percentage of your campers are seasonals?", 92 percent rented some sites to season-long campers, and these made up 33 percent of the average campground's attendance.

Years in Operation and Season Length

The average campground has been in business for 14 years and under the same ownership for the past 10 years. Nearly three-fourths of the campgrounds (73 percent) have been in operation 10 years or more. The oldest campground reported in the study has been in operation for 65 years, and the second oldest for 50 years.

Fifteen percent of the campgrounds were open all year. May is the most common month for opening (73 percent), and October is the most common month for closing (60 percent) (Table 11). July is the leading month for the "peak season" to start (69 percent), and September is the leading month for the "peak season" to end (69 percent) (Table 12).

Services and Facilities

Camper Services

A minority of campgrounds offer rentals of camping equipment (Table 13). Trailers are available for rent at 22 percent of the campgrounds; however, most campgrounds providing this service have only one or two units available.

A majority of campgrounds have camp stores and firewood. Other services commonly offered include vending machines, boat launching ramps, propane gas, movies, suppers, and dances. A complete listing of services is presented in Table 14.

In addition to camping, campground operators characteristically offer a variety of recreational activities. Equipped playgrounds are available at 64 percent of the campgrounds. Other facilities generally available are recreation halls, offered by 54 percent; ballfields, offered by 45 percent; and coin-operated games, offered by 43 percent. Other recreation facilities frequently found at campgrounds include outdoor swimming pools, hiking trails, boat rentals, and stocked fish ponds (Table 15).

Today's modern commercial campgrounds almost univers
offer such camper necessities as hot showers (91 percent), flush toilets (90 percent), and dumping stations (82 perce (Table 16).

Costs and Returns

Revenue

Campsite rentals accounted for 64 percent of average cam ground income during 1979. Average campsite rental inco was $20,000 (Table 17).

The average camping fee, for a family of four using an elec trical connection, was $6.51. The average minimum campi fee was $5.52. Average surcharges for utilities are reporte Table 18.

Premium fees for quality sites were charged at 11 percent the campgrounds. Premiums are more common in New Hampshire than in the Nation as a whole (11 percent vs. 5 percent) (National Campground Owners Association 19 A minority of campgrounds offer discount fees for off-season (4 percent), visit length (31 percent), elderly (1 per cent), and groups (1 percent).

At many camping enterprises, equipment rentals, store sal meals, services, concession income, and vending machines generate more income collectively than do campsite rental In fact, campsite rental income, as a percentage of gross, has become a common indicator of enterprise success because every campground receives some income from sourc other than campsite rentals; the lower the percentage, the more "fully-integrated" the operation (Table 19). When examining their revenue data, it is important to understand t the data contain a wide range of campground operations from overnight stops to resort campgrounds having equipment rentals, stores, lunch counters, services, concessions, and vending machines.

Expenses

The average total cost of campground operation for the campgrounds in this survey was $35,000 in 1979 (Table 2 Of that amount, about one-fourth goes for labor, and one-fifth for purchased goods and supplies. The average campground's per-site cost for utilities is $33.71; for advertising $11.24; for insurance, $22.47; for property taxes, $22.47; for debt services, $56.18; for depreciation, $67.42; and mi cellaneous expenses, $44.94. Fifteen percent of the respor ing campgrounds also reported expenses for purchased (co tract) services of $33.71 per site, and $89.89 for leasing p vately owned land—or $45.98 per acre. Labor costs averag about $4,000 per paid employee.

P fitability

S cess in any business is equated with profitability. Profit-a lity in the campground business is difficult to determine f a variety of reasons. Many campground owners have c er sources of income and apparently feel that they can a ord to put more money into the campground than they r y get out of it in the short run.

l fitability of campgrounds varied greatly in 1979. An ex-a ination of financial data indicated that 41 percent of t campgrounds suffered a loss. Of those making a profit, a out 70 percent made a profit of less than $10,000 (Table).

S mmary

e objective of the census of commercial campground erations is to provide descriptive statistics about the in-stry to:

) improve understanding of private campground econom-i throughout the financial community and in government.

) develop a data base on industry economics that will pro-le a point of comparison for identifying trends in the mpground industry.

) examine the performance of the New Hampshire camp-ound industry for the 1979 season.

) provide a basis for evaluating individual enterprises ainst state-wide averages.

e 138 campgrounds in this survey are 73 percent of the ate's camping enterprises. Representative samples, particu-ly where income and cost data are involved, are impos-le to obtain for such a large and diverse industry. The llowing data are therefore presented as state averages:

Average New Hampshire campground Statistics

Campground size (acres)	67
Total developed campsites	89
Overflow capacity (family units)	23
Maximum capacity (persons)	409
Days operated at maximum capacity	14
1979 attendance as a percentage of 1978	98%
Days open (for 86% who are not open all year)	154
Opening date	April 23
Closing date	October 22
Peak season	July to September
Years in operation	14
Total employees	4
Receipts	$34,000
Cost of operation	$35,000

If our 73-percent sample was representative, the characteristics of New Hampshire's campground industry in 1979 were:

Total persons employed	756
Wages paid	$1,512,000
Property taxes paid	$378,000
Interest paid	$945,000
Income generated	$6,426,000
Acreage involved	12,663
Overnight capacity	16,821
Camper days provided	2,032,128
Number of enterprises	189

Considering income alone, it would appear that the commercial campground industry in New Hampshire is a $6-million contributor to the economy.

Acknowledgments

We express our deepest appreciation to the 138 campground owners who unselfishly shared their 1979 business records with us, and to Wilbur F. LaPage for his cooperation and assistance.

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Form approved
OMB # 40S-80012

NEW HAMPSHIRE CAMPGROUND DECENNIAL ECONOMIC SURVEY

1980

Please complete and return this survey by JULY 11, 1980, in the enclosed pre-stamped envelope.

We have designed this questionnaire to minimize its burden on your time. The instructions and definitions provided are intended to facilitate the collection of comparable data--please follow them as closely as possible. The definitions are arranged as they appear in the questionnaire.

The data must include the summer season and an entire 12-month period. If you wish to send us a copy of your financial statements, we will complete a questionnaire for you. All information will be kept strictly confidential.

Name of campground ______________________________

Address ______________________________

City ____________________ Zip Code __________

Telephone ____________________

Person to contact if further information is required:

____

Person to whom the final report should be sent:

____

THANK YOU!

1. FACILITY AND SERVICE INVENTORY

Facility	(Insert number) In operation	Under construction	(Check one) Owner operated	Concession
a. Campsites:				
With electricity				
With water				
With sewer				
With no hook-ups				
Total developed sites				
Overflow capacity (family units)				
b. Camping Shelters:				
Rental trailers				
Rental tents				
Rental lean-tos				
Rental cabins				
Other (describe)				
c. Service Facilities:				
Store(s)				
Lunch counters				
Dining rooms				
Meals delivered to sites				
Vending machines				
Marinas				
Boat launching ramps				
Boat dock spaces				
Cable TV connections				
Firewood				
Propane gas				
Gasoline pumps				
Rec. vehicle repairs				
Rec. vehicle sales				
Guide services				
Recreation director				
Movies				
Suppers				
Hayrides				
Dances				
Sports instruction				
Nurse/doctor				
Babysitting				
Other (Describe)				

Facility	(Insert number) In operation	Under construction	(Check one) Owner operated	Concession
d. Recreation Facilities:				
Swimming pools (outdoor)				
Swimming pools (indoor)				
Recreation halls				
Coin operated games				
Beach frontage	ft.	ft.		
Hiking trails (owned)	mi.	mi.		
Hiking trails (access to)	mi.	mi.		
Rental boats (w/motors)				
Rental boats (no motor)				
Rental trail bikes				
Rental snowmobiles				
Rental horses/ponies				
Stocked fish ponds				
Playgrounds (equipped)				
Ballfields				
Other (describe)				
e. Sanitary Facilities:				
Flush toilet bldgs.				
Vault toilet bldgs.				
Pit toilet bldgs.				
Other toilet facilities				
Dumping stations				
Hot showers				
Automatic washers				
Clothes dryers				
Other (describe)				

2. OPERATION DATA

a. Number of years in operation ____________ years

b. Number of years owned by you ____________ years

c. Acres owned ____________ acres

d. Acres leased ____________ acres

e. Miles to nearest public campground ____________ miles

f. Miles to nearest private campground ____________ miles

g. Number of other campgrounds within 10 miles ____________ campgrounds

h. Opening date this year ____________________

i. Closing date this year ____________________

j. Dates of your "peak season" from __________ to ______________

k. What is the maximum capacity of your campground? ____________ persons

l. How many days did you operate at maximum? ____________ days

m. What do you feel is a "comfortable capacity?" ____________ persons

n. How many paid employees do you have? ____________ persons

o. How many total employees do you have? ____________ persons

p. By what percentage did your payroll increase this year? _________ percent

q. Did your total attendance increase _____ or decrease _____?

r. By what percentage? ____________ percent

s. Did your total campground income increase _____ or decrease _____?

t. By what percentage? ____________ percent

u. What percentage of your campers are repeat visitors? ____________ percent

v. What percentage of your campers are seasonals? ____________ percent

w. Would you briefly comment on this year's camping business--What weather conditions, travel factors, or changes in your operation and marketing might have affected your performance this year as opposed to 1978?

____

____

____

____

3. 1979 REVENUE AND EXPENSES

(round to nearest $1,000)

a. Revenue:

	Amount:
Campsite rentals	$_______________
Equipment rentals	$_______________
Store sales	$_______________
Meals	$_______________
Services	$_______________
Concession income	$_______________
Vending machines (incl. games)	$_______________
Other campground income	$_______________
Gross revenue	$_______________

b. Expenses:

Salaries & wages (incl. benefits)	$_______________
Advertising, promotion, publicity	$_______________
Utilities	$_______________
Insurance	$_______________
Property taxes	$_______________
Interest	$_______________
Land use fees: public land lease	$_______________
private land lease	$_______________
Depreciation and amortization	$_______________
Purchased goods and supplies	$_______________
Purchased services	$_______________
Miscellaneous expenses	$_______________
Total expenses	$_______________

4. FEES AND CHARGES

a. Please attach a copy of your 1979 fee schedule - OR - describe your camping fees below.

____

____

____

b. Will your fees be increased for the 1980 season? _____Yes _____ No

c. (If "yes") please attach a copy of your 1980 fee schedule - OR - describe the changes below.

____

____

____

ables

Table 1.—Location of New Hampshire camping enterprises in business; 1964, 1971, 1980

County or region	1964[a]	1971[b]	1980
County:			
Belknap	14	25	20
Carroll	22	44	32
Cheshire	6	18	10
Coos	12	22	22
Grafton	19	28	32
Hillsboro	2	11	12
Merrimack	13	17	16
Rockingham	5	28	27
Strafford	8	13	10
Sullivan	7	8	8
Total	108	214	189
Region:			
White Mountains	35	49	47
Dartmouth—Lake Sunapee	16	17	18
Lakes	37	72	61
Monadnock	7	23	13
Merrimack	5	27	20
Seacoast	8	26	30
Total	108	214	189

[a] New Hampshire State Planning Project 1965.
[b] LaPage et al. 1972.

Table 2.—Distribution of small, medium, and large campgrounds in New Hampshire; 1971, 1980, (in percent)

Number of sites	1971[a]	1980
Fewer than 50	53	31
50-99	28	33
100 or more	19	36

[a] LaPage et al. 1972.

Table 3.—Average costs per site

Expense category	1971[a]	1980
Salaries & wages	$21.00	$89.89
Advertising	5.45	11.24
Utilities	10.55	33.71
Insurance	5.27	22.47
Property taxes	14.30	22.47
Interest	19.13	56.18
Depreciation	29.10	67.42
Purchased goods & supplies	4.05	78.65
Purchased services	14.70	33.71
Miscellaneous	11.15	44.94

[a] LaPage et al. 1972.

Table 4.—Daily rates at New Hampshire campgrounds

Type of campsite	1971[a]	1980
Tent site; no utility hookups	$3.00	$5.00
Campsite with electricity or water connections	$3.50	$6.00
Campsite with electricity, water, and sewage connections	$4.00	$6.50

[a]LaPage et al. 1972.

Table 5.—Facilities and services offered at New Hampshire campgrounds, in percent

Facility or service	1971[a]	1980
Hot showers	76	91
Dumping stations	57	82
Firewood	75	91
Camp store	42	62
Recreation hall	26	54
Washers, dryers	19	41
Swimming pool	5	23
Rental trailers	3	22

[a]LaPage et al. 1972.

Table 6.—Campsite combinations

Type of site	NH	NE[a, c]	US[a]
With electricity	69	120	105
With water	68	116	104
With sewer	38	56	57
With no hookups	28	30	30
Total developed sites	89[b]	152	135
Overflow capacity (family units)	23	54	56
Number of campgrounds	138	34	137

[a]National Campground Owners Association 1981.
[b]Compares with 84.33 average for 1978 reported by Woodall Publishing Co.
[c]Northeast: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania.

Table 7.—Land ownership and leasing

Item	NH	NE[a]
Acres owned	67	65
Number of enterprises with leased land[b]	9	3

[a]National Campground Owners Association 1981.
[b]Includes both private and public land.

Table 8.—Proximity of competitive public and private campgrounds

Item	NH	NE[a]
Miles to nearest public campground	13	17
Miles to nearest private campground	5	6
Number of other campgrounds within 10 miles	5	5

[a]National Campground Owners Association 1981.

Table 9.—Operation data for 1979

Item	NH	NE[a]
Maximum capacity in persons	409	775
Number of days operated at maximum	14	25
"Comfortable capacity" in persons	293	644
Percent change in attendance (v. 1978)	-2	-5
Percent change in income (v. 1978)	0	+3
Percent of campers who are repeat visitors	56	56
Percent of campers who are seasonals	33	23

[a]National Campground Owners Association 1981.

able 10.—Percentage of decline in 1979 camping usiness attributed to the 1979 gasoline situation and to weather

Factor	NH	NE[a]	US[a]
isoline situation	60	44	51
eather conditions	20	32	28
her causes	19	24	21

ational Campground Owners Association 1981.

able 11.—Percentage of New Hampshire campgrounds opening and closing each month

Month	Campgrounds opening	Campgrounds closing
arch	1	—
pril	6	—
ay	73	—
ne	5	—
igust	—	1
ptember	—	16
ctober	—	60
ovember	—	6
ecember	—	3
pen all year	15	

Table 12.—Percentage of New Hampshire campgrounds starting and ending their "peak season" each month

Month	Peak season starts	Peak season ends
ay	10	—
ne	20	—
ly	69	3
igust	1	18
ptember	1	69
ctober	—	9
ovember	—	1

Table 13.—Percentage of campgrounds with camping shelters for rent

Item	NH	NE[a]	US[a]
Rental trailers	22	44	25
Rental tents	5	9	8
Rental lean-tos	3	9	4
Rental cabins	12	12	9
Other	6	9	7

[a]National Campground Owners Association 1981.

Table 14.—Service facilities offered at private campgrounds in 1979, in percent

Service offered	NH	NE[a]	US[a]
Store	62	82	93
Lunch counters	9	32	30
Dining rooms	2	9	5
Meals delivered to sites	1	0	1
Vending machines	32	62	67
Marinas	5	9	9
Boat launching ramps	25	26	20
Boat dock spaces	16	24	15
Cable TV connections	0	0	4
Firewood	91	85	75
Propane gas	23	47	60
Gasoline pumps	5	15	23
Rec. vehicle repairs	4	12	7
Rec. vehicle sales	3	6	6
Guide services	7	18	15
Recreation director	13	32	18
Movies	25	53	33
Suppers	23	41	31
Hayrides	18	29	24
Dances	23	56	31
Sports instruction	5	9	9
Nurse/doctor	4	6	7
Babysitting	12	24	22
Other	11	24	23

[a]National Campground Owners Association 1981.

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- University Park, Pennsylvania, in cooperation with the Pennsylvania State University.
- Warren, Pennsylvania.

United States
Department of
Agriculture

Forest Service

Research
Paper NE-490

1981

Taper and Volume Equations for Selected Appalachian Hardwood Species

by A. Jeff Martin

$\sqrt{B^2 - 4AC}$

$(a_2 - Y)^3 J_2$

$X^3 - Y^3$

$I_1 = 1, X \leq a_2$

The Author

A. JEFF MARTIN attended Michigan State University, receiving a degree in forestry in 1965, an M.S. degree in forest management in 1966, and a Ph.D degree in forest management in 1969. He joined the staff of the Northeastern Forest Experiment Station at the Forestry Sciences Laboratory, Princeton, West Virginia, in 1969. He is currently with the Northeastern Station's project on increased supply of hardwood raw materials.

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Abstract

Coefficients for five taper/volume models are developed for 18 Appalachian hardwood species. Each model can be used to estimate diameter at any point on the bole, height to any preselected diameter, and cubic-foot volume between any two points on the bole. The resulting equations were tested on six sets of independent data and an evaluation of these tests is included. A wide variety of volume tables can be constructed with the models; some examples are given.

Table of Contents

Current interest in multiple-product timber harvesting has generated a need for improved volume prediction for individual trees and yield prediction for stands. Knowledge of total cubic-foot or board-foot volumes is no longer sufficient. We now need to know what portions of a tree can be used for specific products, and we need to identify the entire array of products that can be obtained from specific stands.

When available, empirical data will provide some of the answers; however, such information will generally be restricted to existing product specifications. Therefore, to interpolate and extrapolate empirical data, and to provide greater flexibility with changing specifications and with new products, a more generalized approach is needed. One of the most important elements in such a system is reliable taper/volume equations for the species in question. Such equations enable the user to estimate the diameter at any point on the bole, the height to any predetermined diameter, and the volume between any two points on the bole.

Although various methods of developing taper/volume equations have been proposed (Kozak and others 1969; Kozak and Smith 1966; Max and Burkhart 1976; Fries and Matern 1965; Bennett and Swindel 1972; Goulding and Murray 1976; Demaerschalk 1971, 1972, 1973a, 1973b; Bruce and others 1968; Ormerod 1973; Clutter 1980; Cao and others 1980; and Demaerschalk and Kozak 1977), the information is either theoretical or limited primarily to softwood species. Until recently taper functions for eastern hardwood species were not available. However, the work by Hilt (1980) for upland oaks in the Midwest, coupled with the results reported herein, should fill most of the voids.

Data Collection

The objective of this study was to develop taper and volume equations for selected commercial Appalachian hardwood species. Stem measurements were collected from 1,162 trees in West Virginia and southwestern Virginia. Eighteen species were sampled and data were obtained from 39 different stands on poor to excellent sites. Data for black tupelo and black oak came from only 5 stands, whereas sugar maple measurements came from 17 locations; the average was 10 stands per species.

Trees without forks below midheight were randomly selected, with stratification by species and dbh (diameter at breast height) class. Although a balanced distribution by dbh and total height was desired, dbh alone was used in selecting sample trees for practicality and economy. The resulting sample was well balanced by diameter class for nearly all species, whereas the total height distribution was somewhat uneven. With very few exceptions, three to five trees per 1-inch diameter class (between 5 and 22 inches) were selected for each species.

Table 1.—Simple statistics for trees included in the sample

Species	Variable	Range	Mean	SD	No. samp[illegible] tree[illegible]
Red maple	dbh (inches)	5.1 - 22.0	12.4	5.0	7[illegible]
	total height (feet)	48.1 - 103.6	76.2	12.7	
Sugar maple	dbh	5.3 - 22.3	12.9	4.9	6[illegible]
	total height	46.9 - 109.1	80.1	12.9	
Sweet birch	dbh	4.6 - 18.9	11.2	4.0	64
	total height	54.7 - 87.7	70.3	9.4	
Yellow birch	dbh	5.3 - 22.4	12.8	4.7	6[illegible]
	total height	53.3 - 90.4	73.8	7.8	
Hickory, sp.	dbh	4.9 - 22.5	13.0	5.0	6[illegible]
	total height	47.0 - 113.2	80.2	17.7	
American beech	dbh	4.7 - 21.0	12.4	4.6	6[illegible]
	total height	43.8 - 103.1	74.2	14.2	
White ash	dbh	5.8 - 21.5	13.7	4.6	7[illegible]
	total height	61.0 - 105.1	85.6	11.0	
Yellow-poplar	dbh	4.7 - 22.4	13.4	5.2	75
	total height	44.6 - 118.5	84.0	17.4	
Cucumbertree	dbh	5.1 - 22.4	12.7	4.7	56
	total height	50.0 - 109.4	79.7	14.7	
Black tupelo	dbh	5.1 - 22.5	12.4	4.6	58
	total height	35.7 - 87.1	64.3	12.6	
Black cherry	dbh	5.7 - 21.6	12.7	4.8	78
	total height	45.0 - 107.2	77.6	14.0	
White oak	dbh	6.0 - 21.9	11.8	4.4	84
	total height	47.4 - 88.7	69.7	10.5	
Scarlet oak	dbh	6.0 - 20.2	12.4	3.9	49
	total height	53.4 - 93.3	74.9	10.5	
Chestnut oak	dbh	5.6 - 22.0	13.4	4.6	61
	total height	61.0 - 98.7	76.1	8.2	
Red oak	dbh	5.8 - 22.5	13.3	4.8	72
	total height	55.0 - 103.2	79.4	11.8	
Black oak	dbh	5.4 - 21.9	12.7	4.1	45
	total height	54.5 - 93.3	74.0	8.9	
Black locust	dbh	5.3 - 22.1	13.3	4.8	60
	total height	38.5 - 106.4	81.9	16.8	
American basswood	dbh	4.6 - 21.3	13.0	4.8	63
	total height	57.4 - 117.5	85.0	14.8	
All species	dbh	4.6 - 22.5	12.8	4.7	1162
	total height	35.7 - 118.5	77.1	14.0	

Dbh of the sample trees (Table 1) ranged from 4.6 to 22.5 inches (Mean = 12.8 inches) and total height ranged from 35.7 to 118.5 feet (Mean = 77.1 feet). Sample size ranged from 45 trees for black oak to 84 trees for white oak.

Dbh and bark thickness (at breast height) were measured a[illegible] recorded for each sample tree. Stem profile data (diamete[illegible] outside bark and height above ground) were obtained at ei[illegible] points on the bole: stump (1 foot above ground) and at ap[illegible] oximately 1/8, 1/4, 3/8, 1/2, 5/8, 3/4, and 7/8 of total ight. Stem measurements for most of the sample trees were otained during the fall, winter, and spring with a Barr and roud[1] optical dendrometer; however, the sample also in- ıdes direct measurements from 246 felled trees. Total ight (in feet, from groundline to tip) was obtained either th the dendrometer or from direct measurement of felled ees.

nalysis

variety of published taper equations was examined and sted on the stem measurements in the sample. The models ıged from simple to very complex; from models with ly one coefficient to segmented polynominals having two n points and six coefficients. Some were discarded because ey did not fit the data well and prediction was poor; others re discarded because they were too complex.

ıe five models that were retained (Bruce and others 1968; maerschalk 1972; Kozak and others 1969; Max and ırkhart 1976; and Ormerod 1973) still ran the gamut from nple to complex (Tables 2 - 6); however, they all fit the ta reasonably well and yielded good predictions in sub- quent tests. Variables and regression coefficients common all five models are defined as follows:

3H = diameter at breast height (inches)
H = total tree height from groundline to tip (feet)
= height up the bole from groundline to lower
= diameter at height "H" (inches)
L = height up the bole from groundline to lower limit of volume calculation (feet)
IJ = height up the bole from groundline to upper limit of volume calculation (feet)
= volume of bolewood section between "HL" and "HU" (cubic feet)
$_1$ - b_6 = regression coefficients estimated from the sample data.

Tables 2 to 6, equation (1) estimates bole diameter at y height H above ground. This form of each model was ed in all analyses to estimate the regression coefficients r the sample data. Equation (2) is the inverse of equation); it estimates the height above ground to any preselected le diameter D. Equation (3) estimates cubic foot volume

[1]he use of trade, firm, or corporation names in this publica- n is for the information and convenience of the reader. ch use does not constitute an official endorsement or ap- oval by the U.S. Department of Agriculture or the Forest rvice of any product or service to the exclusion of others at may be suitable.

Table 2.—Bruce and others' taper and volume functions

$$D^2/DBH^2 = b_1(X^{1.5})(10^{-1}) + b_2(X^{1.5} - X^3)(DBH)(10^{-2}) + b_3(X^{1.5} - X^3)(TH)(10^{-3}) + b_4(X^{1.5} - X^{32})(TH)(DBH)(10^{-5}) + b_5(X^{1.5} - X^{32})(TH^{0.5})(10^{-3}) + b_6(X^{1.5} - X^{40})(TH^2)(10^{-6}) \quad (1)$$

Where:

$X = (TH - H)/(TH - 4.5)$

H : Must use an iterative method; changing the value for H in equation (1) until the predicted value of D is satisfactorily close to the desired value for D (2)

$$V = (-.005454)(DBH^2)(TH - 4.5)\left[\frac{2A}{5}(XU^{2.5} - XL^{2.5}) + \frac{B}{4}(XU^4 - XL^4) + \frac{C}{33}(XU^{33} - XL^{33}) + \frac{E}{41}(XU^{41} - XL^{41})\right] \quad (3)$$

Where:

$XU = (TH - HU)/(TH - 4.5)$

$XL = (TH - HL)/(TH - 4.5)$

$A = (b_1)(10^{-1}) + (b_2)(DBH)(10^{-2}) + (b_3)(TH)(10^{-3}) + (b_4)(TH)(DBH)(10^{-5}) + (b_5)(TH^{0.5})(10^{-3}) + (b_6)(TH^2)(10^{-6})$

$B = -\left[(b_2)(DBH)(10^{-2}) + (b_3)(TH)(10^{-3})\right]$

$C = -\left[(b_4)(TH)(DBH)(10^{-5}) + (b_5)(TH^{0.5})(10^{-3})\right]$

$E = -\left[(b_6)(TH^2)(10^{-6})\right]$

of the bole between HL and HU. Equation (3) was derived by integrating equation (1) between the limits HL and HU:

$$\int_{HL}^{HU} \frac{\pi}{4} DBH^2 \hat{f}(H)\, dH$$

The model by Bruce and others is a rather lengthy poly- nominal that the authors refer to as their "final equation" in

Table 3.—Demaerschalk's taper and volume functions

$$D^2/DBH^2 = (10^{2b_0})(DBH^{2b_1} - 2)\left[(TH - H)^{2b_2}\right](TH^{2b_3}) \qquad (1)$$

$$H = TH - \left[(10^{-b_0})(D)(DBH^{-b_1})(TH^{-b_3})\right]^{1/b_2} \qquad (2)$$

$$V = \frac{(0.005454)(10^{2b_0})(DBH^{2b_1})(TH^{2b_3})(X_1^Z - X_2^Z)}{Z} \qquad (3)$$

Where:

$Z = (2 \times b_2) + 1$

$X_1 = TH - HL$

$X_2 = TH - HU$

Table 4.—Kozak and others' taper and volume functions

$$D^2/DBH^2 = b_1(H/TH - 1) + b_2(H^2/TH^2 - 1) \qquad (1)$$

$$H = \frac{(-b_1 TH) - \sqrt{(b_1 TH)^2 - 4b_2\left(b_0 TH^2 - \frac{D^2 TH^2}{DBH^2}\right)}}{2b_2} \qquad (2)$$

Where:

$b_0 = -b_1 - b_2$

$$V = (0.005454\,DBH^2)\left[b_0(HU - HL) + \frac{b_1(HU^2 - HL^2)}{2TH} + \frac{b_2(HU^3 - HL^3)}{3TH^2}\right] \qquad (3)$$

Table 5.—Max and Burkhart's taper and volume functions

$$D^2/DBH^2 = b_1(H/TH - 1) + b_2(H^2/TH^2 - 1) + b_3(a_1 - H/TH)^2 I_1 + b_4(a_2 - H/TH)^2 I_2$$

Where:

a_1, a_2 = join points

$I_1 = 1,\ H/TH \leqslant a_1$

$= 0,\ H/TH > a_1$

$I_2 = 1,\ H/TH \leqslant a_2$

$= 0,\ H/TH > a_2$

$$H = TH/2A\left[-B - \sqrt{B^2 - 4AC}\right]$$

Where:

$A = b_2 + I_1' b_3 + I_2' b_4$

$B = b_1 - 2I_1' a_1 b_3 - 2I_2' a_2 b_4$

$C = -b_1 - b_2 - D^2/DBH^2 + I_1' a_1^2 b_3 + I_2' a_2^2 b_4$

$I_1' = 1,\ D \geqslant d_1$

$= 0,\ D < d_1$

$I_2' = 1,\ D \geqslant d_2$

$= 0,\ D < d_2$

d_1 = estimated diameter at height $a_1 TH$

$= DBH\sqrt{b_1(a_1 - 1) + b_2(a_1^2 - 1)}$

d_2 = estimated diameter at height $a_2 TH$

$= DBH\sqrt{b_1(a_2 - 1) + b_2(a_2^2 - 1) + b_3(a_1 - a_2)^2}$

$$V = 0.005454\,DBH^2 TH\left\{\frac{b_2}{3}(X^3 - Y^3) + \frac{b_1}{2}(X^2 - Y^2) - (b_1 + b_2)(X - Y) - \frac{b_3}{3}\left[(a_1 - X)^3 I_1 - (a_1 - Y)^3 J_1\right] - \frac{b_4}{3}\left[(a_2 - X)^3 I_2 - (a_2 - Y)^3 J_2\right]\right\}$$

Where:

$X = HU/TH$

$Y = HL/TH$

$I_1 = 1,\ X \leqslant a_1$

$= 0,\ X > a_1$

$I_2 = 1,\ X \leqslant a_2$

$= 0,\ X > a_2$

$J_1 = 1,\ Y \leqslant a_1$

$= 0,\ Y > a_1$

$J_2 = 1,\ Y \leqslant a_2$

$= 0,\ Y > a_2$

'able 6.—Ormerod's taper and volume functions

$$D^2/DBH^2 = \left[\frac{TH - H}{TH - 4.5}\right]^{2b_1} \quad (1)$$

$$H = TH - \left[\left(\frac{D}{DBH}\right)^{1/b_1}(TH - 4.5)\right] \quad (2)$$

$$V = \frac{(0.005454\ DBH^2)(4.5 - TH)}{Y}\left[\left(\frac{HU - TH}{4.5 - TH}\right)^{Y} - \left(\frac{HL - TH}{4.5 - TH}\right)^{Y}\right] \quad (3)$$

\ere:

$Y = (2 \times b_1) + 1$

t development of red alder taper and volume systems. The n del is conditioned so that D = 0 when H = TH. In addition t its size, particularly in the expression for volume, the n del has another disadvantage for some users: It cannot b rewritten in terms of H; therefore, estimating height a ove ground to the 8-inch mark (for example) must be h ndled by an iterative procedure (e.g., interval halving, N wton-Raphson method, etc.)

Mx and Burkhart's model is also a rather complicated ap- p oach to taper/volume equations. Their approach was to d velop three separate submodels that describe the neiloid f stum of the lower bole, the paraboloid frustum of the n ddle bole, and the conical shape of the upper portion. The t ee submodels are then spliced together at two "join p nts" into an overall segmented polynominal tree model. T e version selected for this study was their quadratic- q adratic-quadratic model. The equation is conditioned so t t D = 0 when H = TH. To use this approach, one must f st decide which of the three bole segments is appropriate; t s determines the values for the two dummy variables. Dur- i the analyses, optimal join points were simultaneously e imated for each species along with the regression co- e icients (Appendix Table 15). Join points are simply pro- p rtions of total height; the lower join point is usually close t 0.1 and the upper is usually between 0.6 and 0.7.

B th Demaerschalk's equation and the equation developed b Kozak and others are much easier to use. Both are condi- t ned so that D = 0 when H = TH, and both can be re- w tten in terms of H. The model by Kozak and others can e ily be solved with any electronic calculator possessing a square root function. Demaerschalk's model requires a some- what more sophisticated machine since the exponents (re- gression coefficients) are not whole numbers. Demaerschalk's taper equation was derived from the basic logarithmic volume equation:

$$\text{Log } V = a + b \text{ Log } DBH + c \text{ Log } TH$$

Therefore, the volume equation obtained by integrating the taper function (Equation 3, Table 3) is compatible with this original logarithmic volume equation; that is, they both yield the same results. Actually, Demaerschalk's equation is com- patible only if the model is not fitted separately for taper and volume.

Ormerod's equation has only one coefficient that needs to be estimated, hence the basic taper equation is very easy to use. The model is conditioned so that D = 0 when H = TH; and D = DBH when H = 4.5 feet.

All of the models were fitted to the sample data using a com- puter program for nonlinear regression. There were eight obser- vations per sample tree and each observation consisted of DBH, TH, D, and H. The dependent variable in each case was D^2/DBH^2; where D = diameter outside bark and DBH = dbh outside bark.

Results of all the regression analyses are presented in the Appen- dix (Tables 12 - 16). Including all of the results allows the user to select whatever model he deems most appropriate. He can choose coefficients for individual species or use those for all species combined. Thus a user has great flexibility in customiz- ing a taper/volume prediction system to suit his needs.

A summary of the regression results is presented in Table 7. One can readily see that there is little difference between models in how well they fit the sample data. Not too surprisingly, Ormerod's model with only one coefficient does not perform quite as well as do the more complicated equations. However,

Table 7.—Comparison of taper models for the overall equations (all species combined); $Y = D^2/DBH^2$ for all models[a]

Model	R^2	Standard error of the estimate
Bruce and others	.912	.132
Demaerschalk	.863	.165
Kozak and others	.864	.164
Max and Burkhart	.911	.133
Ormerod	.800	.200

[a] D = diameter outside bark
DBH = diameter at breast height outside bark

when one considers model complexity and limitations, as well as goodness of fit as evidenced by the statistics in Table 7, the decision as to which model is "best" is anything but clear cut.

Testing the Equations

The equations were evaluated to see how well a taper-based approach would work on independent sets of data, and also to see if any of the models were significantly better than the others. The tests compared diameter prediction, height prediction, and the prediction of volume for different-sized pieces (logs, bolts, and entire merchantable boles).

The data used in the testing were obtained from six different stands (three in northern West Virginia, two in the middle of the state, and one in the southern portion). Species composition varied from Allegheny hardwoods to upland hardwoods. Test area 1 was predominately black cherry, and test 6 was nearly half yellow-poplar. Mean stand age ranged from 55 to 70 years, and composite site index (for all species combined) varied from 60 to 80 feet at 50 years.

The test data consisted of 1,088 pieces from 593 trees (Table 8). Mean dbh of the test trees was 8.1 inches (range = 4.8 to 19.1 inches) and mean total height was 69 feet (range = 25 to 104 feet). Mean piece length was 13 feet; however, the size ranged from less than 1 foot for small cull sections to over 82 feet for entire merchantable portions of the bole.

Actual heights, to the lower and upper ends of each piece, were used in each equation to predict the large end and small end diameters outside bark. The predicted diameters were then compared to the actual values using the following three criteria (adapted from Cao and others 1980): (1) bias (the mean of the differences between the predicted and actual values), (2) mean absolute difference (the mean of the absolute differences), and (3) standard deviation of the differences. The same procedures were followed for comparing height predictions; actual large- and small-end diameters were used to estimate lower and upper heights respectively.

The comparison of volumes for each piece followed a similar pattern, except that no actual figures were available (i.e., the pieces were not immersed in water to determine true volumes). Hence, volume comparison was between two estimates: Smalian's formula versus the volume equations obtained by integrating the taper functions. Volume (including bark) had been previously computed by Smalian's formula for each log and bolt that was bucked from the test trees. Smalian's volume for longer test pieces was determined simply by summing the individual log and bolt volumes contained within the piece.

All comparisons were made by using the appropriate coefficients for individual species in each model. Biases, mean absolute differences, and standard deviations for these comparisons are shown in Table 9.

Table 8.—Summary statistics for the trees and pieces from the six test sites

	Test 1	Test 2	Test 3	Test 4	Test 5	Test [6]
No. of trees	83	95	101	116	95	[illegible]
Dbh (in):						
Mean	8.3	8.7	6.8	8.4	8.8	[illegible]
Std. deviation	2.0	3.2	1.5	3.0	3.1	[illegible]
Minimum	5.0	5.0	4.8	5.0	5.0	[illegible]
Maximum	13.0	17.6	11.7	17.3	19.1	[illegible]
Total height (ft):						
Mean	61	70	67	69	73	[illegible]
Std. deviation	8	13	9	12	13	[illegible]
Minimum	42	25	44	46	47	[illegible]
Maximum	74	91	92	92	93	[illegible]
No. of pieces	123	149	182	228	200	[illegible]
Piece length (ft):						
Mean	12.3	13.1	11.7	13.6	11.8	[illegible]
Std. deviation	12.9	13.4	13.6	10.1	15.6	[illegible]
Minimum	1.0	1.2	1.2	1.0	0.6	[illegible]
Maximum	54.8	61.2	61.5	72.2	72.6	[illegible]
Dob small end (in):						
Mean	6.3	6.7	5.3	6.0	6.6	[illegible]
Std. deviation	1.8	2.8	1.4	2.3	2.6	[illegible]
Minimum	3.7	4.0	4.0	4.0	3.9	[illegible]
Maximum	10.6	15.5	11.0	15.8	16.0	[illegible]
Dob large end (in):						
Mean	7.8	8.3	6.4	7.8	8.0	[illegible]
Std. deviation	2.2	3.2	1.7	3.2	2.9	[illegible]
Minimum	4.1	4.2	4.2	4.1	4.1	[illegible]
Maximum	13.8	18.7	12.7	19.2	20.2	[illegible]

These measures of accuracy and precision indicate that all models do quite well in predicting diameter, height, and v[illegible] Comparing models in Table 9 is easier if we combined the [illegible] from all six sites and recompute the three test criteria (i.e. weighted average of the values in Table 9). If we then igno[re] any resulting negative signs, the absolute bias for predictin[g] diameter ranged from 0.012 inches (0.2 percent of the me[an]) with the model by Kozak and others to 0.22 inches (3.2 p[ercent] of the mean) with Ormerod's model (Table 10). Mean abs[olute] difference was about 1/2 inch for diameter with all five m[odels]. Absolute bias in height prediction ranged from 0.028 feet [illegible] percent of the mean) with Demaerschalk's model to 2.7 fe[et] (12.5 percent of the mean) with Ormerod's model; mean a[bso]lute difference ranged from 3 to 5 feet. The coefficient of [vari]ation was about 100 percent for diameter and height for a[ll] models. With volume prediction, absolute bias ranged fron[m] able 9.—Bias,[a] mean absolute difference (|D|), and standard deviation of the difference (SD) of the various models for six independent sets of data

Model	Test site	Diameter outside bark			Height			Volume including bark		
		Bias	|D|	SD	Bias	|D|	SD	Bias	|D|	SD
		inches			*feet*			*cubic feet*		
ıce and thers	1	.156	.342	.321	.794	2.156	1.994	-.059	.240	.408
	2	.087	.428	.448	- .283	2.649	2.511	-.119	.299	.550
	3	.134	.383	.446	1.046	3.329	3.911	.050	.253	.642
	4	.178	.434	.483	.642	2.920	3.225	.025	.376	.895
	5	.383	.605	.667	2.058	4.365	5.439	.157	.311	.440
	6	.050	.375	.448	.362	2.688	2.662	-.090	.305	.570
maerschalk	1	.063	.332	.298	.661	2.674	2.179	.033	.252	.420
	2	-.018	.489	.369	- .203	3.858	2.864	.137	.338	.570
	3	.039	.453	.419	.360	4.316	3.912	.119	.300	.642
	4	-.054	.608	.502	- .552	4.375	3.185	.234	.493	1.013
	5	.227	.669	.640	1.318	4.914	4.733	.313	.437	.745
	6	-.131	.524	.500	-1.086	4.329	3.746	.046	.315	.507
›zak and thers	1	.056	.322	.293	.475	2.553	2.124	.027	.247	.385
	2	-.051	.471	.374	- .566	3.735	2.848	.086	.326	.575
	3	-.019	.434	.433	- .307	4.226	4.197	.070	.289	.642
	4	-.025	.576	.480	- .436	4.294	3.226	.282	.506	1.088
	5	.261	.657	.653	1.507	4.868	4.751	.352	.459	.805
	6	-.144	.508	.499	-1.404	4.312	3.777	.011	.307	.513
ıx and urkhart	1	.044	.335	.346	- .108	2.024	1.979	-.160	.267	.448
	2	-.039	.448	.386	- .873	2.926	2.645	-.145	.335	.552
	3	.004	.392	.444	- .284	3.186	3.617	-.021	.260	.628
	4	.058	.473	.484	- .297	3.177	3.145	.056	.376	.836
	5	.308	.633	.691	1.551	4.151	4.175	.186	.332	.550
	6	-.054	.392	.454	- .407	2.774	2.575	-.100	.298	.540
merod	1	-.101	.314	.322	-1.162	2.922	2.811	-.164	.261	.446
	2	-.313	.483	.449	-3.494	4.767	4.439	-.290	.402	.590
	3	-.204	.405	.481	-2.872	4.960	6.793	-.107	.279	.621
	4	-.310	.546	.510	-3.294	5.320	5.028	-.235	.421	.800
	5	.019	.537	.633	- .706	4.922	6.342	-.041	.323	.466
	6	-.355	.545	.685	-4.398	6.020	7.640	-.318	.398	.751

ɔsitive bias = overestimation; negative bias = underestimation.

3 cubic feet (0.1 percent of the mean) for the model by ːe and others to 0.19 cubic feet (4.7 percent of the mean) Ormerod's model. Mean absolute difference was between ınd 0.37 cubic feet with a coefficient of variation approach- ?00 percent.

ɔpears from the results in Table 9 that the effects of test ɔtion were minimal. In general, the models were less accurate less precise on the trees from site 5. The trees from this were larger, although mean dbh and mean total height were significantly greater than on site 2.

In a further attempt to determine the best model, the accuracy and precision of each model were examined separately for different portions of the bole. The comparisons previously described, using the six independent sets of data, were repeated three times. First, only the butt pieces (of any length) from the six test sites were used in the comparisons. Second, only butt pieces ⩽ 12.3 feet in length were used. And, third, only upper pieces (of any length) were used to compare the models. To keep from burdening the reader with too many numbers, I have summarized the results from these additional tests in Table 10. Weighted mean values for the three test criteria, computed over

Table 10.—Bias,[a] mean absolute difference (|D|), and standard deviation of the difference (SD) of the various models averaged over all six test sites for different bole sections

Model	Test pieces used	Diameter outside bark			Height			Volume including	
		Bias	|D|	SD	Bias	|D|	SD	Bias	|D|
		inches			*feet*			*cubic feet*	
Bruce and others	All[b]	.169	.434	.498	.807	3.086	3.644	.003	.304
	Butts - any	.248	.500	.540	.604	2.099	2.690	−.045	.547
	Butts ⩽ 12.3 ft	.229	.426	.522	.791	1.841	2.378	−.139	.241
	Uppers - any	.118	.391	.464	.941	3.734	4.023	.034	.145
Demaerschalk	All	.017	.530	.494	.028	4.191	3.672	.158	.368
	Butts - any	.019	.522	.486	.089	4.284	3.753	.337	.626
	Butts ⩽ 12.3 ft	.266	.525	.476	2.160	4.425	3.634	.164	.258
	Uppers - any	.015	.535	.499	− .012	4.132	3.617	.040	.199
Kozak and others	All	.012	.511	.494	− .156	4.117	3.741	.152	.369
	Butts - any	.003	.502	.490	− .161	4.148	3.874	.323	.635
	Butts ⩽ 12.3 ft	.212	.502	.492	1.652	4.184	3.871	.141	.258
	Uppers - any	.017	.517	.496	− .152	4.099	3.650	.040	.195
Max and Burkhart	All	.059	.455	.501	− .033	3.116	3.234	−.014	.316
	Butts - any	.116	.512	.520	− .121	2.246	2.555	−.063	.570
	Butts ⩽ 12.3 ft	.123	.417	.464	.200	1.804	2.077	−.100	.234
	Uppers - any	.022	.417	.485	.024	3.687	3.496	.017	.149
Ormerod	All	−.217	.486	.548	−2.742	4.971	5.974	−.193	.354
	Butts - any	−.426	.582	.647	−5.087	6.473	7.518	−.434	.653
	Butts ⩽ 12.3 ft	−.363	.508	.624	−4.454	5.974	7.668	−.282	.313
	Uppers - any	−.080	.422	.462	−1.205	3.987	4.429	−.035	.158

[a]Positive bias = overestimation; negative bias = underestimation.
[b]All pieces = mean values from Table 9.

all six test sites, as well as weighted mean values from Table 9, are presented.

Looking at the values in Table 10, it is evident that for the most part the models performed best in the upper part of the bole and poorest in the lower butt section. In the upper bole, the actual difference among the models was very small. Except for bias in height prediction, there was no significant difference among the five models for any of the remaining criteria in the upper part of the bole. This may indicate that taper is relatively uniform in the upper bole of hardwood trees, even though a wide variety of species and sizes are considered. On the other hand, predictions for butt sections of the bole resulted in the greatest difference among the models.

Next, the mean values in Table 10 were ranked from 1 (lowest = best) to 5 (highest = poorest). The results of this ranking process are shown in Table 11. We see that for overall prediction (all sections of the bole) the "best" model de pends on your objective. The model by Kozak and othe was the best predictor of diameter. This model was the accurate (lowest bias) and most precise (lowest standar deviation). For predicting height, however, Max and Bu hart's model did the best job by all three criteria, where model by Bruce and others was better for predicting cu foot volume. When the ranks were summed for diamete height, and volume, the least bias (most accurate) mode overall prediction were Demaerschalk's, Max and Burkh and the one by Kozak and others. The model by Max a Burkhart was somewhat more precise overall. When the criteria are considered together, the models by Bruce an others and Max and Burkhart finished in first place. The models by Demaerschalk and Kozak and others ranked next, followed by Ormerod's.

If we look at how well the various models predicted val for butt pieces of any length, we find that the rankings

Table 11.—Rankings of the five models for diameter, height, and volume prediction

Model	All pieces: Rankings for Bias	All pieces: Rankings for D	All pieces: Rankings for SD	All pieces: Sum	Butt pieces: Rankings for Bias	Butt pieces: Rankings for D	Butt pieces: Rankings for SD	Butt pieces: Sum	Butts ≤ 12.3′: Rankings for Bias	Butts ≤ 12.3′: Rankings for D	Butts ≤ 12.3′: Rankings for SD	Butts ≤ 12.3′: Sum	Upper pieces: Rankings for Bias	Upper pieces: Rankings for D	Upper pieces: Rankings for SD	Upper pieces: Sum
DIAMETER OUTSIDE BARK																
and others	4	1	3	8	4	1	4	9	3	2	4	9	5	1	2	8
erschalk	2	5	2	9	2	4	1	7	4	5	2	11	1	5	5	11
and others	1	4	1	6	1	2	2	5	2	3	3	8	2	4	4	10
nd Burkhart	3	2	4	9	3	3	3	9	1	1	1	3	3	2	3	8
rod	5	3	5	13	5	5	5	15	5	4	5	14	4	3	1	8
HEIGHT																
and others	4	1	2	7	4	1	2	7	2	2	2	6	4	2	4	10
erschalk	1	4	3	8	1	4	3	8	4	4	3	11	1	5	2	8
and others	3	3	4	10	3	3	4	10	3	3	4	10	3	4	3	10
nd Burkhart	2	2	1	5	2	2	1	5	1	1	1	3	2	1	1	4
rod	5	5	5	15	5	5	5	15	5	5	5	15	5	3	5	13
VOLUME INCLUDING BARK																
and others	1	1	2	4	1	1	3	5	2	2	4	8	2	1	2	5
erschalk	4	4	4	12	4	3	4	11	4	4	1	9	4	5	5	14
and others	3	5	5	13	3	4	5	12	3	3	2	8	5	4	4	13
nd Burkhart	2	2	1	5	2	2	1	5	1	1	3	5	1	2	1	4
rod	5	3	3	11	5	5	2	12	5	5	5	15	3	3	3	9
SUM OF RANKINGS																
and others	9	3	7	19	9	3	9	21	7	6	10	23	11	4	8	23
erschalk	7	13	9	29	7	11	8	26	12	13	6	31	6	15	12	33
and others	7	12	10	29	7	9	11	27	8	9	9	26	10	12	11	33
nd Burkhart	7	6	6	19	7	7	5	19	3	3	5	11	6	5	5	16
rod	15	11	13	39	15	15	12	42	15	14	15	44	12	9	9	30

early identical conclusions. About the only change was the difference between the top four models was less ounced. Thus, so far, there seems to be little rationale proclaiming one model superior.

ever, if we look just at the more extreme portions of the , upper pieces of any length, and butt pieces ≤ 12.3 feet, evident that Max and Burkhart's model ranked highest ost categories. Their model was more accurate (less ed) for all predictions in the lower 12.3 feet of the bole, the precision of the model ranked high as well. How- , even though Max and Burkhart's model ranked at the for upper-bole predictions, this was mainly due to its sistent performance; because, as noted earlier, there was ignificant difference among the five models in this por- of the tree.

Discussion and Application

Although the study results do not establish an indisputable "best" taper/volume model for Appalachian hardwoods, they do show some general trends. Based on the regression analyses using sample data (Table 7), the independent tests with data from six different stands, and our knowledge of the models' complexities and limitations, we can make some qualified recommendations:

(1) If the computations will not present a problem, use Max and Burkhart's model. Although this model did not rank highest in all cases, it was the most consistent performer. And it was particularly good, compared to the other four models, for predictions in the lower bole. However, it is not a simple model to use; therefore, a computer (and the neces-

sary software) or at least a programmable calculator with sufficient memory is required for efficient calculations.

(2) If, on the other hand, you can sacrifice some accuracy in the lower bole to gain simplicity in use, then the model by Kozak and others would be a good choice. Overall, their model, while not too precise, was as accurate as Max and Burkhart's (Table 11), and it is very easy to use.

Of course, as a user, the choice is yours; the coefficients presented in the Appendix tables provide considerable flexibility in designing a taper/volume estimating system to fit your needs. In selecting a model, you should consider the relative magnitude of the values in Tables 9 and 10 as well as the various rankings. Sometimes the rankings imply greater differences than were actually observed.

Although the models were fitted to outside bark data, the user can easily convert dob (diameter outside bark) estimates to diameter inside bark by using one of the bark options from Grosenbaugh (1974). Three bark options were presented by Grosenbaugh (1974), in his STX 3-3-73 timber cruising package, for estimating diameters inside bark at any point on the bole using the ratio of dbh inside bark to dbh outside bark. The three options are briefly described below (from Colaninno and others 1977):

Option 1 $D_{ib} = D_{ob}\ (DBH_{ib}/DBH_{ob})$
Bark thickness is assumed to be a constant proportion of dob throughout the height of the tree.

Option 2 $D_{ib} = D_{ob}\ (1.0 - (1.0 - DBH_{ib}/DBH_{ob})(1.0/(2.0 - D_{ob}/DBH_{ob})))$
Implies the proportion of bark decreases hyperbolically up the tree.

Option 3 $D_{ib} = D_{ob}\ (DBH_{ib}/DBH_{ob})(9.0/(10.0 - D_{ob}/DBH_{ob}))$
Implies the proportion of bark increases hyperbolically up the tree.

DBH_{ib}/DBH_{ob} ratios can be determined by measuring bark thickness in the field or by using average values determined from the data used in this study (Appendix, Table 17). To estimate height above ground (H) to a specified diameter inside bark (dib), the dib value must first be converted to diameter outside bark using one of the bark options.

However, if bark option 1 is satisfactory, the DBH_{ib} values can simply be used whenever inside bark predictions of diameter, height, or volume are desired. This eliminates the need to convert any of the final estimates.

All three options are presented because, so far, no one seems sure which option is most appropriate for a particular hardwood species. Although Option 1 is probably adequate for most hardwoods, studies by Wiant and Koch (1974), Boehmer and Rennie (1976), and Colaninno and others (1977) indicate that a single option is not adequate for a hardwood species. And a single option may not be satisfactory for trees of the same species from different geograp areas. A summary of recommendations for several species is presented below:

	Wiant and Koch (1974)	Boehmer and Rennie (1976)	Colanin and othe (1977
	(STX bark option recommended		
Yellow-poplar	1	1	2
Red maple	1	—	—
Hickory, sp.	—	—	2
Red oaks	1	1	1
White oaks	—	1	3

Even though a substantial amount of testing was done, t are still a couple of unanswered questions. Since the inde pendent test data contained few big trees (mean dbh wa inches), additional testing in the large diameters (dbh 18 inches) is desirable. Butt swell in larger trees might alter results, although at least some of the taper models shoul be more accurate than Smalian's formula for volume esti tion. Smalian's formula normally overestimates the volu of butt logs from large trees.

This leads to the second question: How close are taper-b volume estimates to the true volume? Since all of the tes (including those in most other studies) have simply com one estimate against another, we really do not know Ho ever, current research at the Forestry Sciences Laborato Princeton, West Virginia, using water displacement techniques, should soon provide the answer.

One problem is that total height is one of the required va ables. Often this is not measured when timber is cruised; it should be. It is the least ambiguous height measureme a tree (no guessing about the 4- or 8-inch mark, etc.); an taper-based system is used, it is the only height measure needed for most trees (height to where the bole breaks u would also be required on some trees). Actually, measuri total height is a small price to pay for having a complete, curate, and consistent estimating system for bolewood. F some uses, an acceptable alternative would be to measur total height on a subsample of the cruised trees. These d could be used to construct a total-height/dbh curve for e mating the heights of the remaining trees.

Any of the taper models can easily be used to prepare a variety of different volume tables: total volume or merch able volume, inside or outside bark, for an individual spe or all species combined, etc. These are just a few of the o tions available to the user. Four example volume tables a ıcluded in this report (Appendix Tables 18 - 21) to show 'hat can be obtained just by changing the upper and lower mits (HU and HL) of volume calculation. Short computer rograms that will generate volume tables such as presented ere have been developed for each of the five models. Source stings and input instructions for any or all programs are vailable upon request from the author. Note that volumes in able 20 plus those in Table 21 equal the values in Table 19. his demonstrates the consistency of taper-based volume calılations. Note also that certain dbh-height combinations in ables 18-21 are obviously unrealistic; however, these are ermitted to simplify the programs and avoid arguments over rbitrary cutoff points.

.s we have seen, a taper-based system, regardless of the ıodel used or the goal in mind, provides accurate and constent estimates of diameter, height, and volume for Appa.chian hardwoods. Some models perform slightly better ıan others, but at the expense of simplicity. However, with ıe information provided (Tables 12 - 16), the user has conderable latitude in choosing the model and the coefficients ıat best suit his needs.

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Appendix A

Parameters for Appalachian Hardwoods Taper and Volume Functions

TABLE 12. PARAMETERS FOR EASTERN HARDWOOD TAPER AND VOLUME FUNCTIONS. MODEL: D**2/DBH**2 = F(DBH,TH,H) --- A POLYNOMIAL BY BRUCE, ET AL. (1968). ESTIMATED VALUES OF D ARE OUTSIDE BARK.

SPECIES	NO. OF OBSERV.	B1	B2	B3	B4	B5	B6	STANDARD ERROR	R SQUARE
		- - - - - - - - - - REGRESSION COEFFICIENTS - - - - - - - - - -							
L	9296	10.2828	-2.1059	6.9869	-0.9731	0.9282	-11.7092	0.1319	0.9125
MAPLE	608	10.4294	-3.2706	6.9694	-2.4575	0.3857	-3.6133	0.1000	0.9362
AR MAPLE	504	10.6713	0.1364	0.7001	-3.1851	-1.3048	-3.6224	0.1160	0.9284
T BIRCH	512	10.0763	-3.4468	7.6647	8.0964	3.1484	-25.8929	0.1522	0.8959
LOW BIRCH	528	10.0781	-3.9630	6.9500	8.9909	16.3795	-41.7064	0.1443	0.9155
CORY, SP.	480	10.0801	4.0467	-2.5104	-2.1674	0.6558	-14.7264	0.1170	0.9425
BEECH	496	10.0164	-1.1153	2.5557	11.9980	11.0472	-34.0218	0.1274	0.9188
E ASH	560	10.1506	-3.2644	7.8975	-0.3633	16.2545	-24.6575	0.1121	0.9318
LOW-POPLAR	600	10.1220	-3.1400	8.7678	4.9025	6.0196	-17.1372	0.0845	0.9535
UMBERTREE	448	10.1864	-1.3422	6.3870	-4.2010	5.9840	-9.0812	0.0839	0.9560
CK TUPELO	464	10.0640	0.9529	3.1858	-2.3718	2.6607	-14.2303	0.1265	0.9309
CK CHERRY	624	9.7644	-5.2088	13.5189	3.0840	9.4764	-19.6663	0.0904	0.9398
E OAK	672	9.7215	-3.4985	11.1399	3.7322	7.7467	-32.9728	0.1167	0.9465
RLET OAK	392	10.6262	-1.0242	6.8596	-10.9711	-6.3697	-2.8698	0.1396	0.9335
STNUT OAK	488	10.2809	-0.6879	3.7916	-2.4675	3.4765	-10.9332	0.1082	0.9325
OAK	576	10.2266	-3.0538	8.1870	-0.0747	4.8519	-18.6862	0.1071	0.9425
CK OAK	360	9.6401	0.5290	2.5419	3.0013	5.1115	-30.2225	0.1116	0.9552
CK LOCUST	480	9.9436	-2.7018	8.0709	-0.6156	7.1518	-14.2425	0.0977	0.9427
BASSWOOD	504	10.4019	-2.0130	8.8898	-0.3135	10.1272	-18.9616	0.1186	0.9245

BLE 13. PARAMETERS FOR EASTERN HARDWOOD TAPER AND VOLUME FUNCTIONS. MODEL: D**2/DBH**2 = 10.0**(2.0*B0) * DBH**(2.0*B1-2.0) * (TH-H)**(2.0*B2) * TH**(2.0*B3) --- DEMAERSCHALK (1972). ESTIMATED VALUES OF D ARE OUTSIDE BARK.

PECIES	NO. OF OBSERV.	B0	B1	B2	B3	STANDARD ERROR	R SQUARE
		- - - - REGRESSION COEFFICIENTS - - - - -					
L	9296	0.1714	0.9999	0.9183	-0.9743	0.1649	0.8632
MAPLE	608	0.1162	0.9882	0.8345	-0.8639	0.1134	0.9176
R MAPLE	504	0.1380	1.0219	0.9421	-0.9956	0.1346	0.9033
ET BIRCH	512	0.0431	0.9728	1.0314	-0.9972	0.1945	0.8293
LOW BIRCH	528	0.0220	0.9423	1.1125	-1.0456	0.1875	0.8568
CORY, SP.	480	0.2187	1.0436	1.0795	-1.1775	0.1786	0.8655
BEECH	496	0.0326	0.9450	0.9520	-0.9027	0.1525	0.8831
E ASH	560	0.0383	1.0009	0.8870	-0.8769	0.1471	0.8823
LOW-POPLAR	600	0.0406	0.9665	0.7508	-0.7292	0.0987	0.9363
MBERTREE	448	0.1023	1.0075	0.7689	-0.8029	0.1074	0.9277
K TUPELO	464	0.2912	1.0062	0.9676	-1.0887	0.1743	0.8681
K CHERRY	624	-0.0513	0.9426	0.7167	-0.6353	0.1067	0.9158
E OAK	672	0.2291	0.9826	1.0833	-1.1469	0.2033	0.8371
LET OAK	392	0.3219	1.0526	1.1728	-1.3219	0.2246	0.8269
TNUT OAK	488	0.0764	0.9974	0.9002	-0.9073	0.1367	0.8918
OAK	576	0.2583	1.0102	0.9610	-1.0657	0.1598	0.8716
K OAK	360	0.1571	0.9997	1.2836	-1.3162	0.2069	0.8451
K LOCUST	480	0.0119	0.9715	0.8091	-0.7747	0.1181	0.9158
BASSWOOD	504	0.1768	1.0206	0.7515	-0.8251	0.1452	0.8865

TABLE 14. PARAMETERS FOR EASTERN HARDWOOD TAPER AND VOLUME FUNCTIONS. MODEL:
D**2/DBH**2 = B1*(H/TH-1.)+B2*(H**2/TH**2-1.) -- KOZAK, ET AL (1969
ESTIMATED VALUES OF D ARE OUTSIDE BARK.

SPECIES	NO. OF OBSERV.	REGRESSION COEFFICIENTS B1	B2	STANDARD ERROR	R SQUARE
ALL	9296	-2.5116	1.1587	0.1645	0.8638
RED MAPLE	608	-2.2122	0.9514	0.1139	0.9166
SUGAR MAPLE	504	-2.5086	1.1911	0.1340	0.9037
SWEET BIRCH	512	-2.8191	1.3999	0.1948	0.8281
YELLOW BIRCH	528	-2.9832	1.5358	0.1914	0.8503
HICKORY, SP.	480	-2.8371	1.4219	0.1799	0.8629
AM. BEECH	496	-2.5942	1.2382	0.1532	0.8815
WHITE ASH	560	-2.3971	1.0821	0.1457	0.8840
YELLOW-POPLAR	600	-2.0085	0.7622	0.0992	0.9354
CUCUMBERTREE	448	-2.0518	0.8045	0.1063	0.9288
BLACK TUPELO	464	-2.7082	1.2785	0.1763	0.8645
BLACK CHERRY	624	-1.8830	0.6637	0.1078	0.9138
WHITE OAK	672	-3.0260	1.5193	0.2055	0.8331
SCARLET OAK	392	-3.1363	1.6148	0.2286	0.8198
CHESTNUT OAK	488	-2.4336	1.1115	0.1353	0.8935
RED OAK	576	-2.6281	1.2477	0.1598	0.8712
BLACK OAK	360	-3.1388	1.6648	0.2129	0.8351
BLACK LOCUST	480	-2.1358	0.8883	0.1167	0.9175
AM. BASSWOOD	504	-2.1236	0.8074	0.1437	0.8884

TABLE 15. PARAMETERS FOR EASTERN HARDWOOD TAPER AND VOLUME FUNCTIONS. MODEL:
D**2/DBH**2=F(DBH,TH,H) - SEGMENTED POLYNOMIAL, MAX & BURKHART (1976)
ESTIMATED VALUES OF D ARE OUTSIDE BARK.

SPECIES	NO. OF OBSERV.	- - - REGRESSION COEFFICIENTS - - - B1	B2	B3	B4	A1	A2	STANDARD ERROR	R SQUA
ALL	9296	-3.9964	2.0087	-2.4624	41.9337	0.6381	0.1241	0.1328	0.91
RED MAPLE	608	-3.9701	2.0384	-2.4816	25.1129	0.6034	0.1208	0.1015	0.93
SUGAR MAPLE	504	-3.2884	1.6583	-2.3854	35.6192	0.5133	0.1209	0.1130	0.93
SWEET BIRCH	512	-4.7790	2.5105	-2.7567	67.2975	0.6738	0.1082	0.1544	0.89
YELLOW BIRCH	528	-3.5897	1.8331	-2.1859	55.3868	0.5857	0.1204	0.1480	0.91
HICKORY, SP.	480	-3.6673	1.8308	-2.6598	43.4116	0.6060	0.1463	0.1150	0.94
AM. BEECH	496	-3.4340	1.7394	-2.6702	34.6121	0.5172	0.1321	0.1307	0.91
WHITE ASH	560	-3.8568	1.9413	-2.4527	887.9036	0.6130	0.0345	0.1128	0.93
YELLOW-POPLAR	600	-4.8424	2.4509	-2.7919	22.0258	0.6978	0.1241	0.0849	0.95
CUCUMBERTREE	448	-4.8937	2.4684	-2.6771	212.2433	0.7215	0.0507	0.0856	0.95
BLACK TUPELO	464	-4.5210	2.2799	-3.0741	29.6952	0.6600	0.1694	0.1313	0.92
BLACK CHERRY	624	-4.9738	2.5251	-3.0382	167.3393	0.6904	0.0544	0.0921	0.93
WHITE OAK	672	-4.2643	2.1658	-3.0514	77.1744	0.6281	0.1207	0.1200	0.94
SCARLET OAK	392	-3.9750	1.9950	-2.7309	70.5026	0.6274	0.1264	0.1471	0.92
CHESTNUT OAK	488	-3.2804	1.6103	-2.3807	42.5301	0.5429	0.1188	0.1067	0.93
RED OAK	576	-4.4635	2.2812	-2.6462	58.2976	0.6752	0.1131	0.1105	0.93
BLACK OAK	360	-3.7816	1.9023	-2.3461	70.8956	0.6522	0.1258	0.1122	0.95
BLACK LOCUST	480	-3.7918	1.8454	-1.9766	65.2427	0.6859	0.0830	0.0982	0.94
AM. BASSWOOD	504	-5.2178	2.5939	-3.0258	193.6099	0.7251	0.0576	0.1187	0.92

TABLE 16. PARAMETERS FOR EASTERN HARDWOOD TAPER AND VOLUME FUNCTIONS. MODEL:
D**2/DBH**2 = ((TH-H)/(TH-4.5))**(2.0*B1) --- ORMEROD (1973).
ESTIMATED VALUES OF D ARE OUTSIDE BARK.

SPECIES	NO. OF OBSERV.	REGRESSION COEFFICIENT B1	STANDARD ERROR	R SQUARE
ALL	9296	0.7247	0.1995	0.7998
RED MAPLE	608	0.7215	0.1328	0.8865
SUGAR MAPLE	504	0.7697	0.1657	0.8524
SWEET BIRCH	512	0.7820	0.2386	0.7418
YELLOW BIRCH	528	0.8223	0.2429	0.7583
HICKORY, SP.	480	0.8003	0.2277	0.7800
AM. BEECH	496	0.7686	0.1876	0.8220
WHITE ASH	560	0.7092	0.1789	0.8250
YELLOW-POPLAR	600	0.6423	0.1215	0.9029
CUCUMBERTREE	448	0.6619	0.1276	0.8972
BLACK TUPELO	464	0.7382	0.2216	0.7854
BLACK CHERRY	624	0.6303	0.1219	0.8895
WHITE OAK	672	0.7595	0.2693	0.7130
SCARLET OAK	392	0.7865	0.2951	0.6989
CHESTNUT OAK	488	0.7333	0.1681	0.8354
RED OAK	576	0.7352	0.2036	0.7905
BLACK OAK	360	0.8934	0.2672	0.7396
BLACK LOCUST	480	0.6965	0.1363	0.8872
AM. BASSWOOD	504	0.5907	0.1801	0.8242

Appendix B

Average Dbh_{ib}/Dbh_{ob} Ratios
for the Sample Data

Table 17.—Average DBH_{ib} DBH_{ob} ratios for the sample data by species

Species	Average ratio
Red maple	.942
Sugar maple	.942
Sweet birch	.939
Yellow birch	.948
Hickory, sp.	.915
American beech	.968
White ash	.913
Yellow-poplar	.896
Cucumbertree	.912
Black tupelo	.866
Black cherry	.923
White oak	.929
Scarlet oak	.926
Chestnut oak	.887
Red oak	.921
Black oak	.906
Black locust	.861
American basswood	.907
All species	.918

Appendix C

Example Volume Tables Prepared with the
Taper Model by Kozak and Others*

- Total volume - Table 18
- Merchantable volume to 4-inch top - Table 19
- Merchantable volume to 8-inch top - Table 20
- Volume between 8- and 4-inch points - Table 21

*All volumes are inside bark. Bark option 1 was used to make the conversion.

Table 18. --GROSS PEELED VOLUME IN CUBIC FEET (EXCLUDING BARK) BY TOTAL HEIGHT.
MODEL BY KOZAK, ET AL. (Y = D**2/DBH**2) USING COEFFICIENTS FOR ALL SPECIES
VOLUME BETWEEN LOWER LIMIT OF 0.0 FEET
AND UPPER LIMIT OF 0.0 INCHES

TOTAL HEIGHT FROM GROUND-LINE TO TIP :

DOB (IN.)	30 FEET	40 FEET	50 FEET	60 FEET	70 FEET	80 FEET	90 FEET	100 FEET	110 FEET	120 FEET
4	1.1	1.4	1.8	2.1	2.5	2.8	3.2	3.6	3.9	4.3
5	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7
6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.8	9.6
7	3.3	4.4	5.4	6.5	7.6	8.7	9.8	10.9	12.0	13.1
8	4.3	5.7	7.1	8.5	10.0	11.4	12.8	14.2	15.6	17.1
9	5.4	7.2	9.0	10.8	12.6	14.4	16.2	18.0	19.8	21.6
10	6.7	8.9	11.1	13.3	15.6	17.8	20.0	22.2	24.4	26.7
11	8.1	10.8	13.4	16.1	18.8	21.5	24.2	26.9	29.6	32.3
12	9.6	12.8	16.0	19.2	22.4	25.6	28.8	32.0	35.2	38.4
13	11.3	15.0	18.8	22.5	26.3	30.0	33.8	37.5	41.3	45.1
14	13.1	17.4	21.8	26.1	30.5	34.8	39.2	43.5	47.9	52.2
15	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0
16	17.1	22.7	28.4	34.1	39.8	45.5	51.2	56.9	62.6	68.2
17	19.3	25.7	32.1	38.5	44.9	51.4	57.8	64.2	70.6	77.0
18	21.6	28.8	36.0	43.2	50.4	57.6	64.8	72.0	79.2	86.4
19	24.1	32.1	40.1	48.1	56.1	64.2	72.2	80.2	88.2	96.2
20	26.7	35.5	44.4	53.3	62.2	71.1	80.0	88.9	97.7	106.6
21	29.4	39.2	49.0	58.8	68.6	78.4	88.2	98.0	107.8	117.6
22	32.3	43.0	53.8	64.5	75.3	86.0	96.8	107.5	118.3	129.0
23	35.3	47.0	58.8	70.5	82.3	94.0	105.8	117.5	129.3	141.0
24	38.4	51.2	64.0	76.8	89.6	102.4	115.2	128.0	140.8	153.6
25	41.7	55.5	69.4	83.3	97.2	111.1	125.0	138.8	152.7	166.6
26	45.1	60.1	75.1	90.1	105.1	120.1	135.2	150.2	165.2	180.2
27	48.6	64.8	81.0	97.2	113.4	129.6	145.8	161.9	178.1	194.3
28	52.2	69.7	87.1	104.5	121.9	139.3	156.7	174.2	191.6	209.0
29	56.0	74.7	93.4	112.1	130.8	149.5	168.1	186.8	205.5	224.2
30	60.0	80.0	100.0	120.0	140.0	159.9	179.9	199.9	219.9	239.9

Table 19. --GROSS PEELED VOLUME IN CUBIC FEET (EXCLUDING BARK) BY TOTAL HEIGHT.
MODEL BY KOZAK, ET AL. (Y = D**2/DBH**2) USING COEFFICIENTS FOR ALL SPECIES
VOLUME BETWEEN LOWER LIMIT OF 1.0 FEET
AND UPPER LIMIT OF 4.0 INCHES

	TOTAL HEIGHT FROM GROUND-LINE TO TIP :								
DBHOB (IN.)	30 FEET	40 FEET	50 FEET	60 FEET	70 FEET	80 FEET	90 FEET	100 FEET	110 FEET
4	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
5	0.8	1.1	1.5	1.8	2.1	2.4	2.8	3.1	3.4
6	1.6	2.2	2.8	3.4	4.0	4.6	5.2	5.9	6.5
7	2.5	3.4	4.3	5.2	6.2	7.1	8.0	8.9	9.9
8	3.5	4.7	6.0	7.3	8.6	9.8	11.1	12.4	13.7
9	4.5	6.2	7.9	9.5	11.2	12.9	14.6	16.2	17.9
10	5.7	7.8	9.9	12.0	14.2	16.3	18.4	20.5	22.6
11	7.0	9.6	12.2	14.8	17.4	20.0	22.5	25.1	27.7
12	8.5	11.6	14.7	17.8	20.9	24.0	27.1	30.2	33.3
13	10.0	13.7	17.3	21.0	24.7	28.3	32.0	35.7	39.3
14	11.7	15.9	20.2	24.5	28.7	33.0	37.3	41.6	45.8
15	13.4	18.3	23.3	28.2	33.1	38.0	43.0	47.9	52.8
16	15.3	20.9	26.5	32.2	37.8	43.4	49.0	54.6	60.3
17	17.3	23.7	30.0	36.4	42.7	49.1	55.5	61.8	68.2
18	19.5	26.6	33.7	40.9	48.0	55.1	62.3	69.4	76.5
19	21.7	29.7	37.6	45.6	53.5	61.5	69.5	77.4	85.4
20	24.1	32.9	41.7	50.6	59.4	68.2	77.1	85.9	94.7
21	26.6	36.3	46.1	55.8	65.5	75.3	85.0	94.8	104.5
22	29.2	39.9	50.6	61.3	72.0	82.7	93.4	104.1	114.8
23	31.9	43.6	55.3	67.0	78.7	90.4	102.1	113.8	125.5
24	34.8	47.5	60.3	73.0	85.8	98.5	111.3	124.0	136.8
25	37.8	51.6	65.4	79.3	93.1	106.9	120.8	134.6	148.5
26	40.9	55.8	70.8	85.8	100.7	115.7	130.7	145.7	160.6
27	44.1	60.2	76.4	92.5	108.7	124.8	141.0	157.1	173.3
28	47.4	64.8	82.1	99.5	116.9	134.3	151.6	169.0	186.4
29	50.9	69.5	88.1	106.8	125.4	144.0	162.7	181.3	200.0
30	54.5	74.4	94.3	114.3	134.2	154.2	174.1	194.1	214.1

20.--GROSS PEELED VOLUME IN CUBIC FEET (EXCLUDING BARK) BY TOTAL HEIGHT.
MODEL BY KOZAK, ET AL. (Y = D**2/DBH**2) USING COEFFICIENTS FOR ALL SPECIES
VOLUME BETWEEN LOWER LIMIT OF 1.0 FEET
AND UPPER LIMIT OF 8.0 INCHES

TOTAL HEIGHT FROM GROUND-LINE TO TIP :

30 FEET	40 FEET	50 FEET	60 FEET	70 FEET	80 FEET	90 FEET	100 FEET	110 FEET	120 FEET
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.6	0.9	1.1	1.4	1.6	1.9	2.2	2.4	2.7
1.8	2.6	3.3	4.1	4.9	5.6	6.4	7.1	7.9	8.7
3.3	4.6	5.9	7.1	8.4	9.7	11.0	12.3	13.6	14.9
4.8	6.6	8.5	10.3	12.2	14.0	15.9	17.7	19.6	21.4
6.4	8.8	11.3	13.7	16.1	18.5	21.0	23.4	25.8	28.3
8.1	11.2	14.2	17.2	20.3	23.3	26.4	29.4	32.5	35.5
9.9	13.6	17.3	21.0	24.7	28.4	32.1	35.8	39.5	43.2
11.8	16.2	20.6	25.0	29.3	33.7	38.1	42.5	46.9	51.3
13.8	18.9	24.0	29.1	34.3	39.4	44.5	49.6	54.7	59.8
15.9	21.8	27.7	33.5	39.4	45.3	51.2	57.1	63.0	68.9
18.1	24.8	31.5	38.2	44.9	51.6	58.3	65.0	71.7	78.3
20.5	28.0	35.5	43.1	50.6	58.1	65.7	73.2	80.8	88.3
22.9	31.3	39.7	48.2	56.6	65.0	73.5	81.9	90.4	98.8
25.5	34.8	44.2	53.5	62.9	72.3	81.6	91.0	100.4	109.7
28.1	38.5	48.8	59.1	69.5	79.8	90.2	100.5	110.8	121.2
30.9	42.3	53.6	65.0	76.3	87.7	99.1	110.4	121.8	133.1
33.8	46.2	58.6	71.0	83.5	95.9	108.3	120.7	133.2	145.6
36.8	50.3	63.9	77.4	90.9	104.4	118.0	131.5	145.0	158.6
40.0	54.6	69.3	84.0	98.6	113.3	128.0	142.7	157.3	172.0
43.2	59.1	74.9	90.8	106.6	122.5	138.4	154.2	170.1	186.0
46.6	63.7	80.8	97.9	115.0	132.1	149.2	166.3	183.4	200.5
50.1	68.4	86.8	105.2	123.6	141.9	160.3	178.7	197.1	215.5
53.7	73.4	93.1	112.7	132.4	152.1	171.8	191.5	211.3	231.0

Table 21.--GROSS PEELED VOLUME IN CUBIC FEET (EXCLUDING BARK) BY TOTAL HEIGHT.
MODEL BY KOZAK, ET AL. (Y = D**2/DBH**2) USING COEFFICIENTS FOR ALL SPECIES
VOLUME BETWEEN LOWER LIMIT OF 8.0 INCHES
AND UPPER LIMIT OF 4.0 INCHES

DBHOB (IN.)	TOTAL HEIGHT FROM GROUND-LINE TO TIP : 30 FEET	40 FEET	50 FEET	60 FEET	70 FEET	80 FEET	90 FEET	100 FEET	110 FEET
4	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
5	0.8	1.1	1.5	1.8	2.1	2.4	2.8	3.1	3.4
6	1.6	2.2	2.8	3.4	4.0	4.6	5.2	5.9	6.5
7	2.5	3.4	4.3	5.2	6.2	7.1	8.0	8.9	9.9
8	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.2	11.3
9	2.7	3.6	4.5	5.5	6.4	7.3	8.2	9.1	10.0
10	2.5	3.3	4.1	4.9	5.7	6.5	7.4	8.2	9.0
11	2.2	3.0	3.7	4.4	5.2	5.9	6.7	7.4	8.2
12	2.0	2.7	3.4	4.1	4.7	5.4	6.1	6.8	7.5
13	1.9	2.5	3.1	3.7	4.4	5.0	5.6	6.2	6.9
14	1.7	2.3	2.9	3.5	4.0	4.6	5.2	5.8	6.4
15	1.6	2.2	2.7	3.2	3.8	4.3	4.8	5.4	5.9
16	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
17	1.4	1.9	2.4	2.8	3.3	3.8	4.3	4.7	5.2
18	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.4	4.9
19	1.3	1.7	2.1	2.5	2.9	3.4	3.8	4.2	4.6
20	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4
21	1.1	1.5	1.9	2.3	2.6	3.0	3.4	3.8	4.2
22	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6	4.0
23	1.0	1.4	1.7	2.1	2.4	2.7	3.1	3.4	3.8
24	1.0	1.3	1.6	2.0	2.3	2.6	2.9	3.3	3.6
25	0.9	1.2	1.6	1.9	2.2	2.5	2.8	3.1	3.4
26	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3
27	0.9	1.1	1.4	1.7	2.0	2.3	2.6	2.9	3.2
28	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.8	3.0
29	0.8	1.1	1.3	1.6	1.9	2.1	2.4	2.6	2.9
30	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8

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Martin, A. Jeff. Taper and volume equations for selected Appalachian hardwood species. Broomall, PA: Northeast. For. Exp. Stn.; 1981; USDA For. Serv. Res. Pap. NE-490. 22 p.

Coefficients for five taper/volume models are developed for 18 Appalachian hardwood species. Each model can be used to estimate diameter at any point on the bole, height to any preselected diameter, and cubic foot volume between any two points on the bole. The resulting equations were tested on six sets of independent data and an evaluation of these tests is included. A wide variety of volume tables can be constructed with the models; some examples are given.

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Keywords: Taper, tree volume, hardwoods

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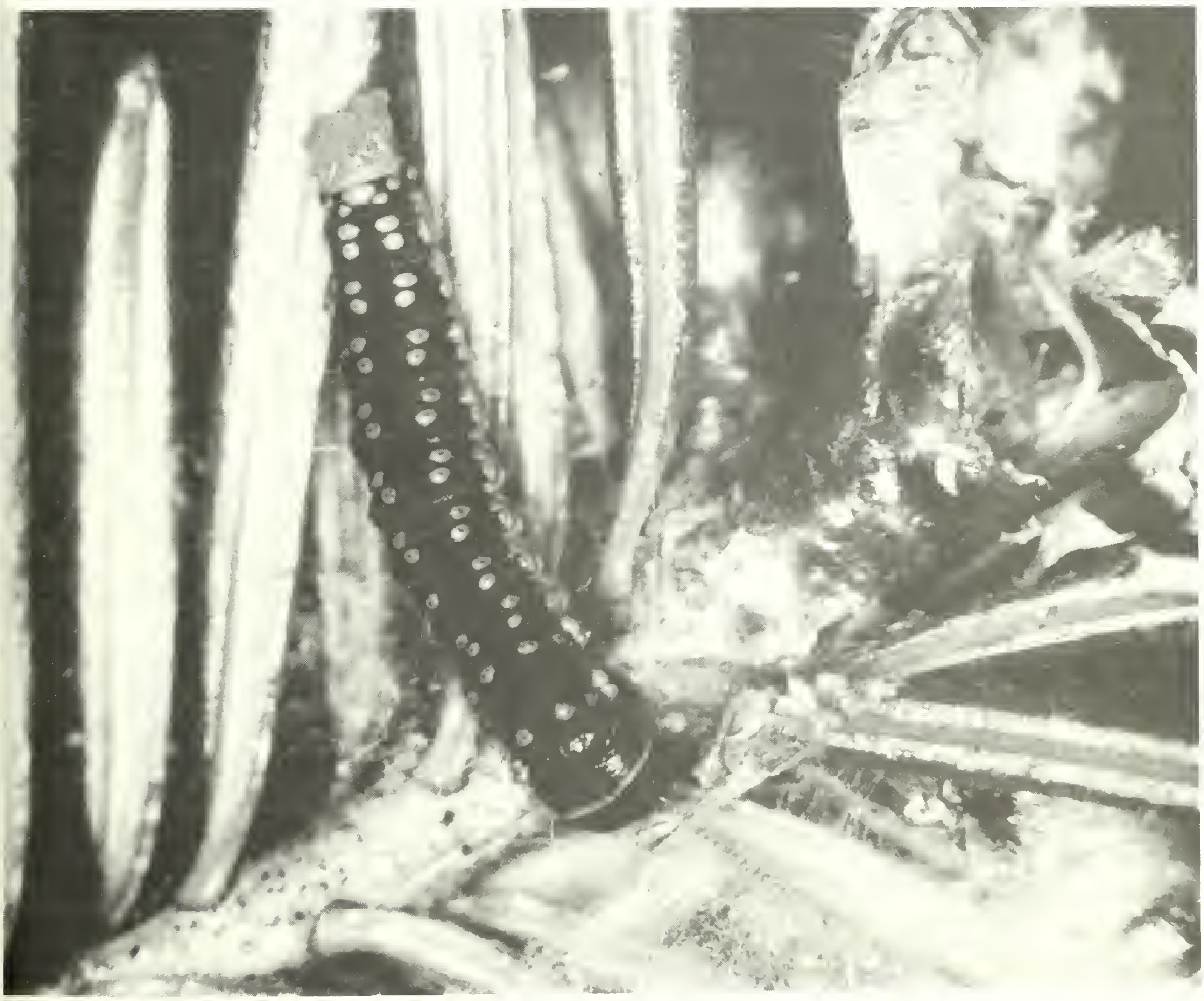
and Stanford L. Arner

Mortality of Spruce and Fir in Maine in 1976-78 due to the Spruce Budworm Outbreak



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Abstract

The spruce budworm population in Maine's spruce-fir forests has been at epidemic levels since the early 1970's. Spruce-fir mortality in 1976-78 is compared with predictions of what mortality would have been had the natural mortality rates remained at the levels experienced before the budworm outbreak. It appears that mortality of spruce and fir has increased 2½-fold since the 1960's, that is, 60 percent of the mortality can be attributed to the budworm outbreak.

n oduction

h spruce budworm has been at epidemic levels in Maine in the early 1970's. One indication of the extent of bud- c n outbreak is the size of the spray program. In the 9 's, an average of 90,000 acres was sprayed annually. e een 1970 and 1974, an average of 400,000 acres was p ed annually. In 1975, the spraying increased to 2.2 mil- o acres. The acreage sprayed peaked at 3.5 million acres in 9 . Between 1 and 2 million acres have been sprayed an- u y since 1976.

h paper compares estimates of the annual mortality of p ce and fir in Maine in 1976-78 with predictions of what mortality would have been had the mortality rates re- ed at levels experienced in the 1960's, a period when the u vorm was at endemic levels.

t igh population levels, the budworm can defoliate and kill a m fir and spruce over large areas. In uncontrolled bud- n outbreaks, mortality usually shows up 4 or 5 years f the beginning of the outbreak and is generally complete i in 10 years (MacLean 1980).

estimates of mortality due to the budworm are for a u region which includes areas that were heavily infested n possibly sprayed. The areas of infestation were expand- or at least 5 years before the time for which the mor- a y is reported.

hods

sources of data were used to estimate the volume of p ce and fir mortality: (1) The Spruce Budworm Growth act Study; and (2) The USDA Forest Service Maine st Survey.

The need for data to evaluate the effects of the budworm epidemic on Maine's spruce-fir resource was recognized by the State of Maine in the fall of 1974 and the Spruce Budworm Growth Impact Study was initiated. The study is based on a probability sample of 406 permanent plots. The area covered by the Growth Impact Study encompasses 7 million acres of softwood and mixedwood stands in the following counties: Aroostook, Franklin, Penobscot, Piscatiquis, Somerset, and Washington. The Growth Impact Study design and procedures are similar to those used in previous and current Maine Forest Surveys, though the sample size is smaller. Field data were collected annually starting the summer of 1975. A description of the Growth Impact Study is given by Ashley et al. (1976).

Spruce and fir mortality estimated for 1976, 1978, and 1979 were reported by Lawrence et al. (1979). The mortality estimates were fairly constant over the 3 years. The annual mortality per acre of spruce and fir was 11.4 and 27.6 cubic feet (ft^3), respectively.

We calculated annual mortality rates for spruce and fir during 1959-71 from Maine forest survey remeasured plots data. The 1971 Maine forest survey design and methods are described in Ferguson and Kingsley (1972).

Three causes of mortality were recorded in 1971 Maine survey remeasured plots: cutting (C), other removals (R), and natural (N). Table 1 gives the 12-year (1959-71) probabilities of mortality from cutting (P_C), other removals (P_R), and natural causes (P_N); and 12-year conditional probabilities of natural mortality (M). The latter is defined as the probability that a tree will die from natural causes given it is not cut or "removed." A discussion of mortality from a specific cause in the presence of multiple mortality factors is

able 1. — Twelve-year crude probabilities of mortality from cutting, other removal, or natural causes, and 12-year net probabilities of natural mortality in spruce-fir region of Maine, 1959-71.

iameter class inches)	Number of sample trees		Crude probabilities						Net probability of natural mortality	
			Cut		Other removal		Natural mortality			
	Red spruce	Balsam fir	Red spruce	Balsam fir	Red spruce	Balsam fir	Red spruce	Balsam fir	Red spruce	Balsam fir
6	1,044	1,733	0.110	0.079	0.000	0.002	0.070	0.101	0.08	0.11
8	481	675	.213	.170	.000	.001	.054	.132	.07	.16
10	386	422	.241	.158	.000	.000	.056	.195	.07	.23
12	199	181[a]	.288	.205[a]	.000	.000[a]	.046	.296[a]	.06	.37[a]
14+	175	—	.436	—	.000	—	.057	—	.10	—

[a]Diameter class is 12+.

found in Kimball (1969). The relationship of M, P_C, P_R, and P_N is

$$M = P_N/(1.0 - P_C - P_R).$$

In this paper, P_C, P_R, and P_N are called crude probabilities, while M is the net probability of natural mortality or net mortality rate. The annual net mortality rate (M_1) is calculated from the 12-year rate (M_{12}) by taking the geometric mean of the survival rate. The results are

$$M_1 = 1.0 - (1.0 - M_{12})^{1/12}.$$

Stock tables for the spruce-fir inventory (Table 2) were calculated from the 1975 Growth Impact Study data by the Resources Evaluation unit of the Northeastern Forest Experiment Station. Multiplying the volume in the stock table by the annual net probabilities of natural mortality provides estimates of the volume of spruce and fir that would have died in 1976 had the mortality rates remained at prebudworm outbreak levels.

Results

The predicted annual mortality per acre is 4.49 ft^3 for spruce and 10.97 ft^3 for balsam fir (Table 2). Compared with the reported annual mortality per acre of 11.4 and 27.6 ft^3, it appears that mortality has increased since the 1960's by a factor of 2.53 for spruce and 2.52 for fir.

The mortality of spruce-fir attributed to the spruce budworm is estimated as the difference between the estimated actual volumes and predicted volumes. The mortality of spruce attributed to the budworm epidemic in 1975-78 is estim at 6.90 ft^3 per acre per year; that is, 61 percent of the na ural mortality is due to budworm. For fir, the mortality tributed to the budworm epidemic is 16.63 ft^3 per acre year; that is, 60 percent of the natural mortality is due t budworm.

What has been the effect of the increased mortality on t spruce-fir inventory? The drain on the inventory depend how many of the mortality trees were included in the ha vest. Cutting should favor the removal of high-risk trees. Ideally, all of the trees that would die naturally should b cut. The actual situation is between these extremes. One sibility is that the trees were cut randomly from the inve tory.

Possible values for the drain on inventory can be calcula from statistics in this paper. The estimated 1975 invento of spruce-fir (Table 2) is 1,382.57 ft^3 per acre. In recent years, the annual cut from Maine's Spruce-Fir Protectior District has been about 225 million ft^3, which is 32 ft^3 per acre or 2.31 percent of the 1975 stock. The annual r mortality per acre of spruce-fir in Maine was 39.0 ft^3 or 2.82 percent of the 1975 inventory according to Lawren et al. (1969). Dividing the cut and mortality percentages 100 gives approximate values of the probabilities of tree being cut (0.0231) and the net probability of natural mo tality (0.0282).

Suppose the only trees harvested were those that would died naturally. Since the mortality exceeds the cut, the on inventory would have been the net mortality, or 2.82 percent of the 1975 stock. If none of the mortality trees

Table 2. — The 1975 spruce-fir inventory, annual net probabilities of natural mortality, and predicted annual mortality in 1975 assuming no change inmortality rates from 1959-71, spruce-fir region of Maine.

Diameter class (inches)	1975 inventory		Annual net probability of mortality		Predicted annual mortality in 1975	
	Red and white spruce	Balsam fir	Red and white spruce	Balsam fir	Red and white spruce	Balsam fir
	ft³/acre				*ft³/acre*	
6	194.79	290.19	0.0069[a]	0.0097	1.34	2.8
8	159.91	226.29	.0060	.0144	.96	3.2
10	132.65	116.41	.0060	.0215	.80	2.5
12	94.00	63.50[b]	.0051	.0378[b]	.48	2.4
14+	104.83	—	.0087	—	.91	—
Total	686.18	696.39			4.49	10.9

[a]values based on red spruce only.
[b]diameter class is 12+.

d in the harvest, the drain on inventory would have e cut plus the net mortality, or 5.13 percent of the ock.

tree had the same probability of being cut, the ty rate would be the probability of a tree not being s the net mortality rate, or 2.75 percent of the in- . The drain on the inventory would be the cut plus le mortality, or 5.06 percent of the 1975 stock.

s in the other growth components must be estimated mine the total effect of the budworm epidemic on ice-fir inventory. We have estimates of survivor before the budworm outbreak from the 1971 re- d plot data. For balsam fir (n = 2474), we found that ual growth was independent of the initial diameter. ual diameter growth can be estimated from the mean which was $\overline{g} = 0.0896$ inch. The sample stan- viation was 0.0609 inch.

spruce (n = 2099), we found that there was a statis- ignificant linear relationship between the annual r growth and the initial dbh. The annual growth of can be estimated from the equation.

$$\hat{g} = 0.0688 + 0.0035 \text{ dbh}.$$

ndard error of regression was 0.0627 inch. The sample only 0.024, which suggests that the annual diameter t of red spruce be estimated by the average, which was 67 inch. The sample standard deviation was s = 3 inch.

-year Results

e completion of this study, Lawrence and House- 981) have reported the results from the fourth year laine Spruce Budworm Growth Impact Study. The annual diameter growth for 1975-79 was 0.059 inch spruce and 0.053 inch for balsam fir. These averages ompared to the average growth rates in 1960-70. It that there has been a growth loss (in dbh) of 39.0 for spruce and 40.8 percent for fir.

, the mortality of fir increased to 34.96 ft^3/acre. mortality was 10.94 ft^3/acre, which is about the same verage annual mortality in the 3 previous years.

sion

ing the amount of mortality attributed to the bud- s the difference between predicted values based on past data and current values is comparable to the procedure used by Baltzer (1973) to estimate net mortality in balsam fir due to budworm defoliation. He estimated the mortality as the difference in mortality between sprayed and un- sprayed plots. We used statistical controls rather than experi- mental controls to estimate the mortality due to budworm.

Lawrence et al. (1979) also presented data on the percentage mortality by causal agent. They estimated that the average mortality due to budworm was 5.3 percent for spruce and 23.9 percent for fir. Our estimates of the mortality due to budworm are higher than the values reported from the Bud- worm Impact Study. The major source of mortality report- ed by Lawrence et al. (1979) was blowdown. But some of the blowdown may be "due to budworm." How much of blowdown is due to budworm and how much is natural blowdown cannot be determined.

We feel that with the current state of knowledge it is not feasible to assign a cause of mortality to dead trees. One approach to estimating mortality due to an insect outbreak is to use past data. Forest Survey is one source of such data.

Our estimates of the volume of mortality due to the current budworm outbreak are based on mortality in the presence of a large-scale spray program. How long the budworm epidemic will last and what the total mortality will be are major un- knowns which bar a determination of the long-term effect of budworm on the spruce-fir inventory.

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Seegrist, Donald W: Arner, Stanford L. Mortality of spruce and fir in Maine in 1976-78 due to the spruce budworm outbreak. Broomall, PA: Northeast. For. Exp. Stn.; 1982; USDA For. Serv. Res. Pap. NE-491. 3 p.

The spruce budworm population in Maine's spruce-fir forests has been at epidemic levels since the early 1970's. Spruce-fir mortality in 1976-78 is compared with predictions of what mortality would have been had the natural mortality rates remained at the levels experienced before the budworm outbreak. It appears that mortality of spruce and fir has increased 2½-fold since the 1960's; that is, 60 percent of the mortality can be attributed to the budworm outbreak.

453:562.22

Keywords: *Choristoneura fumiferana*

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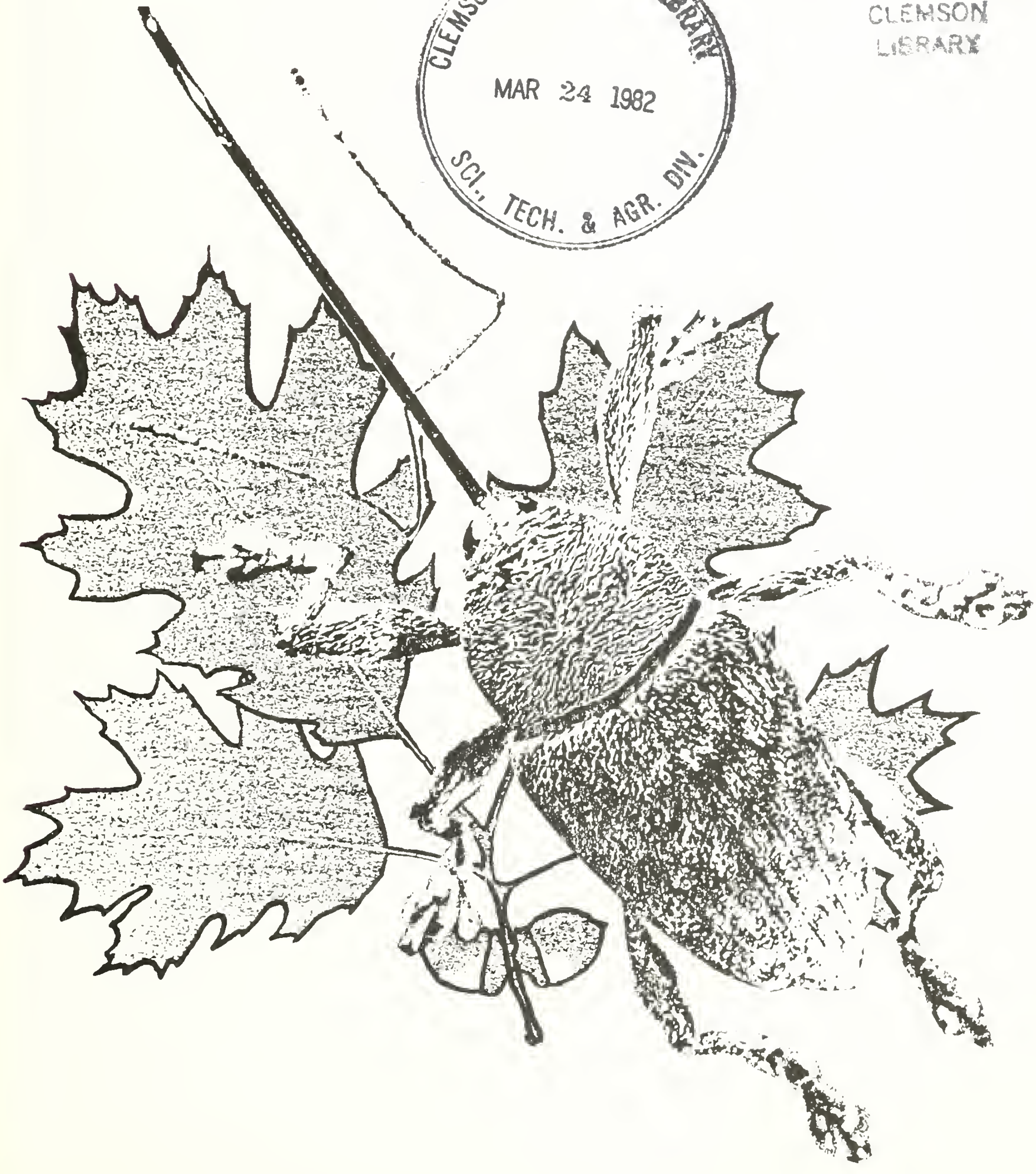
Research Paper NE-492

1982

Insects that Damage
Northern Red Oak Acorns

Lester P. Gibson



The Author

Lester Paul Gibson received his B.S. degree in 1957, his M.S. degree in 1962, and his Ph.D. in 1974, all from the Ohio State University. He joined the Forest Service in 1957 and has served as a Biological Aid (Survey Entomologist) and Research Entomologist at Columbus and Delaware, Ohio. He is a specialist on insects (and their parasites) of nut crops and hardwood seeds. He is the world authority on the biology and systematics of *Curculio* in the New World and of the braconid genus *Urosigalphus.* He has spent several years investigating the insect vectors of tree viruses. Currently he is engaged in research on the impact of insects on oak seed production and oak seedling establishment at the Northeastern Forest Experiment Station, Forestry Sciences Laboratory at Delaware, Ohio.

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Abstract

From 1961 to 1964 and in 1979, the insects found damaging acorns of northern red oak (*Quercus rubra* L.) in their relative order of abundance were: *Curculio proboscideus* F., *C. sulcatulus* (Casey), *Melissopus latiferreanus* (Wals.), *C. nasicus* (Say), *C. orthorhynchus* (Chttn.), *C. longidens* Chttn., *Callirhytis operator* (O.S.), *Callirhytis fructuosa* Weld., *Conotrachelus posticatus* Boh., *Conotrachelus carinifer* Casey, *Conotrachelus naso* LeC., and *Valentinia glandulella* (Riley). During 1961 to 1964, 1979, and 1980 insects damaged an average of 52.32 percent of *Q. rubra* acorns (range 0 to 100 percent).

n oduction

Ic hern red oak, *Quercus rubra* L., is an important tree ies in the eastern United States for timber and for wild- f Each year insects heavily attack northern red oak acorns destroy a large percentage of them, greatly reducing the ber of acorns available to produce seedlings and feed life.

hods

rns from several locations throughout the eastern U.S. Canada were collected and placed in chambers until e emerged. The emergent larvae were sorted by genus, ited, and placed in rearing containers to obtain adults their parasites. After most larvae had emerged, a sample corns from each collection was examined. The nuts were ked open to determine their condition and the type of age they had sustained. Larvae found in the acorns were bined with the emerged larvae to determine the degree of station. The amount of insect damage, the insect species onsible, and their relative importance were tabulated for ous sites within the range of *Q. rubra.*

distribution and relative abundance of individual species *onotrachelus*, *Curculio*, Lepidoptera, and their parasites computed on the number of emergent adults.

ults and Discussion

vils of the genus *Curculio* cause the most insect damage ature acorns. Five species were found infesting northern oak acorns. The majority of those reared from 1961 to 4 and in 1979 were *Curculio proboscideus F.* (54.35 per-), followed by *C. sulcatulus* (Casey) (31.77 percent). *ulio orthorhynchus* (Chttn.) were found infesting 4.07 ent. *Curculio nasicus* (Say) infestations (which averaged percent) varied considerably; in the northern part of range of *Q. rubra*, northern Ohio, Massachusetts, Penn- ania, New Brunswick, Quebec, and Ontario, some collec- s produced only *C. nasicus;* in southern parts of the range e collections produced few or no *C. nasicus. C. longidens* tn. infested northern red oak only in the southern half of ange, and then only rarely (0.05 percent). These per- ages are based on 1,600 adult *Curculio* reared from ns collected throughout the range of northern red oak.

ee species of *Conotrachelus* weevils have been reared n northern red oak: *C. naso* LeConte and *C. posticatus* eman were reared from the northern half of the range *C. posticatus* and *C. carinifer* Casey from the southern of the range. Usually less than 3 percent of the acorns e infested by *Conotrachelus.*

reason for the low infestation rate is that *Conotrachelus* not infest a sound nut. Therefore only previously infested hysically damaged nuts are available for oviposition.

Lepidoptera infesting northern red oak acorns were *issopus latiferreanus* (Walsingham) and *Valentinia glandulella* (Riley). The latter is a secondary invader. These two species infested from 0 to 36.1 percent of acorns sampled from 1961 to 1964. In collections in Missouri from 1973 to 1976, Steven Myers (1978) found from 0 to 63 percent of mature northern red oak acorns and from 0 to 30 percent of immature acorns infested by lepidopterous larvae. Combining these data to make them comparable to my data (my data included immature acorns) yields an infestation rate ranging from 0 to 34.5 percent which closely agrees with the 0 to 36.1 percent rate I found.

Three types of galls were found in or on northern red oak acorns: 1) a large gall on the acorn cup produced by *Amphibolips prunus* Walsh., 2) a pip gall in the side of the acorn shell produced by the agamic fall form of *Callirhytis operator* (O.S.), and 3) a mass of stony gall cells that fills the entire interior of the nut, produced by *Callirhytis fructuosa* Weld. The last two usually kill the acorn: the pip gall causes the nut to fall prematurely and the stone gall replaces the seed.

Samples showed that the infestation rate for *Callirhytis* sp. galls varied from 0 to 31 percent in the United States collections and 0 to 37 percent in Canadian collections made during 1961 to 1964. Myers found the infestation rate to be 0 to 31 percent in Missouri (0 to 48 percent in immature acorns and 0 to 24 percent in mature acorns).

Table 1 shows the percentage of acorns in each sample that were infested by any species of insect. The degree of infestation varies from year to year and from tree to tree in the same area as well as throughout the northern red oak range. Thus the data presented in Table 1 indicate only the infestation of the acorns on each sampled tree. However, the data do suggest the density and diversity of the insect infestation.

Secondary invading insects similar to those found in bur oak (Gibson 1971) and white oak (Gibson 1972) were found in northern red oak acorns. Some of these added to the destruction of acorn viability.

Table 2 shows the infestation rates for *Curculio*, *Conotrachelus*, *Melissopus*, and *Callirhytis* spp. The rates for the first three are for individual insects per 100 acorns but the rate for *Callirhytis* is the percentage of galled acorns that may contain 1 to 2 dozen gall wasp larvae. The number of insects per 100 acorns sometimes exceeds the percentage of acorns infested. For example, in the Delaware Co. Ohio sample for 1979 the rates were 295.2 percent for *Curculio*, 0.9 percent for *Conotrachelus*, 15.2 percent for *Melissopus*, and 3.8 percent for *Callirhytis* galls, for a total of 315.1 per 100. The infestation rate was 90.4 percent. This shows that several insects infested the same acorn. Usually acorns infested with *Callirhytis fructuosa* do not contain any of the other infesting insects. However, acorns infested by *Callirhytis operator* (fall form) may also contain *Melissopus latiferreanus* larvae. The acorns infested by *Curculio* usually contain only one species of *Curculio* but normally contain two to five *Curculio* larvae, and may contain one or more *Conotrachelus* larvae or a moth larva, or both.

Table 1. — Conditions of northern red oak acorns (in percent)

Locality	Sound	Insect infested	Rotten	Malformed
1961				
Auglaize Co., OH	76.4	21.8	1.8	0
Erie Co., OH	35.9	58.4	4.4	1.3
Madison Co., OH	3.2	79.3	11.2	6.3
Ottawa Co., OH	39.1	48.7	11.9	0.3
Union Co., OH	1.5	67.1	0	31.4
Average	31.22	55.06	5.86	7.86
1962				
Auglaize Co., OH	14.7	52.8	27.0	5.5
Champaign Co., OH	1.0	82.5	11.3	5.2
Champaign Co., OH	1.1	91.2	7.7	0
Clinton Co., OH	0	73.3	10.0	16.7
Madison Co., OH	5.5	55.6	37.3	1.6
Madison Co., OH	10.4	72.9	11.5	5.2
Ottawa Co., OH	76.6	22.5	0.9	0
Putnam Co., OH	58.1	24.7	17.2	0
Ross Co., OH	28.1	56.9	11.1	3.9
Shelby Co., OH	0	86.9	11.9	1.2
Trumbull Co., OH	67.0	12.5	19.6	0.9
Trumbull Co., OH	0.9	6.3	88.9	3.9
La Crosse Co., WI	19.2	56.5	10.6	13.7
New Haven Co., CT	79.8	14.0	6.2	0
Average	25.89	50.61	19.37	4.13
1963				
Auglaize Co., OH	5.0	65.0	25.0	5.0
Marion Co., OH	0	77.0	22.0	1.0
Marion Co., OH	10.0	73.0	17.0	0
Ottawa Co., OH	53.0	8.0	39.0	0
York Co., N.B.	17.0	55.0	24.0	4.0
Ste. Foy, Que.	22.0	49.0	27.0	2.0
Berthier Co., Que.	92.0	4.0	0	4.0
Sault Ste. Marie, Ont.	14.0	41.0	37.0	8.0
Kings Co., N.B.	1.0	8.0	91.0	0
Penobscot Co., ME	63.0	0	37.0	0
Berkshire Co., MA	9.0	61.0	30.0	0
Belknap Co., NH	25.0	22.0	52.0	1.0
Chittenden Co., VT	5.0	63.0	—	—
Chittenden Co., VT	0	81.0	17.0	2.0
Schenectady Co., NY	0	63.0	27.0	10.0
Middlesex Co., NJ	69.0	26.0	1.0	4.0
New Castle Co., DE	28.0	40.0	32.0	0
Washington, D.C.	4.0	27.0	—	—
Monongalia Co., WV	3.0	75.0	18.0	4.0
McKean Co., PA	26.0	26.0	48.0	0
Rowan Co., KY	5.0	84.0	11.0	0
Franklin Co., TN	9.0	20.0	70.0	1.0
Macon Co., GA	53.0	19.0	26.0	2.0
Harris Co., GA	17.0	40.0	41.0	2.0
Owen Co., IN	2.0	79.0	17.0	2.0
Du Page Co., IL	42.0	48.0	10.0	0
Hardin Co., IL	1.0	77.0	20.0	2.0
Iowa Co., IA	1.0	60.0	38.0	1.0
Oceana Co., MI	50.0	30.0	20.0	0
Dane Co., WI	50.0	9.0	41.0	0

Locality	Sound	Insect infested	Rotten	Malformed
Marathon Co., WI	6.0	66.0	27.0	1.0
Trempealeau Co., WI	20.0	55.0	25.0	0
Larimer Co., CO	74.0	0	24.0	2.0
Average	23.52	43.97	29.48[a]	1.87[a]
1964				
Auglaize Co., OH	8.0	86.0	6.0	0
Champaign Co., OH	0	84.0	16.0	0
Crawford Co., OH	4.0	84.0	12.0	0
Harrison Co., OH	0	97.0	3.0	0
Marion Co., OH	28.0	64.0	8.0	0
Trumbull Co., OH	0	100.0	0	0
Average	6.67	85.83	7.5	0
1979			(combined)	
Delaware Co., OH	6.0	90.4	3.6	
Delaware Co., OH	0	80.0	20.0	
Delaware Co., OH	15.0	82.0	3.0	
Marion Co., OH	45.9	51.4	2.7	
Morrow Co., OH	9.0	87.0	4.0	
Morrow Co., OH	33.0	62.0	5.0	
Morrow Co., OH	10.2	80.6	9.2	
Centre Co., PA	87.0	7.0	6.0	
Centre Co., PA	95.2	3.9	0.9	
Huntingdon Co., PA	4.7	84.1	11.2	
Mifflin Co., PA	8.4	90.7	0.9	
Stone Creek Road, PA	1.8	81.0	17.2	
Licking Creek Dr., PA	0.9	91.3	7.8	
Dryden, NY	17.1	68.6	14.3	
McClure, NY	28.2	58.1	13.7	
Watkins Glen, NY	87.2	11.7	1.1	
Watkins Glen, NY	93.3	6.5	0.2	
Watkins Glen, NY	96.2	3.8	0	
Buffalo, NY	0	97.4	2.6	
Average	33.64	59.87	6.49	
1980				
Mt. Gilead, OH	58.0	37.0	5.0	
Dryden, NY	23.0	59.0	18.0	
Dryden, NY	58.0	42.0	0	
McClure, NY	8.0	56.0	36.0	
Hammond Hill, NY	44.0	40.0	16.0	
Watkins Glen, NY	78.0	21.0	1.0	
Average	44.83	42.50	12.67	
Average of all years	27.02	52.32	20.66	

[a] 1.16 percent error due to lack of data for Rotten and Malformed columns for collections from Chittenden Co., VT and Washington, D.C.

Table 2. — Insect infestation rates/100 acorns by location

Locality	*Curculio* weevils	*Conotrachelus* weevils	*Valentinia* and *Melissopus* moths	*Callirhytis* galls
1961				
Auglaize Co., OH	10.3	0	0	0
Auglaize Co., OH	21.8	0	0	0
Erie Co., OH	67.4	0	9.2	1.2
Madison Co., OH	104.1	0	21.4	0.5
Ottawa Co., OH	74.2	0.1	19.4	0.1
Union Co., OH	77.4	0	11.6	0
1962				
Auglaize Co., OH	68.1	0	2.5	1.8
Champaign Co., OH	149.5	0	3.1	0
Champaign Co., OH	112.1	0	7.7	2.2
Clinton Co., OH	83.3	0	13.9	0
Madison Co., OH	97.6	0	5.6	0
Morrow Co., OH	16.5	0.2	3.4	0
Ottawa Co., OH	22.5	—	—	—
Putnam Co., OH	34.4	0	2.7	0.3
Ross Co., OH	84.9	0	1.9	0
Shelby Co., OH	84.5	0	29.2	0
Trumbull Co., OH	6.3	0	0.6	0
Trumbull Co., OH	12.5	—	—	—
La Crosse Co., WI	56.5	0	2.8	0
New Haven Co., CT	14.0	0	0	0
Greene, Co., OH	90.6	0	19.6	1.0
Franklin Co., OH	16.2	0	0	0
Marathon Co., WI	11.4	0.2	0.8	0
Lawrence Co., PA	15.4	0	0.7	0
Clinton Co., MI	44.9	0.2	3.9	0
Franklin Co., TN	31.3	0.3	0	0
Buncombe Co., NC	27.1	0	0	0
Rabun Co., GA	10.1	0.9	0	0
Rabun Co., GA	18.0	2.9	.03	0
Fort Collins, CO	0	0	0	0
1963				
Auglaize Co., OH	60.0	1.2	10.0	0
Marion Co., OH	101.0	0	15.3	0
Marion Co., OH	93.0	0	8.0	0
Ottawa Co., OH	30.5	3.0	1.5	0
York Co., NB	58.0	0	14.0	14.0
Ste. Foy, Que.	44.0	0	11.0	10.0
Berthier Co., Que.	1.5	0	0	37.0
Sault Ste. Marie, Ont.	42.0	0	11.0	0
Penobscot Co., ME	6.5	0	0	0
Belknap Co., NH	26.4	0	1.3	7.0
Berkshire Co., MA	60.0	0	24.8	1.0
Schenectady Co., NY	60.0	0	14.8	6.0
Chittenden Co., VT	54.0	0	6.0	5.0
Chittenden Co., VT	38.0	0	22.0	31.0
Middlesex Co., NJ	74.8	0	0.8	7.0
New Castle Co., DE	49.6	0.4	7.0	0
Washington, D.C.	48.6	0.7	1.6	0
Monongalia Co., WV	96.0	0	21.5	0
Tucker Co., WV	0	0	0	0
Owen Co., IN	96.0	0	18.0	1.0

Locality	*Curculio* weevils	*Conotrachelus* weevils	*Valentinia* and *Melissopus* moths	*Callirhytis* galls
McKean Co., PA	29.0	0	1.9	0
Rowan Co., KY	170.0	0	14.0	0
Franklin Co., TN	50.0	0	.04	0
Macon Co., GA	17.5	0	0.7	0
Harris Co., GA	36.0	1.0	12.0	7.0
Du Page Co., IL	35.2	0	3.0	0
Hardin Co., IL	74.0	0	26.0	0
Iowa Co., IA	56.0	0	8.5	0
Oceana Co., MI	44.0	0	0	0
Dane Co., WI	6.9	0	0.2	1.0
Trempealeau Co., WI	71.0	0.4	3.0	0
Marathon Co., WI	54.0	0	21.8	0
Dent Co., MO	34.0	2.4	41.0	0
1964				
Auglaize Co., OH	132.0	0	3.2	0
Champaign Co., OH	66.1	0	16.4	1.0
Crawford Co., OH	66.1	0	16.8	0
Harrison Co., OH	110.3	0	14.5	0
Marion Co., OH	100.0	7.0	4.7	0
Trumbull Co., OH	83.3	0	36.1	16.0
1979				
Delaware Co., OH	295.2	0.9	15.2	3.8
Delaware Co., OH	82.2	0	60.0	20.0
Delaware Co., OH	238.0	18.0	9.0	0
Marion Co., OH	204.3	0	0.8	0
Morrow Co., OH	226.7	1.8	8.7	1.0
Morrow Co., OH	212.3	0	4.5	3.0
Morrow Co., OH	179.5	0	3.1	1.0
Centre Co., PA	8.1	0	0	4.0
Centre Co., PA	5.7	0	1.0	2.0
Huntingdon Co., PA	258.8	0	0.9	0
Mifflin Co., PA	294.4	0	8.4	0
Stone Creek Rd., PA	204.5	2.7	9.1	10.0
Licking Creek Dr., PA	170.2	0	2.9	0
Dryden, NY	58.1	0	27.6	8.6
McClure, NY[a]	109.9	0	0	4.0
Watkins Glen, NY	28.1	0	0.4	0
Watkins Glen, NY	11.4	0	0.4	0
Watkins Glen, NY	2.8	0	0	0
Buffalo, NY	0	0	0.9	97.4
1980				
Mt. Gilead, OH[b]	30.8	0	5.7	9.0
Dryden, NY	65.4	0.6	7.3	3.0
Dryden, NY[b]	35.4	0	1.1	0
McClure, NY	45.2	0	10.6	6.0
Hammond Hill, NY	46.1	1.3	2.9	0
Watkins Glen, NY	38.0	0	4.0	12.0

[a]36.3% of acorns eaten by rodents.
[b]Some *Curculio* emergence prior to acorn collection.

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Gibson, Lester P. Insects that damage northern red oak acorns. Broomall, PA: Northeast. For. Exp. Stn.; 1982; USDA For. Serv. Res. Pap. NE-492. 6 p.

Insect damage to northern red oak acorns is extensive throughout the range of northern red oak, and greatly reduces the number of acorns available to produce seedlings and feed wildlife. Five species of *Curculio* weevils (*proboscideus* F., *sulcatulus* (Casey), *orthorhynchus* (Chttn.), *nasicus* (Say), and *longidens* (Chttn.), three species of *Conotrachelus* weevils (*posticatus* Boh., *carinifer* Casey, and *naso* LeC.), two species of moths (*Melissopus latiferreanus* (Walsh.) and *Valentinia glandulella* (Riley)), and two species of gall wasps (*Callirhytis operator* (O.S.) (fall form) and *C. fructuosa* Weld.) cause most of the damage.

ODC: 453-145.7 x [-18.09 - 18.27 -19.91 -21.3] (81):176.1

Keywords: *Quercus rubra* L., acorn, weevil, *Curculio*

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- Warren, Pennsylvania.

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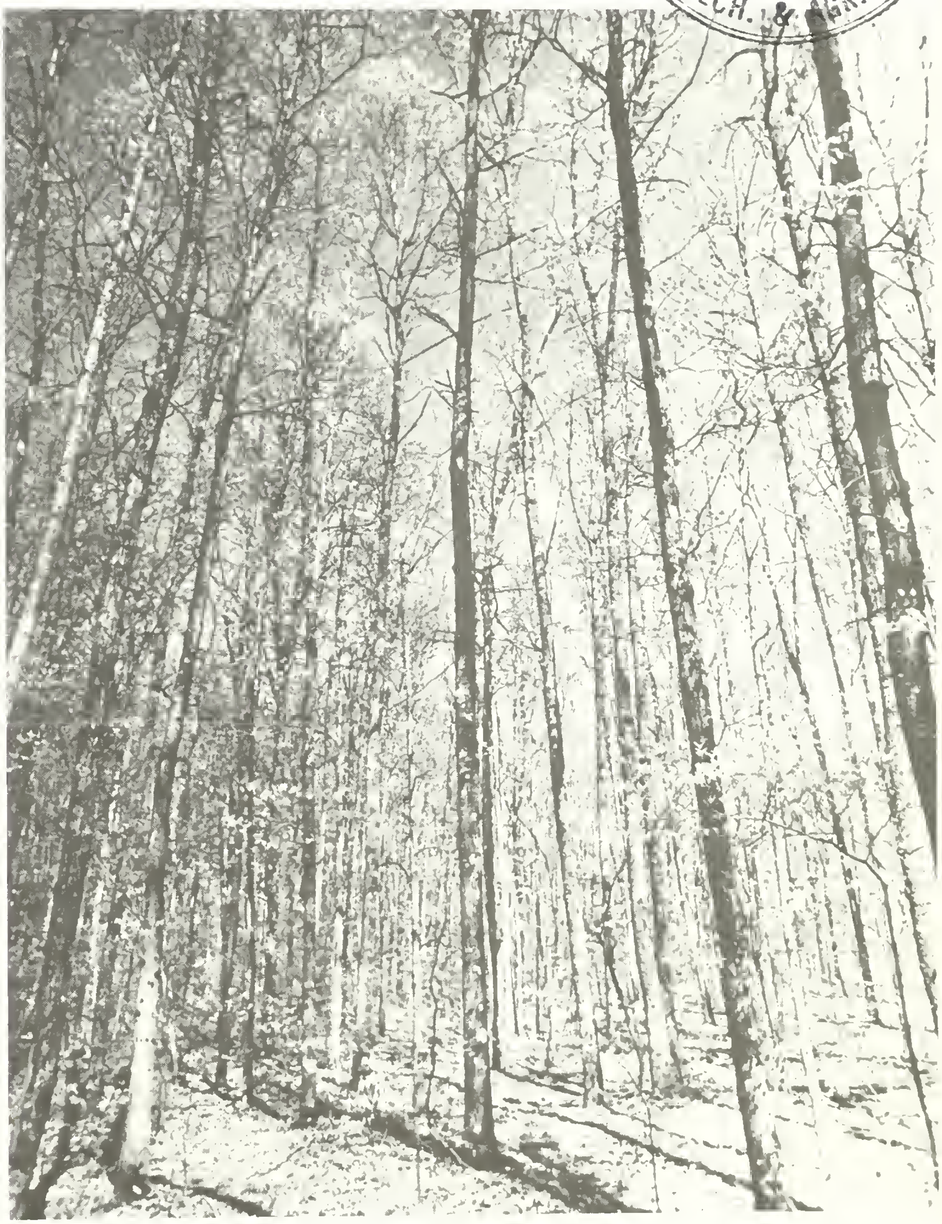
Height Prediction Equations for Even-Aged Upland Oak Stands

by Donald E. Hilt
and Martin E. Dale



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Abstract

Forest growth models that use predicted tree diameters or diameter distributions require a reliable height-prediction model to obtain volume estimates because future height-diameter relationships will not necessarily be the same as the present height-diameter relationship. A total tree height prediction equation for even-aged upland oak stands is presented. Predicted tree heights follow a biologically consistent progression with increasing dbh, age, and site index. The consistent progression of heights does not allow erratic or illogical volume increments. The proposed equation satisfactorily predicted the heights of 4,619 oak trees measured in six states.

Introduction

Diameter-growth models for individual trees, diameter distribution models, and stand table projection methods are all examples of forest growth modeling techniques that use predicted tree diameters or diameter distributions to estimate future stand characteristics. These types of forest growth models are receiving increased attention because they provide detailed information on the structure, and in some instances the species composition, of the future stand. Since the volume of the future stand is also of interest, heights must be assigned to predicted tree diameters or to the diameter classes of a predicted diameter distribution to obtain volume.

Methods for estimating future heights should be thoroughly investigated because future height-diameter relationships will not necessarily be the same as the present height-diameter relationship (Chapman and Meyer 1949). The preferred method of assigning future heights is to model *height growth* as a function of variables such as dbh, age, and site index. However, data necessary for the construction of a height-growth model are not available at the present time for the upland oak timber type. Reliable height growth data for the deliquescent-branching upland oaks can only be obtained through detailed stem analyses of felled trees. An alternate method for estimating future heights is to construct a general model that expresses *total tree height* as a function of variables such as dbh, age, and site index.

This paper presents a method for predicting total tree heights that follow a biologically consistent progression with increasing dbh, age, and site index. The consistent progression of heights does not allow erratic or illogical volume increments. The resulting height prediction equations are applicable to even-aged upland oak stands.

Data

Data for developing and testing the height equations were taken over a range of age and site conditions in unmanaged even-aged upland oak stands in Ohio, Kentucky, Missouri, Iowa, Illinois, and Indiana. A total of 2,306 felled-tree heights on 150 plots (stands) from an oak decay study were used in the analysis. Plot size was 0.08 ha (1/5-acre). These data were augmented with 2,313 standing-tree heights measured with a Spiegel-relaskop[1] on 158 0.2- and 0.4-ha (1/2- and 1-acre) growth and yield plots. Dbh and total height were measured on trees from all crown classes in both studies. Total age was determined by counting annual rings for felled trees, and increment borings for standing trees. Site index, the height attained by the average dominant and codominant oak at total age 50, was determined for each plot from Schnur's (1937) site index curves for upland oaks.

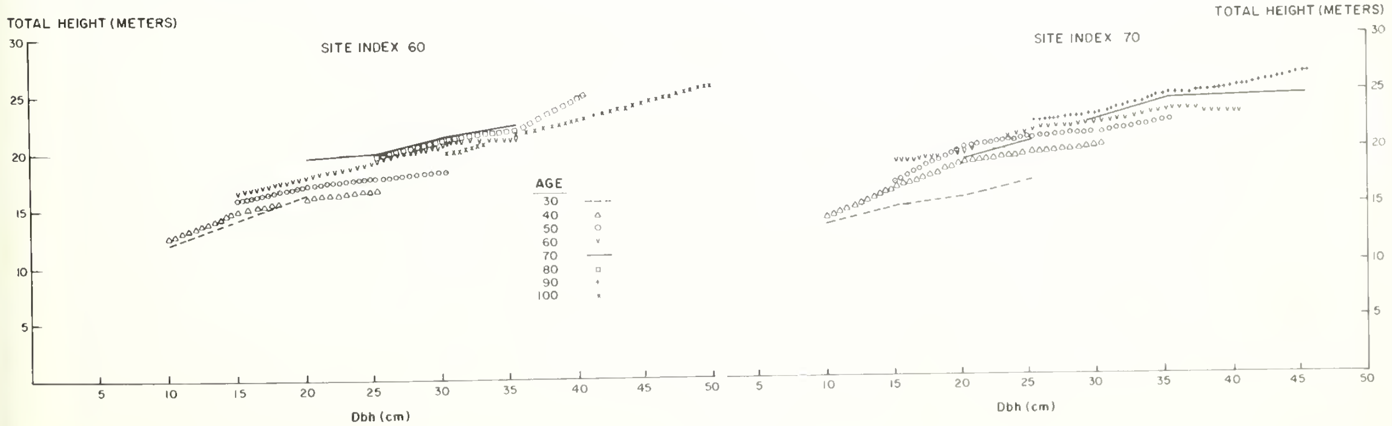
The data were divided for analysis according to species with similar growth patterns. The black oak group of 2,116 heights consisted of black oak (*Quercus velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), and northern red oak (*Q. rubra* L.). The white oak group of 2,503 heights consisted of white oak (*Q. alba* L.) and chestnut oak (*Q. prinus* L.). Site index for both species groups ranged from approximately 50 to 80, age from 25 to 125 years, and dbh from 6.6 to 66 cm (2.6 to 26 inches).

Analysis

Mean black oak heights of various dbh x age x site index categories plotted in Figure 1 show that dbh, age, and site index are important factors related to tree height. Similar relationships were observed on other sites for black oak, and also for the white oak data. Our goal was to build the observed relation-

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 1. Average heights for black oak by dbh, age, and site index.



ships into the height prediction model. The following conditions for a logical and consistent height prediction equation were proposed:

1. Height equals breast height (1.37 m) when dbh equals zero.
2. Height increases at a decreasing rate as dbh increases.
3. Height increases at a decreasing rate for a given dbh as age increases.
4. Height increases for a given dbh and age as site index increases.

Linear regression models for height-diameter-age equations were explored by Curtis (1967). Many of these proposed models, including site index, were fitted to the oak data. While many of the fitted equations produced R^2 values near 0.80, none fulfilled all of the above conditions. Some equations "peaked" within the data, predicting shorter heights for larger diameters. Other equations failed to produce reasonable maximum heights for a given age and site combination.

Meyer (1940) investigated a modified exponential height-diameter model of the form

$H = 1.37 + \alpha [1 - \exp(-\beta D)]$,

where H = total height in meters, D = dbh in centimeters, and exp is the base of the natural logarithms. The intercept of this model is 1.37 m (breast height). Height increases at a decreasing rate as dbh increases, but can not exceed the asymptotic height, $\alpha + 1.37$ meters. The parameter β determines the rate at which the curve approaches the asymptotic height. Meyer found that this model provides an excellent fit to observed data for trees larger than about 5 inches dbh and older than 10 to 20 years. For practical purposes then, this curve is satisfactory for height-diameter equations for a given age and site index. It fulfills conditions 1 and 2 stated previously.

Meyer's equation works well for a specific stand at a given age and site index because α and β are usually estimated with a sample of dbh, and total height data. To obtain a general model that is suitable when sample heights are not available, we needed a method based on stand age and site index for estimating the parameters α and β.

The proposed height prediction model has the form

$$H_{ij} = 1.37 + \alpha_i [1 - \exp(-\beta_i D_{ij})], \quad (1)$$

where H_{ij} = height of the jth tree in the i^{th} stand,
D_{ij} = dbh of the jth tree in the i^{th} stand,
α_i = asymptotic height parameter for the i^{th} stand,
and β_i = slope parameter for the i^{th} stand.

In this form the model is not useful as a height prediction model because it is stand-specific. One way to build a general height prediction equation would be to model the parameters α_i and β_i as functions of stand age and site index. The parameters of such a stochastic coefficients model could be estimated by the two-stage procedure proposed by Ferguson and Leech (1978). However, the two-stage least squares computer program for estimating the coefficients is not readily available. The approach we use in modeling the parameters is based on existing site index curves and stand tables for normal stands.

We first assume that the asymptotic height parameter, α_i, for any stand is related to the maximum tree height, and the maximum tree height is related to average height of the dominant and codominant trees in a stand (height of the site trees). Based on experience and investigation of the data, the maximum height is assumed to be a constant percentage taller than the mean height of the site trees. Since the asymptotic height for a given stand is $\alpha_i + 1.37$ meters, we can express α_i as a function of the mean height of the site trees for the stand, $\overline{H}_{si}$:

$$\alpha_i + 1.37 = k\,\overline{H}_{si},$$

or

$$\alpha_i = k\overline{H}_{si} - 1.37, \quad (2)$$

where k is greater than one.

We next condition the height equation to pass through the point $(\overline{D}_{si}, \overline{H}_{si})$ for a given stand, where $\overline{D}_{si}$ is the mean dbh of the site trees in the i^{th} stand. The condition that has to be met is

$$\overline{H}_{si} = 1.37 + \alpha_i [1 - \exp(-\beta_i \overline{D}_{si})].$$

Solving for β_i gives

$$\beta_i = -\ln[(\alpha_i + 1.37 - \overline{H}_{si})/\alpha_i]\,\overline{D}_{si}^{-1}. \quad (3)$$

Substituting the value of α_i from (2) into (3),

$$\beta_i = -\ln[(k\,\overline{H}_{si} - \overline{H}_{si})/(k\,\overline{H}_{si} - 1.37)]\,\overline{D}_{si}^{-1}. \quad (4)$$

Substituting the right hand sides of equations (2) and (4) into equation (1) gives a conditioned height model which is written as

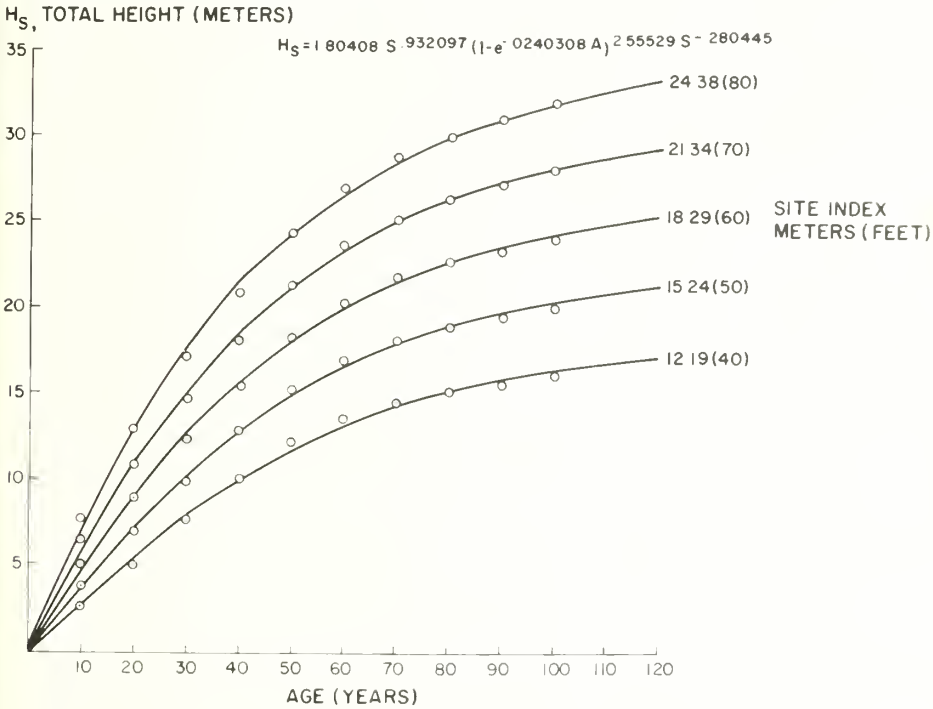
$$H_{ij} = 1.37 + (k\,\overline{H}_{si} - 1.37) \times \{1 - \exp[\ln[(k\,\overline{H}_{si} - \overline{H}_{si})/(k\,\overline{H}_{si} - 1.37)]\,\overline{D}_{si}^{-1} D_{ij}]\}, \quad (5)$$

The conditioned height model is nonlinear with one unknown parameter, k. The model is still stand-specific and not useful as a height prediction equation unless the mean height and dbh of the site trees can be modeled as functions of stand age and site index.

We used values read from Schnur's site index curves to model the relationship between $\overline{H}_s$, stand age and site index. The mean height of the site trees, regardless of oak species, can be read directly from Schnur's curves for any age and site index. We fitted Schnur's curves to a modified Richards' growth function (Ek 1971 and Payandeh 1974). The mean height of the site trees can be estimated as a function of stand age (A) and site index (S) with the following equation:

$$\overline{H}_s = 1.80408\,S^{.932097}\,[1 - \exp(-.0240308\,A)]^{2.55529\,S^{-.280445}} \quad (6)$$

Figure 2. Nonlinear equations for Schnur's site index curves. Circles represent points read from Schnur's curves.



The equation fitted the site curve data very well (Fig. 2). The R^2 was greater than 0.99. Since $\overline{H}_s$ is a function of stand age, equation (6) can be used to project $\overline{H}_s$ to some future age.

If data are collected from a large number of stands, observed values of $\overline{D}_{si}$ could be used to model the relationship between $\overline{D}_s$, stand age, and site index. Although we had a large amount of data, the trees used to determine the site index of a plot could not be identified. To circumvent this problem, we used the mean diameter of the trees in the upper 20 percent of the diameter distribution from Schnur's stand tables as our estimate of $\overline{D}_s$ for a given stand. Our experience in upland oaks has shown that the site index trees are generally in the upper 20 percent of the diameter distribution for the trees in a stand. A field test of this assumption on 32 permanent growth and yield plots revealed that on the average 75 percent of the site trees selected on a given plot were in the upper 20 percent of the diameter distribution for that plot. Values of $\overline{D}_s$ calculated from Schnur's stand tables increase with increasing stand age and site index (Figs. 3a-3b). We used a modified Richards' function to model the relationship between the mean diameter of the site trees, stand age (A), and site index (S). The resulting equation for black oaks,

$$\overline{D_s} = 5.49927\, S^{.744034} [1 - \exp(-.0192593\, A)]^{1.25342}, \quad (7)$$

had an R^2 greater than 0.99.

White oaks are generally smaller in diameter than black oaks for a given age and site index. Therefore, we fitted separate curves for white oaks based on Schnur's stand tables. The resulting equation for white oak,

$$\overline{D_s} = 6.40146\, S^{.631893} [1 - \exp(-.0227614\, A)]^{1.21892}, \quad (8)$$

also had an R^2 greater than 0.99.

We calculated values of $\overline{H}_{si}$ and $\overline{D}_{si}$ for each stand with equations (6), (7), and (8). These values, along with the observed values of H_{ij} and D_{ij} were used to estimate the value of the parameter k in the conditioned height model, equation (5). Our initial estimate of the asymptotic height ($k\,\overline{H}_s$) for trees at a given stand age and site index, based on experience and investigation of the data, was 10 percent greater than the average height of the site trees. That is, K = 1.1. Our final estimate of k was determined with an iterative fitting routine that minimized the percentage differences between estimated and actual heights (estimated height less actual height × 100/ actual height).

Results

Black oaks. A k value of 1.07 resulted in a model that fitted the black oak data well. The average of the percentage differences for the 2116 black oak trees was −0.15 percent with a standard deviation of 9.05 percent, and the calculated R^2 was 0.79. The fitted curves are shown in Figures 4a–4c.

The average percentage differences were then tabulated by age and site index categories to check for bias in certain parts of the curve

Figure 3a. Average diameters of the largest 20 percent of the trees for black oak, by age and site index. Circles represent points calculated from Schnur's stand tables.

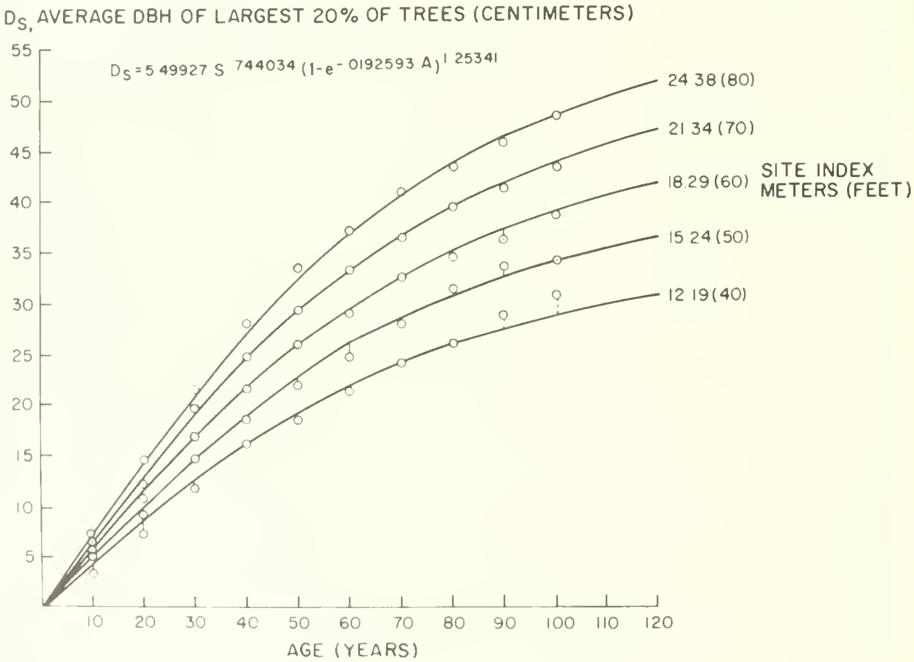


Figure 3b. Average diameters of the largest 20 percent of the trees for white oak, by age and site index.

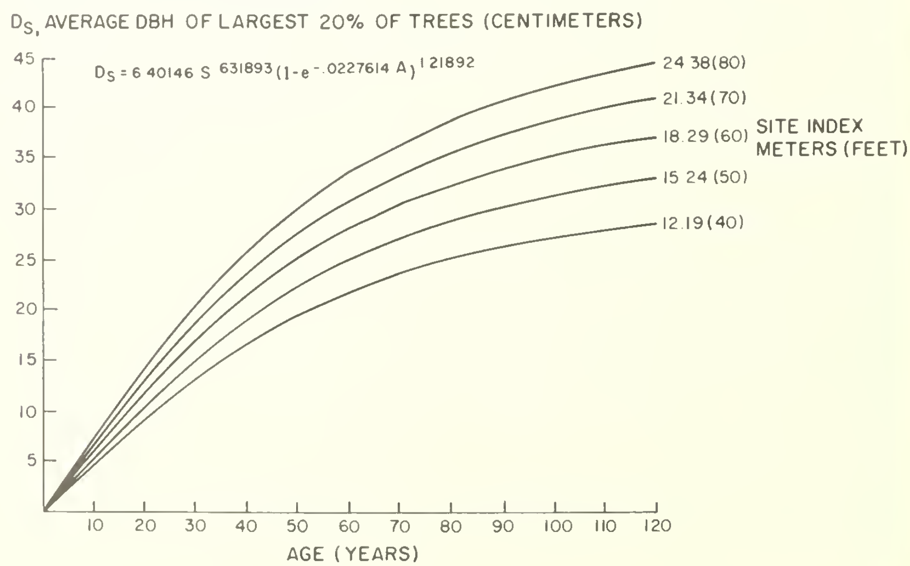


Figure 4a. Height-diameter-age curves for black oak, site index 15.24 m (50 feet). Circles represent the point ($\overline{D}_s$, $\overline{H}_s$) that curve is forced through.

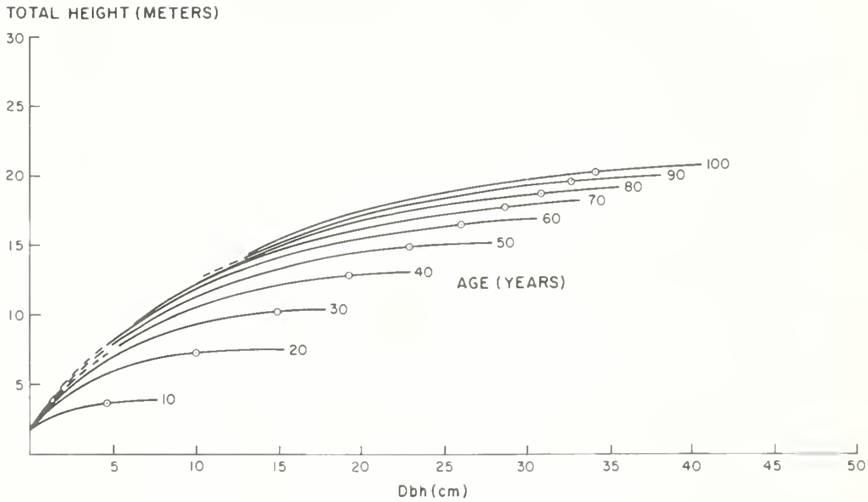


Figure 4b. Black oak site index 18.29 m (60 feet).

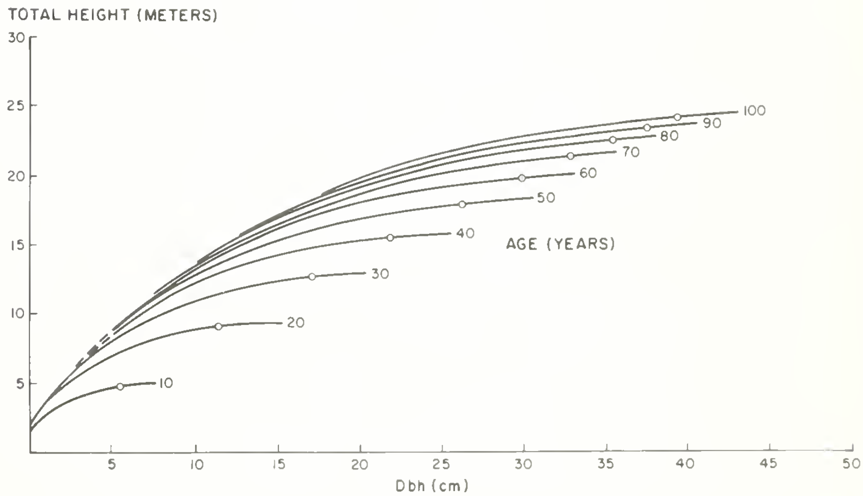
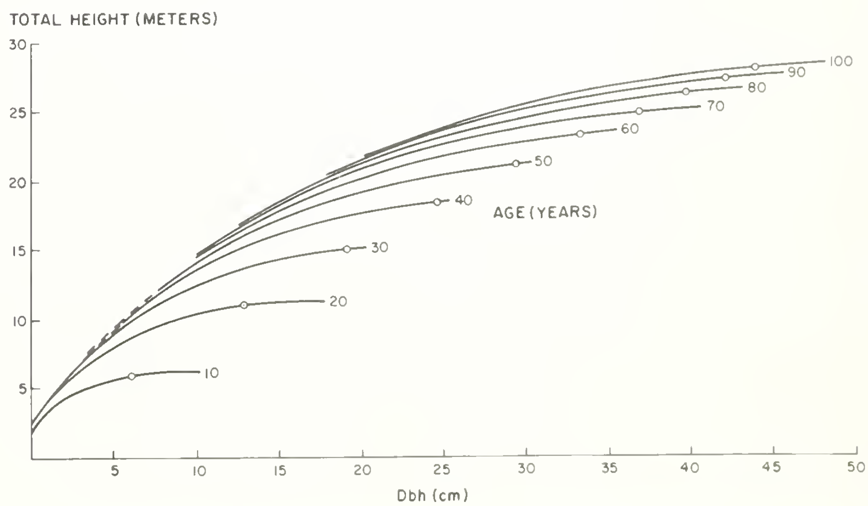


Figure 4c. Black oak site index 21.34 m (70 feet).



(Table 1). Most of the percentage differences, especially for those age × site index categories with a large number of trees in them, were within ± 4 percent. There was a slight trend from negative to positive bias with increasing age and site index.

The percentage differences were also tabulated by age, site index, and dbh as illustrated in Table 2 for site index 70. Except for the slight trend with age, no significant bias was detectable. Differences for other site index categories were similar.

White oak. The value of k for white oak was 1.12. The resulting average percentage difference for the 2503 white oak trees was 0.42 percent with a standard deviation of 10.0 percent, and the calculated R^2 was 0.81. The magnitude and trends of the percentage differences were similar to those for black oak. The fitted curves are shown in Figures 4d–4f.

We feel that the general height model does a good job of predicting individual tree heights. Conditioning the height model to pass through the point ($\overline{D}_s$, $\overline{H}_s$) guarantees logical height predictions for a given stand. All of the conditions stated previously for a logical and consistent height prediction equation were met.

Table 1.—Average percentage differences in height by age × site index categories for black oak.

Age	Site index class: 15.24 m (50 feet)		18.29 m (60 feet)		21.34 m (70 feet)		24.38 m (80 feet)	
	No. of trees	Average % deviation	No. of trees	Average % deviation	No. of trees	Average % deviation	No. of trees	Average % deviation
30	—	—	39	− 10.3	169	3.5	116	8.8
40	—	—	282	− 4.7	284	− 3.2	73	− 1.7
50	6	− 7.3	91	− 1.7	272	− 1.6	79	3.9
60	23	− 4.0	76	− 2.0	121	0.7	72	− .8
70	21	− 3.2	59	− .9	55	5.0	33	3.6
80	13	− 13.9	29	3.0	15	8.6	5	2.4
90	16	− 4.6	10	8.6	30	4.4	—	—
100	25	− 1.4	18	9.2	11	9.9	20	14.0

[1] Percentage difference = [(estimated height-actual height)/actual height] × 100. Only those age × site categories with five or more trees are shown.

Table 2.—Average percentage differences of age × dbh categories for black oak, site index 21.34 m (70 feet).[1]

Age	Dbh Class: 10.16 cm (4 inches)	15.24 cm (6 inches)	20.32 cm (8 inches)	25.40 cm (10 inches)	30.48 cm (12 inches)	35.56 cm (14 inches)	40.64 cm (16 inches)	45.72 cm (18 inches)
30	1.9	3.4	4.7					
40	0.0	− 2.8	− 4.4	− 3.2	− 1.7			
50	10.4	2.5	− 5.2	− 3.2	1.1	− 2.3		
60		− 2.9	1.3	− .9	2.3	− .6		
70			11.3	6.5	4.1	1.3	3.1	5.8
80					9.0	6.4		
90					7.8	6.8	3.6	− .3
100						5.6	11.9	

[1] Percentage difference = [(estimated height-actual height)/actual height)] × 100. Only those age × dbh categories with five or more trees are shown.

Figure 4d. Height-diameter-age curves for white oak, site index 15.24 m (50 feet). Circles represent the point ($\overline{D}_s$, $\overline{H}_s$) that curve is forced through.

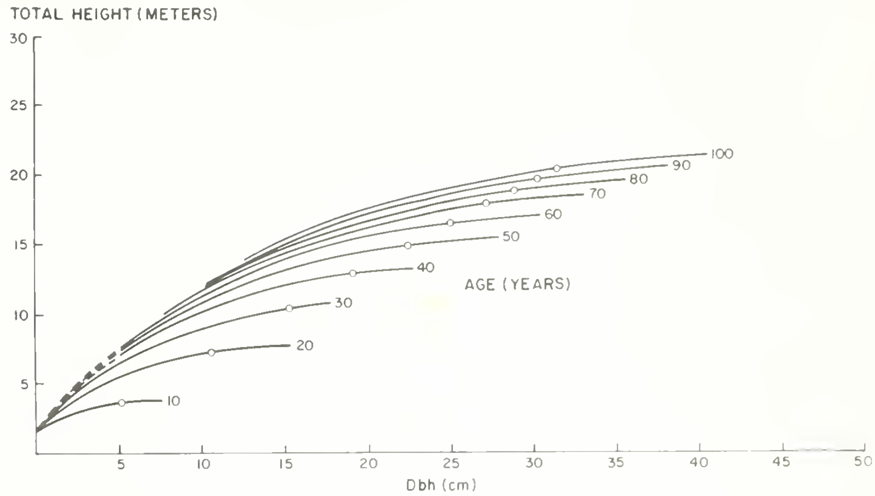


Figure 4e. White oak site index 18.29 m (60 feet).

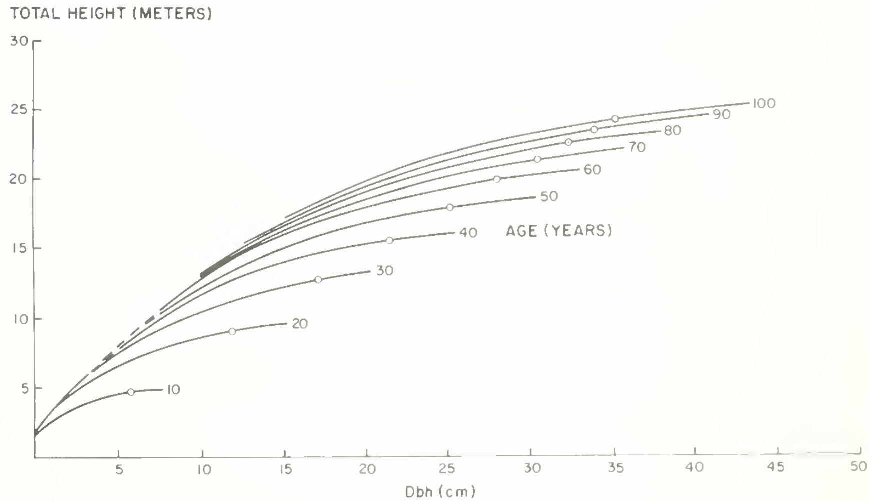
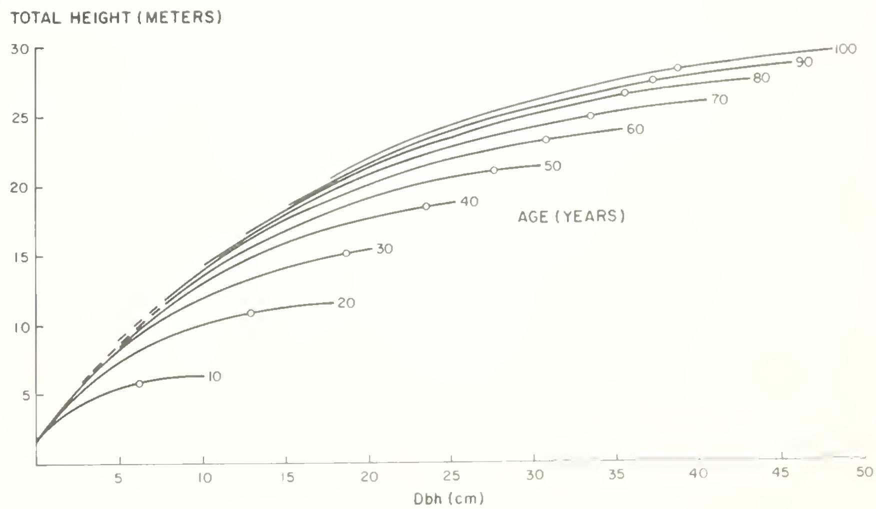


Figure 4f. White oak site index 21.34 m (70 feet).



Thinned Stands

The proposed height equation predicts heights of trees from unmanaged stands very well. However, many growth simulation models are developed from managed stands. Increased diameter growth of residual trees after thinning would necessarily alter the height-diameter relationship at future ages if height growth is not affected. However, the effect of thinning on height growth of residual trees may neutralize any change caused by increased diameter growth, or it may even augment the change. Changes in the height-diameter relationship due to thinning are beyond the scope of this paper. Our intention here is to determine whether the height equations developed in this paper for unmanaged stands perform satisfactorily for thinned stands as well.

Sample tree heights were measured in 1977 on four different thinning studies, 16 years after thinning. The thinning method used is best described as "free"—the marker was free to remove trees from all crown classes. The degree of thinning was controlled by reducing the basal area or the stocking level to the desired percentage. Stocking percent (Gingrich 1967) less than 50 represents a heavily thinned stand, 50–75 percent a medium thinning, and 75+ percent a light thinning. Sample tree heights were predicted by using the height models developed in this paper, and the average percentage differences were tabulated by study and stocking level (Table 3).

The height equations predicted the sample tree heights satisfactorily. Even though some of the study x stocking level categories had a limited number of trees, none of the average percentage differences exceeded 10 percent. Although not conclusive, these results indicate that thinning did not dramatically alter the height-diameter relationship present in unthinned stands. The effects of thinning on the height-diameter relationship may become apparent when thinned stands are observed after a period longer than 16 years.

Discussion

Tree heights estimated by the method presented in this paper follow a logical and consistent progression with increasing tree dbh, age, and site index. The conditions imposed on the height equations prevent erratic and illogical tree-height predictions that sometimes occur with traditional regression techniques. The equations can be inserted with only a few programming statements into many forest-growth computer routines.

The height equations are intended for use with growth models for upland oaks that involve the prediction of tree diameters or diameter distributions to estimate future stand characteristics. We do not advocate using these height equations for existing stands of known age and site index. Height-diameter equations should be constructed for such stands from sample tree heights and diameters.

While we have demonstrated that the height equations perform satisfactorily for thinned stands, changes in the height-diameter relationship due to thinning need to be investigated more thoroughly in future studies.

Table 3. Average percentage differences for stands 16 years after thinning.[1]

Thinning study	Predominant species	Initial avg. age (years)	Avg. site index	Stocking level (percent) <50: No. of trees	<50: Average % deviation	50–75: No. of trees	50–75: Average % deviation	75+: No. of trees	75+: Average % deviation
1	White oak	34	70	56	– 3.4	38	– 9.5	38	– 3.3
2	Black, scarlet oak	34	73	104	6.9	112	3.0	39	6.9
3	Black, scarlet oak	62	64	64	0.9	37	6.4	17	0.8
4	White oak	80	64	172	– 1.8	119	– 6.7	—	—

[1] Percentage difference = [(estimated height-actual height)/actual height)] × 100. Only those age × stocking categories with five or more trees are shown.

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A total tree height prediction equation for even-aged upland oak stands is presented. Predicted tree heights follow a logical and consistent progression with increasing dbh, age, and site index.

ODC 522.2, 522.31, 561.1

Keywords: Height prediction; upland oaks

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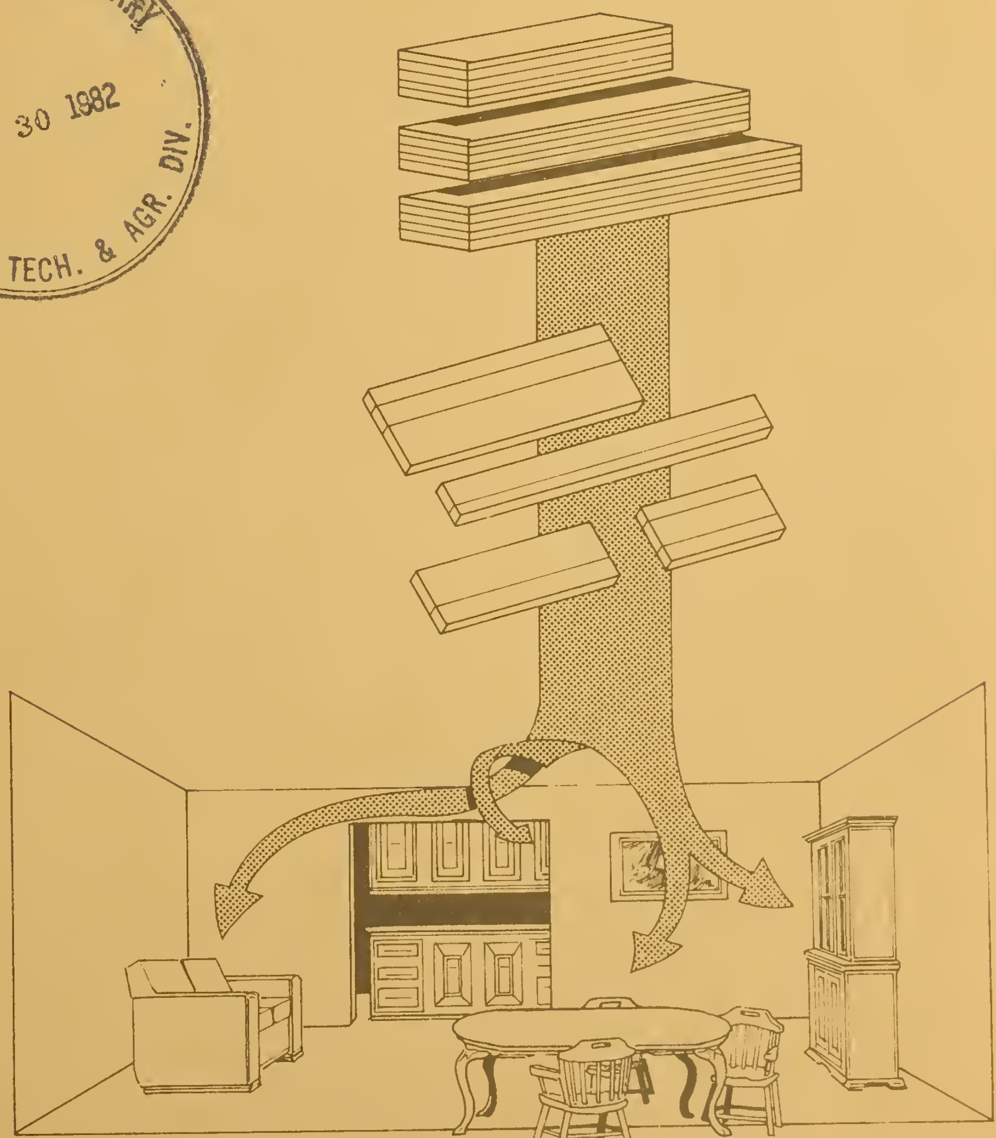
Meeting the Solid Wood Needs of the Furniture and Cabinet Industries: Standard-size Hardwood Blanks

by Phillip A. Araman
Charles J. Gatchell
Hugh W. Reynolds



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Abstract

Standard-size, kiln-dried hardwood blanks (panels) of specified lengths, widths, thicknesses, and qualities can be used instead of lumber to produce rough dimension furniture parts. Standard sizes were determined by analyzing thousands of part requirements from 20 furniture and 12 kitchen cabinet companies. The International Woodworking Machinery and Furniture Supply Fair-USA collected the data and supported the analysis. Recommended blank sizes and examples of rough dimension parts for furniture and cabinets made from blanks are included.

Manuscript received for publication 24 April 1981

Introduction

The actual needs for parts by the furniture and kitchen cabinet industries have never been completely known. The multiplicity of products within and among firms has made strict definition impossible. Each firm believes it is unique, but different pieces of similar furniture have about the same sizes and shapes. Knowing the qualities and quantities, sizes and shapes, of the parts used to make these similar pieces would allow more efficient use of wood resources.

To determine the overall needs of the industry, we worked with data compiled from a sample of major furniture and kitchen cabinet companies by the International Woodworking Machinery and Furniture Supply Fair-USA (The Louisville Fair). Twenty furniture makers and 12 kitchen cabinet makers provided data for the analysis. Parts information was collected for (1) solid furniture, (2) veneered furniture, (3) upholstered furniture, (4) recliners, and (5) kitchen cabinets.

Thousands of individual part sizes were analyzed and grouped by length, width, thickness, and quality. We used this information to develop a new "standard blank" concept. Kiln-dried blanks of standard sizes can be manufactured from low-grade lumber and small-diameter low-grade logs. These standard blanks can then be processed into the individual parts desired by any manufacturer with only small end-trim losses. There may be other uses for the data, but simple knowledge of what is needed will make processing more efficient all the way back to the tree.

Determining Product Part Requirements

Parts requirements survey

For data collection, we divided our cooperators along major product lines: (1) furniture or case goods (solid and veneered); (2) upholstered furniture and recliners; and (3) kitchen cabinets. Because of the large number of different items in a furniture style grouping (beds, dressers, tables, chairs, etc. made with the same primary species and one basic style) and the large number of different styles made by a single company, data were collected only on those styles that were in greatest demand. The furniture companies provided specific information on rough parts requirements for the most frequently produced pieces of bedroom, dining room, and living room furniture. Along with length and width data, the manufacturers provided information on lumber thickness, parts grade or quality, and number of rough pieces per article. On the average, 37 pieces of furniture were reported on per group (or suite) by 13 companies. Data were collected on 25 groups of furniture.

In similar fashion, five manufacturers of upholstered furniture supplied data on an average of 22 different pieces each. Three manufacturers of recliners provided information on about 20 recliner frames each.

The 12 kitchen cabinet makers were able to provide almost total information on their lines. Information included the rough size and quality for each part as well as the part type (such as parts for doors, drawers, or frames).

Method of analysis

Because the sizes of the different segments of the furniture industry are not precisely known, data were separated by product type: solid wood furniture, veneered furniture, upholstered furniture, recliners, and kitchen cabinets. Within product type classifications, parts were separated according to their quality and dimensions (length, width, and thickness).

The names given grades of parts sometimes differ among different product types. We used the grade definitions developed by the Hardwood Dimension Manufacturer's Association (1961) with one exception: C1F and C2F (clear one face and clear two faces) were combined into a single clear grade. The breakdown between C1F and C2F can be made available upon request.

The sound frame grade of the upholstered furniture and recliner manufacturers is the same as the sound interior grade of the case goods and cabinet makers. For convenience, we have included both terms.

The grades and their definitions are as follows:

Clear—C1F and C2F.

C1F (clear one face)—This material shall be clear on one face, both edges, and both ends, and shall otherwise comply with the clear-two-faces quality, except that the reverse face may contain defects of sound quality.

C2F (clear two faces)—This material shall be clear on both faces, the edges, and the ends, except that sapwood, slight streaks, and small burls or swirls and light stain shall be permitted.

Core—This material shall be sound on both faces admitting tight sound knots, small worm holes, slight surface checks, or their equivalent.

Sound interior—This material may contain any defects that will not materially impair the strength of the individual piece for the use intended.

Sound frame—Same as sound interior.

A major question was how to sort the data into meaningful length and width groups that reflected the actual needs of the industry. Computer analysis showed that there was a greater demand for certain nominal lengths than for others. Grouping by arbitrary equal-length increments would not reflect this demand. Further, a great percentage of the needed parts were less than 36 inches long.

Consequently, we decided to let the needs of the industries dictate the length groupings thus: if from within a length classification, say 33.01 to 38 inches long, we were to manufacture all the needed lengths from stock that was 38 inches long, there would be a certain amount of end-trim loss. The length categories in this report reflect an average end-trim loss of no more than 10 percent. That is, all parts for each thickness and quality classification could be made from stock of the maximum length in each length grouping with no more than an average 10 percent end-trim loss. To this 10 percent rule we added the constraint that length groups had to be at least 2 inches apart. And we hoped each group would contain around 10 percent of the part needs.

Two comments need to be made about the actual length groupings shown in the results section. First, the upper limit of a length group such as 22.01 to 26 inches (Table 2) is generally selected because most of the pieces are near 26 inches in length. Second, within a product type classification, the length groupings vary from one thickness and quality to another. But regardless of product type, all parts of the same thickness and quality have the same length groupings. We did this to facilitate application of this information; it will be discussed more thoroughly in the section dealing with standard-size blanks.

Results by product type

The rough dimension part requirements for solid, veneered, and upholstered furniture, recliners, and kitchen cabinets are listed in Tables 1 through 36. Tables 1 (solid furniture), 8 (veneered furniture), 17 (upholstered furniture), 25 (recliners), and 32 (kitchen cabinets) summarize the tables that follow. Each shows the distribution of total parts requirements by nominal thickness and part quality, expressed as a percentage of the total surface area. For example, about 80 percent of the area of parts in solid wood furniture (Table 1) are in thicknesses of 5/4 or thinner, and at least 80 percent of it is in the clear grades.

The veneered wood furniture summary (Table 8) shows a greater variability in part quality than that for solid wood furniture (Table 1). Core grade makes up almost 30 percent of the total; sound grade another 10 percent. Most of the remaining 60 percent is in the clear grades. Clear grades comprise at least 80 percent of the needs in the solid wood product, and at least 57 percent of the veneer wood furniture requirements. The clear grade percentage for veneer wood furniture should increase as more and more composite panels are used for cores.

For upholstered furniture (Table 17), most (87 percent) of the parts requirements are in the sound frame quality category. This is not surprising, as these frame parts will be covered with fabric and their main purpose is strength. About 80 percent of the total need for upholstered furniture is for 5/4 or thinner parts.

Almost all of the wood used by manufacturers of recliners is used for frames (Table 25). Only 5.6 percent is clear (C1F and C2F). Eighty percent of all the frame parts needed are 5/4 or thinner.

Kitchen cabinet parts requirements (Table 32) are quite different. The nominal thickness is 5/4 or thinner for more than 98 percent of all cabinet parts. Ninety-five percent of all parts are in the clear grades.

Tables of length-width distributions for each product type follow the overview tables. There are tables for each combination of part thickness and quality. The total area of parts for each length-width grouping in a table is given as a percentage of the total surface area needed in that particular part thickness and quality.

It is important to understand how these data can and cannot be used. They provide an accurate picture of the demands for parts within a segment of the industry (solid wood furniture, for example). However, determining the relative sizes of various segments (solid wood furniture versus kitchen cabinets, for example) is beyond the scope of this study. Therefore, requirements cannot be summed across segments.

The information in Tables 1 through 36 can help suppliers decide whether their particular circumstances make supplying more than one product type manufacturer desirable. For example, a supplier whose raw material mix contains a lot of low-grade lumber might well want to supply parts to upholstered furniture and recliner manufacturers as well as to solid or veneered wood makers. In this way, he could use more of his raw material more efficiently than if he were to supply clear parts only. Another manufacturer may decide, because of factors such as equipment and raw material availability, to concentrate on supplying parts that are 5/4 or thinner. In any event, for the first time, the needs of the various wood-using industries are clearly presented.

The Standard Blank Concept

Development of standard-size blanks

Tables 1 through 36 show an enormous number of different parts when length, width, thickness, part quality, and product type are separately considered. From a supply point of view, this number is impractically high. One solution is to reduce the number of different sizes; another solution is to combine the needs of the various product types; and yet another is to describe the most commonly needed parts regardless of product type. We have combined all of these solutions in creating the concept of standard blanks.

"Standard blanks" are defined as pieces of solid wood (which may be of edge-glued construction) of a predetermined size and quality (Fig. 1). From these standard sizes, manufacturers can cut the pieces for their own products (Fig. 2). Standard-size blanks in no way imply standardized furniture.

The success of any plan for standardizing blank sizes depends on the choice of the blank lengths and widths. We based our length specifications on the most-needed parts, allowing an additional 1/2 inch or so for trim.

While all intermediate lengths between two specified lengths must be resawed from the longest length, waste is controlled by the use of the 10 percent rule. Simply put, the specified or target blank lengths were acceptable if the production of all needed parts for a given combination of part thickness and part quality could be achieved with no more than an average 10 percent end-trim loss. As a result, length classes sometimes differ for parts of the same quality but different thicknesses.

Eleven width groupings were used in the analysis of parts of Tables 1 through 36. Because the most frequently needed parts were narrower than 4 inches, a 1/2 inch width increment was used for parts between 1-1/2 inch and 4 inches

Standard Blanks

Rough dimension material with specific:

Lengths
Widths
Thicknesses
Qualities

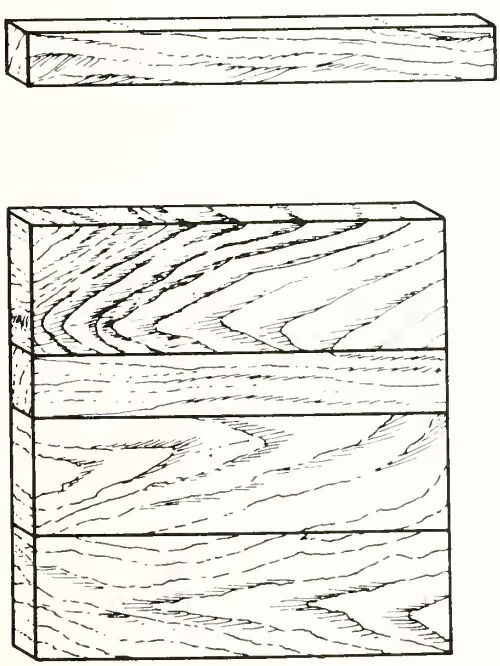

Figure 1.—Standard blanks—rough kiln-dried dimension material with specific length, width, thickness, and quality.

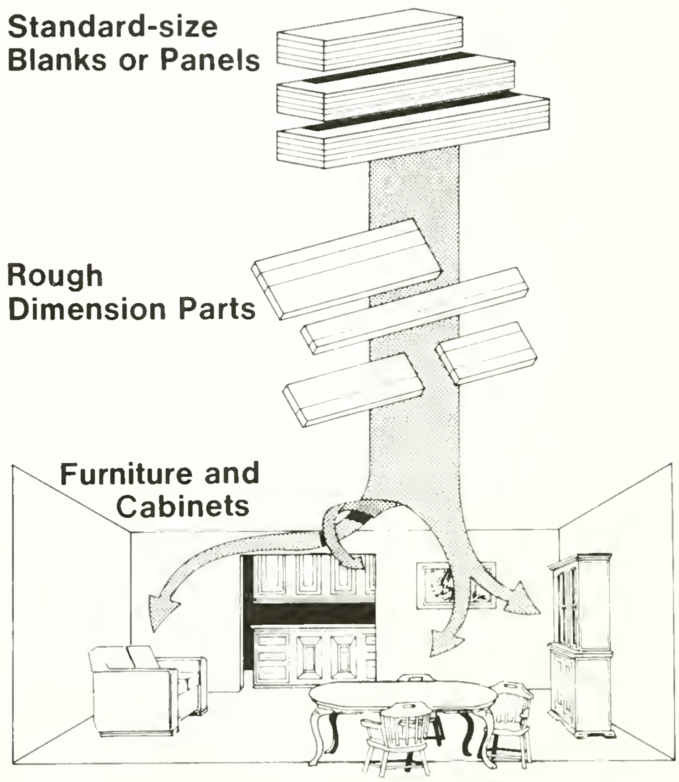

Figure 2.—The standard blank concept—standard-size blanks are processed to rough dimension parts that are used to make furniture and cabinets.

wide; from 4 to 6 inches, a 1-inch increment was used. Width increments of 6 inches or more were used above that.

We chose one width of blank for each quality for all product types. The width was equal to the largest part width needed.[1] All other widths can be produced by ripping the wide blank to narrower pieces. Odd pieces left over can be reglued and ripped again. Our recommended blank widths are:

Clear quality	26 inches wide
Core quality	26 inches wide
Sound frame quality (upholstered)	20 inches wide
Sound interior quality (case goods)	20 inches wide

Although other widths can be used, the widths given will provide all needed parts and have significant production and inventory advantages.

The recommended standard sizes for furniture and cabinet manufacturers are given in Table 37. Nominal part thicknesses are usually 1/4 inch or more thicker than the intended thickness of the finished product. Our experience in manufacturing standard blanks for subsequent processing by major furniture makers shows that actual blank thickness needs to be only 1/8 inch over finished part requirement. All three thicknesses are listed in Table 37.

Examples of Standard-Size Blank Use

The overall value of standard blanks to manufacturers will depend mainly on how efficiently the needed parts can be ripped from these panels. We have included an illustration for each of four major product types: kitchen cabinets (Table 38), solid furniture (Table 39), veneered furniture (Table 40), and upholstered furniture (Table 41).

In each example:

- The product chosen was considered representative of that product type.
- The rough part needs were grouped by species, thickness, and quality.
- The proper standard-size blanks were selected from Table 37. In some cases, to improve the yield, parts were made in double lengths.
- The number of blanks needed per standard length was determined by calculating the best ripping combinations to satisfy part requirements and minimize edge trim. A 1/8-inch ripping kerf was used in the calculations.
- Strips left over after ripping, 1 inch in width or wider, were reglued.
- The yield from the blanks (percentage used), the amount of reusable strips (percentage regluable), and the amount of waste were calculated. Waste included strips less than 1 inch wide, saw kerfs, and end trimmings.

Blanks to provide front frame, door insert, door frame, and drawer front parts for 50 sets of typical kitchen cabinets are given in Table 38. Choice of blank sizes were straightforward except for the 12-3/8- and 9-7/8-inch-long parts, which were cut double length to increase the material utilization. The overall yield of parts from the blanks was 90 percent. Leftover material that could be reglued and reused was 3 percent.

The blanks to produce the parts for 100 solid dining room servers are shown in Table 39. Clear quality 4/4 and 5/4 red oak, sound interior 4/4 yellow-poplar, and core quality 4/4 yellow-poplar blanks were needed. Yield of parts from the blanks was 82 percent, with 12 percent left over in 1 inch or wider material for regluing and reuse. Six percent was lost.

Blanks to satisfy part requirements for 100 veneered tables and 400 chairs are listed in Table 40. Clear quality 6/4 and 8/4 oak blanks and 4/4 core quality yellow-poplar blanks are needed. Yield of parts from the blanks was 87 percent; 4 percent was leftover material suitable for regluing and reuse.

Standard-size blank requirements to produce 50 sets of frame parts for an upholstered love seat are shown in Table 41. Sound frame-grade 4/4 mixed hardwood blanks were needed for the parts. Two 8-inch-long parts were double cut from 17-inch-long blanks to increase material utilization. Overall, 86 percent of the blank material was used with 6 percent left over for regluing and reuse. Eight percent was wasted.

The overall yield in parts for the four examples ranged from 82 to 90 percent. Yield in regluable pieces to make additional blanks for subsequent use ranged from 3 to 12 percent. Although percent waste for each blank size ranged from 3 to 14 percent, the total waste for each product was under 10 percent. Most of the waste occurred as end trim and saw kerf.

Eight manufacturers have used standard-size blanks successfully in trial runs. The blanks were made from small diameter, low-grade red oak, white oak, and black cherry bolts harvested on National Forests. A report on these trial runs is being prepared. Other tests are in the planning stages.

Literature Cited

Hardwood Dimension Manufacturers Association. Rules for measurement and inspection of hardwood dimension parts, hardwood interior trim and moldings, hardwood stair treads and risers. 5th ed. Nashville: Hardwood Dimension Manufacturers Association; 1961:6–8.

[1] A few solid wood dining room tables were found to require parts wider than 26 inches, but these were produced in such limited quantities that the parts data for these tables were removed from the analysis.

Table 1.—Overview of rough part requirements for solid wood furniture

Nominal thickness (inches)	Part quality	Percent of requirement[a]
5/8	Clear (C1F and C2F)	5.5
4/4	Clear (C1F and C2F)	44.5
4/4	Sound interior	14.9
5/4	Clear (C1F and C2F)	16.0
6/4	Clear (C1F and C2F)	6.7
8/4	Clear (C1F and C2F)	6.7
All other combinations		5.7
		100.0

[a] Percentage of total surface area of required rough parts.

Table 2.—Length/width distribution[a] (in percent) of 5/8 nominal thickness, clear (C1F and C2F) quality rough parts for solid wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-13	--	--	0.4	--	0.2	0.9	0.8	0.2	1.7	--	--	4.2
13.01-15	--	0.1	--	--	--	--	.6	--	1.8	--	--	2.6
15.01-17	--	--	.1	--	.1	4.9	2.5	7.5	20.5	--	--	35.6
17.01-18	--	--	--	--	--	4.2	--	7.9	9.6	--	--	21.6
18.01-22	--	--	--	--	--	1.2	.4	.5	4.5	--	--	6.6
22.01-26	--	--	--	--	--	.6	1.3	1.9	7.9	--	--	11.8
26.01-31	.4	--	--	--	--	--	--	7.1	8.5	--	--	16.0
31.01-36	--	--	--	--	--	--	--	--	1.3	--	--	1.3
36.01-42	--	--	--	--	--	.3	--	--	--	--	--	.3
Percent of total	0.4	0.1	0.5	--	0.4	12.2	5.6	24.9	55.9	--	--	100.0

[a] Percentage of total surface area of required rough parts.

Table 3.—Length/width distribution[a] (in percent) of 4/4 nominal thickness, clear (C1F and C2F) quality rough parts for solid wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	0.2	0.7	0.7	0.3	0.2	0.2	0.3	0.3	1.1	1.8	0.5	6.3
15.01-18	.3	1.1	1.0	.4	.4	.2	.5	.1	1.6	3.1	1.1	9.7
18.01-21	.4	.5	.5	.4	.2	.1	.3	.3	2.1	3.5	1.6	9.8
21.01-25	.2	.4	.9	.4	.3	.1	.2	.2	1.7	4.4	1.1	9.8
25.01-29	.3	.3	.2	.3	--	.1	.1	.1	1.6	5.6	1.2	9.7
29.01-33	.1	.6	.2	.2	.1	.3	.3	.2	2.7	5.0	.8	10.4
33.01-38	.1	.4	.2	.2	.2	.2	.3	.3	2.5	4.5	1.0	9.9
38.01-45	.1	.4	.2	.4	.1	.1	.1	--	1.4	7.8	2.7	13.4
45.01-50	.1	.1	.2	--	--	.1	.1	.1	.5	1.4	.2	2.7
50.01-60	--	.4	.1	.4	.1	--	--	.1	2.0	2.9	1.2	7.2
60.01-75	.1	.4	.3	.2	.2	.1	.2	.1	.5	3.6	.9	6.5
75.01-100	.1	.1	.1	--	.1	.2	--	.1	1.8	--	2.1	4.6
Percent of total	2.0	5.4	4.4	3.2	2.0	1.6	2.3	1.7	19.4	43.5	14.5	100.0

[a] Percentage of total surface area of required rough parts.

Table 4.—Length/width distribution[a] (in percent) of 4/4 nominal thickness, sound interior quality rough parts for solid wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	3.2	2.6	2.4	1.6	1.3	0.9	0.2	--	0.8	6.9	0.7	20.7
15.01-18	3.4	6.4	5.6	2.7	3.3	--	.5	--	.2	12.7	--	34.9
18.01-21	1.0	1.3	3.7	.2	--	--	.4	--	--	2.2	.8	9.5
21.01-25	.6	3.0	.7	--	.3	--	--	0.1	--	1.5	.2	6.5
25.01-29	.6	.9	.1	--	--	--	--	--	--	1.6	--	3.2
29.01-34	.4	.2	.2	.6	--	--	--	--	.7	2.0	.3	4.5
34.01-40	.3	2.2	1.8	.3	--	--	--	--	.8	1.8	.3	7.5
40.01-50	.8	1.0	.5	--	--	--	--	--	--	--	--	2.3
50.01-60	.2	2.2	1.7	.3	--	--	--	--	--	--	1.4	5.8
60.01-70	--	1.6	2.0	--	--	--	--	--	--	.4	.4	4.4
70.01-95	--	.7	--	--	--	--	--	--	--	--	--	.7
Percent of total	10.6	22.1	18.7	5.7	5.0	1.0	1.1	0.2	2.5	29.0	4.1	100.0

[a] Percentage of total surface area of required rough parts.

Table 5.—Length/width distribution [a] (in percent) of 5/4 nominal thickness, clear (C1F and C2F) quality rough parts for solid wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	0.3	0.1	0.7	0.5	0.7	0.8	0.3	0.1	0.6	1.1	0.4	5.7
15.01–18	.2	.4	.5	1.1	.4	.9	.6	.7	2.2	3.9	.4	11.4
18.01–21	.2	.2	.6	.5	.3	--	.4	.5	.8	2.1	5.1	10.7
21.01–25	.1	.7	.2	.6	2.2	--	.7	.1	.7	1.8	.9	8.0
25.01–29	.1	.4	.6	.2	1.1	.3	--	--	.9	2.3	.1	5.8
29.01–33	--	.9	.1	1.0	.1	.1	.3	--	2.3	3.8	.5	9.2
33.01–38	--	.3	.5	.3	.2	.5	--	.2	.7	5.6	1.2	9.5
38.01–45	.1	.5	1.3	.3	.9	.7	.9	.1	1.7	5.8	2.3	14.4
45.01–50	--	--	1.0	.1	.3	--	1.0	--	.7	1.6	.3	5.0
50.01–60	.1	.5	.1	.5	--	.4	.5	--	.8	1.6	0.4	4.9
60.01–75	--	.1	.2	.8	.3	3.0	.3	.2	1.6	4.6	3.5	14.6
75.01–100	--	--	--	--	--	--	--	--	--	.7	.1	.8
Percent of total	1.1	4.2	5.7	5.8	6.7	6.8	5.1	1.8	12.9	34.9	15.0	100.0

[a] Percentage of total surface area of required rough parts.

Table 6.—Length/width distribution [a] (in percent) of 6/4 nominal thickness, clear (C1F and C2F) quality rough parts for solid wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	1.0	0.8	--	0.7	0.8	0.3	0.5	0.3	0.4	1.4	0.2	6.4
15.01–18	.2	.5	.3	1.0	.6	.2	.1	--	--	4.1	.9	8.0
18.01–21	.9	.7	.3	.7	.5	.2	.7	.4	1.3	2.1	2.6	10.4
21.01–25	.3	.1	--	.8	--	--	.3	--	2.8	5.5	6.1	15.9
25.01–28	.2	.3	.3	.5	.4	--	.6	--	1.6	1.1	.9	5.8
28.01–32	.1	.1	--	.9	--	.3	2.6	--	1.4	.5	--	5.8
32.01–35	--	--	.7	1.0	.6	.2	.4	.1	2.6	1.8	.9	8.3
35.01–40	--	.2	.3	.5	.5	.4	--	2.0	--	.8	--	4.7
40.01–45	--	--	.4	.7	.6	--	--	--	4.2	.7	3.5	10.0
45.01–50	--	.1	--	--	.4	--	--	1.0	--	2.7	3.5	7.8
50.01–60	--	--	.3	1.2	--	--	--	--	--	--	1.6	3.1
60.01–70	.1	.4	--	.3	--	--	--	--	2.3	2.6	5.6	11.3
70.01–85	--	--	--	--	--	--	.4	--	--	--	2.1	2.5
Percent of total	2.9	3.2	2.7	8.3	4.3	1.6	5.5	3.8	16.6	23.3	27.8	100.0

[a] Percentage of total surface area of required rough parts.

Table 7.—Length/width distribution[a] (in percent) of 8/4 nominal thickness, clear (C1F and C2F) quality rough parts for solid wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	4.1	0.4	0.9	0.3	0.2	0.5	--	0.8	2.2	--	9.4
15.01-18	--	5.1	.9	1.2	--	1.1	.5	--	--	3.1	0.6	12.5
18.01-21	--	6.8	.9	.1	--	.7	2.0	.2	.4	6.5	3.0	20.6
21.01-25	--	3.9	1.6	1.6	--	--	.2	--	--	4.2	2.1	13.6
25.01-28	--	2.9	.3	.2	.4	--	--	--	--	2.5	--	6.3
28.01-32	--	1.7	.6	--	.9	.5	1.3	--	--	.2	--	5.2
32.01-35	--	.5	.7	--	--	.3	--	--	--	.6	--	2.0
35.01-40	--	--	.6	2.1	.3	--	--	1.0	--	5.2	--	9.1
40.01-45	--	--	--	--	--	.8	.9	.6	3.6	5.1	1.0	11.9
45.01-50	--	.4	--	--	--	.4	--	--	--	3.3	--	4.2
50.01-60	--	--	1.2	1.3	--	--	--	--	--	1.8	--	4.3
60.01-70	--	--	.3	--	--	.6	--	--	--	--	--	.9
70.01-90	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	--	25.4	7.5	7.4	1.9	4.6	5.5	1.7	4.8	34.6	6.6	100.0

[a] Percentage of total surface area of required rough parts.

Table 8.—Overview of rough part requirements for veneered wood furniture

Nominal thickness (inches)	Part quality	Percent of requirements[a]
5/8	Clear (C1F and C2F)	10.1
4/4	Clear (C1F and C2F)	14.3
4/4	Core	23.8
4/4	Sound interior	10.9
5/4	Clear (C1F and C2F)	14.7
5/4	Core	4.8
6/4	Clear (C1F and C2F)	9.5
8/4	Clear (C1F and C2F)	7.9
All other combinations		4.0
		100.0

[a] Percentage of total surface area of required rough parts.

Table 9.—Length/width distribution [a] (in percent) of 5/8 nominal thickness, clear (C1F and C2F) quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–13	--	--	0.1	0.2	0.2	0.3	1.1	1.3	1.3	--	--	4.4
13.01–15	--	--	--	.1	.5	.2	2.1	3.4	5.8	--	--	12.1
15.01–17	0.2	--	.1	.5	.8	.6	3.2	6.5	29.1	--	--	41.1
17.01–18	--	.5	--	--	--	--	.4	--	.9	--	--	1.8
18.01–22	--	--	.2	.2	1.3	.3	.6	2.0	6.9	--	--	11.5
22.01–26	--	--	--	.3	.3	.2	1.5	1.9	8.5	--	--	12.8
26.01–31	--	--	--	--	.1	.1	.3	1.0	5.8	--	--	7.4
31.01–36	--	--	--	--	--	--	.6	1.1	5.3	--	--	6.9
36.01–42	--	--	--	--	--	--	--	--	1.9	--	--	1.9
Percent of total	0.2	0.5	0.4	1.4	3.1	1.9	9.8	17.2	65.5	--	--	100.0

[a] Percentage of total surface area of required rough parts.

Table 10.—Length/width distribution [a] (in percent) of 4/4 nominal thickness, clear (C1F and C2F) quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	1.5	0.7	0.7	0.9	1.0	0.4	0.5	0.3	0.8	0.2	--	7.1
15.01–18	2.4	.8	1.2	.6	.9	1.1	.4	2.0	2.5	.4	.8	13.1
18.01–21	1.5	.7	1.4	1.3	.5	.6	1.1	.3	.9	.6	.7	9.4
21.01–25	2.1	1.4	2.3	1.9	.7	.3	.7	.3	2.3	1.3	.2	13.5
25.01–29	.7	1.0	1.4	1.0	.6	.1	.3	.1	1.0	.1	--	6.3
29.01–33	.7	.7	.6	.4	.2	.3	1.5	.1	2.2	.6	.3	7.4
33.01–38	.7	2.3	1.6	1.0	.5	.1	.2	.1	1.2	.9	.2	8.7
38.01–45	.8	.8	1.6	.6	.5	.4	--	--	1.1	.2	1.0	6.9
45.01–50	.9	1.1	.6	1.5	.3	.2	.2	--	.4	.1	--	5.2
50.01–60	1.1	2.1	1.1	.5	.6	.4	.5	.2	.5	1.1	--	8.0
60.01–75	.9	1.6	1.8	.7	.1	1.0	1.1	.5	1.1	--	--	8.8
75.01–100	--	1.6	1.3	.6	.3	--	--	--	1.8	--	--	5.5
Percent of total	13.4	14.8	15.5	10.8	6.3	4.8	6.4	3.7	15.6	5.4	3.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 11.—Length/width distribution [a] (in percent) of 4/4 nominal thickness, core quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	0.1	--	0.1	0.2	0.1	--	--	2.4	0.8	0.8	2.4
15.01-18	--	.1	0.1	.1	.2	--	0.3	--	1.3	3.8	2.2	8.0
18.01-21	--	.1	--	--	.1	--	.1	--	.3	6.7	3.9	11.3
21.01-23	--	.1	--	--	.1	--	--	--	4.6	8.3	3.3	7.7
23.01-26	--	.1	--	--	.1	.2	.2	--	1.1	3.6	4.4	9.8
26.01-29	--	.3	--	--	.1	--	.1	--	.5	2.1	3.1	6.2
29.01-34	--	.3	--	--	.1	.1	--	--	1.5	4.1	3.2	9.3
34.01-40	--	.4	--	.1	.1	--	--	--	.6	4.7	2.9	8.9
40.01-50	--	.4	--	--	.3	--	--	--	1.1	4.6	3.1	9.5
50.01-60	--	.1	--	.1	--	--	--	--	.4	3.8	3.6	8.0
60.01-70	--	.3	--	.2	.6	.1	.1	.1	.5	3.3	2.5	7.7
70.01-95	--	.3	--	.2	.8	.1	.1	.1	2.3	3.8	3.3	11.2
Percent of total	--	2.7	0.1	0.8	2.7	0.6	0.9	0.2	10.3	45.2	36.5	100.0

[a] Percentage of total surface area of required rough parts.

Table 12.—Length/width distribution [a] (in percent) of 4/4 nominal thickness, sound interior quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	3.0	7.3	0.8	0.3	0.4	0.1	0.7	0.5	--	--	--	13.2
15.01-18	3.9	9.6	1.5	.2	.3	.2	1.5	.1	--	--	--	17.2
18.01-21	2.7	3.0	.5	.4	.1	.2	.1	.1	--	--	--	7.0
21.01-25	1.9	4.2	1.4	.4	--	.1	.1	--	--	--	0.3	8.4
25.01-29	1.6	3.5	.8	.7	--	.1	.1	--	.1	--	.1	7.0
29.01-34	.7	4.1	.5	1.0	.1	.2	--	--	--	--	.1	6.8
34.01-40	.7	6.2	1.1	.6	.4	.2	.1	--	--	--	.1	9.5
40.01-50	1.3	7.1	.8	1.0	--	.3	--	--	--	--	--	10.5
50.01-60	.9	4.3	.3	.6	--	.3	.3	--	--	--	--	6.7
60.01-70	.7	4.2	.7	.9	.4	.7	.2	--	--	--	--	7.7
70.01-95	.7	3.7	.2	.6	.3	.4	.2	--	--	--	--	6.0
Percent of total	18.1	57.3	8.7	6.7	1.9	2.7	3.3	0.6	0.1	--	0.4	100.0

[a] Percentage of total surface area of required rough parts.

Table 13.—Length/width distribution [a] (in percent) of 5/4 nominal thickness, clear (C1F and C2F) quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	0.3	0.5	1.3	0.6	0.6	0.7	0.2	0.3	0.2	1.0	0.1	5.8
15.01-18	.6	.5	1.3	1.7	4.1	1.3	.9	.6	.9	2.4	--	14.3
18.01-21	.6	.9	1.8	1.3	1.3	.5	.8	.7	.4	1.2	.1	9.7
21.01-25	.8	.9	2.2	.6	3.0	.9	1.4	1.2	.8	1.7	.3	13.7
25.01-29	.5	.7	1.4	1.1	1.2	--	1.7	--	.6	.8	1.0	9.0
29.01-33	.3	.4	.9	.2	2.0	1.0	2.9	.5	1.4	.9	.6	11.1
33.01-38	.5	.3	.6	.3	.3	.3	.1	.2	.9	.4	.3	4.2
38.01-45	.6	.4	.4	.6	.7	.4	.9	.1	.3	.8	.3	5.6
45.01-50	.5	.2	1.2	.1	.4	--	--	--	--	.9	--	3.4
50.01-60	.6	.8	1.8	1.3	.8	.4	1.0	.6	.8	.9	.2	9.1
60.01-75	.7	.1	1.6	1.9	1.3	.2	.5	.6	.7	.2	--	7.9
75.01-100	1.0	.2	.6	1.5	2.4	.1	.1	.2	--	--	--	6.2
Percent of total	7.0	5.9	15.3	11.3	18.0	5.7	10.7	4.9	7.0	11.2	3.0	100.0

[a] Percentage of total surface area of required rough parts.

Table 14.—Length/width distribution [a] (in percent) of 5/4 nominal thickness, core quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	--	--	0.8	1.7	--	--	--	1.7	1.3	0.4	6.0
15.01-18	--	--	--	--	.1	--	--	--	--	.7	.8	1.5
18.01-21	--	--	--	--	.1	--	.3	--	.5	4.8	.7	6.4
21.01-23	--	--	--	--	--	--	--	--	--	1.7	2.8	4.5
23.01-26	--	--	--	--	.8	--	--	--	--	4.0	8.9	13.7
26.01-29	--	--	--	--	.2	--	--	--	.6	--	2.1	2.9
29.01-34	--	--	--	.3	--	--	--	--	.2	4.0	.3	4.9
34.01-40	.1	--	--	--	--	--	--	--	.8	1.6	.5	3.0
40.01-50	--	.2	--	.4	.2	--	.3	--	.9	10.4	7.3	19.8
50.01-60	--	--	--	--	--	.4	--	--	1.9	11.0	7.1	20.4
60.01-70	--	.1	.3	--	.4	--	.5	--	.7	.5	5.4	7.8
70.01-85	--	--	--	--	.9	--	--	--	7.4	.8	--	9.1
Percent of total	0.1	0.3	0.3	1.6	4.4	0.4	1.1	--	14.7	40.8	36.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 15.—Length/width distribution[a] (in percent) of 6/4 nominal thickness, clear (C1F and C2F) quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	1.0	0.5	0.2	1.2	0.3	0.3	0.6	0.5	1.2	0.8	--	6.6
15.01–18	.8	.9	.6	2.6	1.8	2.2	1.0	.4	.9	2.9	--	14.0
18.01–21	.5	.7	1.6	1.8	1.8	.4	.7	.8	.4	1.0	0.3	10.1
21.01–25	.4	1.3	.8	2.7	1.3	.7	.8	.9	.6	.5	--	10.0
25.01–28	.6	.7	.8	2.3	1.1	.9	.6	.7	.4	.2	--	8.5
28.01–32	1.0	.1	.4	2.8	1.6	1.7	.9	.4	.5	.9	--	10.5
32.01–35	--	.3	.5	1.7	--	.2	.1	.2	.4	--	--	3.4
35.01–40	.4	.3	.2	.8	1.4	--	.8	--	.5	.7	--	5.2
40.01–45	.1	.2	1.0	1.6	1.4	1.3	.2	--	.2	.4	--	6.4
45.01–50	.6	.2	1.0	.5	1.0	.8	--	--	.3	--	--	4.5
50.01–60	.4	.8	.5	2.5	.3	.2	.3	.2	1.9	.7	--	7.8
60.01–70	.5	.2	.5	.9	.9	.2	.2	.2	.5	.4	.3	4.6
70.01–85	.7	.8	2.3	1.3	.4	.4	.2	.8	.7	.7	--	8.4
Percent of total	7.2	7.0	10.5	22.8	13.2	9.3	6.6	5.0	8.6	9.2	0.6	100.0

[a] Percentage of total surface area of required rough parts.

Table 16.—Length/width distribution[a] (in percent) of 8/4 nominal thickness, clear (C1F and C2F) quality rough parts for veneered wood furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	0.1	0.3	0.5	0.7	0.4	--	0.5	0.1	0.4	0.2	--	3.1
15.01–18	.2	2.4	.5	1.3	2.3	1.7	1.2	.1	--	1.4	.1	11.2
18.01–21	.2	1.5	1.3	1.2	1.9	.8	.1	.4	.7	1.6	.2	9.9
21.01–25	.2	2.9	.9	.3	1.2	1.4	1.1	.1	2.2	1.3	--	11.6
25.01–28	--	1.0	.6	.1	--	1.9	1.6	--	--	1.1	--	6.3
28.01–32	.2	.8	1.7	1.0	.7	4.0	5.2	1.0	--	8.8	--	15.9
32.01–35	.1	.1	--	.1	.2	.1	--	--	--	.8	--	1.3
35.01–40	--	1.0	.4	--	.2	.3	.8	--	--	3.5	--	6.3
40.01–45	.1	1.1	.9	.4	.7	.3	.3	.6	--	3.1	--	7.6
45.01–50	.1	.4	.6	1.3	.5	.6	.4	--	--	1.2	2.0	7.1
50.01–60	.2	.2	1.2	--	.5	2.6	.6	.5	--	--	--	5.8
60.01–70	--	.5	.9	1.4	.7	--	.2	--	.5	--	--	4.2
70.01–90	.5	1.7	3.6	1.7	1.8	--	.1	.3	--	--	--	9.7
Percent of total	2.0	13.8	13.1	9.5	11.1	13.7	12.1	3.2	3.7	15.5	2.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 17.—Overview of rough part requirements for upholstered furniture

Nominal thickness (inches)	Part quality	Percent of requirements[a]
4/4	Clear (C1F and C2F)	3.2
4/4	Sound frame	58.6
5/4	Sound frame	21.5
6/4	Clear (C1F and C2F)	4.9
6/4	Sound frame	3.0
8/4	Clear (C1F and C2F)	3.2
8/4	Sound frame	4.1
All other combinations		1.5
		100.0

[a] Percentage of total surface area of required rough parts.

Table 18.—Length/width distribution[a] (in percent) of 4/4 nominal thickness, clear (C1F and C2F) quality rough parts for upholstered furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	--	--	--	2.2	--	3.8	--	--	--	--	6.0
15.01-18	--	--	--	--	--	--	--	--	--	--	--	--
18.01-21	--	--	2.6	--	--	4.5	5.4	--	--	--	--	12.5
21.01-25	--	--	--	--	--	--	4.3	--	--	14.1	--	18.4
25.01-29	--	--	--	--	7.6	6.2	3.4	--	--	--	--	17.2
29.01-33	--	--	--	--	--	--	25.2	--	--	--	--	25.2
33.01-38	--	--	--	--	--	--	--	--	--	--	--	--
38.01-45	--	--	--	--	--	--	--	--	--	--	--	--
45.01-50	--	--	--	--	--	--	--	--	--	--	--	--
50.01-60	--	--	--	--	--	--	--	--	--	--	--	--
60.01-75	--	--	--	--	--	--	8.5	--	--	--	--	8.5
75.01-100	--	--	--	--	--	--	12.2	--	--	--	--	12.2
Percent of total	--	--	2.6	--	9.8	10.7	62.8	--	--	14.1	--	100.0

[a] Percentage of total surface area of required rough parts.

Table 19.—Length/width distribution [a] (in percent) of 4/4 nominal thickness, sound frame quality rough parts for upholstered furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-13	0.6	0.5	0.4	1.1	1.0	0.1	0.5	--	0.2	--	0.2	4.7
13.01-17	.7	1.2	.6	1.0	.3	.8	.3	0.2	.1	--	.1	5.3
17.01-19	.7	1.6	.5	1.8	.4	.2	.5	--	--	--	--	5.7
19.01-22	1.6	2.1	.5	1.2	1.0	.9	1.1	.7	.8	1.0	2.1	13.0
22.01-24	.4	1.2	.4	1.1	.3	.7	1.5	--	.7	--	.1	6.4
24.01-27	.7	3.1	.8	1.9	.5	1.5	1.7	.9	.6	1.0	2.2	14.8
27.01-29	1.1	3.0	.5	1.9	.7	4.1	.1	--	.5	--	.4	12.4
29.01-33	.8	2.3	.9	3.6	.9	.9	2.0	--	.4	.5	.2	12.4
33.01-44	.5	1.3	.1	1.5	.2	1.4	.3	--	1.0	--	--	6.4
44.01-54	.1	.6	.9	.5	--	.3	.9	--	--	--	--	3.2
54.01-70	--	2.6	.4	1.7	--	.2	--	--	--	--	--	5.0
70.01-80	.1	2.6	1.4	1.1	.4	1.9	.6	--	--	.3	--	8.4
80.01-100	--	1.0	--	1.4	--	--	--	--	--	--	--	2.3
Percent of total	7.3	23.0	7.5	20.0	5.7	13.1	9.4	1.7	4.3	2.7	5.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 20.—Length/width distribution [a] (in percent) of 5/4 nominal thickness, sound frame quality rough parts for upholstered furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	0.5	0.3	--	0.2	0.3	--	--	--	--	--	0.4	1.6
15.01-18	.2	.4	0.6	.3	.7	0.3	0.4	--	0.6	--	.1	3.5
18.01-20	.1	.3	.5	.1	.3	--	.2	--	2.4	0.2	1.8	6.0
20.01-23	--	.9	1.6	2.9	.8	--	2.0	1.0	.4	--	1.4	10.9
23.01-25	.4	--	.3	.7	.2	.7	.3	.4	.2	--	.7	4.1
25.01-28	.2	.7	1.3	.5	--	1.6	--	--	1.8	--	5.3	11.3
28.01-33	.8	.4	1.4	2.7	1.1	--	1.5	--	1.6	--	2.6	12.0
33.01-45	--	5.6	--	--	1.8	--	.5	2.5	--	--	--	10.4
45.01-55	--	--	--	.8	1.7	--	--	.8	1.8	--	--	5.1
55.01-65	--	--	--	2.3	2.2	--	1.5	.8	1.1	--	--	7.8
65.01-80	--	--	--	2.9	4.7	--	--	--	6.5	--	--	14.1
80.01-90	--	--	.4	1.9	3.9	--	1.1	1.1	2.9	--	--	11.3
90.01-100	--	--	--	.7	--	--	1.2	--	--	--	--	1.9
Percent of total	2.3	8.5	6.1	16.1	17.5	2.6	8.7	6.6	19.2	0.2	12.2	100.0

[a] Percentage of total surface area of required rough parts.

Table 21.—Length/width distribution [a] (in percent) of 6/4 nominal thickness, clear (C1F and C2F) quality rough parts for upholstered furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	--	--	--	--	6.6	--	--	--	--	--	6.6
15.01-18	--	--	--	--	--	--	--	--	--	11.2	--	11.2
18.01-21	--	--	--	--	--	--	--	--	--	--	2.3	2.3
21.01-25	--	--	--	--	--	5.6	1.2	--	--	--	2.8	9.6
25.01-28	--	--	--	--	2.0	--	6.6	--	--	1.9	5.1	15.6
28.01-32	--	--	--	--	--	21.6	--	--	--	--	--	21.6
32.01-35	--	--	--	--	--	4.4	--	--	--	--	--	4.4
35.01-40	--	--	--	--	--	--	--	--	--	--	2.7	2.7
40.01-45	--	--	--	--	--	--	--	--	--	--	--	--
45.01-50	--	--	--	--	--	--	--	--	--	--	--	--
50.01-60	--	--	--	6.7	3.8	--	--	--	--	--	--	10.5
60.01-70	--	--	--	--	--	--	--	--	--	--	--	--
70.01-85	--	--	--	9.9	5.6	--	--	--	--	--	--	15.5
Percent of total	--	--	--	16.6	11.4	38.2	7.8	--	--	13.1	12.9	100.0

[a] Percentage of total surface area of required rough parts.

Table 22.—Length/width distribution [a] (in percent) of 6/4 nominal thickness, sound frame quality rough parts for upholstered furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-14	--	2.6	--	0.6	--	--	--	--	--	--	--	3.2
14.01-18	--	.5	3.9	--	2.0	--	--	--	1.1	--	2.0	9.5
18.01-21	--	5.9	.2	4.9	--	--	3.5	--	1.2	--	3.6	19.3
21.01-24	--	--	--	--	--	--	--	--	--	--	4.9	4.9
24.01-28	--	.3	8.4	6.3	--	3.8	--	--	3.4	--	--	22.3
28.01-31	3.7	5.1	5.6	--	3.2	--	--	--	--	--	--	17.5
31.01-34	--	7.5	5.0	3.6	3.9	--	--	--	--	--	--	20.0
34.01-40	--	--	--	--	--	--	--	--	--	--	3.3	3.3
Percent of total	3.7	21.8	23.1	15.5	9.2	3.8	3.5	--	5.7	--	13.7	100.0

[a] Percentage of total surface area of required rough parts.

Table 23.—Length/width distribution[a] (in percent) of 8/4 nominal thickness, clear (C1F and C2F) quality rough parts for upholstered furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	10.8	--	2.7	--	4.3	--	--	--	--	1.3	19.1
15.01-18	--	2.3	--	1.6	2.1	--	--	0.7	--	12.0	--	18.7
18.01-21	--	--	--	1.9	--	--	--	--	--	--	--	1.9
21.01-25	--	3.3	--	--	19.0	--	--	--	--	--	8.7	31.0
25.01-28	--	5.8	--	--	--	--	--	--	5.8	--	--	11.6
28.01-32	--	--	--	--	--	--	13.3	--	--	--	--	13.3
32.01-35	--	--	--	--	--	--	--	--	--	--	--	--
35.01-40	--	--	--	--	--	--	--	--	--	--	--	--
40.01-45	--	--	--	--	--	--	--	--	--	--	4.4	4.4
45.01-50	--	--	--	--	--	--	--	--	--	--	--	--
50.01-60	--	--	--	--	--	--	--	--	--	--	--	--
60.01-70	--	--	--	--	--	--	--	--	--	--	--	--
70.01-90	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	--	22.2	--	6.2	21.1	4.3	13.3	0.7	5.8	12.0	14.4	100.0

[a] Percentage of total surface area of required rough parts.

Table 24.—Length/width distribution[a] (in percent) of 8/4 nominal thickness, sound frame quality rough parts for upholstered furniture

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-12	0.2	12.9	1.4	--	--	--	1.2	--	--	--	--	15.7
12.01-16	1.4	4.0	2.3	2.5	3.6	6.9	2.0	0.5	--	--	--	23.3
16.01-19	--	7.1	--	4.2	.9	1.0	--	--	2.7	--	--	15.9
19.01-21	--	2.2	1.7	4.9	--	1.5	--	1.4	--	--	--	11.8
21.01-24	--	1.1	3.6	--	3.9	--	--	1.8	--	--	3.3	13.6
24.01-28	--	2.3	--	--	--	3.1	--	--	5.2	--	--	10.6
28.01-30	--	2.0	--	--	--	--	--	--	--	--	--	2.0
30.01-34	--	2.0	2.0	1.7	--	--	--	--	1.5	--	--	7.1
Percent of total	1.6	33.6	11.0	13.3	8.3	12.6	3.2	3.7	9.4	--	3.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 25.—Overview of rough part requirements for recliners

Nominal thickness (inches)	Part quality	Percent of requirements[a]
4/4	Sound frame	52.7
5/4	Clear (C1F and C2F)	3.6
5/4	Sound frame	28.0
6/4	Sound frame	1.9
8/4	Clear (C1F and C2F)	2.0
8/4	Sound frame	8.1
All other combinations		3.7
		100.0

[a] Percentage of total surface area of required rough parts.

Table 26.—Length/width distribution [a] (in percent) of 4/4 nominal thickness, sound frame quality rough parts for recliners

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-13	--	0.1	0.1	--	--	--	--	--	--	0.2	--	0.5
13.01-17	1.6	1.4	.9	2.4	--	--	0.1	--	0.6	3.4	3.7	14.1
17.01-19	1.7	1.7	1.3	.9	2.0	.5	--	.6	--	.9	3.0	12.6
19.01-22	4.0	3.8	1.6	.6	.8	.1	--	.6	2.1	2.0	6.8	22.6
22.01-24	.8	2.0	1.6	1.7	.4	2.9	.6	--	1.1	3.6	5.7	20.5
24.01-27	.4	2.6	2.8	.6	--	1.5	1.0	2.0	.3	2.7	2.8	16.6
27.01-29	.6	.5	2.7	1.3	1.0	.6	--	.9	1.1	--	--	8.8
29.01-33	--	--	.4	--	.3	--	.8	1.9	1.1	--	--	4.3
33.01-44	--	--	--	--	--	--	--	--	--	--	--	--
44.01-54	--	--	--	--	--	--	--	--	--	--	--	--
54.01-70	--	--	--	--	--	--	--	--	--	--	--	--
70.01-80	--	--	--	--	--	--	--	--	--	--	--	--
80.01-100	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	9.0	12.2	11.5	7.5	4.6	5.6	2.4	6.0	6.2	12.9	22.1	100.0

[a] Percentage of total surface area of required rough parts.

Table 27.—Length/width distribution [a] (in percent) of 5/4 nominal thickness, clear (C1F and C2F) quality rough parts for recliners

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	--	--	--	--	--	--	--	--	--	--	--
15.01-18	--	--	--	--	--	1.4	--	--	--	--	--	1.4
18.01-21	--	14.7	--	2.5	--	--	--	--	10.1	3.7	3.6	34.6
21.01-25	--	--	--	1.2	--	--	--	--	--	40.2	8.8	50.3
25.01-29	--	--	4.9	--	--	--	--	--	--	--	--	4.9
29.01-33	--	--	--	--	--	--	--	--	--	--	8.8	8.8
33.01-38	--	--	--	--	--	--	--	--	--	--	--	--
38.01-45	--	--	--	--	--	--	--	--	--	--	--	--
45.01-50	--	--	--	--	--	--	--	--	--	--	--	--
50.01-60	--	--	--	--	--	--	--	--	--	--	--	--
60.01-75	--	--	--	--	--	--	--	--	--	--	--	--
75.01-100	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	--	14.7	4.9	3.7	--	1.4	--	--	10.1	43.9	21.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 28.—Length/width distribution [a] (in percent) of 5/4 nominal thickness, sound frame quality rough parts for recliners

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	0.2	--	--	--	--	--	--	--	--	1.1	1.9	3.1
15.01-18	8.4	1.9	2.7	0.8	--	--	0.9	--	--	1.0	.5	16.2
18.01-20	4.8	6.4	6.1	1.7	1.0	--	.1	--	--	1.5	7.8	29.5
20.01-23	--	1.3	4.3	.3	.8	.5	--	--	0.4	1.0	1.9	10.5
23.01-25	.1	--	2.8	--	--	--	--	--	--	.9	6.2	10.0
25.01-28	.9	--	2.4	--	5.0	1.0	--	--	2.4	1.4	9.9	23.0
28.01-33	--	.3	.7	--	.5	--	--	--	2.5	--	3.6	7.7
33.01-45	--	--	--	--	--	--	--	--	--	--	--	--
45.01-55	--	--	--	--	--	--	--	--	--	--	--	--
55.01-65	--	--	--	--	--	--	--	--	--	--	--	--
65.01-80	--	--	--	--	--	--	--	--	--	--	--	--
80.01-90	--	--	--	--	--	--	--	--	--	--	--	--
90.01-100	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	14.4	9.9	19.0	2.8	7.2	1.5	1.0	--	5.3	7.0	31.9	100.0

[a] Percentage of total surface area of required rough parts.

Table 29.—Length/width distribution[a] (in percent) of 6/4 nominal thickness, sound frame quality rough parts for recliners

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-14	--	--	--	--	--	--	--	--	--	--	--	--
14.01-18	4.2	8.7	6.5	3.8	9.7	--	--	--	--	--	--	32.8
18.01-21	--	8.5	--	8.1	--	11.1	--	--	--	--	--	27.8
21.01-24	--	6.0	--	--	10.7	--	--	--	--	--	--	16.7
24.01-28	--	18.7	--	--	--	--	--	--	--	--	--	18.7
28.01-31	--	4.0	--	--	--	--	--	--	--	--	--	4.0
31.01-34	--	--	--	--	--	--	--	--	--	--	--	--
34.01-40	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	4.2	45.9	6.5	11.9	20.4	11.1	--	--	--	--	--	100.0

[a] Percentage of total surface area of required rough parts.

Table 30.—Length/width distribution[a] (in percent) of 8/4 nominal thickness, clear (C1F and C2F) quality rough parts for recliners

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-15	--	--	--	--	--	--	--	--	--	--	--	--
15.01-18	--	--	--	--	--	--	--	--	--	--	5.7	5.7
18.01-21	--	5.1	--	--	--	--	--	--	21.3	--	17.1	43.5
21.01-25	--	--	--	17.8	4.9	--	--	--	--	--	--	22.7
25.01-28	--	--	--	--	--	--	8.8	--	--	19.3	--	28.1
28.01-32	--	--	--	--	--	--	--	--	--	--	--	--
32.01-35	--	--	--	--	--	--	--	--	--	--	--	--
35.01-40	--	--	--	--	--	--	--	--	--	--	--	--
40.01-45	--	--	--	--	--	--	--	--	--	--	--	--
45.01-50	--	--	--	--	--	--	--	--	--	--	--	--
50.01-60	--	--	--	--	--	--	--	--	--	--	--	--
60.01-70	--	--	--	--	--	--	--	--	--	--	--	--
70.01-90	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	--	5.1	--	17.8	4.9	--	8.8	--	21.3	19.3	22.8	100.0

[a] Percentage of total surface area of required rough parts.

Table 31.—Length/width distribution[a] (in percent) of 8/4 nominal thickness, sound frame quality rough parts for recliners

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0-12	--	--	--	--	--	--	--	--	--	--	2.6	2.6
12.01-16	--	1.3	0.6	--	--	--	--	--	--	--	2.2	4.1
16.01-19	6.5	48.5	2.7	2.8	3.1	--	--	--	--	2.5	1.4	67.5
19.01-21	1.1	1.1	5.2	--	--	1.4	3.3	--	--	--	.4	12.6
21.01-24	.7	.4	4.4	--	--	--	--	--	1.2	--	2.9	9.6
24.01-28	.7	2.0	--	--	--	--	--	--	--	--	.9	3.6
28.01-30	--	--	--	--	--	--	--	--	--	--	--	--
30.01-34	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	9.0	53.4	13.0	2.8	3.1	1.4	3.3	--	1.2	2.5	10.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 32.—Overview of rough part requirements for kitchen cabinets

Nominal thickness (inches)	Part quality	Percent of requirements[a]
3/4	Clear (C1F and C2F)	18.9
4/4	Clear (C1F and C2F)	70.0
4/4	Sound interior	4.7
5/4	Clear (C1F and C2F)	4.8
All other combinations		1.6
		100.0

[a] Percentage of total surface area of required rough parts.

Table 33.—Length/width distribution [a] (in percent) of 3/4 nominal thickness, clear (C1F and C2F) quality rough parts for kitchen cabinets.

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–14	0.3	1.4	5.1	1.0	1.6	0.8	0.3	0.4	2.5	0.5	--	13.9
14.01–17	.2	1.6	2.2	1.1	.6	.3	.7	.2	2.2	.7	--	9.8
17.01–19	.4	.6	.3	.9	.3	.1	.7	.2	2.1	.9	--	6.5
19.01–22	.7	1.0	3.5	1.8	.2	2.8	3.5	1.8	2.7	.1	--	18.0
22.01–25	1.7	1.7	1.4	1.5	1.0	--	.2	.2	3.9	1.8	--	13.5
25.01–29	.6	3.3	4.9	2.2	.8	--	.2	--	.3	--	--	12.4
29.01–31	5.0	2.6	1.2	.1	1.5	.2	.3	--	--	--	--	11.0
31.01–35	.4	5.2	2.0	--	1.1	--	--	.1	--	--	--	8.7
35.01–41	.2	1.4	.2	.1	.3	--	--	--	--	--	--	2.2
41.01–47	.1	1.1	--	.1	.2	--	.1	.1	.4	--	--	2.0
47.01–58	.2	.1	.2	.1	--	--	--	--	--	--	--	.6
58.01–86	.7	.3	--	.1	.2	--	--	--	--	--	--	1.3
Percent of total	10.5	20.3	21.0	8.9	7.9	4.3	6.1	3.2	14.0	3.9	--	100.0

[a] Percentage of total surface area of required rough parts.

Table 34.—Length/width distribution [a] (in percent) of 4/4 nominal thickness, clear (C1F and C2F) quality rough parts for kitchen cabinets

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	0.2	1.9	1.2	3.0	1.1	0.6	1.3	0.5	1.1	0.1	0.4	11.6
15.01–18	.2	1.8	1.1	1.3	.6	.5	.7	.9	1.7	.5	.5	9.8
18.01–21	.2	1.2	1.6	1.6	.6	.3	1.7	.5	1.6	1.1	1.1	11.5
21.01–25	.6	2.6	2.2	2.8	1.9	.8	.7	.7	3.5	2.5	1.8	19.9
25.01–29	.4	2.7	3.4	2.7	1.3	1.5	.2	.1	.5	--	1.2	14.0
29.01–33	.9	7.0	.2	1.1	2.0	.5	.1	.1	.3	--	1.5	13.8
33.01–38	.3	1.2	--	.3	1.4	.6	.3	--	--	--	--	4.1
38.01–45	.3	.9	--	.2	.9	.2	.1	--	.2	--	--	2.7
45.01–50	.2	.4	.1	1.6	.7	.1	1.2	.2	.5	--	.5	5.5
50.01–60	--	.1	.1	.4	.3	--	.1	--	.1	--	1.3	2.4
60.01–75	--	.2	.1	.1	.2	.1	.2	.3	.5	--	--	1.6
75.01–100	.1	.5	.1	.3	.3	--	--	.4	1.3	--	--	3.1
Percent of total	3.4	20.5	10.1	15.4	11.2	5.2	6.5	3.7	11.4	4.3	8.3	100.0

[a] Percentage of total surface area of required rough parts.

Table 35.—Length/width distribution[a] (in percent) of 4/4 nominal thickness, sound interior quality rough parts for kitchen cabinets

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	3.7	1.5	2.6	--	--	--	--	--	--	--	--	7.9
15.01–18	5.4	3.5	2.6	--	--	--	--	--	--	--	--	11.6
18.01–21	.6	2.2	3.1	--	--	--	--	--	--	--	--	5.9
21.01–25	2.1	7.3	10.2	0.9	--	--	--	--	--	--	--	20.4
25.01–29	.6	1.8	1.8	--	--	--	--	--	--	--	--	4.3
29.01–34	3.2	3.0	9.1	.4	--	--	--	0.8	--	--	--	16.4
34.01–40	3.4	4.8	10.0	--	--	--	--	--	--	--	--	19.6
40.01–50	2.5	3.7	7.8	--	--	1.4	--	--	--	--	--	14.0
50.01–60	--	--	--	--	--	--	--	--	--	--	--	--
60.01–70	--	--	--	--	--	--	--	--	--	--	--	--
70.01–95	--	--	--	--	--	--	--	--	--	--	--	--
Percent of total	21.6	27.8	47.1	1.3	--	1.4	--	0.8	--	--	--	100.0

[a] Percentage of total surface area of required rough parts.

Table 36.—Length/width distribution[a] (in percent) of 5/4 nominal thickness, clear (C1F and C2F) quality rough parts for kitchen cabinets

Length groupings (inches)	Width groupings (inches)											Percent of total
	0-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-5.0	5.01-6.0	6.01-14.0	14.01-20.0	20.01-26.0	
0–15	0.5	3.6	0.1	0.1	0.9	--	1.0	--	0.3	--	--	6.5
15.01–18	.5	3.9	--	--	--	--	.4	--	.2	--	--	5.0
18.01–21	.3	1.6	--	.1	--	--	8.1	--	2.2	--	--	12.3
21.01–25	.6	3.7	--	--	.1	--	--	--	--	--	0.9	5.3
25.01–29	.4	4.7	--	--	--	--	--	--	--	--	--	5.1
29.01–33	1.0	12.6	--	1.0	1.6	--	--	--	--	--	--	16.2
33.01–38	.7	8.4	--	1.4	.5	--	2.2	--	2.8	2.7	--	18.7
38.01–45	.4	3.7	--	.3	--	--	--	--	--	--	--	4.5
45.01–50	.2	1.7	--	--	.2	--	--	--	.7	--	--	2.9
50.01–60	--	--	--	--	--	--	--	--	--	2.2	--	2.2
60.01–75	--	--	--	--	--	--	--	--	--	--	--	--
75.01–100	--	4.5	2.6	.3	.5	--	.6	--	6.9	6.1	--	21.5
Percent of total	4.5	48.2	2.7	3.1	3.9	--	12.4	--	13.2	11.0	0.9	100.0

[a] Percentage of total surface area of required rough parts.

Table 37.—Recommended hardwood blank standard sizes for furniture and cabinet manufacturers (inches)

Nominal thickness	Intended product finish thickness	Actual blank thickness	Blank lengths												
Clear Quality/26-inch Wide Blanks															
5/8	3/8	1/2	13	15	17	18	22	26	31	36	42				
3/4	1/2	5/8	14	17	19	22	25	29	31	35	41	47	58	86	
4/4	3/4	7/8	15	18	21	25	29	33	38	45	50	60	75	100	
1-1/4	1	1-1/8	15	18	21	25	29	33	38	45	50	60	75	100	
1-1/2	1-1/4	1-3/8	15	18	21	25	28	32	35	40	45	50	60	70	85
2	1-5/8	1-3/4	15	18	21	25	28	32	35	40	45	50	60	70	90
Core Quality/26-inch Wide Blanks															
1	3/4	7/8	15	18	21	23	26	29	34	40	50	60	70	95	
1-1/4	1	1-1/8	15	18	21	23	26	29	34	40	50	60	70	85	
Sound Frame Quality (for upholstered frames)/20-inch Wide Blanks															
1	3/4	7/8	13	17	19	22	24	27	29	33	44	54	70	80	100
1-1/4	1	1-1/8	15	18	20	23	25	28	33	45	55	65	80	90	100
1-1/2	1-1/4	1-3/8	14	18	21	24	28	31	34	40					
2	1-5/8	1-3/4	12	16	19	21	24	28	30	34					
Sound Interior Quality (for case goods)/20-inch Wide Blanks															
1	3/4	7/8	15	18	21	25	29	34	40	50	60	70	95		

Table 38.—Using blanks to satisfy kitchen cabinet part requirements for front frame, door and drawer parts for 50 sets of 9 cabinets[a]

Material species/lumber thickness	Quality	Rough part information		Standard-size blanks required			Blanks to parts conversion results		
		Size T × L × W	No. needed	Quality	Size T × L × W	No. needed	% used	% reglu-able	% waste
Red oak 4/4	C1F	7/8 × 31-1/2 × 1-7/8	100	Clear	7/8 × 33 × 26	8	86	4	10
	C2F	7/8 × 28-5/8 × 3-3/4	200		7/8 × 29 × 26	133	90	2	8
	C2F	7/8 × 28-1/4 × 2-1/4	700						
	C1F	7/8 × 27-3/4 × 1 × 3/4	500						
	C2F	7/8 × 24-3/4 × 8-7/8	200		7/8 × 25 × 26	172	89	5	5
	C2F	7/8 × 24-3/4 × 5-7/8	150						
	C1F	7/8 × 22-1/2 × 2-1/4	400						
	C1F	7/8 × 12-3/8 × 1-3/4	50						
	C1F	7/8 × 12-1/4 × 5-1/4	200						
	C2F	7/8 × 21 × 4-1/2	150		7/8 × 21 × 26	151	90	1	9
	C1F	7/8 × 20-1/2 × 2-1/4	350						
	C2F	7/8 × 20 × 8-7/8	50						
	C2F	7/8 × 18-3/4 × 8-7/8	200						
	C1F	7/8 × 9-7/8 × 1-3/4	100						
	C2F	7/8 × 15 × 7-5/8	100		7/8 × 15 × 26	179	91	1	7
	C2F	7/8 × 15 × 5-1/4	100						
	C1F	7/8 × 15 × 1-7/8	800						
	C1F	7/8 × 15 × 1-3/4	350						
	C2F	7/8 × 14-1/2 × 5	25						
	C2F	7/8 × 14-1/2 × 2-1/4	75						
	C2F	7/8 × 13-3/8 × 3-3/4	50						
	C1F	7/8 × 13 × 2-1/4	200						
Total					5050	643	90	3	7

[a] Parts are ripped from blanks with a 1/8-inch kerf ripsaw blade.

Table 39.—Using blanks to satisfy solid furniture part requirements for 100 servers[a]

Material species/lumber thickness	Rough part information			Standard-size blanks required			Blanks to parts conversion results		
	Quality	Size T × L × W	No. needed	Quality	Size T × L × W	No. needed	% used	% reglu-able	% waste
Red oak 5/4	C2F	1-1/8 × 43 × 5-1/8	200	Clear	1-1/8 × 45 × 26	53	90	[b]	10
	C1F	1-1/8 × 43-1/2 × 1-3/8	200						
	C1F	1-1/8 × 20-1/2 × 1-3/8	200		1-1/8 × 21 × 26	12	86	2	12
	C1F	1-1/8 × 18 × 1-7/8	400		1-1/8 × 18 × 26	77	92	3	6
	C1F	1-1/8 × 17-1/2 × 5-1/8	200						
	C1F	1-1/8 × 8-1/2 × 1-7/8	100						
	C1F	1-1/8 × 7-1/4 × 1-7/8	400		1-1/8 × 15 × 26	16	87	4	9
Red oak 4/4	C2F	7/8 × 43-1/2 × 19	100	Clear	7/8 × 45 × 26	100	85	9	6
	C1F	7/8 × 39-3/4 × 2-1/8	200						
	C1F	7/8 × 31-1/2 × 16-3/8	200		7/8 × 33 × 26	200	65	31	4
	C1F	7/8 × 31-1/2 × 2-3/4	100						
	C1F	7/8 × 12-1/4 × 11-1/8	200		7/8 × 25 × 26	73	87	10	3
	C1F	7/8 × 8-1/8 × 8-1/2	200						
	C1F	7/8 × 5 × 1-7/8	200		7/8 × 21 × 26	4	86	4	10
	C2F	7/8 × 18 × 3-3/8	400		7/8 × 18 × 26	75	94	[b]	6
	C2F	7/8 × 17 × 1-7/8	200						
	C2F	7/8 × 17-3/4 × 1-1/4	100						
	C2F	7/8 × 14-1/2 × 10-1/2	200		7/8 × 15 × 26	115	90	5	5
	C2F	7/8 × 14-1/2 × 3-3/8	200						
Yellow-poplar 4/4	Sound interior	7/8 × 39-3/4 × 2-1/4	300	Sound interior	7/8 × 40 × 20	48	88	5	7
		7/8 × 37-1/4 × 1-7/8	100						
		7/8 × 17-1/2 × 1-1/4	200		7/8 × 18 × 20	15	81	5	14
		7/8 × 14-3/4 × 2-3/8	200		7/8 × 15 × 20	25	93	--	7
Yellow-poplar 4/4	Core	7/8 × 38-7/8 × 8-1/2	100	Core	7/8 × 40 × 26	34	93	2	5
Total			4900			847	82	12	6

[a] Parts are ripped from blanks with a 1/8-inch kerf ripsaw blade.
[b] Less than 1/2 percent.

Table 40.—Using blanks to satisfy veneered dining room furniture part requirements for 100 tables and 400 chairs[a]

Material species/lumber thickness	Rough part information			Standard-size blanks required			Blanks to parts conversion results		
	Quality	Size T × L × W	No. needed	Quality	Size T × L × W	No. needed	% used	% reglu-able	% waste
Ash 8/4	C2F	1-3/4 × 43-3/4 × 1-7/8	800	Clear	1-3/4 × 45 × 26	62	90	1	9
	C2F	1-3/4 × 30-1/2 × 3-3/8	800		1-3/4 × 32 × 26	115	86	6	8
	C2F	1-3/4 × 21 × 1-1/4	200		1-3/4 × 21 × 26	11	87	4	9
	C2F	1-3/4 × 17 × 2	800		1-3/4 × 18 × 26	67	87	[b]	13
Ash 6/4	C2F	1-3/8 × 43-1/2 × 3-3/4	200	Clear	1-3/8 × 45 × 26	100	83	10	7
	C2F	1-3/8 × 42-3/4 × 3-3/4	400						
	C2F	1-3/8 × 21 × 3-1/2	400		1-3/8 × 21 × 26	80	91	3	5
	C2F	1-3/8 × 21 × 2-1/2	200						
	C2F	1-3/8 × 17-1/4 × 2-1/2	400		1-3/8 × 18 × 26	156	86	[b]	14
		1-3/8 × 16-1/2 × 2-1/2	800						
		1-3/8 × 16 × 2	400						
Yellow-poplar 4/4	Core	7/8 × 40 × 2	400	Core	7/8 × 40 × 26	50	90	--	10
	Core	7/8 × 37-1/2 × 2	200						
	Core	7/8 × 21 × 2-1/2	534		7/8 × 21 × 26	80	86	8	6
		7/8 × 20 × 2-3/8	200						
Total			6734			721	87	4	9

[a] Parts are ripped from blanks with a 1/8-inch kerf ripsaw blade.
[b] Less than 1/2 percent.

Table 41.—Using blanks to satisfy upholstered love seat frame part requirements for 50 frames[a]

Material species/lumber thickness	Rough part information			Standard-size blanks required			Blanks to parts conversion results		
	Quality	Size T × L × W	No. needed	Quality	Size T × L × W	No. needed	% used	% reglu-able	% waste
Mixed hardwoods 4/4	Sound frame	7/8 × 65 × 2-1/2	50	Sound frame	7/8 × 70 × 20	8	73	18	9
		7/8 × 52 × 4	50		7/8 × 54 × 20	25	87	3	10
		7/8 × 52 × 3	50						
		7/8 × 52 × 2	50						
		7/8 × 33 × 3-1/2	100		7/8 × 33 × 20	24	91	--	9
		7/8 × 32 × 7/8	100						
		7/8 × 29 × 3	100		7/8 × 29 × 20	34	88	5	7
		7/8 × 29 × 2	150						
		7/8 × 22 × 5-1/2	100		7/8 × 22 × 20	61	90	7	4
		7/8 × 22 × 4-1/2	100						
		7/8 × 18 × 2	50						
		7/8 × 17 × 2	100		7/8 × 17 × 20	28	84	3	13
		7/8 × 16 × 2	100						
		7/8 × 8 × 2	50						
		7/8 × 8 × 1-1/2	50						
		7/8 × 12 × 3	50		7/8 × 13 × 20	9	77	13	10
Total			1250			189	86	6	8

[a] Parts are ripped from blanks with a 1/8-inch kerf ripsaw blade.

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Standard-size, kiln-dried hardwood blanks (panels) of specified lengths, widths, thicknesses, and qualities can be used instead of lumber to produce rough dimension furniture parts. Standard sizes were determined by analyzing thousands of part requirements from 20 furniture and 12 kitchen cabinet companies. The International Woodworking Machinery and Furniture Supply Fair-USA collected the data and supported the analysis. Recommended blank sizes and examples of rough dimension parts for furniture and cabinets made from blanks are included.

836.1; 854.1; 854.2

Keywords: Hardwood dimension; panels; standard sizes

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