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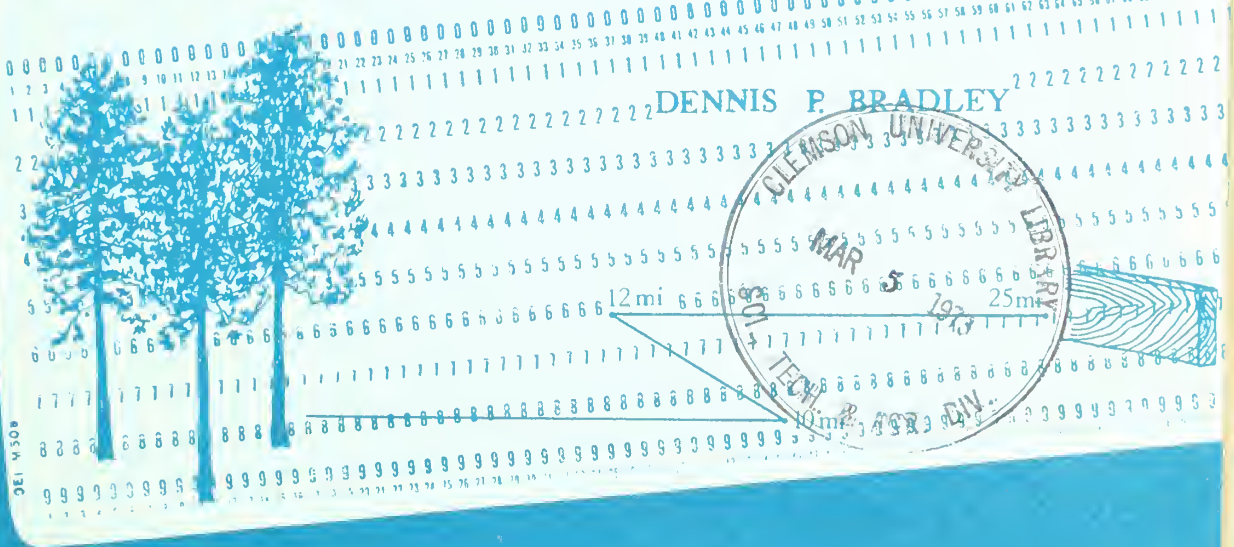
IMPROVE FOREST INVENTORY WITH ACCESS DATA -- MEASURE TRANSPORT DISTANCE AND COST TO MARKET



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Manuscript approved for publication March 27, 1972

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IMPROVE FOREST INVENTORY WITH ACCESS DATA— MEASURE TRANSPORT DISTANCE AND COST TO MARKET

Dennis P. Bradley

Forest inventories, through a lack of suitable methods, have typically been unable to provide the economic data essential to long-term forestry planning for both public and private decision-makers. Yet the efficient allocation of our forest resource demands that we know as much as possible about the factors affecting its value.

Because forests are generally dispersed over wide areas and at some distance from ultimate users, *forest access* is one of the principal determinants of value. Indeed, value can only be defined in relation to a specific time and place. In almost all inventories, however, forest access is either ignored completely or described only in the broadest terms.

Forest access refers to the distribution of the forest in relation to the transport system—highway, rail, and water. The objective in studying access is to determine the economic implications of present transport systems—how the systems affect the costs of harvesting, protecting, and otherwise using the forest—and to suggest ways to reduce forest-use costs.

Realizing the great practical significance of these questions, forest researchers in Sweden, Norway, and Finland have taken the lead in developing the necessary methods. We owe a great deal to their work.

This paper describes the adaptation of a method developed in Sweden at the Royal College of Forestry. The method is based on a fairly simple model relating transport distances to (1) length of the road net per unit land area, (2) the distribution of the road net, (3) the terrain, and (4) the location of specific delivery points. While the process has some novel features, *in principle it is a simple extension of any forest inventory;* and it is based on the location of the same sample points used for the conventional inventory. However, in addition to growing stock volume estimates provided by the inventory, the method makes it possible to summarize type areas and volumes by cross-country access, transport distances, and transport costs as well!

It must be emphasized that this method is a long-range planning tool to estimate the strategic impact of forest access. It is not an optimization procedure nor is it a route selector.

Forest investigators in Sweden have also pioneered in applying the results of access studies to many of the strategic questions that have plagued resource managers and planners for some time. For example, they have used the methods to answer questions such as: How much wood, in what sizes, species, and at what cost, can be brought to alternative mill sites? In areas with existing mills: If mill expansion takes place, will the delivered costs of additional supplies go up? If so, how much? The data are also useful in determining investment guidelines for silvicultural activities, road construction, and land purchase.

In summary, this study suggests a simple, inexpensive, and effective method for describing the effect of road systems and terrain on transport distances and costs to mill—problems inadequately treated in the past.

THE GENERAL METHOD

We will attempt to answer two complementary questions about forest access:

1. How far, on the average, is the nearest road from any given stand of timber?
2. How far, on the average, must a given volume of timber be transported to a mill?

In addition to averages, we would also like to describe the variation around the average and to answer all these questions in terms of transport costs.

To answer the first question, it is necessary to develop a model of forest access for ideal road nets and then to modify the model for more complex yet more realistic conditions. The answer to the second question requires only a simple extension of the answer to the first.

Forest access evaluation depends on the use of aerial photographs or a complete and accurate road map of the forest survey unit. Since most inventories already use aerial photos to locate plots, this is the ideal choice. Furthermore, photos generally show even the poorest roads, including those that are overgrown but still a part of the transport net. The photos can also be used to identify road quality and terrain characteristics. A road map rarely shows the complete road net in enough detail.

The same sample plots or points used in the conventional forest inventory are also used to obtain access data. These inventory plots have usually been located by some random process to give a representative and unbiased picture of cover types, species distribution, etc. This random feature is essential to the measurement of forest access as well.

Road Networks and the Estimation of Cross-Country Access Distance[1]

Ideal Road Nets

First, consider an ideal road network (fig. 1), a plane surface with all roads parallel and equidistant.[2] Moreover, the forest is uniformly distributed over the entire area. This type of road net can be described exhaustively by these parameters.

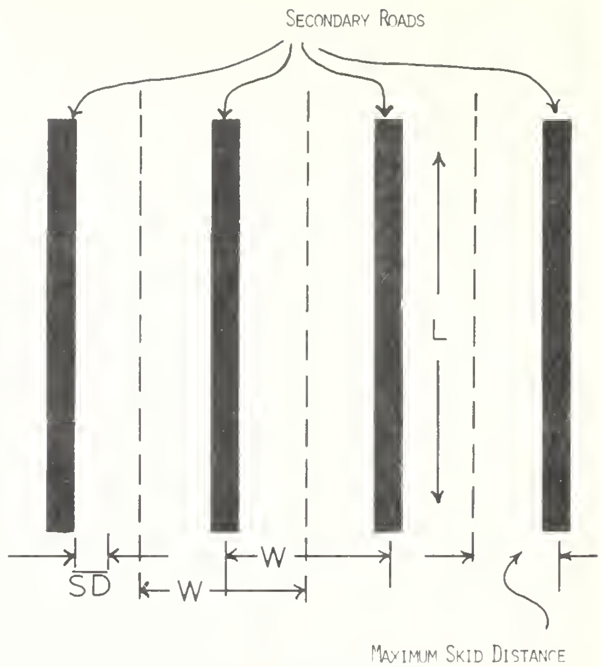

Figure 1.–An ideal road net.

W = *width* of area between roads. From figure 1, it also equals the width of the area from which all the timber is transported cross-country to a central road.

L = *length* of the road. It also equals the length of the area influenced by the road.

$\overline{SD}$ = *mean straight-line cross-country access distance* for the entire area.

Δ = road length per unit area or *road-net density*.

$$(1)\quad \overline{SD} = \frac{W}{4}.$$

Since area = length (L) x width (W), then

$$(2)\quad \Delta = \frac{L}{L x W} = \frac{1}{W}.$$

Taking the reciprocal of (2), we get

$$(3)\quad W = \frac{1}{\Delta},$$

substituting (3) in (1)

$$(4)\quad \overline{SD} = \frac{1}{4\Delta}.$$

Thus, by knowing either width (W), road-net density (Δ), or mean straight-line cross-country access distance ($\overline{SD}$), the complete characteristics of the ideal road net can be described.

[1] *Cross-country access distance will not be defined precisely because it has several different definitions depending on the model used. Roughly, it is the distance between a certain volume of timber and the nearest existing road. The different kinds of access distances will be illustrated in the following description. However, the use of the term "cross-country" does not imply the use of any "cross-country vehicle" to transport the timber.*

[2] *Most of this explanation is based on a landmark publication from Sweden by Gustaf von Segebaden, Studies of cross-country transport distances and road net extension, Studia Forestalia Suecica, No. 18, 1964. Applications of these methods in Sweden are described in several later publications by von Segebaden and others; see bibliography.*

Real Road Nets

While an ideal network provides an introduction to several important parameters of all road nets, it obviously has limited usefulness because:

1. Real road nets are not composed of straight, parallel and equidistant roads. Real nets have cross roads.

2. Cross-country access distances are seldom straight lines.

3. Timber is seldom skidded the shortest possible distance to the road but is usually brought to concentration points or landings along the road for efficient loading and sorting.

4. Timber is not uniformly distributed over the land.

Thus, the problem is to estimate a mean *practical* cross-country access distance for real road nets.

Consider first, an irregular road net on a perfectly flat surface (fig. 2). From equation 2,

$$\text{Road-net density}, \Delta = \frac{\text{road length}}{\text{area}}.$$

If in figure 2 road length[3] = 52 miles and area = 150 square miles,

$$\Delta = \frac{52 \text{ mi.}}{150 \text{ mi.}^2} = 0.347 \text{ miles of road/sq.mile.}$$

Presumably we can now calculate *mean straight-line cross-country access distance,* $\overline{SD}$, from equation 4,

$$\overline{SD} = \frac{1}{4\Delta} = \frac{1}{4(.347)} = 0.720 \text{ miles.}$$

This result is invalid, however, because equation 4 applies *only* if the road net is straight, parallel, and equidistant, as in figure 1. The use of equation 4 results in an under-estimate of the mean cross-country access distance for this plane but irregular net.

Instead of using equation 4, consider another measure $\overline{sd}$ defined as the *mean straight-line cross-country access distance for irregular,* plane road nets.

$\overline{sd}$ always exceeds $\overline{SD}$.

[3] *A useful and interesting method for estimating road length where this information is not available is shown in Appendix A and discussed in the next section.*

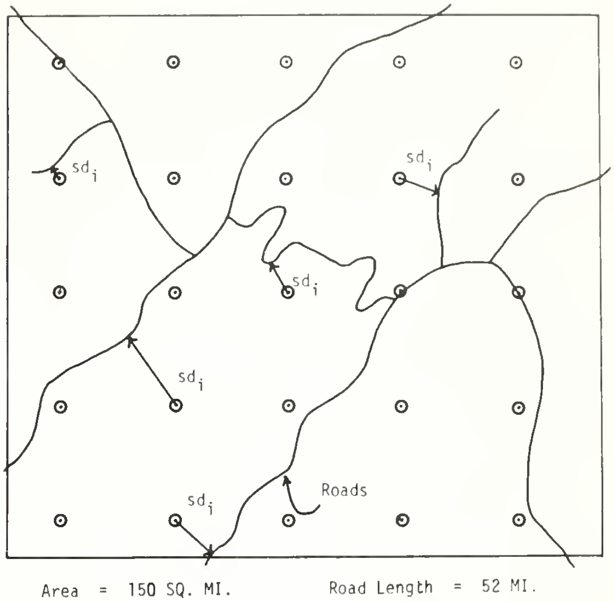

Figure 2.—Plane, irregular road net with dot grid overlay, and examples of sd_i.

While there is no analytical way to calculate $\overline{sd}$, it is possible to estimate $\overline{sd}$ in the following way. Using the dot grid overlay shown in figure 2 and a pair of dividers, measure the shortest straight-line distance from each dot to the nearest road. The arithmetic mean of these measures is $\overline{sd}$.

$$(5) \quad \overline{sd} = \frac{\Sigma sd_i}{n}$$

The number of dots required is a function of total area, the value of $\overline{SD}$ from equation 4 and the desired precision.[4]

Assume

$$n = 25 \text{ and that } \Sigma sd_i = 24.3 \text{ miles;}$$

then

$$\overline{sd} = \frac{24.3 \text{ miles}}{25} = 0.972 \text{ miles.}$$

Recall that $\overline{SD}$ = 0.720 miles. There is a difference because $\overline{SD}$ assumes the 52 miles of road are distributed as in figure 1, while $\overline{sd}$ = 0.972 is from the irregularly distributed road net with crossroads of figure 2.

[4] *Gustaf von Segebaden has prepared a formula and table for estimating the number of sample points. Appendix B.*

We can now define a ratio, R, called the *road net adjustment* by dividing $\overline{sd}$ by $\overline{SD}$.

$$(6) \quad R = \overline{sd}/\overline{SD} = \frac{0.972 \text{ miles}}{0.720 \text{ miles}} = 1.350.$$

Basically, this unitless factor means that this particular irregular net results in a *mean straight-line cross-country access distance,* $\overline{sd}$, 35 percent greater than an ideally distributed road net of the same length in the same area.

This ratio is a constant for road nets having the same kinds of geometry regardless of the absolute size of the net or the road-net density, Δ (Segebaden 1964).

Consider now, the same irregular road net superimposed on a topographic surface (fig. 3). Because we are now facing mountains, creeks, lakes, and various slopes, another measure must be introduced, $\overline{PD}$, the *mean practical cross-country access distance.* Returning to our overlay, the shortest *practical* distance from each point to a road, PD_i, is measured. The arithmetic mean of this measures is $\overline{PD}$.

$$(7) \quad \overline{PD} = \frac{\Sigma PD_i}{n}$$

What constitutes the shortest *practical* route must be determined from on-the-ground examination or from detailed topographic maps. Obviously, the shortest practical route equals or exceeds the shortest straight-line distance.

$$PD_i \geq sd_i$$

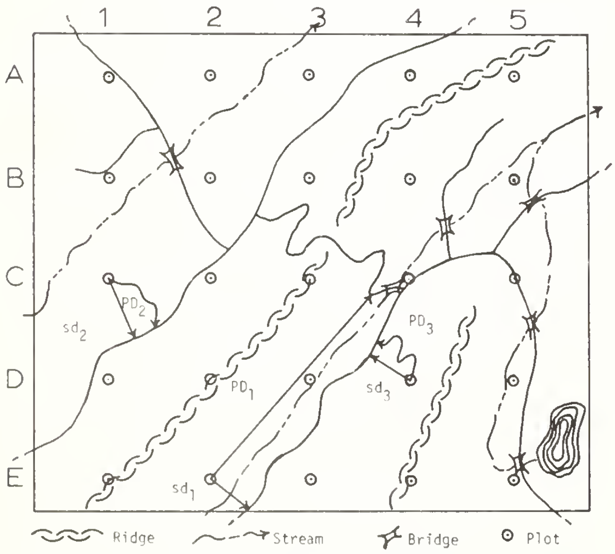

Figure 3.–Real road net, showing the difference between sd_i and PD_i. Numbers and letters at margins designate each sample point.

The transport technology greatly affects the route taken. In fact, the road used as the destination for the shortest straight-line route may change once topography is considered. For example, in sample point E-2 in figure 3, the *shortest straight-line distance* (sd) that ignores topography would be measured to the southeast. The *shortest practical cross-country access distance,* PD, would have to consider the stream lying between point E-2 and the closest road. Assuming the stream is impassable, PD would be measured to the northeast along the slope.

If

$$\Sigma PD_i = 29.0 \text{ miles}$$

then

$$\overline{PD} = \frac{29.0}{25} = 1.160 \text{ miles.}$$

Recall that $\overline{sd}$, the *mean straight-line cross-country access distance* for this plane, irregular road net, = 0.972 miles. $\overline{PD}$ is greater because a practical route would have to wind horizontally and vertically to its destination. We can now define another ratio, C, called the *cross-country transport adjustment,* by dividing $\overline{PD}$ by $\overline{sd}$.

$$(8) \quad C = \frac{\overline{PD}}{\overline{sd}} = \frac{1.160 \text{ miles}}{0.972 \text{ miles}} = 1.200.$$

This unitless factor accounts for the effect of terrain on cross-country transport distances. Thus, for these points and the given terrain, a practical distance exceeds the straight-line by 20 percent.

The cross-country adjustment factor C is a constant for similar terrain types, but it is not necessary to define the terrain type. It is sufficient to be able to classify an area as having the same general terrain, such as all glacial moraine, or all rolling piedmont.

This explanation has gone into more detail than necessary for practical application. The extra rigor was undertaken to make the process clearer. As the example described later will show, a practical answer to our first question–how far, on the average, is the nearest road from any given stand of timber? –requires: (1) The measurement of straight-line cross-country access distances sd_i, for all plots, (2) the measurement of the practical distances PD_i from a subsample and the calculation of the cross-country adjustment $C = \frac{\overline{PD}}{\overline{sd}}$, and (3) the multiplication of the sd_i for all plots by C to obtain estimates of the practical cross-country access distances for all plots: i.e., $PD_i = Csd_i$. A summary of the derivation is given in Appendix C.

Estimating Transportation Distances and Costs to Market

Measuring Road Haul Distances

The answer to the second question—how far, on the average, must a given volume of timber be transported to market?—requires a simple extension of the answer to the first. Immediately after measuring the shortest straight-line distance (sd) for a sample plot, transport distances by road quality class to a specific delivery point are measured.

In figure 4 for example, in addition to sd (the distance AB), there are 7 miles of road from B to C whose quality permits a round-trip speed of 25 m.p.h. From C to D are 8 miles permitting 15 m.p.h. (the map shows a steep adverse grade). From D to E and on to the mill at F are 7 miles permitting a 45 m.p.h. round-trip speed.

These road haul distances can be stepped off on a map with a divider, but it is more convenient to use a small map measurer, a clockwork device with a graduated wheel.

Regardless of where the "delivery point" is located, there are usually several different ways of getting there. Thus, a criterion must be established to decide which route to measure; for this method, it will depend on how much the person doing the measuring knows about the locale.

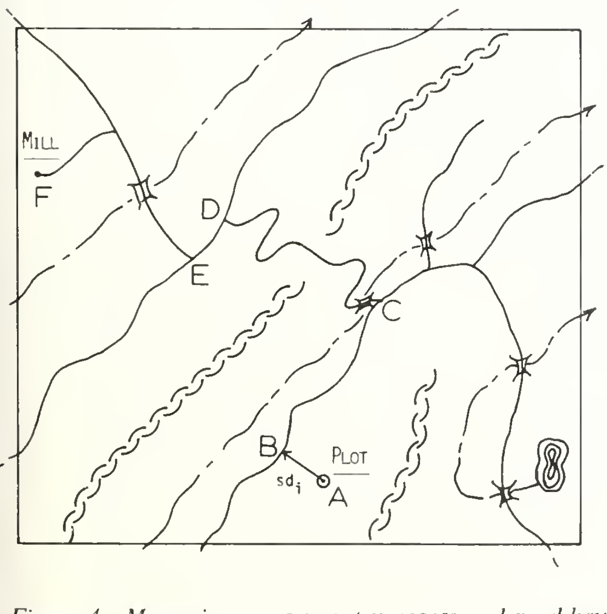

Figure 4.–Measuring cross-country access and road haul distances to delivery point.

For example, one might select the best route in terms of minimum distance as the criterion. However, this would probably not be realistic because transport cost is a function of distance *and* road quality. On the other hand, a true "least cost" criterion is impractical to apply because it requires an examination and cost calculation for every possible route.[5]

A more practical solution and the one used in the example is to get on successively higher quality roads as soon as possible. While this criterion is not without its ambiguities, the correct choice is usually obvious. If local knowledge of hauling routes and other relevant data are handy, these should be the guiding principle.

Choosing a Delivery Point

A principal feature of the method is that only one delivery point can be considered at any one time.

The selection of a specific "delivery point" is highly desirable in inventory units with little competition for the wood supply or if competition is concentrated at one location. It is under these conditions that the method is most useful to public or private planners. However, inventory units with overlapping competition pose a problem. In these cases "delivery point" can take a more general but less useful form. The "nearest all-weather road" or "nearest railroad landing" are alternatives. A final decision between specific or more general points will require a trade-off between the number of users and the value of the data. As the number of competing groups using the method in a given inventory unit increases, the less useful will be any choice of a specific delivery point.

However, because the process is so easy and cheap to apply, it can be repeated with alternative "delivery points." These different runs, while not easily com-

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[5] *While this method, and more specifically the ACCESS computer program to be described later, do not have the power to calculate a least cost route, one could run comparisons of transport costs for different routes from a specific plot by hand. This so-called "best" route could then be used for the computer input. However, it is felt that this exercise would impute more accuracy to the estimates of road quality than warranted. If this is true, the exercise could be misleading as well as a waste of time. Refer again to the statement of objectives of this process, page 1, paragraph six.*

parable, offer advantages in mill feasibility studies where either there is no existing competition or where there is a clear surplus of harvestable timber offering a potential for new development. Alternative delivery points might also be considered for different species or products.

Transport Costs

To be really useful, the distributions of volume by distance to "delivery point" must be convertible to transport costs per cord. The principal factors determining these costs are: (1) road quality, (2) truck capacity, and (3) hauling distance.

We have already mentioned the requirement that road distances be measured by road quality to delivery point. Road quality affects costs two ways. First, it affects round-trip speed. Because trucks and drivers incur cost per unit time, transport costs per cord go up as speed declines. Second, and more difficult to judge, road quality affects vehicle wear and tear.

Haul cost information with respect to road quality is usually available from equipment manufacturers and contract haulers. Many companies and governmental agencies have constructed their own cost relationships. For example, the USDA Forest Service has prepared tables relating fixed and variable costs for various truck sizes and road qualities (see Appendix D). Given the distances from plot to "delivery point" by road classes, costs per cord mile are easily calculated for a variety of truck sizes.

Data Summary and Presentation of Results

When *straight-line access distance* and *road haul distances* have been collected from each plot and the *cross-country adjustment* C has been computed from the subsample, they are combined with the cover type and species volume data gathered from each plot in the conventional cruise.

At this point the computation of volumes in each cover type is changed slightly from the usual practice. Because cover type is the smallest summary unit in most surveys, the computations of volumes in each type are generally calculated in the following way:

1. Cover type areas are determined from the proportion of total plots in each cover type. If 50 percent of the plots is aspen, then 50 percent of the area is aspen.

2. Combining all plots in each type together, a total mean volume per acre (all species) and a mean volume per acre (ac.) by species are calculated. For example, the total mean volume per acre for the aspen cover type might be 11.0 cd. per ac.; and of this total, 6 cd. per ac. are aspen, 3 cd. per ac. are birch, and 2 cd. per ac. are balsam fir.

3. Total volumes by species within cover types are determined by multiplying cover type area by each of the mean species volumes for the type. For this example, if there are 10,000 acres of aspen cover type,

10,000 ac. x	6 cd./ac. aspen	=	60,000 cd. aspen
+10,000 ac. x	3 cd./ac. birch	=	30,000 cd. birch
+10,000 ac. x	2 cd./ac. balsam fir	=	20,000 cd. balsam fir
10,000 ac.	11 cd./ac. total	=	110,000 cd. all species

However, this procedure is unsuitable for summaries of volumes by access distances because the use of a mean volume for all plots within a type ignores the variation in plot volumes by access distance. For example, after measuring all aspen plots for access one might find some plots 10 miles from delivery point and some 100 miles. Using a mean volume per acre for all plots assumes equal volumes for plots at all distances. In fact, it is clear that plot volumes will vary by distance from delivery point. Thus volumes should not be calculated until plots have been separated into distance classes. Once this is done, conventional methods can be applied to the plots in each distance class. While both methods yield correct total volumes for each type, only the latter method realistically estimates the distribution of volumes by transport distances.

To avoid the tedium of hand tabulation as well as speed the widespread testing of the process by others, a computer program in Fortran IV was written to calculate and display the distribution of areas and volumes by transport distances and costs. Results are displayed in two forms. First, a series of tables, one for each cover type, shows the distribution of areas and species by 10 total distance classes, and for up to four transport options. Next, a series of tables, one for each species, summarizes the data from the first set of tables. Specific examples are illustrated in the Koochiching County example. Appendix E describes the program in detail.

Limitations in the Method

Most of the limitations of this method, including the consideration of only one "delivery point" at a time, arise out of restrictions imposed by the underlying forest inventory. A principal problem is the estimation of sampling error.

Most forest inventories are designed to yield answers with a specified accuracy for total volume based on estimates of population variation in type area and volume. Rarely is an attempt made to have an individual cover type meet a criterion for accuracy. Thus, sampling errors for individual cover type areas and volumes are usually large.

Yet, by using the same data to measure access, we unavoidably push the limits of reliability even farther. The resultant sampling errors are presently unknown, and should certainly be the subject of future study. As an approximate guide to the size of the sampling errors for the volumes in distance or cost classes, one might use error tables provided by most inventory summaries that estimate sampling error for various sized aggregates.

After following this process, what can we say about the accessibility of the resource? Briefly, we can say that given the restraints imposed by the underlying sample, this method describes the proportions of cover type areas and volumes lying at various distances from the "delivery point." However, we *cannot* say precisely where and in what size stands these areas and volumes are located. For example, if the cover type table for white pine says that 4,700 acres are within 11 to 20 miles of the "delivery point," these 4,700 acres may be in two stands of 2,000 and 2,700 acres or in 4,700 stands of 1 acre, etc. This follows from the basic inventory which cannot locate type areas either. However, general type maps are often available that may give a good idea of stand distribution.

EXAMPLE: FOREST ACCESS IN KOOCHICHING COUNTY, MINNESOTA

Because the objective of this paper is to describe procedures, a complete picture of forest access in Koochiching County will not be presented here. Only enough detail to clearly explain the practical problems and to illustrate typical output will be shown.

Cost data are especially susceptible to misinterpretation and transport cost data borrowed from the U.S. Forest Service do not necessarily describe actual transport cost conditions in Koochiching County.

Situation

Koochiching County, with an area exceeding 2,000,000 acres, is located on the Minnesota-Ontario border. Almost 80 percent of the county is classified as commercial forest, and as one might imagine, the forest resource dominates the economy of the county.

The 1,575,000 acres of commercial forest are distributed among the following ownerships (Iron Range Resources and Rehabilitation Commission 1962):

	Acres
State lands	792,200
County and municipal lands	292,600
Forest industry lands	204,000
Farmer and misc. private lands	194,000
Federal owned and trust lands	92,200
Total	1,575,000

Major forest types in the county are black spruce, 25 percent, and aspen, 21 percent of the area. Total output of forest products over the last 8 years has averaged around 200,000 cords annually (Iron Range Resources and Rehabilitation Commission 1962).

Why Koochiching County

A rationale for examining forest access in this county seems almost unnecessary, yet there were other less obvious reasons why Koochiching County was chosen. First, most of the harvested wood is processed in the largest town. This allowed us to realistically assume one delivery point. Second, Koochiching County and Boise Cascade, Inc., the largest industrial forest landowner in the county, had prepared a map that included all public roads, their own privately maintained system, and the seasonal logging roads as well. Third, the county contained an exceptionally large number of forest inventory plots, which permitted a detailed picture of forest access. Fourth, the small number of farms and resorts caused no problems in determining which roads would allow forest access and timber hauling.

Forest Survey Plot Record

The forest inventory plot records were obtained from all cooperators of the last survey: the Minnesota Department of Lands and Forests, Koochiching County, Bureau of Indian Affairs, North Central Forest Experiment Station, and Boise Cascade Corporation.

Measuring Forest Access

Road Network Quality

Although photos offer the best alternative for determining road quality, a photo-ground check of road quality should be made at the same time the plots are visited. This was beyond our resources and instead the detailed road map prepared by Koochiching County and Boise Cascade, Inc. was used. In contrast to most maps, it included the network of seasonal and privately maintained logging roads.

The five road types indicated by the map were assigned to cost-haul classes developed by the USDA Forest Service for timber appraisal purposes. Their table, relating round-trip speed in dollars per cord-mile to truck size and road quality, and the accompanying definitions, is presented in Appendix D.

The following tabulation shows how the roads in Koochiching County were classified according to the USDA Forest Service system.

As shown on the Koochiching county map	*USDA Forest Service quality class*
Paved, county, and State aid highways	High speed, permitting round-trip speed, 45 m.p.h.
Graveled township roads	Cost Haul Class I, permitting round-trip speed 35 m.p.h.
All-weather forest roads	Cost Haul Class II, round-trip speed 25 m.p.h.
Dry weather forest roads	Cost Haul Class III, round-trip speed 16 m.p.h.
Winter forest roads	Cost Haul Class IV, round-trip speed 8 m.p.h.
Cross-country access distances (assumed to be covered at a later date by a low-class road)	Cost Haul Class V, round-trip speed 4 m.p.h.

This classification is relatively accurate for road conditions in Koochiching County, but the assumption of a Cost-Haul Class V road for cross-country access distance was arbitrary. It cannot be known what road quality will eventually be used in any given situation. Certainly it depends on factors not foreseeable by this or any other study, such as total sale volume and the access distance itself. However, it is an easy matter to change this assumption if desired.

Estimating Road Lengths

Knowing the lengths of various road types is obviously essential to a complete understanding of the forest access picture. According to the various agencies responsible for road maintenance there are:

	Miles
County- and State-aid highways	250
County township roads	180
State forest roads	150
Privately maintained logging roads	150
Total	730

In addition, the detailed road map of the county shows an extensive network of seasonal woods roads. This network has been estimated to be 200 to 300 miles. If these figures are accepted for the moment, the total road length in the county approaches 1,000 miles of all types.

However, the application of Buffon's solution to a problem in geometrical probability (Appendix A, equation 11) allows us to estimate road lengths with surprising ease and accuracy:

$$L = \frac{\pi}{2} bn$$

where

L = road length in miles.
b = spacing in miles of a system of parallel, equidistant, randomly located, transect lines.
n = the number of intersections between the road net and the transect.
π = 3.1415.

To eliminate possible bias, two transects were used; the first was randomly located and the second was positioned perpendicular to the first (fig. 5).

Since it has been shown (Segebaden 1964) that the spacing of the transect system is related to the standard error of the road length estimate, it is possible to determine the spacing, b, in order to meet a desired level of confidence in the estimated length of the road net, L. An example of this calculation is shown in Appendix A. Setting b = 6 miles should permit an estimate of L to within ±5 percent of its true value 67 percent of the time (i.e., 1 standard error = 5 percent).

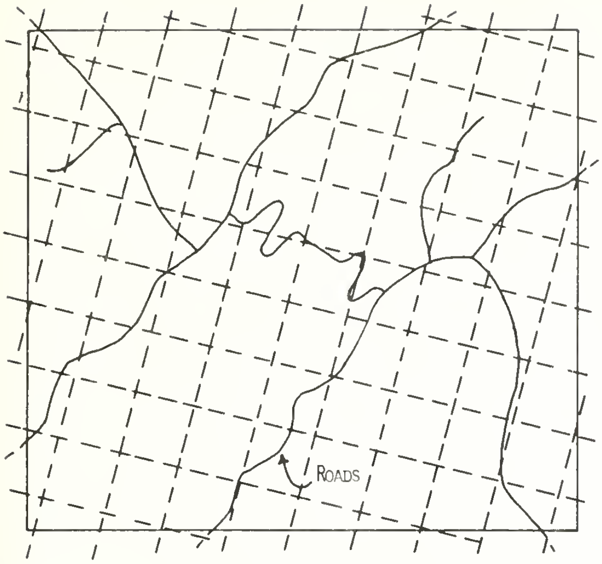

Figure 5.–Randomly located perpendicular line transect system on a road net.

After drawing the two transect systems on the map, the intersections between the road net and each transect were recorded by road quality as indicated on the map.

$$\text{Road length, L} = \frac{\pi \cdot 6 \cdot n}{2} = 3\pi n.$$

The method results in an estimated 2,700 miles of roads of all types (table 1).

Table 1.–Estimated road lengths in Koochiching County by a randomly located perpendicular transect

Road quality	Transect NE-SW	Transect NW-SE	Transect Combined	Estimated relative error1/
	Miles			Percent
Paved	301.6	329.9	315.7	9.3
Gravel	75.4	75.4	75.4	19.0
All-weather woods road	829.4	820.0	824.7	5.7
Dry weather woods road	207.3	113.1	160.2	13.0
Winter woods road	1,131.0	1,460.8	1,295.9	4.6
Total	2,544.7	2,799.2	2,671.9	3.2
Railroads	84.8	94.2	89.5	17.4

1/ Where relative error (ϵ) = $76/\sqrt{n}$, from an empirical formula developed by von Segebaden (Segebaden 1964).

How accurate are these results? Certainly, they differ substantially from the initial estimate of 1,000 miles.

Comparing the NE-SW and the NW-SE transects shows little variation and their average is the final result. The last column estimates approximate error where relative error percent percent $= \frac{76}{\sqrt{n}}$, and where n = number of intersections with the transect and road system (Segebaden 1964). The estimated overall error is well within 5 percent.

To test the transect method another way, we measured the lengths of paved and graveled roads and railroads *on the map*. Mileage as determined by:

	Random transect	*Map measure*	*Percent error*
Paved roads	315.7	340.0	-7.1
Gravel roads	75.4	73.0	+3.0
Railroads	89.5	93.0	-3.8

Results from the two procedures agree closely, suggesting that available statistics grossly underestimate the extent of the seasonal woods road network in Koochiching County.

Straight-Line Cross-Country Access Distance

This is the "crow-fly" distance from plot center to the nearest road of any kind. Because the base map had a scale of 0.5 inch = 1 mile and we measured distances to 0.125 inch, cross-country access and road haul distances were actually measured to the nearest 0.25 mile. While it would have been possible to measure more precisely, we did not because the inherent error in the map was unknown.

Using a pair of dividers, the shortest straight-line distance was measured from each plot center to nearest road. For example, in figure 4 it is the distance $\overline{AB}$.

Road Haul Distances

Road haul distance is the distance from the "delivery point" to the spot where the straight-line cross-country access distance intersects the road. These distances were measured immediately after the straight-line access distance and entered on the same form.

Adjusting Straight-Line Access Distances for Actual Conditions

This study did not take a subsample of plots to estimate a cross-country access adjustment factor. Instead, Swedish studies in similar terrain (Segebaden 1964) and unpublished correspondence with Gustaf von Segebaden were used. He found that the cross-country access adjustment factor (C) equaled 1.25 in terrain much like northern Minnesota. This value of C was used for illustration.

Results

Cross-Country Access

Cross-country access varied considerably by ownership (table 2), but the results agree with expectations. For example, private lands, both miscellaneous private and forest industry, were more accessible on the average than public. This makes sense because access is a necessary condition for most private land ownership. The State of Minnesota holds the least accessible land, and this also agrees with their large holdings of bog and swampland in the county.

Table 2.–Straight-line (sd) and practical (PD) cross-country distances by owner–Koochiching County

Owner	Area	Sample points	$\overline{sd}$	$\overline{PD}$	Relative error, practical distances[1/]
	Acres	n	Miles	Miles	Percent
County	292,600	520	0.47	0.58	5.2
State	792,200	204	.69	.86	8.1
Federal	92,200	162	.48	.60	8.3
Misc. private	194,000	117	.30	.38	15.8
Forest industry	204,000	552	.30	.38	5.3
Total	1,575,000	1,555	--	--	--
Area weighted mean	--	--	.54	.67	5.7

1/ Relative error = $\dfrac{S_{PD}/\sqrt{n}}{\overline{PD}} \times 100$.

While the different bases for calculation may cast some doubt on the combination, the average point in Koochiching County is 0.54 "crow-fly" miles from the nearest road of any kind, or 0.67 "over the ground" miles.

As suggested in the previous section, the data from table 2 can be used to estimate the "unevenness" of the real road net as compared with an ideally distributed net of the same length. Earlier the entire road net was estimated to equal 2,762 miles. From equation 2,

$$\text{road net density } \Delta = \frac{\text{length}}{\text{area}} = \frac{2{,}672 \text{ miles}}{3{,}129 \text{ sq. mi.}}$$

$$= 0.85 \text{ miles/sq. mi.}$$

From equation (4) an ideal mean cross-country access distance $\overline{SD}$;

$$\overline{SD} = \frac{1}{4\Delta} = 0.29 \text{ miles.}$$

It has been pointed out that this calculation falsely assumes an equal areal distribution of the 2,672-mile road net. However, dividing $\overline{sd}$ from table 2 by $\overline{SD}$ yields the road net adjustment R.

$$R = \frac{\overline{sd}}{\overline{SD}} = \frac{0.54}{0.29} = 1.86.$$

Transport Distances and Costs by Cover Type and Species

A computer program (ACCESS) was developed that calculates volumes and cover type areas by total transport distance and cost to a specified "delivery point" from the following data:

1. Cover type areas up to 20 cover types.
2. Access measures for each plot up to 2,000 plots.
3. Cover type classification and species volumes per acre for each plot up to 20 species.
4. Cross-country adjustment factor, C.
5. Transport costs per cord mile for six road quality classes and up to four different truck sizes (referred to as Option 1, 2, 3, or 4).

Two sets of tables result; one set of cover type tables, and one set of species tables.

Table 3 is an example of the cover type output of the ACCESS program. There is another like it for each cover type. Briefly, it displays type areas, mean distances by road classes, transport costs for different truck sizes, and species volumes and volume-weighted transport costs for several "total distance to delivery point" classes. For a graphic look at these data, see figure 6.

Several species are usually present in a cover type in varying proportions; thus, table 4 shows the distribution of aspen volume from all cover types. These data may be useful to forest industries whose processes require only certain species. The distribution of aspen volume by distance to delivery point is shown in figure 7. This figure resembles figure 6 closely because most of the aspen volume comes from the aspen type. This is not always so, however. In some cases the volume distribution of a *species* may be quite different from the distribution of the corresponding *cover type*.

While the distributions of cover type and species volume by distance to delivery point are interesting,

Table 3. – Abbreviated example of ACCESS cover type output showing type areas and volumes by transport distances and costs (Type: aspen; area: 100,000 acres; number of plots: 100; acres per plot: 1,000)

Item	Distance to delivery point (miles)					Totals
	0-20	21-40	41-60	61-80	81+	
Number of plots	10	30	50	5	5	100
Percent of total	10.0	30.0	50.0	5.0	5.0	100.0
Type acreage	10,000	30,000	50,000	5,000	5,000	100,000
Class mean total distance (miles)	17.5	31.0	55.5	68.0	98.5	
Class mean distance by road quality (miles):						
1. Paved	15.0	20.0	50.5	60.0	85.0	
2. Gravel	2.0	10.7	2.5	5.1	13.0	
3. Woods	.0	.0	2.2	2.5	.3	
4. Cross country	.5	.3	.3	.4	.2	
Transport cost/cord not weighted by volume (dollars):						
Option 1	2.75	5.50	7.00	9.00	11.25	
Option 2	3.00	6.25	7.50	9.75	12.00	
Species volume (cords) followed by volume-weighted transport costs/cord (dollars):						
White pine:						
Volume	5,000	40,000	200,000	--	5,000	250,000
Option 1 cost	2.75	5.00	7.10		10.00	
Option 2 cost	3.10	6.00	8.00		12.00	
Paper birch:						
Volume	5,000	60,000	350,000	25,000	60,000	500,000
Option 1 cost	2.50	4.75	9.00	9.50	11.00	
Option 2 cost	2.90	6.00	9.50	10.00	11.50	
Aspen:						
Volume	90,000	200,000	1,250,000	150,000	60,000	1,750,000
Option 1 cost	3.25	5.60	7.25	10.00	12.00	
Option 2 cost	3.50	5.70	7.75	11.00	12.50	
Total volume	100,000	300,000	1,800,000	175,000	125,000	2,500,000

a picture of transport cost is of even greater value to a decision maker.

Figure 8 illustrates the transport *cost-volume* distribution of the data in table 4. Although it is similar to the *distance-volume* distribution (fig. 7), anomalies may exist because some volumes, while closer to "delivery point," require transport over poorer roads and thus are more costly to deliver.

The bottom graph in figure 8 is especially important. It is the cumulative transport cost-volume distribution of the upper portion. If the axes are reversed, placing volume on the x-axis and transport cost on the y-axis, the *marginal transport cost* curve for aspen results. For example, if mill management wishes 460,000 cords delivered, the cost of the last cord (assuming that the cheapest wood is harvested first) will be $5.40 for Option 1. This is not an average cost, however; only the last 340,000 cords would cost that much.

More to the point, mill management might ask: If we wish 460,000 cords delivered and a representative group of stands are harvested, what will our *average transport cost* be? An approximate answer can be found by dividing the sum of the transport costs of all volumes up to a specific total volume by that total volume. For example, from table 4, the first 120,000 cords cost $2.85 per cord and the next 340,000 cords cost $5.40 per cord to transport. *Average transport cost per cord* for 460,000 cords then equals:

$$\frac{(120{,}000 \text{ cds. x } \$2.85/\text{cd.}) + (340{,}000 \text{ cds. x } \$5.40/\text{cd.})}{460{,}000}$$

$$= \frac{\$2{,}178{,}000}{460{,}000 \text{ cds.}} = \$4.73/\text{cd.}$$

Figure 9 shows the average transport cost curve for the aspen growing stock from figure 8.

While the preceding table and discussion apply to the entire aspen growing stock, the marginal and average transport cost picture for aspen desirable cut can be estimated by assuming that desirable cut is distributed proportionately among the distance classes. This assumption may not be entirely correct, but it offers a useful starting point for reaching conclusions about desirable cut access. The last row of table 4 from the ACCESS program uses this assumption to calculate the distribution of desirable cut by distance and transport cost class.

Table 4. — Abbreviated examples of ACCESS species output showing species growing stock and desirable cut volumes by transport distances and costs (Specie: aspen; annual desirable cut: 30,000 cords)

Item	Distance to delivery point: 0-20	21-40	41-60	61-80	81+	Total
Type:						
White pine	--	20,000	10,000	5,000	5,000	40,000
Paper birch	30,000	120,000	175,000	100,000	75,000	500,000
Aspen	90,000	200,000	1,250,000	150,000	60,000	1,750,000
Total volume	120,000	340,000	1,435,000	255,000	140,000	2,290,000
Overall-volume weighted transport costs (dollars/cord):						
Option 1	2.85	5.40	7.00	8.95	11.00	
Option 2	3.15	6.35	7.45	9.70	12.50	
Percent of growing stock	5.2	14.8	62.7	11.2	6.1	100.0
Distribution of desirable cut (cords)	1,560	4,440	18,810	3,360	1,830	30,000

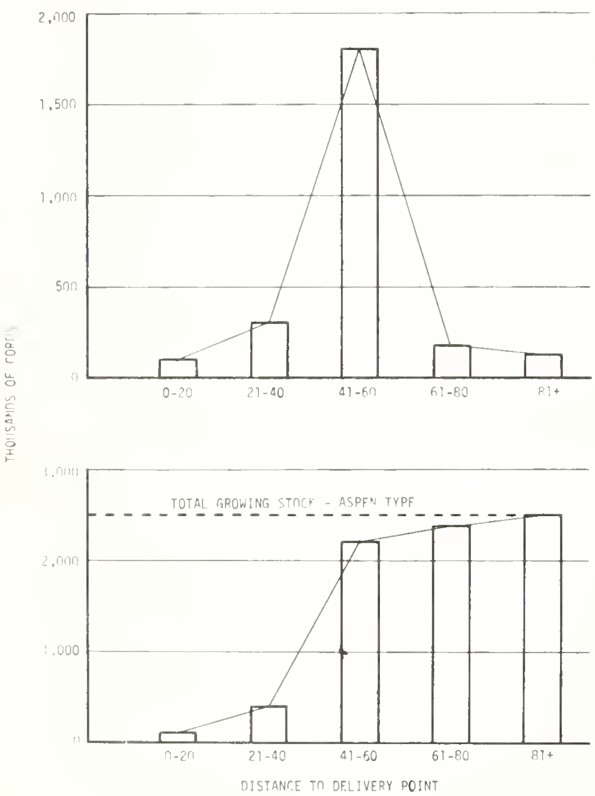

Figure 6.—Distribution of volume by distance from International Falls for all species within the aspen cover type. The top graph shows volumes at class mean distance; the bottom graph shows cumulative volumes at class upper limit.

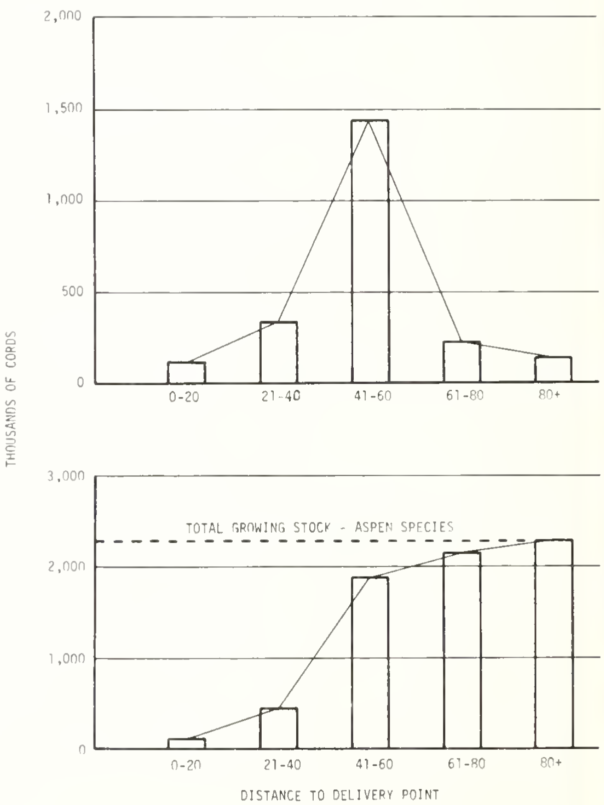

Figure 7.—Distribution of volume by distance from International Falls, aspen growing stock from all cover types. The top graph shows volumes; the bottom graph shows cumulative volumes.

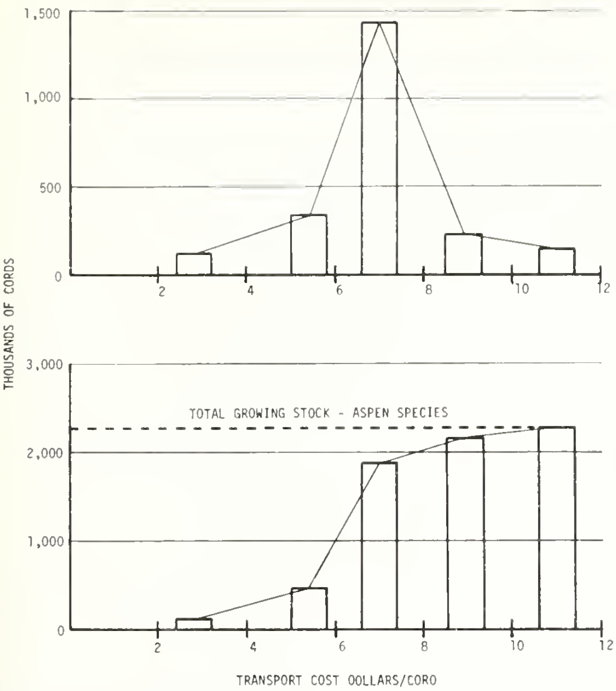

Figure 8.—Distribution of volume by Option 1 transport costs to International Falls, aspen growing stock from all types. The top graph shows volumes; the bottom graph shows cumulative volumes.

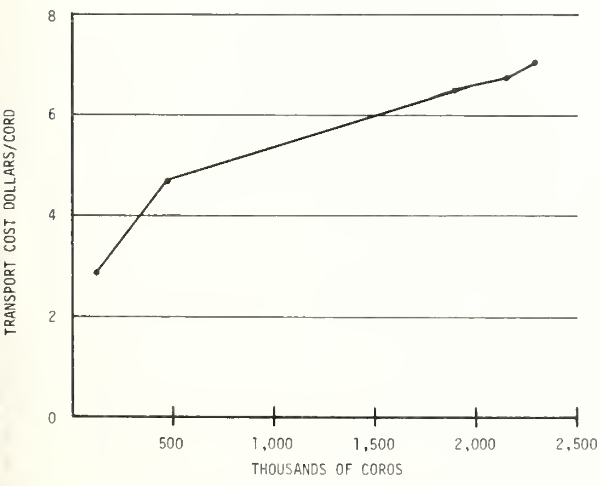

Figure 9.—Average transport cost per cord for option No. 1 to International Falls, aspen growing stock from all types.

Applications

There are three general areas in which forest access data have been of value (Segebaden 1969). First, the most common problem is to reduce a gross estimate of growing stock (or desirable cut) to that portion which is economically accessible (accessible in terms of the effects of terrain and distance on transport costs, and with a specific transport technology).

Second, the problem is to identify how location affects the desirability—i.e., profitability—of forest investments such as planting, release, or even fire protection.

Finally, the problem is to identify how the answers to the first and second questions affect the purchase, sale, or exchange of forest lands.

The average transport cost curve, figure 9, furnishes a brief example. For any mill with a fixed capacity in the short run, this average transport cost curve is the relevant one because it indicates how much wood is deliverable within a cost restraint. Given the mill's technology and the price its output demands in the market, this kind of graph should allow the mill to estimate what price it can afford to pay, on the average, for its pulpwood. Generally, the harvest-cost portion of a cord's total delivered price is relatively constant. Transport cost is the variable factor.

Therefore, if it is possible for a mill to estimate how its supply of wood is distributed by transport costs, it may be possible to predict short-run profits.

And for the long run, this process makes it possible (using a computer, for example) to examine the economic impact of changes in the extent, distribution, and quality of a road network, on land purchase policies, and forest investments (Segebaden 1969).

RECOMMENDATIONS

Forest inventory data are fundamentally incomplete if one cannot judge the impact of location upon value. This brief look at the methodology and the potential of forest access data is intended to whet the appetite of all public agencies and private corporations that have had to answer the most difficult kinds of resource analysis questions with insufficient data. While these procedures have been developed and tested in Sweden for almost 5 years, there has been almost no parallel development in North America. This lamentable situation is all the more remarkable because of the method's basic simplicity. Although it has limitations, arising primarily from sample size, it offers a rich potential.

This resource information deficiency can be improved in several ways. First, inventories of public lands should seriously consider the collection and presentation of access data. This could range from only a determination of the extent of the transport system up to a complete application of the process described here. The actual level of additional effort should be a function of anticipated benefits.

At the present time we are conducting a cooperative test of the process for a corporation undergoing a major expansion of wood requirements. This test should give us a clearer picture of costs and benefits.

One of the results of this work to date is the realization that present forest inventory systems lack flexibility, making the data difficult to geographically rearrange or retabulate. For the very reason that forest inventories cannot anticipate every future request, the entire data handling process should be made more flexible.

On the other hand, the tremendous increase in the demand for all kinds of resource data from timber development groups, recreationists, and wildlife managers precludes a system flexible enough to satisfy everyone. Some middle ground exists, however, and survey procedures at the North Central Forest Experiment Station are moving in this direction.

Hopefully, this paper heralds a more intensive and widespread investigation of the practical problems posed by location on the economics of forest resource use.

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Appendix A

Estimating Road Lengths Using a Randomly Located Rectangular Transect System[6]

As the previous section indicates, the length of the present road network is an important statistic. Except for the better classes of public roads, these data are often not available. This is especially true for seasonal and private logging roads. However, a rather simple method to determine road length is available, and it can easily be adapted to any inventory system.

The method is derived from the "Needle Problem," a classical exercise in geometrical probabilities, as follows: A system of parallel equidistant lines is drawn on a sheet of paper with (b) the distance between the lines. A needle with length (a) is placed at random on the paper. What is the probability that the needle intersects the lines?

The probability according to the 18th century French naturalist Buffon is:

$$(9) \quad P = \frac{2}{\pi}\frac{a}{b}$$

For example, if the needle is 2 inches long and the lines are 4 inches apart, the probability that the randomly dropped needle will touch or cross a line is:

$$P = \frac{2}{\pi} \quad \frac{2}{4} = 0.3183$$

If the needle is dropped on the paper a great number of times, this probability can be used to calculate the expected number of contacts or intersections of the needle with a line. In the example given, the needle would touch or contact a line about P times the number of attempts, or 32 percent of the time.

Consider now a chain of N links, each link with length a, and total length L = Na. Conversely $a = \frac{L}{N}$. If the chain is placed at random on the line system, the probability of an intersection between any link and the system is given by equation (9). But if the probability of one intersection is $\frac{2}{\pi}\frac{a}{b}$ and there are N links, what is the expected number of intersections between the chain and the system? Since

$$P = \frac{2}{\pi}\frac{a}{b} \text{ and } a = \frac{L}{N},$$

$$\text{then } P = \frac{2}{\pi}\frac{L}{Nb};$$

$$(10) \therefore E(I) = PN = \frac{2}{\pi} \quad \frac{L}{b}.$$

The term "expected number" refers to a mean value that would be approached if this chain were dropped a large number of times. Thus, while a specific trial may yield no intersections (if all the links fell between the line system) or an infinite number of intersections (if all the links coincided exactly with the line system), the average number of intersections with many trials will equal $\frac{2}{\pi}\frac{L}{b}$.

Obviously the same result is obtained if the process is reversed by first placing the chain on the paper and then locating the parallel equidistant line system by random translation and rotation of the system in relation to fixed coordinate axes.

Consider next an area with a road network of length L. If a parallel equidistant line system is now placed at random over the network, the expected number of intersections is from equation 10:

$$E(I) = \frac{2}{\pi}\frac{L}{b}.$$

Assume for the moment that a specific test of this procedure results in n intersections. Substituting n for E (I) in the above and solving for L:

$$n = \frac{2}{\pi}\frac{L}{b},$$

$$L = \frac{\pi \ b \ n}{2}.$$

While this is only one trial, the expected value of this expression is L. That is,

$$(11) \quad E\left\{\frac{\pi \ b \ n}{2}\right\} = L.$$

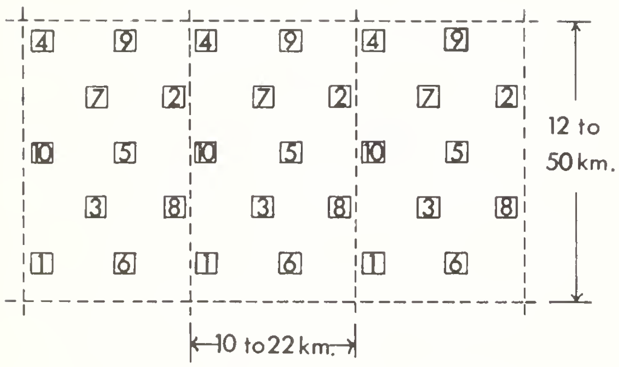
Thus, if the length of a road net is unknown, one may estimate its length by: (1) randomly locating a parallel,

[6] *The outline for this description is taken from an appendix by Bertil Matérn which appears in a publication by Gustaf von Segebaden: Studies of cross-country transport distances and road net extension: Studia Forestalia Suecica, 18, 70 p. 1964.*

equidistant line system with spacing b, over a road net or its map equivalent; (2) counting the number of intersections n; and (3) substituting the value of n in equation 11.

As mentioned before, individual estimates of L will vary from the expected value. Only the average of many trials will equal L. In fact, the variation may be great even if the equidistant lines are close together. This may happen, for example, if the roads are approximately parallel. However, the possibility of serious bias is greatly reduced if two line systems, perpendicular to each other, are used.

Other modifications of the line system to avoid bias are also possible using the basic principle of perpendicular systems. For example, the Swedish Forest Service uses closed rectangular transects located regularly throughout Sweden, figure 10. The four sides of the transect represent fragments of two perpendicular line systems.



--- Boundary of "survey area" with one tract surveyed each year.

☐ Tract boundary; perimeter varies from 4.8 to 8.8 km. in different provinces.

[1] Tract surveyed the first year, etc.

[4] Tract surveyed the fourth year, etc.

Figure 10.—Approximate layout of the Swedish national forest survey tracts. The dimension of the survey area varies between provinces.

Note from equation 11 that the estimate of length L is independent of the size of the area covered by the road net, the only parameter being the spacing of the transect lines, b. The parameter b works fine as long as one parallel equidistant line system is used. However, the spacing b is a meaningless term when applied to perpendicular systems such as the one used in Sweden. Instead, the length of the line system per unit area, t, is used. To calculate t for any shape of transect, divide the total length of the transect system by the total area in the survey unit.

$$t = \frac{1}{b} \quad \frac{\text{miles of road}}{\text{square mile of area}} .$$

This relationship is proved by the following, figure 11. Say, for example, that

$$b = \frac{1}{3} \text{ km.}$$

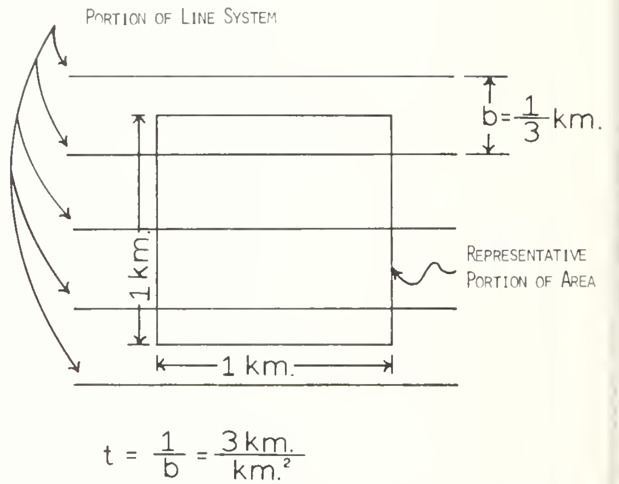


Figure 11.—The relationship between transect spacing (b) and transect length per unit area (t).

Multiply numerator and denominator by 1 kilometer to get the area per unit length,

$$b = \frac{1 \text{ km x km}}{3 \text{ km}} = \frac{1 \text{ km}^2}{3 \text{ km}} .$$

Taking the reciprocal of b we have

$$t = \frac{1}{b} = \frac{1}{\frac{1 \text{ km}^2}{3 \text{ km}}} = \frac{3 \text{ km}}{\text{km}^2} .$$

Determining the Spacing (b) of a Randomly Located Perpendicular Transect System

Segebaden (1964) has shown that the spacing of the transect system b is related to the standard error of the road length estimate according to the following approximate formula:

$$\text{Standard error percent} = \frac{76}{\sqrt{n}}$$

where n = number of intersections and standard error percent is for a confidence coefficient of 0.67.

This formula can be combined with a preliminary estimate of road length, L, to estimate an appropriate spacing, b, in the following manner.

First, choose a desired relative error. That is, a desired upper limit on the relative error in L to be estimated from the transect. For example, you may wish to estimate L from the transect to within ± 5 percent of its true value.

Next substitute the 5 percent in the approximate formula above and solve for n:

$$5 = \frac{76}{\sqrt{n}},$$

$$n = 231.$$

Next substitute a preliminary estimate of L (1,000 miles) and n (231) in the formula:

$$L = \frac{\pi b n}{2},$$

and solving for b,

$$b = \frac{2\ L}{\pi\ n} = \frac{(2)\ (1000)}{(3.14)(231)} = 2.75.$$

Thus, the spacing b of the line transect $\simeq$ 3 miles.

Appendix B

Determining the Proper Number of Point Samples to Accurately Estimate the Cross-Country Access Distances (sd) for Real Road Nets

Segebaden (1964) has designed an approximate formula to estimate the number of sample points from which to estimate the mean straight-line cross-country access distances for real road nets, $\overline{sd}$ (table 5).

While the formula was designed for rectangular arrays of sample points, it is also thought to be applicable to triangular arrays of points and other regular arrays as well. The approximate formula is as follows:

$$(12)\quad \log \sigma = 1.42 + \log\left\{\frac{A}{n\overline{SD}^2}\right\} \frac{6}{20 + \left[\log\left\{\frac{A}{n\overline{SD}^2}\right\}\right]^2},$$

and where the relative standard error of $\overline{sd}$ can be obtained from the formula:

$$(13)\quad \epsilon = \frac{\sigma}{\sqrt{n}}.$$

To use table 5, determine total area A, road length L, and calculate $\overline{SD}$ as if the road net was ideally distributed.

For example, if area A = 2,500 sq. miles and road length L = 833 miles,

Table 5. – Approximate number of points in a regular square spacing required to obtain a desired standard error of estimate of a mean straight-line cross-country access distance for a real net, $\overline{sd}$

Area	Desired limit of relative error, ε – percent1/														
(mi.^{2})	2.5 percent $\overline{SD}$, miles					5 percent $\overline{SD}$, miles					10 percent $\overline{SD}$, miles				
	0.25	0.50	0.75	1.0	1.25	0.25	0.50	0.75	1.0	1.25	0.25	0.50	0.75	1.0	1.25
5	95	60	45	35	30	40	25	20	15	15	15	10	10	5	5
10	125	75	55	45	40	55	30	25	20	15	20	15	10	10	5
15	145	90	65	55	45	60	35	25	20	20	25	15	10	10	10
20	160	95	70	60	50	65	40	30	25	20	30	15	15	10	10
25	175	105	75	65	55	75	45	35	25	20	30	20	15	10	10
50	230	135	100	80	70	95	55	40	35	30	40	25	20	15	15
75	265	160	115	95	80	110	65	50	40	35	40	25	20	15	15
100	290	175	130	105	90	120	75	55	45	40	45	30	25	20	15
250	405	245	185	150	125	160	105	75	60	55	60	40	30	25	20
500	510	320	240	195	160	195	130	100	80	65	70	50	40	30	30
1,000	640	405	305	245	215	240	160	125	105	85	85	60	50	40	35
2,500	840	550	425	345	295	300	210	165	135	120	100	75	60	55	45
5,000	1,010	670	530	440	370	350	255	205	170	150	110	90	75	65	55

1/ Relative standard error of the estimate at one standard deviation.

That is, $P\left[\hat{\overline{sd}} - \epsilon(\hat{\overline{sd}}) \leq \overline{sd} \leq \hat{\overline{sd}} + \epsilon(\hat{\overline{sd}})\right] = 0.67$

$$\Delta = \frac{833 \text{ mi.}}{2{,}500 \text{ sq.mi.}} = 0.333 \text{ mi./mi.}^2,$$

$$\overline{SD} = \frac{1}{4\Delta} = 0.75 \text{ mi.}$$

Choose an acceptable standard error; i.e., 5 percent. Now look in the table for an area of 2,500 square miles, a desired error of 5 percent, and an $\overline{SD}$ of 0.75 miles. The result is 165, the number of sample points that should provide an estimate of $\overline{sd}$, the mean straight-line cross-country access distance for a real road net, with an error equal to or less than 5 percent.

Table 5 was prepared by solving equation 13 for σ,

$$(14) \quad \sigma = \epsilon \sqrt{n},$$

substituting the right-hand portion in equation 12,

$$(15) \quad \log(\epsilon\sqrt{n}) = 1.42 + \log\left\{\frac{A}{n\overline{SD}^2}\right\} \frac{6}{20 + \left[\log\left\{\frac{A}{n\overline{SD}^2}\right\}\right]^2}$$

and solving equation (15) for n by iteration.

Appendix C

Summary of Terms Relating Road Net Length and Distribution to Cross-Country Access

For ideally distributed road nets (fig. 1):

W = width of area between roads.
L = length of road or area influenced by road.
SD = straight-line cross-country access distance.
Δ = road net density, road length per unit area.

For irregularly distributed roads (fig. 2):

sd_i = straight-line cross-country access distance for the i *th* sample point.
R = road net adjustment.

For real road nets, both irregular and topographic (fig. 3):

PD_i = practical cross-country access distance for the i *th* sample plot.
C = cross-country transport adjustment.

These parameters are related in the following way:

$$(16) \quad \overline{SD} = \frac{W}{4},$$

$$(17) \quad \Delta = \frac{L}{LxW} = \frac{1}{W}.$$

Taking the reciprocal of (17),

$$(18) \quad W = \frac{1}{\Delta}.$$

Substituting (18) in (1),

$$(19) \quad \overline{SD} = \frac{1}{4\Delta}.$$

From an irregular road net,

$$(20) \quad \overline{sd} = \frac{\Sigma sd_i}{n}.$$

Tying ideal road nets to irregular nets is the equation:

$$(21) \quad R = \frac{\overline{sd}}{\overline{SD}} \geqq 1.0,$$

where R is a measure of road net irregularity. Rearranging (21),

$$(22) \quad \overline{sd} = R\,\overline{SD}$$

From a real road net,

$$(23) \quad \overline{PD} = \frac{\Sigma PD_i}{n}.$$

Tying irregular road nets to real road nets is the equation

$$(24) \quad C = \frac{\overline{PD}}{\overline{sd}} \geqq 1.0$$

Rearranging (24),

$$(25) \quad \overline{PD} = C\,\overline{sd}.$$

Substituting (22) in (25),

$$(26) \quad \overline{PD} = CR\,\overline{SD}.$$

Substituting 19 in 26, ideal, irregular, and real road nets are tied together by:

$$(27) \quad \overline{PD} = \frac{C\,R}{4\Delta}.$$

This last result means that an overall practical cross-country access distance for a real road net ($\overline{PD}$) can be estimated from a knowledge of the existing road net geometry (R), the terrain (C), and the road net density (Δ).

Appendix D

Forest Service's Road Classification System[7] and Transport Costs for Minnesota Pulpwood

Hauling rates are based on drivers' wages, including compensation insurance and other payroll taxes, cost of equipment, depreciation insurance, and all operating costs (table 6). The costs were based on 1968 data for wages, truck, trailer, and loader selling prices, insurance rates, and tire and fuel costs. Current depreciation rates of straight-line 6-year life and 6 percent interest rates were used. All adjustments were made on a comparison basis with the 1957 R-7 truck hauling cost study and the Byrnes-Nelson-Coogin report on log hauling costs.

Table 6.—Hauling costs for Minnesota pulpwood by road quality and truck size (In dollars per cord-mile)

Road class	Truck size--mean load (cords)1/			
	4	6	8	10
High speed, 45 m.p.h.	0.09	0.08	0.08	0.06
Class I, 35 m.p.h.	.13	.12	.11	.08
Class II, 25 m.p.h.	.18	.17	.16	.12
Class III, 16 m.p.h.	.26	.24	.24	.18
Class IV, 8 m.p.h.	.47	.43	.46	.34
Class V, 4 m.p.h.	.85	.78	.86	.65
Fixed costs (standby, delay, load, unload)	1.78	1.65	1.41	1.81

1/ Truck description--all are equipped with loader: 4 cords, flat bed, 4 by 2, single axle, GVW 28,000 lbs.; 6 cords, flat bed, 6 by 4, tandem axle, GVW 37,000 lbs.; 8 cords, truck tractor, 4 by 2, single axle, with 28-30 ft. platform bed, GVW 59,000 lbs.; 10 cords, truck tractor, 4 x 6, tandem axle, with 30-35 ft. platform trailer, GVW 72,000 lbs.

262—Road Capacity and Service Class Description

High speed highways, average running speed 45 m.p.h.— This class of road includes the best highways where trucks are able to maintain a high average speed. However, consideration should be given to delays through towns, etc.

Cost haul Class I, average running speed 35 m.p.h. This class includes Federal, State, and primary county highways with concrete or bituminous pavement of well stabilized gravel surfacing. The design speeds for highways in this group will fall within the range of 40 to 60 miles per hour. Truck running speed for this group will range from 30 to 40 miles per hour, with an average of 35 miles per hour. If a section of a highway in this class has a 1/4 mile or more of sustained adverse grades of 6 percent or greater, that portion should be considered as a Class II road.

Cost haul Class II, average running speed 25 m.p.h.— This class includes county secondary, township, and forest roads with a design speed of 30 miles per hour and truck running speed averaging 25 miles per hour. Roads in this class will be two-lane width or single-lane with intervisible passing sections. The roadway surface may have bituminous, compacted gravel, or stabilized soil wearing course well maintained. Horizontal alignment is limited to minimum radius curves of 300 feet and maximum grades of 7 percent. If a section of a road within this group has a 1/4 mile or more of sustained adverse grades exceeding 7 percent, that portion should be considered as a Class III road.

Cost haul Class III, average running speed 16 m.p.h.— This class includes county, local, township, and one-lane forest roads with a design speed of 20 miles per hour, and truck running speed of 16 miles per hour. One-lane roads will have passing sections, but not always located at intervisible points. The roadway will usually have fair gravel or soil wearing surface with intermittent blade maintenance. Horizontal alignment is limited to minimum radius curves of 200 feet and maximum grades not exceeding 10 percent. If a section of a road within this group has a 1/4 mile or more of sustained adverse grades exceeding 10 percent, that portion should be considered as a Class IV road.

Cost haul Class IV, average running speed 8 m.p.h. This class includes roads, regardless of jurisdiction, that are single-lane in width and lacking adequate passing sections. These roads will classify as low service facilities with little or no consideration given to design speed during route selection or construction. They will usually have winding alignment with numerous sharp curves. The vertical alignment closely follows the rolling natural ground line with hidden dips and undulating grades. Maximum grades may be up to 12 percent. Roads in this class are usually unsurfaced with

[7] *Source: Handbook of timber appraisal. USDA For. Serv. Reg. 9. Chap. 260, June 1968, Amend. 36; Oct. 1968, Amend. 39.*

limited spot graveling on unstable sections. Drainage is usually limited to natural drainage channels where they cross the roadway. Truck running speeds may range from 6 to 11 miles per hour with an average of 8 miles per hour.

Cost haul Class V, average running speed 4 m.p.h. – This class includes the poorest service roads within the sale area. They are usually narrow and undrained with winding alignment and rolling grades. They are average one-lane dozer-constructed roads with low protruding rocks and stumps in the driving surface and with limited or no passing sections. Truck running speeds may range from 3 to 5 miles per hour with an average speed of 4 miles per hour. Do not allow for short sections (up to 400 feet) out of landings as this cost is taken care of in standby time.

Appendix E

ACCESS, a Fortran IV Program[8]

This program was written to conform to an algorithm supplied by Dennis P. Bradley. It takes as partial input the plot record from a forest survey. This record can consist of the following data for each plot: (1) cover type, size, and density up to 20 cover types and (2) species volumes per acre–up to 20 species. At present, size and density are not used in the summary tables but the program can be easily modified to provide this feature.

In addition, the cross-country access distances and the hauling distances for up to six road quality classes for each plot are required. Finally, if transport costs are desired, up to four different truck or other transport options are permissible. Program output by cover type and species is illustrated in tables 3 and 4, respectively in the text.

Program Statistics. Size: main 110,048 bytes, subprogram 1,584 bytes, total 111,632 bytes of core. Disk requirements: 108 bytes per plot. Typical run time (compilation and execution) with approximately 1,000 plots: 8 minutes.

Equipment used.–At Michigan Technological University, Houghton, Michigan: (1) IBM/360, Model 44–(a) 256,000 bytes of core, (b) HASP operating system (c) Fortran IV: FORGO–and (2) 2314 Disk Drive.

To obtain this program for study or use, send inquiry to D.P. Bradley, North Central Forest Experiment Station, 118 Old Main Building, Duluth, Minnesota 55812.

The following flow chart (fig. 12) is a simplified description of the program.

[8] *Written by Donald Moore, Forest Engineering Laboratory, North Central Forest Experiment Station, USDA Forest Service, Houghton, Michigan.*

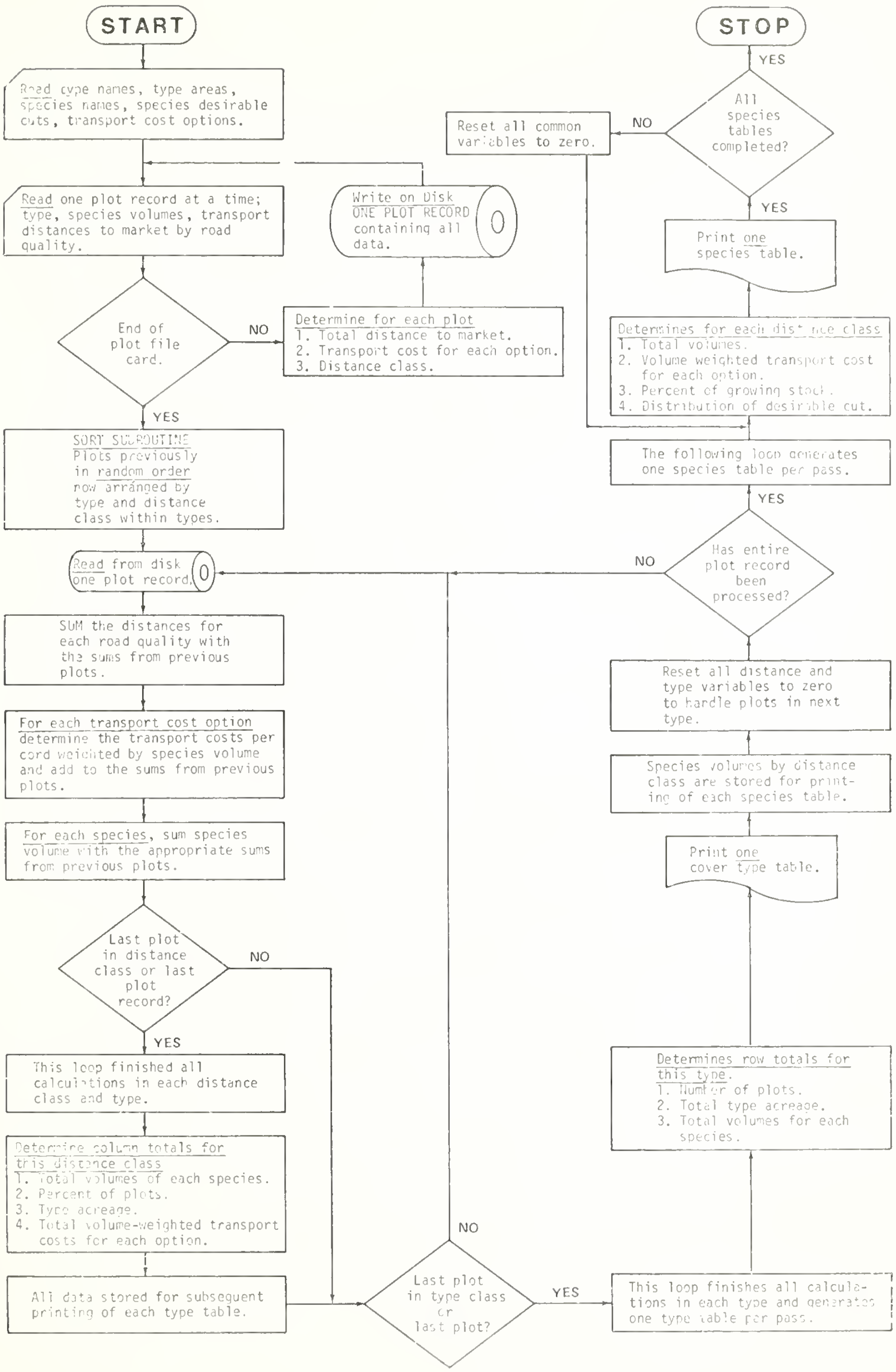


Figure 12. - Flow chart for ACCESS program.

SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

Crosscut Shearing of Roundwood Bolts, by Rodger A. Arola. USDA For. Serv. Res. Pap. NC-68, 21 p., illus. 1971.

Storm Flow from Dual-Use Watersheds in Southwestern Wisconsin, by Richard S. Sartz. USDA For. Serv. Res. Pap. NC-69, 7 p., illus. 1971.

Annotated Bibliography of Walnut Supplement No. 1, by Martha K. Dillow and Norman L. Hawker. USDA For. Serv. Res. Pap. NC-70, 23 p. 1971.

Fire Whirlwind Formation Over Flat Terrain, by Donald A. Haines and Gerald H. Updike. USDA For. Serv. Res. Pap. NC-71, 12 p., illus. 1971.

The Changing Hardwood Veneer and Plywood Industry of Michigan and Wisconsin, by Gary R. Lindell and Lewis T. Hendricks. USDA For. Serv. Res. Pap. NC-72, 8 p., illus. 1972.

Estimating Force and Power Requirements for Crosscut Shearing of Roundwood, by Rodger A. Arola. USDA For. Serv. Res. Pap. NC-73, 8 p., illus. 1972.

Effect of Topography on Microclimate in Southwestern Wisconsin, by Richard S. Sartz. USDA For. Serv. Res. Pap. NC-74, 6 p., illus. 1972.

Weights and Centers of Gravity for Red Pine, White Spruce, and Balsam Fir, by H.M. Steinhilb and John R. Erickson, USDA For. Serv. Res. Pap. NC-75, 7 p., illus. 1972.

Fire Weather and Behavior of the Little Sioux Fire, by Rodney W. Sando and Donald A. Haines. USDA For. Serv. Res. Pap. NC-76, 6 p., illus. 1972.

Canoeist Suggestions for Stream Management in the Manistee National Forest of Michigan, by Michael J. Solomon and Edward A. Hansen. USDA For. Serv. Res. Pap. NC-77, 10 p., illus. 1972.

ABOUT THE FOREST SERVICE . . .

As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

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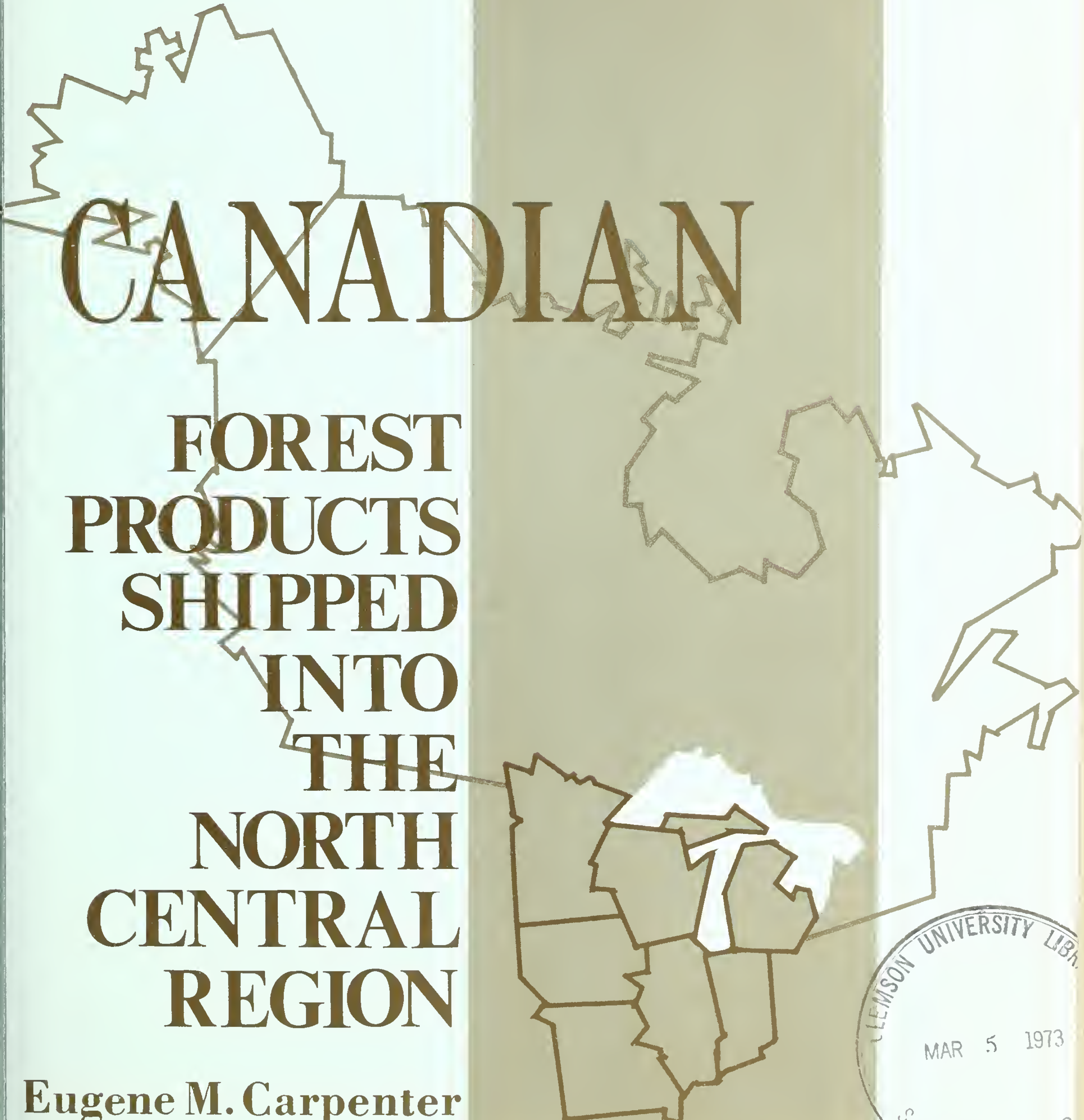

CANADIAN FOREST PRODUCTS SHIPPED INTO THE NORTH CENTRAL REGION

Eugene M. Carpenter

NORTH CENTRAL FOREST EXPERIMENT STATION • FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

THE AUTHOR, a Market Analyst, is headquartered at the Station's office in Duluth, Minnesota, which is maintained in cooperation with the University of Minnesota-Duluth. Special acknowledgment is made to Robert V. McIntyre, Assistant Commissioner, Office of Regulation and Rulings, Bureau of Customs, Washington, D.C., and Mr. Fred R. Boyette, Regional Commissioner of Customs, Chicago, Illinois, for the cooperation of their agencies in this study.

Also special recognition is given to Dino S. Villa, Chief, Foreign Trade Division, and Mrs. Lala B. Pipkin, Chief, Trade Information Branch, Bureau of the Census, for their help in supplying District import data.

CONTENTS

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Manuscript approved for publication July 17, 1972

CANADIAN FOREST PRODUCTS SHIPPED INTO THE NORTH-CENTRAL REGION

Eugene M. Carpenter

HIGHLIGHTS

The increased use of domestic aspen and other hardwoods and expanded importation of softwood woodpulp in recent years have caused a significant decline in imports of Canadian pulpwood and have contributed to the steady growth of the Lake States paper industry. However, it is unlikely that the Lake States forest resource can compete for a much larger share of the market for most major forest products imported from Canada.

Total U.S. imports of forest products from Canada in 1969 were valued at $2.138 billion, which was 79 percent of the total $2.706 billion of forest products imported from all foreign countries. Corresponding figures for 1965 were $1.599 billion and $1.941 billion, or increases of 34 and 39 percent, respectively, in terms of current dollars.

The value of Canadian forest products imported through North Central Customs Districts was $906.5 million in 1969, up 33 percent from the $679.5 million in 1965. The north-central region received slightly more than 42 percent of U.S. forest product imports from Canada in 1969 (figure 1, table 1). These value data represent the market value in the foreign country in U.S. dollars and exclude freight, insurance, and duty charges.

Three commodities — newsprint, softwood lumber, and woodpulp — accounted for 89 percent of the value of all forest products imported from Canada into the United States, and 87 percent of the value of all Canadian forest products that came into the north-central region in 1969. Shingles and shakes, uncoated book paper, hardwood veneer, hardwood lumber, wood siding and pulpwood and chips made up most of the remainder. The volume of north-central region imports decreased from 1960 to 1969 for pulpwood, birch plywood, drilled and/or treated lumber, wood siding, and sulfite and soda pulps. However, importation of these products increased: newsprint, uncoated book paper, wrapping paper, hardboard, softwood lumber, shingles and shakes, building board, birch and maple veneer, hardwood flooring, hardwood lumber, poles and piling, and sulfate pulp. Imports of groundwood and specialty pulps have remained about the same in spite of significant increases in U.S. production.

DISCUSSION AND PERSPECTIVE

Canada historically has been and will continue to be an important source of forest products for the north-central region. This report summarizes recent trends in the importation of various forest products from Canada and approximates the volumes of these products that have a first destination within the region. Also, it indicates the volumes of materials shipped through the area and the region to which these products were apparently destined. Thus, it documents the degree of dependence that the area places on the Canadian forest resource and the importance of this international trade to the economy of the region. At the same time it may suggest opportunities for increasing the utilization of local forest resources, particularly for products that have been increasingly imported and for which the local forest resource could be successfully utilized.

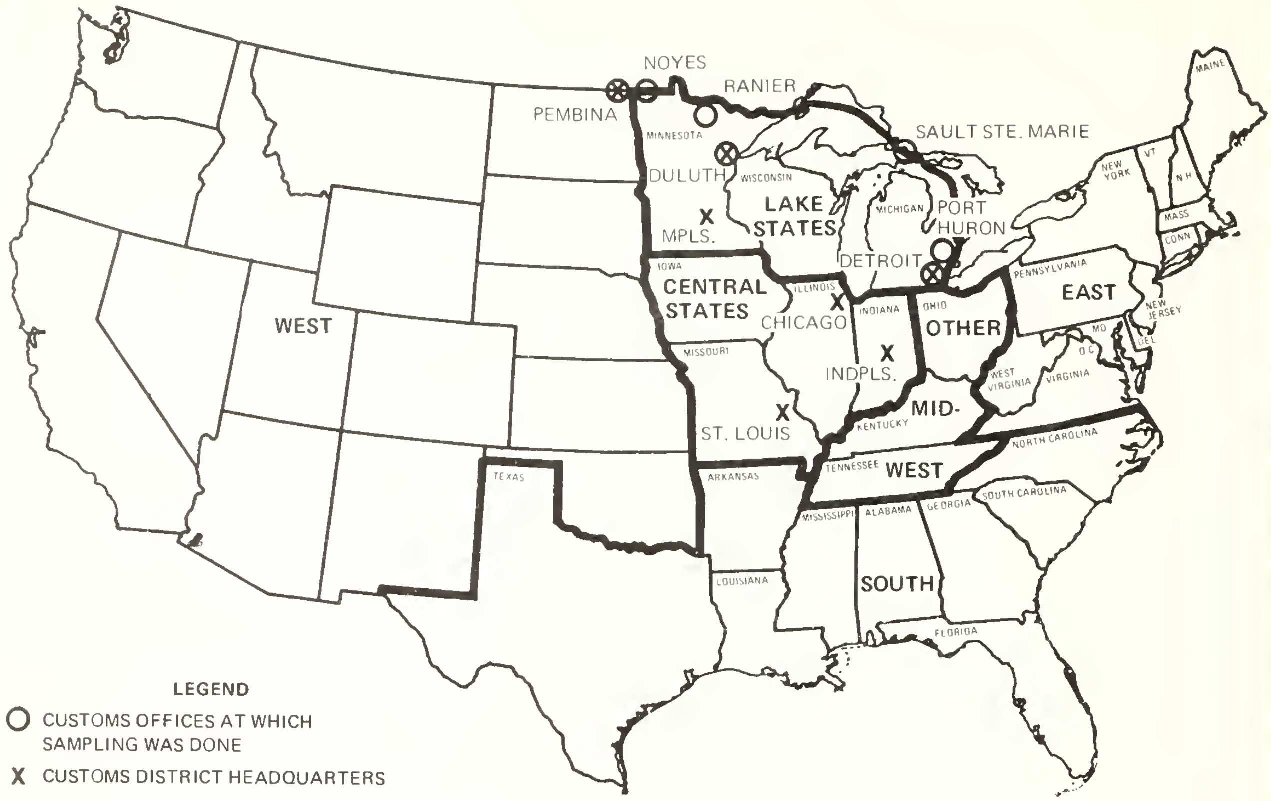

Figure 1.—*Regions of destination and Customs offices at which sample data were collected. The north-central region includes Lake States and Central States.*

The problem of forest resource underutilization in the region is basically a need for expanded market opportunities for surplus volumes of hardwood growing stock and small sawtimber — trees which can be used in the manufacture of fiber products such as woodpulp, hardboard, and particleboard, or for pallet-type lumber and railroad ties.[1] Of the softwoods, balsam fir is vastly undercut. The most recent forest survey of Michigan shows that the growing stock harvest for every species except jack pine could be increased.[2] The annual cut of balsam fir, hard and soft maple, aspen, and white birch is well below the allowable cut[3] and should be increased considerably. Although up-to-date forest survey information is not available for Minnesota and Wisconsin, it appears that surplus hardwood poletimber[4] is available in Wisconsin, and that surpluses of aspen, white birch, and balsam fir are available in Minnesota.

The availability of surplus saw log material is limited to certain species and survey districts; for example, northern white cedar in Michigan's eastern Upper Peninsula and aspen in northern Minnesota. Most saw log surpluses are not large enough to cause

[1] *Growing stock is defined as all live trees of any size except rough and rotten trees.*

[2] *Chase, Clarence D., Ray E. Pfeifer and John S. Spencer, Jr. The growing timber resource of Michigan. USDA For. Serv. Resour. Bull. NC-9, 62 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn. 1966. This and other timber resource reports for the north-central States can be obtained from the North Central Forest Experiment Station, Folwell Avenue, St. Paul, Minn.*

[3] *Allowable cut is the average net volume that should be cut annually on commercial forest land to improve the tree stocking and bring about a better distribution of age classes.*

[4] *Poletimber trees are live trees of commercial species at least 5.0 inches d.b.h (diameter breast height) but smaller than sawtimber. Sawtimber trees contain at least one 12-foot saw log, and must be 9.0 inches d.b.h. for softwoods and 11.0 inches d.b.h. for hardwoods.*

Table 1. — *Value of U.S. and north-central region imports[1] of Canadian forest products, 1965 and 1969*

Commodities	U.S. imports from Canada 1969 Rank	Value	1965 Rank	Value	North Central imports from Canada 1969 Rank	Value	1965 Rank	Value
		Million dollars		Million dollars		Million dollars		Million dollars
Newsprint	1	903.5	1	762.2	1	313.4	1	268.6
Softwood lumber	2	517.4	3	294.7	2	253.8	3	150.1
Woodpulp	3	482.5	2	363.1	3	226.6	2	165.0
Shingles and shakes	4	42.9	4	29.0	4	24.0	6	12.8
Uncoated book paper	5	35.8	8	15.5	5	22.0	7	10.4
Hardwood lumber	6	32.0	5	27.3	7	15.0	5	13.8
Hardwood veneer	7	20.9	6	26.3	6	16.9	4	24.0
Pulpwood and chips	8	13.9	7	18.2	9	4.7	8	6.6
Siding	9	10.8	9	12.3	8	5.9	9	6.4
Posts, poles, and piling	10	7.0	12	5.2	10	3.9	12	2.9
Drilled, treated or glued	11	6.1	13	4.4	11	3.7	11	3.2
Plywood and veneer panels	12	5.0	10	6.7	12	2.9	10	4.1
Waste and scrap paper	13	4.5	11	5.4	16	1.5	13	1.8
Logs	14	4.5	18	1.7	17	1.3	16	1.0
Fence pickets and palings	15	3.7	19	1.6	--	(2/)	--	(2/)
Building board	16	3.5	16	2.2	14	1.7	18	.8
Wrapping paper	17	3.4	17	1.8	13	2.3	15	1.4
Hardboard	18	3.3	14	3.3	15	1.6	14	1.5
Softwood veneer	19	2.5	--	.8	--	(2/)	--	(2/)
Packing boxes and crates	20	2.4	--	1.2	--	(2/)	--	(2/)
Wallpaper	21	2.3	--	.9	--	(2/)	--	(2/)
Paper board and shoe board	22	2.2	--	.8	--	(2/)	--	(2/)
Crepe paper	23	2.1	--	.2	--	(2/)	--	(2/)
Hardwood flooring	24	2.0	15	2.4	18	.9	17	.9
Lath	25	1.8	20	1.3	19	.8	19	.4
Hardwood moulding	26	1.3	--	.1	--	(2/)	--	(2/)
Softwood plywood	27	1.1	--	(2/)	--	(2/)	--	(2/)
Softwood moulding	28	1.0	--	.6	--	(2/)	--	(2/)
Miscellaneous	--	18.2	--	9.8	--	3.4	--	3.6
Total 3/		2,137.9		1,599.3		906.5		679.5

1/ Source: U.S. Bureau of the Census, U.S. Imports for Consumption and General Imports, TSUSA Commodity and Country Report FT 246 Annual.

2/ Included in miscellaneous.

3/ Totals may not add because of rounding.

concern about underutilization. However, short-lived species such as aspen and balsam fir do not develop into large sawtimber trees on average sites, and must be harvested soon after reaching the sawtimber size class. Lack of markets can cause heavy losses of mature timber in these species due to insects and disease.

Underutilization of the forest resource leads to imbalances in stand age-class distribution, making it difficult to practice sustained yield forestry. Also, the forest manager is deprived of opportunities for improvement cuts and thinnings that are needed to enhance the growth and value potential of the forest. Equally important is the degradation of wildlife habitat, which occurs in the absence of frequent harvest and regeneration to provide feeding and nesting areas.

Many upper Lake States areas suffer from chronic unemployment and out-migration of the labor force because of inadequate job opportunities — a situation aggravated by periods of economic recession. More complete utilization of the forest resource could allow local industries to expand production and offer increased job opportunities. It may also be possible to increase the use of regional manpower in operations that add to the value or utility of certain imported materials. Exploitation of these service opportunities on an in-transit basis can be as important to the economic development of an area as expanded resource utilization.

Proximity to market should not be a problem in expanding use of the local resource, because imports usually require a much longer shipping distance. Success might depend more on a competitive labor force and transportation system plus an efficient production facility.

In summary, imports of several products that could be supplied by the north-central region's forest resource have increased. Attention should be concentrated on products less selective of species or grades, such as fiber products or particleboard, which can be produced from timber species with allowable cuts still well above actual removals.

PROCEDURE

We recorded the destination of Canadian forest products imported through north-central entry points in 1965. Factors developed from these data were then applied to 1969 import data with the assumption that there were no significant shifts in shipping patterns since 1965. Obviously, for some products further interregional distribution may be made. The products are presented in descending order of importance in terms of dollar value of shipments to the north-central region, and are analyzed with regard to their potential for replacement by the local forest resource.

The U.S. Customs Districts considered as part of the north-central region for recording entries in 1965 were: No. 34 North Dakota (Pembina), No. 35 Minnesota (Minneapolis), No. 36 Minnesota (Duluth), No. 37 Wisconsin (Milwaukee), No. 38 Michigan (Detroit), No. 39 Illinois (Chicago), No. 40 Indiana (Indianapolis), and No. 45 Missouri (St. Louis). For a detailed list of entry ports within these Districts see: *Schedule D, Code Classification of United States Customs Districts and Ports,* U.S. Department of Commerce, Bureau of Census.

Time series data for this study were obtained from Bureau of Census summaries of information collected by the Bureau of Customs.[5] To determine destinations, a sample of Customs files of 1965 import declaration forms was taken. Beginning with the first entry in January and July, the apparent first destination of every entry was recorded for commodities having a low total import volume. For newsprint and lumber the destination of every tenth entry was recorded, and for woodpulp, pulpwood, siding, and shingles and shakes the destination of every fourth entry was recorded.

Because of the large number of entry forms at some offices compared with others, a variable time period was covered by the sample at each office. In some cases the entire year was accounted for; in others the period was as limited as January through March, or July through September. Even though a shorter period of time was covered at some offices, a larger volume of material was usually included in the sample. For products that moved in large quantity through several different entry points, there was no discernible difference in destination patterns. The two starting points (January and July) were used to reduce the possibility of bias for commodities that might have seasonal shipping patterns and for which the entire year could not be covered because of time limitation.

Destination regions identified were the Lake States, Central States, Other Midwest, East, South, and West (fig. 1). The Lake States and Central States were then combined to make up the North-Central Region.

The study covered all modes of transportation; however, most of the freight moved by rail. Several assumptions relating to these traffic movements need explanation. Because railroads tend to keep freight on their own lines as much as possible, and because of the pattern of railroad development, it was assumed that most shipments originating in western Canada that are destined for the north-central region, the East, or South, would enter the U.S at points no farther west than central North Dakota. Furthermore, North Dakota entries generally are funneled into the north-central region because the rail lines are oriented toward Minneapolis and/or Duluth, Minnesota. Also, traffic coming from eastern Canada and destined for the north-central region would enter no farther east than the Detroit, Michigan, District. The Customs Districts included in the north-central region but not sampled for destination were those having no land border points. Import volumes in these Districts were extremely small, and were assumed to have been consumed within the region.

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[5] *The specific summaries used as data sources were the IA 253 Annual, Tariff Schedules of the U.S. Annotated, and FT 246 U.S.* Imports for Consumption and General Imports, *both publications of the Bureau of Census, Department of Commerce. These show volume and value of imports by Customs District, exporting country, and TSUSA commodity classes.*

Schedule 2 of the Tariff Schedules of the United States Annotated (TSUSA), shown below, relates the broad products classification for wood, paper, and printed matter imported into the U.S. Several categories were eliminated from the analysis, including all of Part 2 and Part 5. Some subcategories in the remaining parts were eliminated because they were not applicable to the study, because product volumes were extremely low, or to avoid disclosure of individual firm data.

Schedule 2
Wood and Paper, Printed Matter

- Part 1. Wood and wood products.
    - A. Rough and primary wood products, wood waste.
    - B. Lumber, flooring, and mouldings.
    - C. Densified wood and articles thereof.
    - D. Wood containers.
    - E. Miscellaneous products of wood.
    - F. Articles not specifically provided for, of wood.
- Part 2. Cork and cork products, bamboo, rattan, willow and chip, basketwork, wickerwork, and related products of fibrous vegetable substances.
- Part 3. Wood veneers, plywood and other wood-veneer assemblies, and building boards.
- Part 4. Paper, paperboard, and products thereof.
    - A. Papermaking materials.
    - B. Paper and paperboard, in rolls and sheets, not cut to size or shape.
    - C. Paper and paperboard cut to size or shape, articles of paper and paperboard.
    - D. Articles not specifically provided for of pulp, of papier-mache, of paper, or of paperboard.
- Part 5. Books, pamphlets, and other printed and manuscript material.

COMMODITY SITUATION
Newsprint

Newsprint is by far the most important wood product imported from Canada into the U.S. in terms of dollar value. While imports held level during the early 1960's, there was a slight increase in volume toward the end of the period (fig. 2). Canada supplies more than 95 percent of the total newsprint imports, with Finland supplying the balance; these total imports have increased by 25 percent since

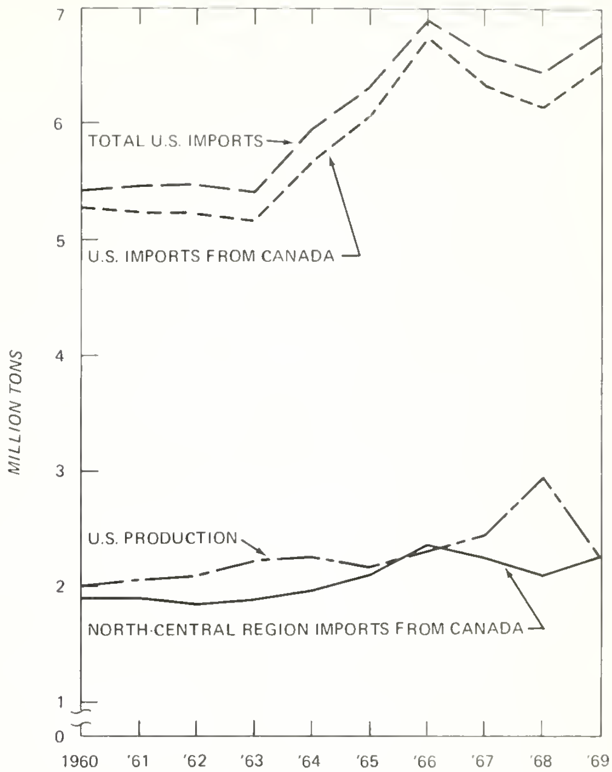

Figure 2.—*Production and imports of newsprint, 1960-1969. Source for U.S. production is: Current Industrial Reports, Pulp, Paper and Board. Ser. M26A-13. USDC Bureau of the Census, Washington, D.C.*

1963. Three-quarters of the Canadian newsprint entering the north-central region had a first destination within this region; almost half of the total went to the Central States. The Other Midwest and West areas received 15 and 8 percent, respectively. Minor amounts went to the South and East.

The following tabulation shows the destination of the newsprint imported in 1969 as estimated from a 5 percent sample of the 2.1 million tons imported in 1965.

First destination	*1969 Volume (M tons)*	*Percent*
Lake States	619.6	27.4
Central States	1,071.9	47.4
North Central	[1,691.6]	[74.8]
Other Midwest	339.2	15.0
East	22.6	1.0
South	18.1	.8
West	190.0	8.4
Total	2,261.4	100.0

Lake States timber has limited opportunity for wide-scale use in manufacture of newsprint. In the first place most newsprint is made from unbleached softwood pulp, a substantial quantity of which is now imported to supplement local supplies. Although surplus balsam fir is available, it is not competitive because of its low pulp yield. Surplus volumes of other softwood pulpwood species are not available.

Secondly, many large users of newsprint in the U.S. have substantial investments in paper-making facilities in Canada; thus, the market share available to independent newsprint manufacturers is much less than it appears from gross consumption data. Furthermore, now that U.S. southern pine newsprint mills have established their market position in areas where they have a definite advantage, future domestic growth will be largely limited to normal per capita increases.

Newsprint made from hardwood-based pulps, although technically feasible, apparently does not have sufficient economic appeal to Lake States mills to encourage expansion of production facilities to include this line of paper.

Softwood Lumber

United States imports of Canadian softwood lumber were approximately 16 percent of U.S. production during most of the study period, but climbed to 19 percent in 1969. One-half of these imports entered through north-central border points and have totaled between 2 and 2¾ billion board feet annually since 1961 (fig. 3). Most is shipped as dressed lumber. In 1969 spruce accounted for 58 percent of the 2.76 billion board feet of regional imports, compared with 44 percent of the total U.S. imports of Canadian lumber.

A significant portion of this lumber is shipped unsold and is routed to a furtherance point. The two most popular first destinations were Marshalltown, Iowa, and Gary, Indiana. In our 1965 sample they accounted for approximately two-thirds of the 906.9 million board feet shipped on a "for-furtherance" basis. Other common marshalling points were Minneapolis, Minnesota, Spooner and Hudson, Wisconsin, and Chicago and East St. Louis, Illinois. These "for-furtherance" carloads are often sold while enroute and may be diverted in any direction. Thus it was

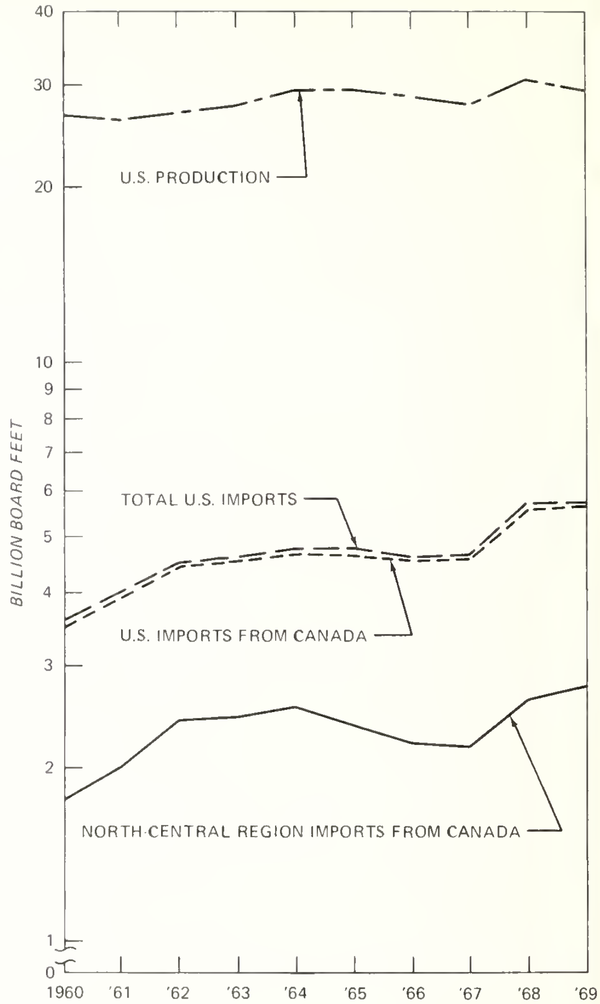

Figure 3. — *Production and imports of softwood lumber, 1960-1969. Regional imports, U.S. imports from Canada, and total U.S. imports include spruce, white and red pine, pine NES (principally jack, ponderosa, and lodgepole), Douglas-fir, hemlock, larch, and cedar. The source for U.S. production is: Current Industrial Reports, Lumber Production and Mill stocks. Ser. M-24T. USDC Bureau of the Census, Washington, DC.*

impossible to determine an apparent region of final destination for this volume. However, it is likely that it was distributed regionally in approximately the same proportions as the volume for which an apparent regional destination is known. It is possible that large wholesalers may later distribute or reroute a portion of the lumber to other regions. It is felt, however, that the major portion is utilized within the north-central region.

The bulk of Canadian lumber entered through Dakota or Minnesota points, although a major portion of the white and red pine came into the region through Michigan. Most of the material destined for the West Region went to one of the northern or central plains States (table 2).

Those species accounting for 84 percent of imports — spruce, Douglas-fir, and pine NES (not elsewhere specified, largely lodgepole and jack pine) — are basically used for construction lumber. The surplus softwood sawtimber resource of the Lake States is not large and sawtimber is being cut at close to the feasible limit under present levels of forest management. Thus, while opportunities may be present for increased cutting in some areas, it is obvious that the north-central area is dependent on imports from the western and southern U.S. and Canada for a major portion of its construction lumber needs.

Table 2. — *Destinations of regional imports of softwood lumber from Canada, 1969 volume*[1]
(In million board feet)

Species	First destination							
	Lake States	Central States	North Central 2/	Other Midwest	East	South	West	Total 3/
Spruce	87.7	430.5	518.2	3.7	0.5	--	--	522.5
	232.1	226.7	458.9	148.4	316.7	143.1	14.6	1,081.6
White and red pine	--	--	--	--	--	--	--	--
	32.9	2.0	34.8	.8	--	--	--	35.6
Pine, N.E.S. 4/	26.2	60.5	86.6	1.7	(5/)	--	5.0	93.2
	60.9	44.9	105.8	24.7	65.3	50.6	2.6	249.3
Douglas-fir	101.8	110.1	212.8	6.4	2.0	--	--	215.2
	34.9	21.5	56.4	8.9	38.8	26.7	6.4	137.0
Fir, N.E.S.	3.7	15.7	19.3	--	--	--	--	19.3
	12.5	.9	13.4	4.6	.6	4.7	.6	23.8
Hemlock	10.2	53.1	63.4	.7	--	--	.4	64.5
	25.3	9.8	35.1	6.3	10.4	8.9	1.7	62.4
Larch	5.5	13.2	18.7	--	--	--	--	18.7
	1.7	.1	1.8	3.4	--	--	--	5.2
Cedar	22.3	15.8	38.1	2.8	--	--	.5	41.5
	8.8	4.0	12.0	26.7	24.5	108.5	16.9	189.3
Softwood, N.E.S.	--	--	--	--	--	--	--	--
	.1	--	.1	--	--	--	--	.1
Subtotal	310.9	722.0	1,032.9	9.3	3.7	--	5.3	1,051.2
	391.9	286.2	678.1	208.8	429.2	345.2	46.6	1,707.9
Total 3/	702.7	1,008.1	1,710.8	218.0	432.9	345.2	51.9	2,759.1

1/ Based on a sample of 1965 shipments that included 106,968 M bd. ft. or 4.5 percent of all regional imports of Canadian lumber. Top figures represent lumber shipped to a furtherance point for redistribution, bottom figures to an apparent first destination.

2/ The north-central region is the sum of the Lake States and Central States.

3/ Totals may not add because of rounding.

4/ N.E.S. = Not elsewhere specified.

5/ Less than 50,000 bd. ft.

Woodpulp

Except for sulfate, the volume of Canadian woodpulps entering the north-central region from 1960 to 1969 has remained relatively static or has declined (figs. 4-8). Regional sulfate imports have more than doubled, rising from 579.7 thousand tons to 1.43 million tons; in 1969 they represented 80 percent of north-central woodpulp imports from Canada. Woodpulp imports for the country as a whole have exhibited similar trends. U.S. production has increased substantially during the study period for sulfate, groundwood, and special alpha and dissolving pulps. Sulfite production has remained between 2.5 and 2.7 million tons annually, while soda pulp has decreased by nearly 50 percent to 240 thousand tons in 1969.

Regional destinations for north-central imports vary by type of pulp (table 3). In 1969 nearly 90 percent of the north-central regional sulfate woodpulp imports were softwood-based, and two-thirds had a first destination in the Lake States; almost all of the relatively small amount of hardwood-based sulfate woodpulp imports had a first destination in the Lake States. At the same time, Lake States pulpmills have increased their production of hardwood woodpulp significantly. Nearly all the groundwood and approxi-

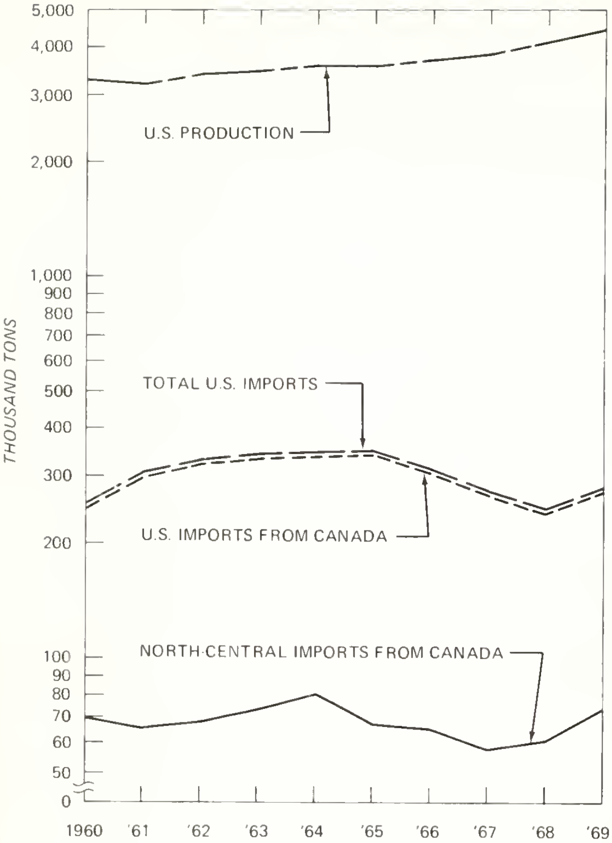

Figure 4. — *Production and imports of groundwood pulp, 1960-1969. The source for U.S. production is: Current Industrial Reports, Pulp, Paper and Board. Ser. M26A-13. USDA Bureau of the Census, Washington, D.C. Does not include mixtures and screenings and pulp NSPF of 24,362 tons.*

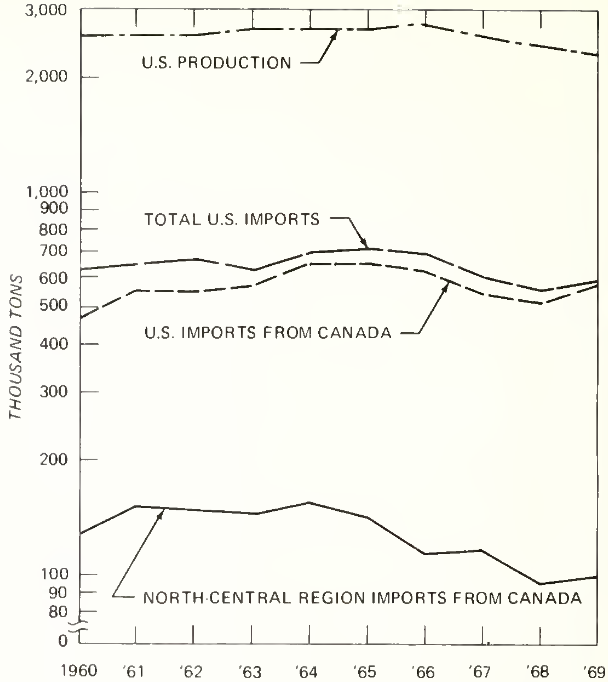

Figure 5. — *Production and imports of sulfite pulp, 1960-1969. The source for U.S. production is: Current Industrial Reports, Pulp, Paper and Board. Ser. M26A-13. USDC Bureau of the Census, Washington, D.C. Does not include mixtures and screenings and pulp NSPF of 24,362 tons.*

mately three-quarters of the sulfite pulp had a first destination in the north-central region. Three-quarters of the alpha and dissolving pulp had a first destination outside of the region, and no soda pulp was included in the sample.

The pulp and paper industry of the north-central area has taken an encouraging stride in the direction of utilizing the surplus hardwood resource through advances in hardwood pulping technology and increased expertise in using a variety of pulps in the paper furnish.

Table 3. — *First destination of regional imports of Canadian woodpulp, 1969*[1]
(In short tons)

Item	Groundwood	Sulfite	Sulfate	Alpha and dissolving	Total
Lake States	2/ D	D	948,233	D	1,091,411
Central States	D	D	62,719	D	113,711
Total North Central	71,765	74,356	1,010,952	48,048	1,205,121
Other Midwest	D	22,885	312,308	D	364,127
East	D	D	46,818	D	106,520
South	D	D	58,817	D	112,911
West	D	D	5,273	D	5,419
Total	73,751	98,682	1,434,168	187,498	1,794,099
Percent volume in sample	33	8	8	10	
Percent of pulp with first destination in:					
Lake States	D	D	66	D	
Central States	D	D	4	D	
North Central States	97	75	70	26	

1/ Based on a sample of 1965 woodpulp imports.
2/ D = Data withheld to avoid disclosure of individual company volumes.

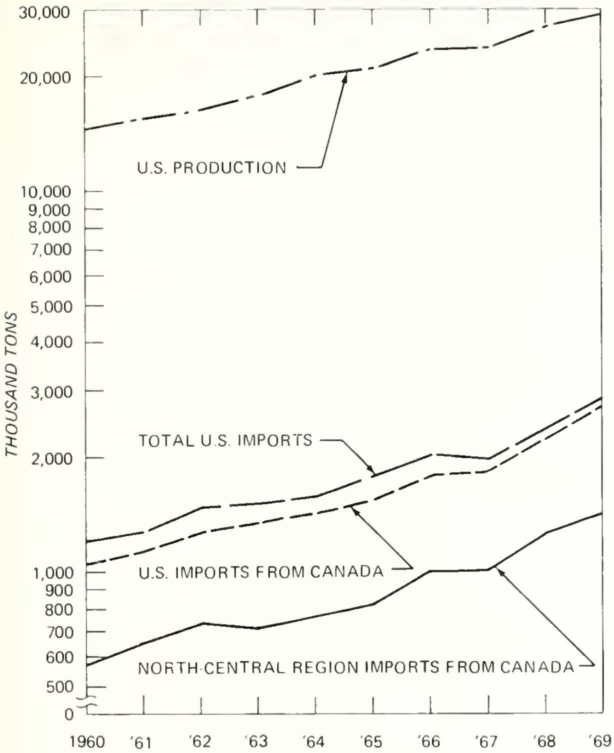

Figure 6. — *Production and imports of sulfate pulp, 1960-1969. The source for U.S. production is: Current Industrial Reports, Pulp, Paper and Board. Ser. M26A-13. Does not include mixtures and screenings and pulp NSPF of 24,362 tons.*

As the Lake States softwood pulpwood resource comes closer to a full harvest of the allowable cut, the Canadian softwood woodpulp imports are needed to allow expansion of the pulp and paper capacity within the region; the surplus hardwood resource can support an increased rate of expansion in several survey districts. On the other hand, the softwood resource could be increased significantly through more intensive forest management.

Shingles and Shakes

Imports of shingles and shakes from Canada, which accounted for 99.9 percent of all shingle and shake imports, have amounted to approximately 60 percent of U.S. production since 1963. The trend in imports has been slightly upward during the study period (fig. 9) and over 95 percent of these imports have been red cedar.

Shingle and shake imports from Canada coming through the north-central region, which represent approximately 40 percent of the total, are distributed regionally as follows. The 1965 sample comprised 4 percent (50,722 squares) of the regional import volume.

First destination	*1969 Volume (Squares)*	*Percent*
Lake States	9,193	0.7
Central States	30,612	2.2
North Central	[39,805]	[2.9]
Other Midwest	3,165	.2
East	1,032,099	74.3
South	270,926	19.5
West	5,962	.4
For furtherance:		
Lake States	1,446	.1
Central States	34,861	2.5
Total	1,388,264	99.9

The comeback of wood shingles and shakes is a result of the pleasing rustic appearance now popular in high-quality homes, the impressive revival of the mansard roof design in homes, apartments, and commercial buildings, and building code changes to incorporate fire retardant construction techniques. Most are made from red cedar, and it is doubtful if Lake States species could successfully compete in this market.

Uncoated Book Paper

Categories of paper products in the *Tariff Schedules of the United States Annotated* (TSUSA) are based on a variety of factors and few individual import categories amount to a significant dollar value.[6] Newsprint is one exception. However, two other categories are reasonably important, although they are minor when compared with U.S. production. These are uncoated book printing paper and wrapping paper.

Uncoated book paper includes those book and printing papers not cut to size or shape and with no surface treatment, coloring, or embossing. It excludes

[6] *Tariff schedules of the United States annotated (1969), U.S. Tariff Commission, Washington, D.C. T.C. publ. 272, 1968.*

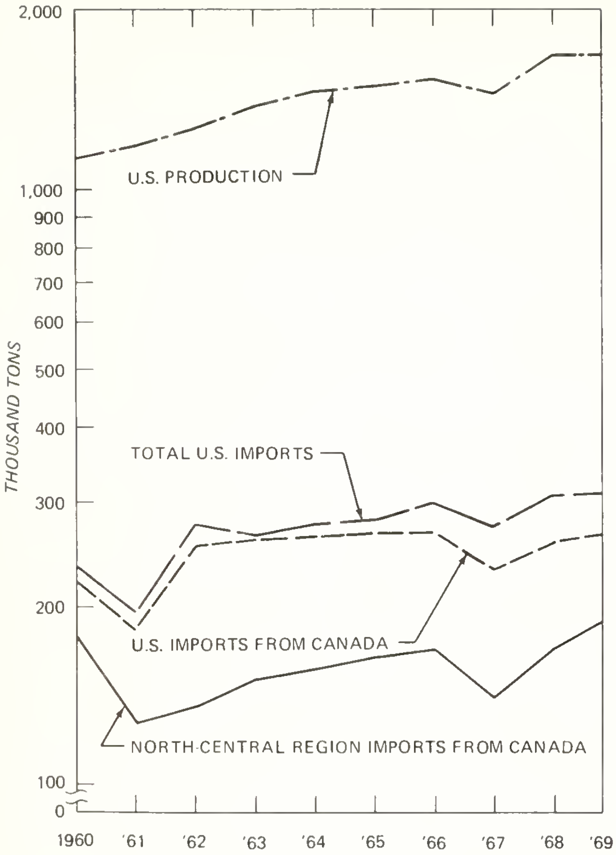

Figure 7. — *Production and imports of alpha and dissolving pulp, 1960-1969. The source for U.S. production is: Current Industrial Reports, Pulp, Paper and Board. Ser. M26A-13. USDC Bureau of the Census, Washington, D.C. Does not include mixtures and screenings and pulp NSPF of 24,362 tons.*

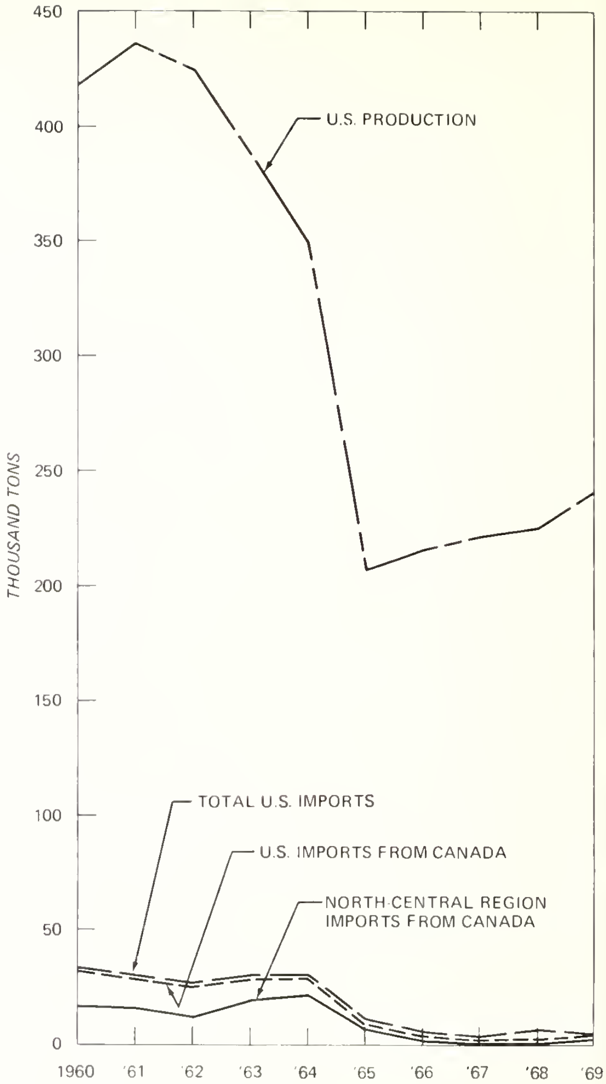

Figure 8. — *Production and imports of soda pulp, 1960-1969. The source for U.S. production is: Current Industrial Reports, Pulp, Paper and Board. Ser. M26A-13. USDC Bureau of the Census, Washington, D.C. Does not include mixtures and screenings and pulp NSPF of 24,362 tons.*

cover paper, India or bible paper, and newsprint. Ninety-five percent of these imports are papers containing 25 percent or more groundwood pulp. Undoubtedly, a high proportion is softwood-based. Imports from Canada were valued at $15.5 million in 1965, $26.25 million in 1967, and $35.78 million in 1969. The increase in these imports has been impressive since 1963 (fig. 10). Regional imports accounted for approximately two-thirds of the total from Canada, which in turn amount to approximately 90 percent of the total U.S. imports of uncoated book paper.

More than 60 percent of the uncoated book paper imported through regional points from Canada in 1969 had a first destination in the north-central region.

First destination	*1969 Volume* (Tons)	*Percent*
Lake States	19,553	15.2
Central States	59,046	45.9
North Central	[78,599]	[61.1]
Other Midwest	28,172	21.9
East	5,146	4.0
South	7,204	5.6
West	9,519	7.4
Total	128,640	100.0

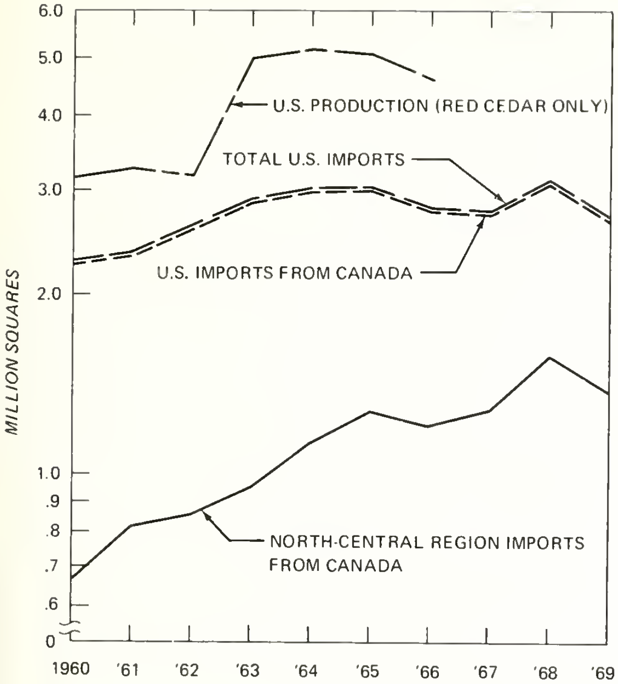

Figure 9. — *Production and imports of shingles and shakes, 1960-1969.*

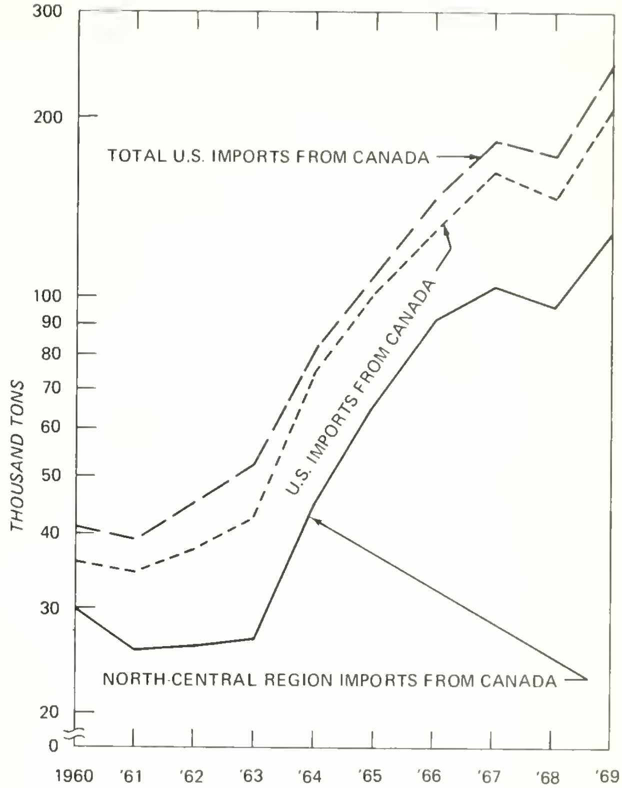

Figure 10. — *Imports of uncoated book paper, 1960-1969.*

The 1965 sample comprised 6 percent of the regional import volume.

As with newsprint, the extent to which Lake States surplus hardwoods could be utilized in book paper production would hinge on how successfully aspen and dense hardwood pulps could replace softwood pulps in the furnish. The prospects are not overly bright considering the extra cost of bleaching hardwood pulp, although bleached hardwood grades are increasingly being used with softwood grades in fine papers. In addition, the tariff on uncoated book paper under the Kennedy Round of 1967 will be reduced from 17 cents per pound and 4 percent ad valorem to 8 cents and 2 percent by 1972. Obviously this will favor increased imports only to the extent that tariffs have been a deterrent to international trade in the past.

Hardwood Lumber

The study included hardwood species indigenous to the U.S. and Canada and excluded foreign and tropical woods, except for those miscellaneous species lumped into the category "Hardwood, Not Elsewhere Specified." Imports of Canadian hardwood lumber showed a slightly increasing trend during the study period for both the U.S. and the north-central region; imports for the U.S. amounted to between 1½ to 2 percent of domestic production (fig. 11). The sharp upturn in total U.S. imports in 1968 and 1969 is the result of significant increases of miscellaneous tropical hardwoods from Brazil, Colombia, several other South American countries, and Malaysia. The South American forest resource has been referred to as a "sleeping giant" and is just beginning to be utilized on an expanded commercial scale. How much of this material comes into the north-central region is unknown.

There has been a general decrease in the quality of local hardwood sawtimber such as yellow birch and maple, due to the harvest of larger trees. However, this situation will stabilize and may be expected to reverse as more intensive sustained yield forest management practices are applied to the domestic hardwood resource. For example, the poletimber hardwood resource of Michigan is quite extensive and

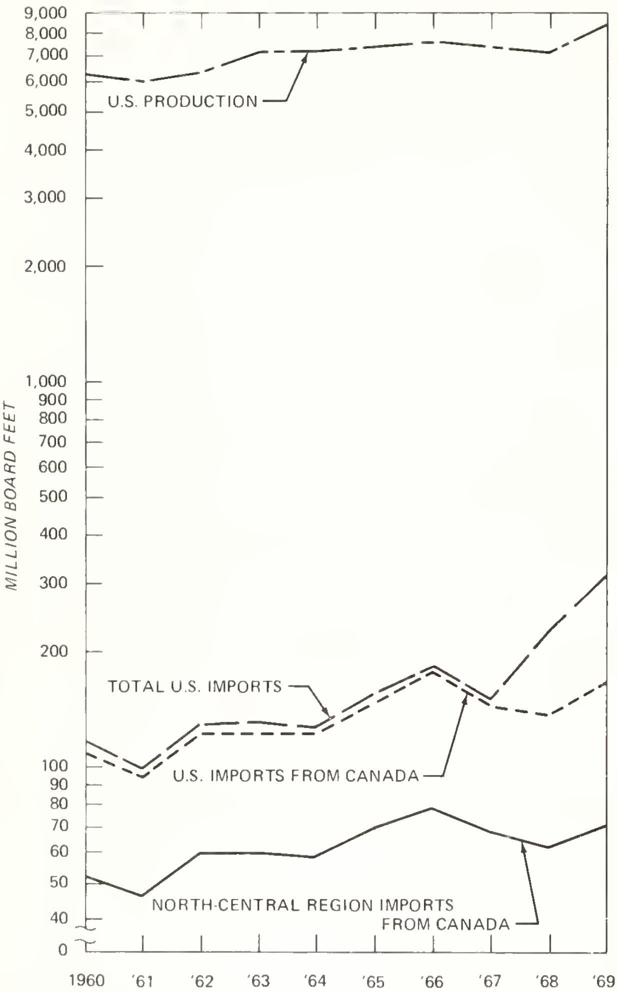

Figure 11.—*Production and imports of hardwood lumber, 1960-1969 (includes rough and dressed lumber only; excludes flooring, drilled or treated lumber, mouldings, and tropical hardwoods). The source for U.S. production is: Current Industrial Lumber Production and Mill Stocks. Ser. M24T. USDC Bureau of the Census, Washington, D.C.*

underutilized. As these trees grow, the sawtimber inventory will increase markedly. In the interim, imports will be vital to the hardwood-using industries of the area.

In 1965, more than 95 percent of the hardwood lumber imports entering the north-central region came through eastern entry points, and 64 percent had first destinations within the region. The sample comprised 10.7 percent of the total regional import volume for 1965.

First destination	*1969 Volume (M bd. ft.)*	*Percent*
Lake States	30,351	42.5
Central States	15,079	21.1
North Central	[45,430]	[63.7]
Other Midwest	10,546	14.8
East	2,419	3.4
South	5,568	7.8
West	7,403	10.4
Total	71,366	100.0

Hardwood Veneer

Based on dollar value, imports from Canada accounted for approximately 47 percent of all U.S. imports of hardwood veneer in 1969, down from 60 percent in 1965. Birch made up 91 percent of these imports, and maple 5 percent.

Birch and maple veneer imports exhibited a general upward trend from 1960 to 1965, then leveled off somewhat (fig. 12). Approximately 78 percent entered through Lake States points. One-third had a first destination in the north-central region, with over one-half destined for California, Washington, and Oregon. The 1965 sample comprised 13 percent of the regional imported volume.

First destination	*1969 Volume (M sq. ft., surface measure)*	*Percent*
Lake States	170,633	30.6
Central States	20,246	3.6
North Central	[190,879]	[34.3]
Other Midwest	4,923	0.9
East	1,795	0.3
South	30,243	5.4
West	329,087	59.1
Total	556,928	100.0

Imports of Canadian veneer may be expected to remain at the same level or increase only slightly as veneer imports from other countries gain a larger market share. Imports may gain a slight advantage over domestic production from the Kennedy Round of tariff adjustments in 1967, which reduced the

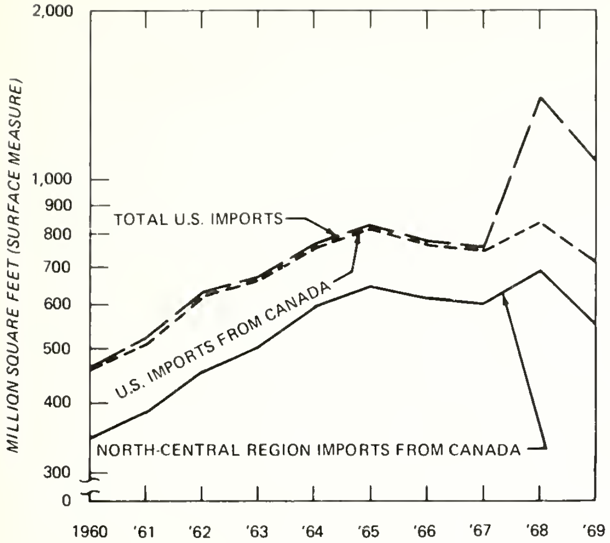

Figure 12. — *Imports of birch and maple veneer, 1960-1969.*

tariff from 8 percent ad valorem prior to 1967 to 4 percent ad valorem in 1972. The bulk of the Canadian imports are destined for the West Coast, and what is utilized in the north-central region simply supplements the local resource.

The Lake States veneer industry has experienced a severe competitive struggle, especially with Asian species and suppliers. However, it appears that other factors are more important in causing a decrease in market share than the quality or availability of the local veneer log resource, which while not available in surplus quantities appears adequate in the face of current market difficulties.

Wood Siding

Prior to 1964 the only siding category was entitled "cedar siding"; since then wood siding has been reported as (1) resawn western redcedar, (2) resawn except western redcedar, (3) western redcedar except resawn, and (4) except western redcedar except resawn. Also, siding that is drilled and/or treated or glued is excluded here and is reported along with other glued, drilled, or treated lumber.

Since 1964, approximately two-thirds of the wood siding imported from Canada was western redcedar, most of which was resawn. The amount that enters the study area from Canada finds wide regional

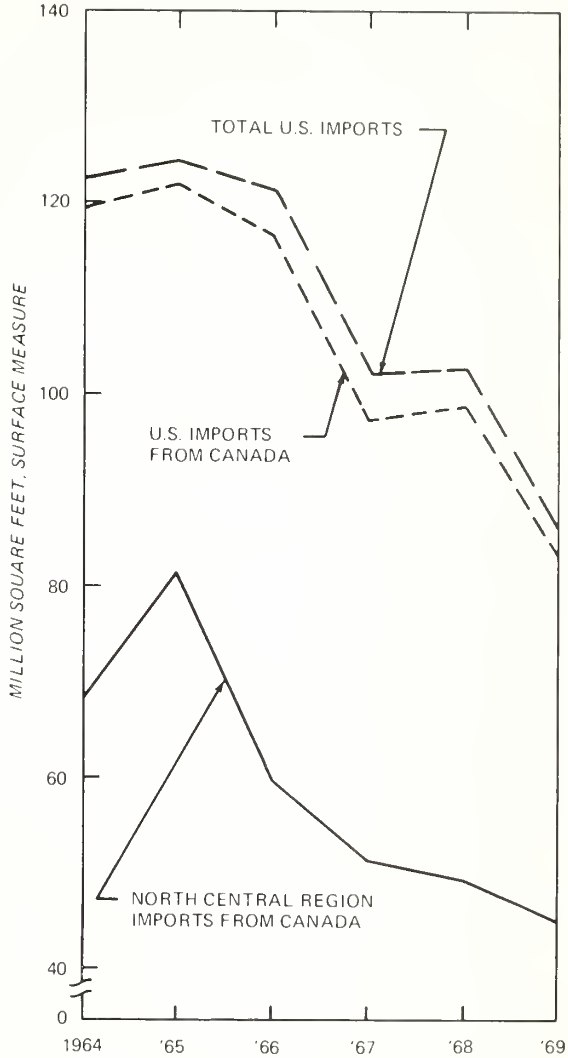

Figure 13. — *Imports of wood siding, 1964-1969.*

distribution; based on the sample of 1965 shipments (which accounted for 4.2 percent of the volume so imported), nearly three-quarters had a first destination within the north-central region. Imports reached a peak in 1965 and have since slowly diminished (fig. 13).

The wood siding market has felt the impact of competition from aluminum, steel, and vinyl as well as hardboard, which may be the reason for the significant decrease in imports of Canadian solid wood siding. The market for Lake States hardwood growing stock material has benefited from the production of hardboard siding. It is not likely that the local forest resource can be more competitive in this declining solid wood siding market.

First destination	1969 Volume (M sq. ft.)	Percent
Lake States	21,541	47.7
Central States	10,391	23.0
North Central	[31,932]	[70.7]
Other Midwest	4,895	10.8
East	4,934	10.9
South	2,937	6.5
West	442	1.0
Total	45,140	99.9

Pulpwood

Prior to 1964 several pulpwood categories used by the Bureau of Customs did not differentiate between softwood and hardwood. In addition, pulpwood import data summarized by the Bureau of Census Foreign Trade Division were given in roundwood bolt volumes as declared by the shipper, while data in the Current Industrial Series (*Pulp, Paper and Board,* published by the Census's Industry Division) also include slabs, chips, and sawmill waste converted to cords of 128 cubic feet — rough-wood basis. Thus, the data are not directly comparable. For example, total U.S. imports of pulpwood in 1966 from the former source amounted to 793,341 cords, and from the latter 1,284,450 cords. Our analysis uses Foreign Trade Division data, which are in cords of 128 cubic feet, deal only with roundwood, and do not specify whether rough or debarked.

Of all U.S. imports of pulpwood since 1964, approximately three-quarters have come from Canada. The remainder is primarily pine from the Bahamas. One-half of the pulpwood imported from Canada is spruce and one-sixth is hardwood.

Forty-five percent of all the pulpwood imported from Canada comes into the north-central region; of this portion, approximately 60 percent is spruce and less than 10 percent is hardwood. A sample (12 percent) of the volume coming into the region in 1965 showed 99.8 percent having a first destination within the Lake States. Chip imports were insignificant during the study period.

Pulpwood imports have decreased substantially during the study period (fig. 14). The decrease has been shared by both softwood and hardwood pulpwood, although softwood has had a somewhat larger

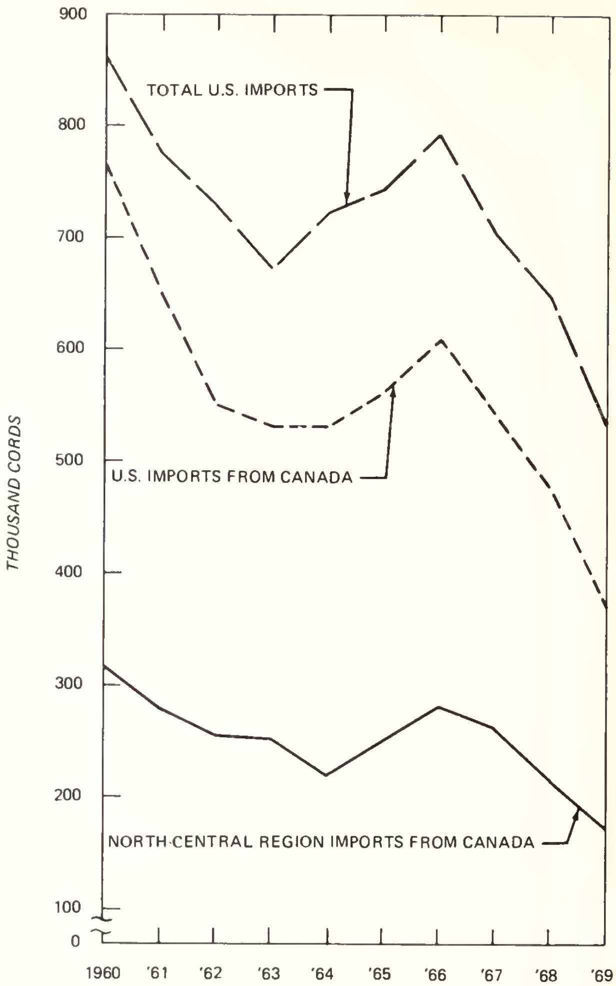

Figure 14. — *Imports of pulpwood, 1960-1969.*

percentage decrease. Coupled with the large increase in softwood sulfate woodpulp imports, it appears the Canadians are shipping a more advanced product in lieu of roundwood. At the same time, the increased use of chipped domestic sawmill and veneer mill residues, the substantial increase in the use of readily available local hardwood pulpwood, and the closing of Lake States sulfite pulpmills undoubtedly has been influential in decreasing roundwood import demands.

Increased utilization of the surplus hardwood pulpwood resource should continue to offer expanded employment opportunities in the Upper Great Lakes region.

Posts, Poles, Piling

The dollar value of fence posts coming into the region has been relatively small, and during the study period represented 10 percent or less of total U.S.

post imports. Too few were picked up in the sample to give a reliable estimate of regional distribution. The dollar value of poles and piling has been significant, however, totaling $3 to $4 million for the period.

Canada supplied between 95 and 98 percent of all U.S. pole and piling imports, of which nearly two-thirds entered the north-central region (fig. 15). Two distinct shipping trends were recognized from the 1965 sample. Much hardwood piling entered through eastern entry points, while softwood poles and piling entered through northwestern regional entry points. Of the two, the latter accounted for an overwhelming proportion of the dollar value. More than 95 percent of the poles and piling had a first destination in the Lake States. Because of the large number of pole-treating plants and pole yards, especially in Minnesota, it is likely that subsequent interregional distribution is made.

Considering the substantial dollar value of pole imports in the "over 15 feet in length" category, local forest resource managers should make every effort to investigate the potential of this market. Red pine and jack pine are the two species that might be competitive. A significant portion of the pole imports are

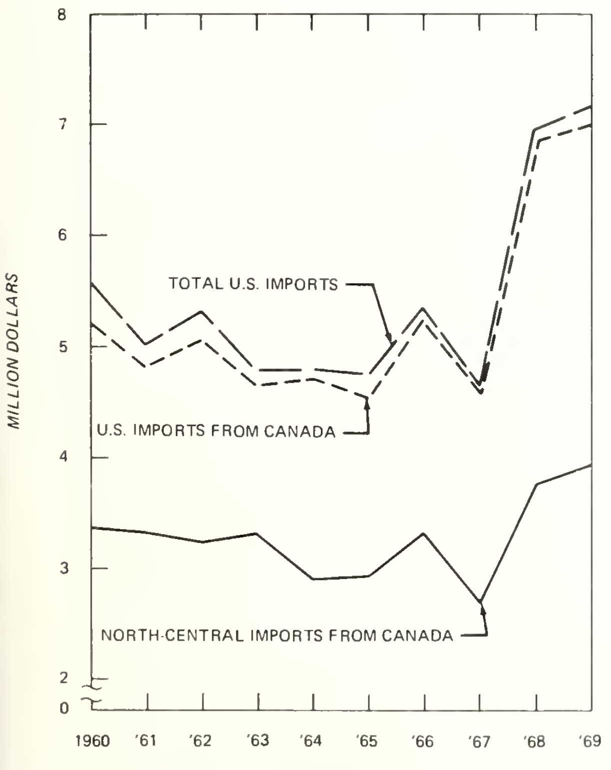

Figure 15. — *Imports of poles and piling, 1960-1969.*

in the 40- to 70-foot length classes, and pole specifications are often detailed concerning sweep, crook, butt diameter, top diameter, and diameter: length ratio.

Building Board

Building board is defined as panels of rigid construction, including tiles and insulation board used chiefly in the construction of walls, ceilings, or other parts of buildings. The category does not include particleboard.

U.S. imports of building board from Canada have amounted to 60 to 87 percent of total U.S. building board imports since 1964, and between 36 and 41 percent of these Canadian shipments entered the north-central region (fig. 16). Import volume peaked in 1964, decreased from 1965 through 1967, then reached new highs in 1968 and 1969.

The 1965 sample comprised 28 percent of the regionally imported volume and indicated that the entire amount had a first destination in the Lake States. This volume in 1969 was 26.0 million square feet, surface measure, valued at $1.7 million.

Building boards offer a definite opportunity for the utilization of Lake States surplus growing stock. Both hardwood and softwood roundwood as well as wood residues are a basic raw material. Although the volume of imports is still relatively small, the increase in imports suggests a potential market may exist for expanded local production.

Wrapping Paper

This category includes papers weighing over 18 pounds per ream that are not cut to size or shape, not surface treated, colored or embossed in any way, and that are used primarily for wrapping purposes.

U.S. imports of wrapping paper from Canada increased during the study period, with approximately three-quarters of the volume coming into the north-central region (fig. 17). While the proportion of wrapping paper imports from Canada has increased from under 10 percent in the early 1960's to over 30 percent in 1969, the bulk of it was supplied by Sweden and Finland. Some of this material may come directly to the north-central region through the St. Lawrence Seaway.

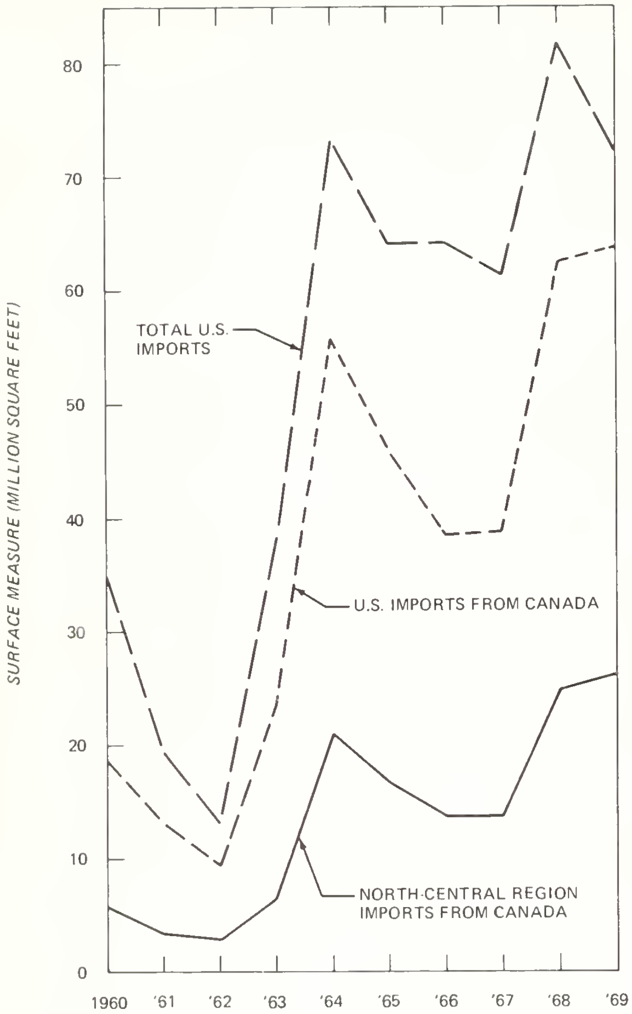

Figure 16. — *Imports of building board, 1960-1969.*

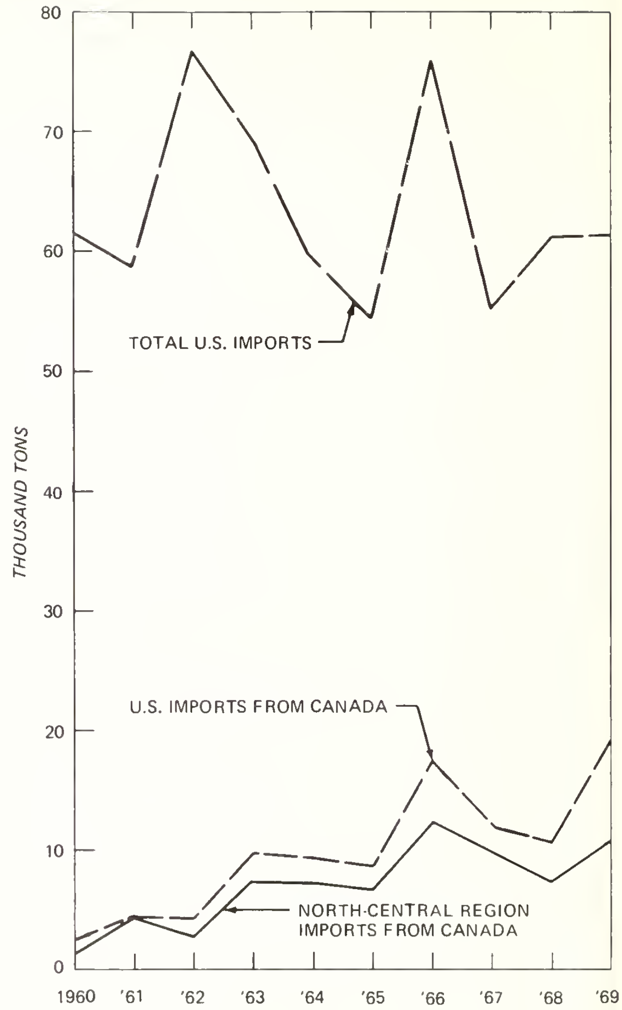

Figure 17. — *Imports of wrapping paper, 1960-1969.*

The following tabulation shows the destination of wrapping paper imported in 1969 estimated from a 16-percent sample of the regional imports from Canada in 1965. (D = data withheld to avoid disclosure of individual company volumes.)

Final destination	*1969 Volume (Tons)*	*Percent*
Lake States	4,686	43.9
Central States	D	—
North Central	D	—
Other Midwest	D	—
East	0	0
South	D	—
West	D	—
Total	10,674	100.0

The potential importance of wrapping paper to Lake States producers may be somewhat disguised when only Canadian imports are considered, as in table 1, because Canada supplies less than one-third of total U.S. imports of wrapping paper (amounting to more than $6.6 million in 1969). What seems important is that Canada has been able to increase its market share significantly in the past 10 years in the U.S.

Wrapping paper is made from a variety of pulp furnishes, but strength and toughness are important qualities. This would suggest that softwood sulfate pulps are most desirable, and production by Lake States mills might again hinge on a successful technology for utilizing hardwood semichemical and sulfate pulps in the furnish.

Hardboard

Hardboard is not defined by density in the tariff schedules, but is categorized as "not face finished" or "face finished." Imports of the latter are minor. The "not face finished" category includes oil treated whether or not regarded as tempered, and is divided into three value classes — under $48 per ton, $48 to $97 per ton, and over $97 per ton. These classes accounted for 2 percent, 87 percent, and 11 percent of the total volume of U.S. imports of "not face finished" hardboard in 1969. The category excludes particleboard and building boards.

Total U.S. imports of hardboard climbed steadily from 1960 through 1965, faltered somewhat in 1966 and 1967, then rose significantly in 1968 and 1969. They have comprised almost 15 percent of U.S production throughout the period. U.S. imports of hardboard from Canada have risen from 6 percent in 1960 to 23 percent in 1969. None came into the north-central region in 1960, while 45 percent did in 1969 (fig. 18).

Imports from Canada have been substantially below those from Sweden and Finland, and some of this European hardboard has come directly to the north-central region through the St. Lawrence Seaway.

A minor influence in imports might be the gradual reduction in tariff rates betwen 1967 and 1972 on hardboard that is not face finished, as follows:

Class *(Dollars/ton)*	*1967 rate*	*1972 rate ad valorem (Percent)*
Under 48	15% ad valorem	7.5
48 to 97	$7.25 per short ton	7.5
Over 97	26% ad valorem	15.0

Nearly all the Canadian hardboard coming into the north-central region entered through Michigan points, and most had a first destination in the Lake States or Other Midwest. The sample of 1965 shipments comprised 15 percent of the imported volume.

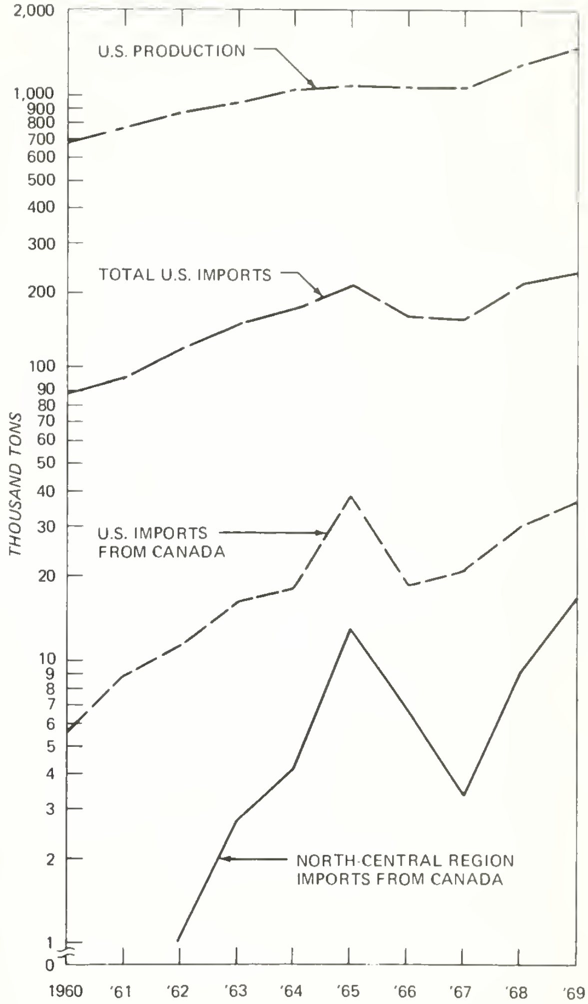

Figure 18. — *Imports of hardboard, 1960-1969. The source for U.S. production is: Current Industrial Report, Pulp, Paper and Board. Ser. M26A-13. USDC Bureau of the Census, Washington, D.C.*

First destination	*1969 Volume (Tons)*	*Percent*
Lake States	6,830	41.3
Central States	2,229	13.5
North Central	[9,059]	[54.8]
Other Midwest	7,288	44.0
East	0	.0
South	0	.0
West	201	1.2
Total	16,548	100.0

Hardboard production has increased in the Lake States during the study period, primarily utilizing the aspen resource. Import trends for the area indicate further expansion might be possible.

Hardwood Flooring

Significant shipments of hardwood flooring to the U.S. from countries other than Canada began in 1963 (fig. 19). In 1961 shipments from Canada were at the lowest point in the last 15 years, and at that time only 6.8 percent of flooring imports from Canada entered through regional points. This proportion had climbed to more than 40 percent by 1969. All regional flooring imports entered through Michigan in 1969, and maple, birch, or beech strips and planks made up 95 percent of the total.

The estimated distribution for the 1969 volume, based on the 1965 sample which comprised 24 percent of the regional import volume is as follows:

First destination	*1969 Volume (M bd. ft.)*	*Percent*
Lake States	474	16.4
Central States	164	5.7
North Central	[638]	[22.2]
Other Midwest	120	4.2
East	1,110	38.6
South	555	19.3
West	455	15.8
Total	2,878	100.1

Two-thirds of U.S. hardwood flooring imports in 1969 were birch, beech, or maple strips and planks. Oak strips and planks accounted for 5 percent, miscellaneous strips and planks for 15 percent, and hardwood flooring other than strips and planks for 14 percent. Of the birch, beech, and maple imports, 97 percent came from Canada.

At one time birch, beech, and especially maple flooring were used extensively in industrial, institutional, and home construction. The market has declined significantly and is now primarily limited to gymnasium floors and bowling alleys because consumers have turned to other flooring materials.

Two factors that affect the availability of competitively priced rough lumber for domestic flooring mills are furniture demands and railroad tie production. During periods of strong demand for light-colored furniture or early American styles, flooring grade lumber may be diverted to that market. When tie production is down, sideboards, an important source of flooring material, are in short supply. Thus, in the face of a somewhat marginal market the shortage of suitable flooring grade lumber may allow Canadian imports a competitive advantage. This points out that factors other than the forest resource can play an important part in international trade.

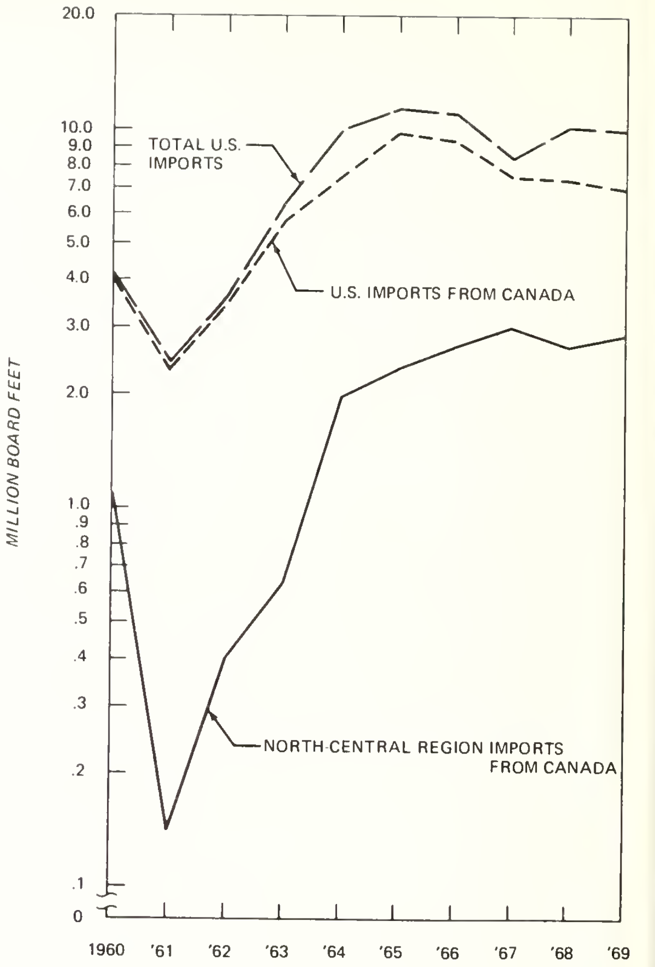

Figure 19.—*Imports of hardwood flooring, 1960-1969.*

Hardwood Plywood and Panels

Imports of Canadian hardwood plywood and veneer panels were much less important than hardwood veneer.[7] However, Canada supplied only 2 percent of the dollar value of all U.S. hardwood plywood and panel imports in 1969. This was down from 5 percent in 1965. Of a total $248.1 million of imports in 1969, $5 million came from Canada; $4.1 million of this was birch-faced plywood. It is interesting that even for birch plywood, both Japan with $22.2 million and Finland with $20.5 million far exceeded Canadian shipments to the U.S.

Because Canadian shipments of species other than birch as well as veneer panels were relatively insignificant, our analysis is limited to birch-faced plywood. Shipments from Canada reached a peak of nearly 70 million square feet in 1963 and have since steadily declined (fig. 20). Fifty-eight percent of these imports entered through the north-central region, and approximately two-thirds had a first destination there. The 1965 sample comprised 22 percent of the volume of birch plywood entering the region; the distribution pattern was as follows:

First destination	*1969 Volume (Million sq. ft.)*	*Percent*
Lake States	7.3	36.2
Central States	6.1	30.3
North Central	[13.4]	[66.6]
Other Midwest	2.5	12.6
East	—	—
South	3.1	15.5
West	1.1	5.3
Total	20.1	100.0

Canada, Finland, and Japan contributed 99 percent of the birch faced plywood imports in 1969; 40 percent of this was 5/32 inch or less in thickness and 60 percent was over 5/32 inch. Imports from Canada accounted for 16 percent of the thinner category and only 4 percent of the thicker. With total U.S. imports increasing substantially during the study period, it appears the Canadians are having problems similar to the domestic industry in competing in this market. As with veneer, the quality and availability of the local resource are not as important as other factors in limiting production.

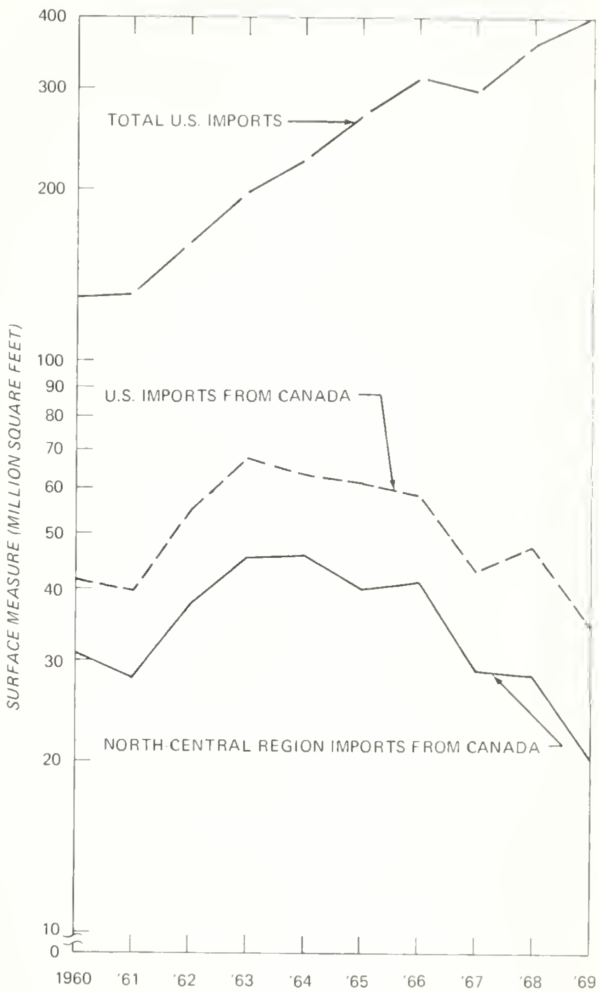

Figure 20. — *Imports of birch plywood, 1960-1969.*

Drilled and/or Treated and Glued Lumber

In 1964 three special categories were established for these materials: (1) drilled and/or treated softwood lumber and siding, (2) edge- or end-glued hardwood lumber, and (3) lumber and wood siding NSPF (not specifically provided for), and end-glued lumber NSPF. These imports are defined as follows:

[7] *Plywood is defined as a rigid wood-veneer assembly bonded with adhesives and having a core of veneer or lumber with one or more plies of wood veneer on each side thereof and in which at least one ply being at an angle with one or more other plies. A wood veneer panel is also a rigid wood-veneer assembly except plywood, bonded with adhesives with a wood veneer ply on one side of a backing, or on both sides of a core which may be of veneer, lumber, hardboard, particleboard, or other material.*

Drilled or treated softwood lumber. — Drilled at intervals for nails, screws, or bolts; sanded or otherwise surface-processed in lieu of, or in addition to, planing and working; or treated with creosote or other wood preservatives or with fillers, sealers, waxes, oils, stains, varnishes, paints or enamels, but not including antistain or other temporary applications.

Glued lumber. — Edge- or end-glued hardwood lumber not over 6 feet in length or over 15 inches in width, not drilled or treated. Edge-glued or end-glued wood over 6 feet in length and not over 15 inches in width that would otherwise meet lumber standards shall be deemed lumber and not included here.

For the softwood lumber and siding category, total U.S. imports from Canada from 1965 to 1969 decreased from 43.9 to 32.2 million board feet (MM bd. ft.) (fig. 21). However the value of these imports rose from $3.7 million to $4.4 million. For glued hardwood imports, both volume and value increased, rising from 1.5 MM bd. ft. and $0.7 million to 3.3 MM bd. ft. and $1.6 million (fig. 22). The NSPF

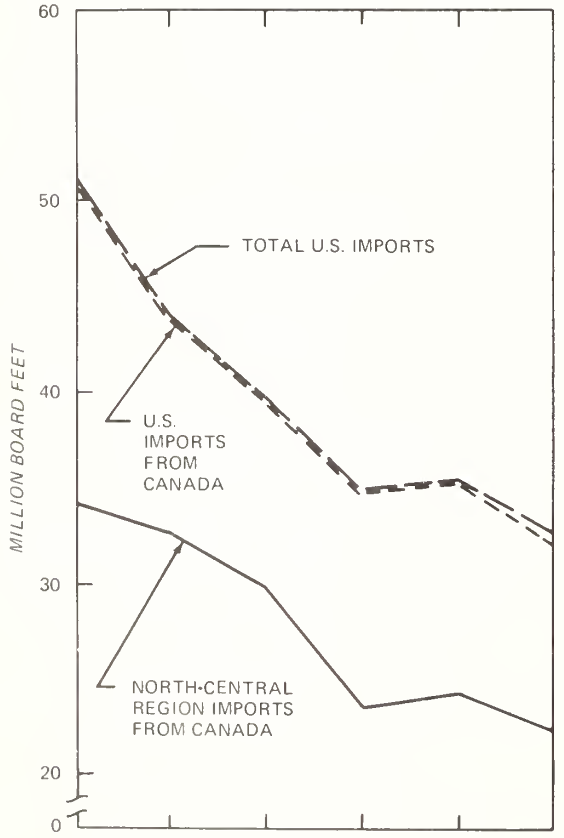

Figure 21. — *Imports of drilled and/or treated softwood lumber and siding, 1964-1969.*

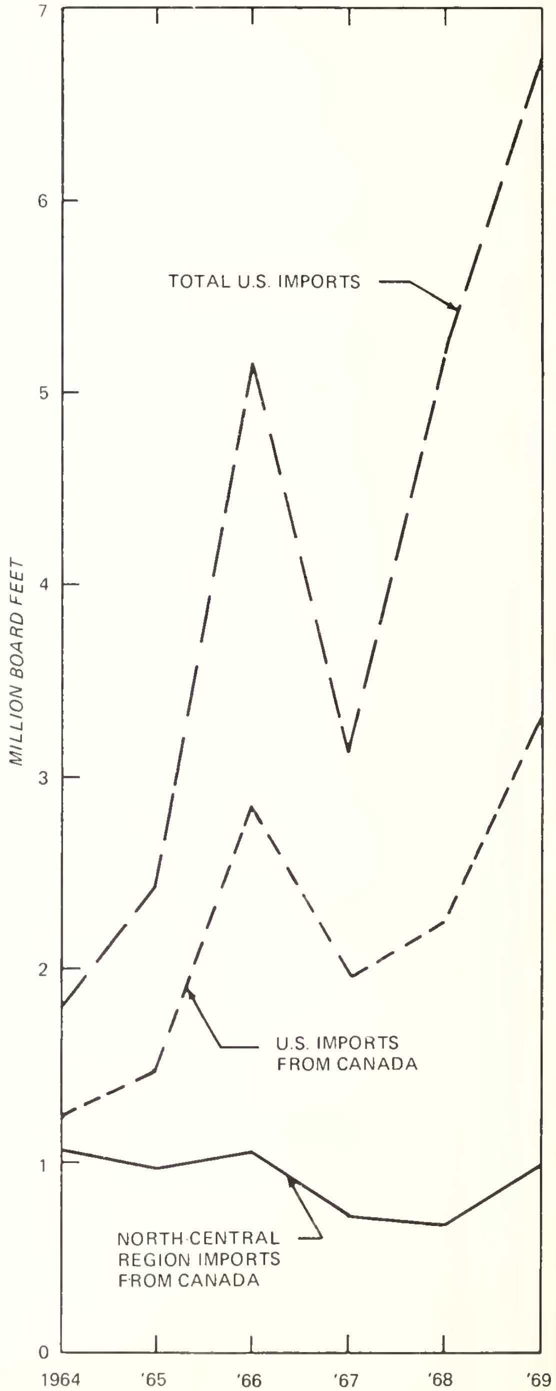

Figure 22. — *Imports of edge- or end-glued hardwood lumber and siding, 1964-1969.*

category was relatively insignificant in volume and value.

Only drilled and/or treated softwood lumber and siding was included in the 1965 sample of north-central region imports, and siding was a minor portion of these shipments. The following data relate only to this category. A steadily downward trend since 1964 culminated in 22,587,000 bd. ft. shipped into the region in 1969. Based on the sample (which comprised 5.6 percent of the volume imported), the material was distributed as follows:

First destination	*1969 Volume (M bd. ft.)*	*Percent*
Lake States	8,137	36.0
Central States	4,093	18.1
North Central	[12,230]	[54.1]
Other Midwest	3,471	15.4
East	2,720	12.0
South	3,527	15.6
West	639	2.8
Total	22,587	99.9

A high proportion of these imports was thick, predrilled roof decking for use in construction where the inner surface is exposed as the finished roof. Several species are used, including white spruce and western redcedar. This is an architectural specialty item often shipped on special order and which might require promotion by local mills.

Birch and Maple Logs

Because birch and maple logs generally represent over 95 percent of hardwood log imports from Canada, our study is limited to this category. Excluded are the categories Cativo, Mahogany, Lauan, and Logs NES, of which only the latter includes a relatively small amount of miscellaneous species from Canada. Also, data prior to 1964 are excluded because changes in categories make them inconsistent with later years.

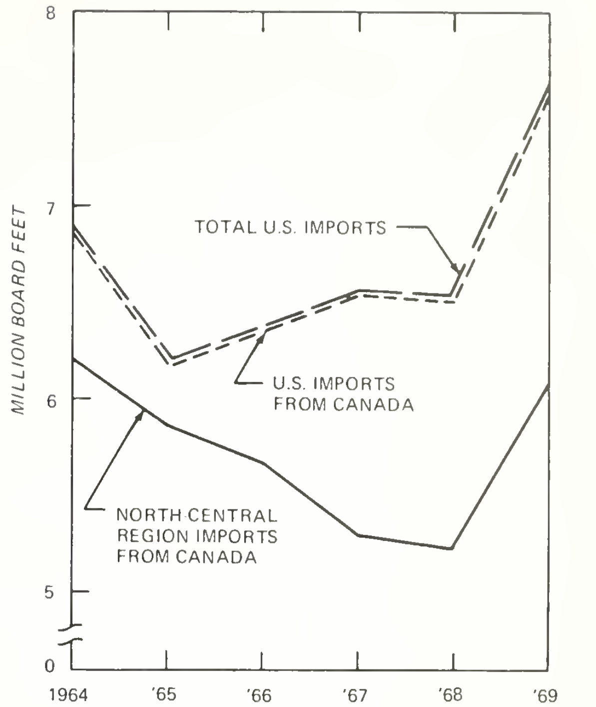

Figure 23. — *Imports of birch and maple logs, 1964-1969.*

From 1964 to 1966 more than 90 percent of imported maple and birch logs came through Lake States ports of entry; this figure dropped to 80 percent in 1967 and has stayed there ever since. Import trends were slightly downward throughout the study period but recovered well in 1969, amounting to 6 MM bd. ft. (fig. 23).

The sample of 1965 log imports comprised 19 percent of the total regional import volume Most of the logs were of veneer quality and nearly all entered through Michigan border points. Based on the sample, 88 percent had a first destination in the Lake States and 12 percent went to the Central States. These inports have been an important supplement to the regional veneer log resource. Regional imports of softwood logs were insignificant.

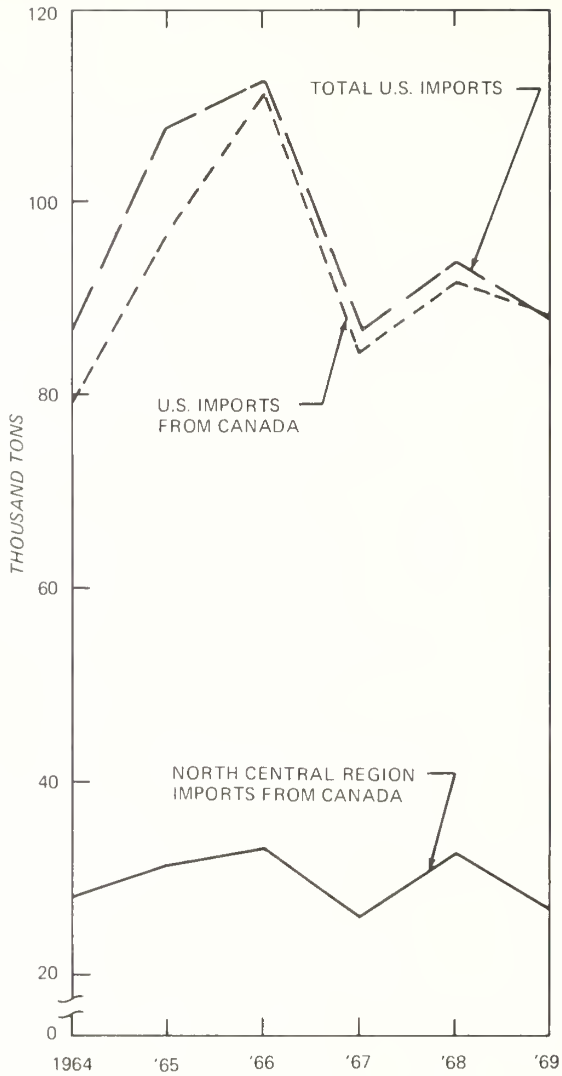

Figure 24.—*Imports of scrap paper, 1964-1969.*

Scrap Paper

Regional imports of scrap paper have held rather steady since 1964 when the category was initiated (fig. 24). More than 80 percent have a first destination in the Lake States with most of the balance destined for the Other Midwest and West. In the future this category may be influenced by the pressure for recycling wastes and the requirement by some organizations that certain paper products contain a proportion of salvaged fiber.

First destination	*1969 Volume (Tons)*	*Percent*
Lake States	22,160	81.9
Central States	219	.8
North Central	[22,379]	[82.7]
Other Midwest	2,140	7.9
East	0	......
South	0	......
West	2,548	9.4
Total	27,067	100.0

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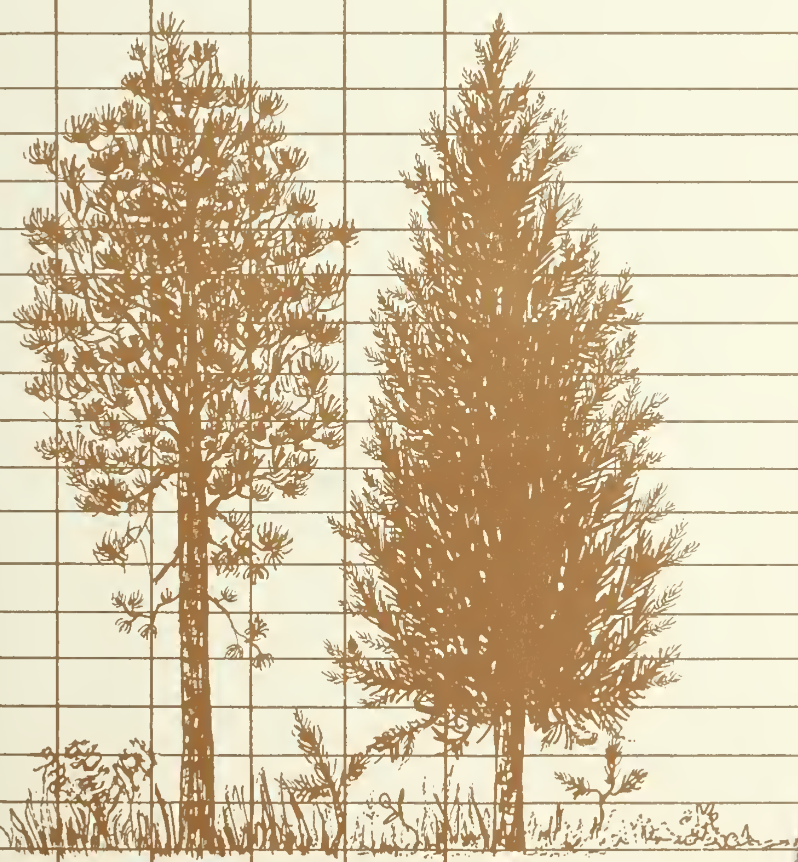
A Method of Evaluating Crown Fuels in Forest Stands

RODNEY W. SANDO
CHARLES H. WICK



NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

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Manuscript approved for publication July 11, 1972

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A METHOD OF EVALUATING CROWN FUELS IN FOREST STANDS

Rodney W. Sando and Charles H. Wick

Although fire control efforts have historically been keyed to fire danger ratings based on weather data alone, current danger rating systems also incorporate fuels data (Deeming and Lancaster 1971). A greater appreciation of the importance of fuel in affecting fire behavior is likely to develop as fire control operations become increasingly sophisticated. The first step necessary to incorporate fuel data into the danger rating is a reliable system of fuel classification, which is defined as "division of forest areas into units according to their characteristics with respect to rate of spread and difficulty of establishing and holding control line" (USDA Forest Service 1956). This concept was originally established by Hornby (1936) and has been widely applied. However, the methods for classifying fuels have been largely subjective in nature. Values for important fuel parameters have been established for only a few fuel types, and attempts to integrate these parameters into a system relating to fire behavior are just beginning.

IMPORTANT FUEL CHARACTERISTICS INFLUENCING FIRE BEHAVIOR

Perhaps the most important fuel characteristics influencing fire behavior are the amount and continuity. Fuel continuity, or horizontal distribution, influences the rate of fire spread. Discontinuities in fuel distribution tend to slow the spread of fire and simplify fire control efforts under most conditions.

The vertical arrangement of fuel particles and the porosity within the fuel bed also greatly influence fire behavior. Compact fuel beds usually do not burn as rapidly as porous fuel beds, because there is freer movement of air and gasses in the latter. Another important fuel characteristic is particle size. Fine fuels burn readily, dry out rapidly, and contribute greatly to the spread of a flame front.

Fuels can also be described according to their flammability. Differences between live and dead fuels, conifers and hardwoods, and fuel chemistry should be recognized when classifying fuels. Present fire danger rating systems include the influence of regional weather on fuel moisture, but the effects of stand density, exposure, and aspect on the drying rates of fuels have not been quantified. These factors also influence fire behavior and should be considered in a fuel description system.

Fuel classification methods developed by Hornby (1936) have been applied throughout most of the United States. His methods are based on the subjective evaluation of a fuel type in terms of rate of spread and resistance to control. This method is used at the present time by the USDA Forest Service (1938, 1968). Fahnestock (1970) has recently developed a method of fuel description that requires the use of keys to evaluate rate of spread and crown fire potential. This method appears promising but also is largely subjective.

Past studies in which quantitative fuel descriptions were developed have largely been concerned with laboratory fuel beds or individual particles. Heterogeneous fuel complexes, such as are found in forest stands, have only recently been described in quantitative terms (Kiil 1968, Muraro 1971, Countryman and Philpot 1970). However, several studies dealing with prediction of tree-crown weight have been made. Storey *et al.* (1955, 1957) developed regression equations to predict crown weights for several selected tree species using methods described by Kittredge (1944) and Tufts (1919). Fahnestock (1960), Brown (1963, 1965), Loomis *et al.* (1966), Kiil (1967, 1968), Storey (1969), Wade (1969), and Baskerville (1965) have all determined crown weights for various species. Through these studies excellent progress has been made toward quantifying forest fuels. Crown weight alone, however, is not entirely satisfactory for describing a fuel complex. Fuel arrangement and continuity also must be described in a meaningful manner and differences in flammability must be considered.

A fuel description system that uses conventional inventory data (tree height, d.b.h., basal area, stems per acre, etc.) to provide a quantitative measure of important fuel parameters is needed before we can bridge the gap to fuel appraisal, which will relate fuel description to actual fire behavior. A fuel description system would also be useful for fire behavior prediction and for comparing fuel types throughout the Nation.

We have developed a technique of describing fuel complexes that quantifies some of the important parameters required for fuel classification. The method deals primarily with the weight of crown fuels and the vertical and horizontal distribution of these fuels. The method is a new approach to fuel description and needs to be fully evaluated before any attempt is made by fire control agencies to utilize it.

METHODS

The description of a fuel complex requires knowledge about both the amount and physical location of fuel present. Our method attempts to describe the fuels in this manner. Forest stands characteristically have three important vertical fuel levels: ground fuels, intermediate fuels, and crown fuels. We deal primarily with the intermediate and crown fuels because descriptions for ground fuels in many timber types have already been developed for use in the National Fire Danger Rating System (Deeming *et al.* 1971). The input data needed for our method can be obtained from a wide variety of sampling methods. This method requires observations of stem diameter, height, crown length, and crown width.

Total height, crown length, and crown width were estimated to the nearest foot for trees larger than 1 inch d.b.h. and to the nearest half-foot for smaller trees. Stem d.b.h. was measured to the nearest inch for trees over 1 inch d.b.h., and stem diameter 6 inches above the ground was measured to the nearest one-tenth inch for smaller trees. All trees less than 1 foot tall were considered to be part of the ground fuels and were not sampled. Any appropriate sampling scheme may be used to collect these data. We found plots of fixed radius to be convenient. Other sampling methods may be used depending on the characteristics of the fuel complex being described.

The field data were used as inputs to regression equations for predicting ovendry weight of crown material (table 1). Only foliage and that portion of the tree smaller than 2.5 inches in diameter are included in crown weight. A computer program was written to calculate crown weight and crown volume of each sample tree. The program determines the crown position above the ground and distributes the weight for each tree crown in 1-foot increments above the ground surface. This procedure is followed for each sample plot; when all plots in a stand have been processed, a summary is generated for the stand. The final weight values are then graphed by the computer. Crown-weight values are kept separate for conifer and hardwood tree species and are graphed with separate characters by the computer. The resulting graph depicts the vertical distribution of crown weight and the portion of the total weight for conifers and hardwoods. This permits an interpretation of the role of hardwood fuels in the fuel complex. The final product of this analysis is a graphic representation of the vertical distribution of crown weights and species mixtures.

This method requires some assumptions that need explanation. First, it is important that an appropriate model of the tree crown shape be selected for each species. A cone with the altitude equal to the crown length and the base diameter equal to the crown width was used to represent the crown shape of spruce and fir. A hemiprolate spheroid, with the altitude equal to the crown length and the diameter equal to the crown width, was used to model the shape of jack pine, red pine, and hardwood tree species. It was assumed that the weight of the tree crown is uniformly distributed throughout the volume of the crown. The total crown weight was then distributed vertically according to the vertical distribution of the crown volume. This procedure allowed a more meaningful approximation of the vertical distribution of the crown weight than if a uniform distribution over the length of the crown had been assumed. This technique is obviously subject to several sources of error. For example, crown weight may not be equally distributed over the entire crown volume. The selection of a crown model is also a source of error, since the distribution of crown weight is dependent on the shape given by the model selected. Moreover, the regression equations used may not be sensitive to differences in stand density. These differences are real (Brown 1963) and can be significant in some fuel types. A measure of stand density such as basal area, stems per acre, or crown width would improve the applicability of the prediction equations.

Table 1.—*Equations for predicting ovendry weights of individual tree crowns; where Y = Ln total crown weight in pounds, X = Ln stem d.b.h. in inches, and Z = Ln stem diameter in inches 0.5 foot above ground*

Species	Equation	N	R^2	Standard error of the estimate
TREES LARGER THAN 1 INCH D.B.H.				
Jack pine[1]	Y = 0.4646 + 2.0270X	95	0.91	0.2729
Red pine[2]	Log_{10} crn. wt. = .9072 + .1087 d.b.h. in.	84	.91	--
Balsam fir[1]	Y = .8342 + 1.6970X	19	.95	.2155
Black spruce[1]	Y = .9767 + 1.5259X	20	.86	.3482
Aspen[1]	Y = .7933 + 1.4566X	25	.84	.3705
TREES SMALLER THAN 1 INCH D.B.H.				
Jack pine[1]	Y = 0.2080 + 2.3233Z	25	0.93	0.3201
Red pine[1]	Y = .1363 + 2.2376Z	25	.98	.1303
Balsam fir[1]	Y = .2308 + 2.0548Z	25	.97	.1476
Black spruce[1]	Y = .2442 + 2.0843Z	25	.96	.2650
Aspen[1]	Y = .1942 + 2.8426Z	28	.96	.2429

[1]Sando, Rodney W., and Charles H. Wick. Crown fuel weights of some important species in the Lake States region. (Manuscript in preparation for publication.)
[2]From Brown (1963).

The graphic representation provides a way of visualizing the fuel complex but does not provide a discrete quantitative description. The mean crown height is used to describe the vertical distribution of fuel weight in the fuel complex. Because little is known about the amount of fuel required to support combustion vertically, we selected an arbitrary value of 100 pounds within each 1-foot interval. The mean crown height was then calculated by determining the mean height above ground containing a minimum of 100 pounds per acre of crown material. Only conifers were considered because hardwood fuels probably do not support fire spread except under very severe conditions. For example, if the fuel complex had more than 100 pounds per acre per foot of fuel in all levels except the lowest 10 feet, the resulting mean crown height would be 10.0.

As previously stated, the porosity of the fuel bed greatly influences fire behavior. Rothermel and Anderson (1966) and Anderson (1969) have described various fuel beds using the dimensionless parameter Sigma-Lambda. This parameter is defined as fuel bed void volume/fuel volume. We have calculated this parameter using our data for the different fuel complexes we sampled (table 2). We defined the fuel bed depth as the average height of the dominant trees. We determined the fuel

Table 2.—*Stand description and computed indexes*

Stand description	Total crown weight/acre[1]	Stems per acre	Basal area	Mean crown height	Crown volume ratio	Sigma-Lambda
	Pounds	Number	Sq.ft./acre	Feet		
32-year-old red pine plantation	26,495	1,000	121	13	10.5	1,990
32-year-old red pine plantation commercially thinned	19,695	640	90	15	14.8	2,995
50-year-old red pine plantation	26,433	400	147	25	9.3	2,895
40-year-old jack pine stand	30,737	540	105	11	6.2	2,065
105-year-old jack pine stand	23,700	816	85	2	3.0	1,905

[1]Includes foliage and branchwood and bolewood less than 2.5 inches in diameter.

volume by assuming an average fuel density of 35 pounds per cubic foot and dividing the total crown weight by this value.

We calculated another parameter that may be more useful for describing forest stands—the ratio of the total fuel bed volume to the volume occupied by crowns. We named this the crown volume ratio. It is computed by determining the average height of the stand and considering this to be the upper limit of the total fuel bed volume. Then, crown volumes are computed individually and summed. Total fuel bed volume is then divided by the total crown volume. It can be used to describe some of the important characteristics of a stand that influence movement of air through the stand and also the penetration of solar radiation.

These parameters—the mean crown height, the crown volume ratio, and total crown weight per acre—then serve as a means of quantitatively describing the fuel complex. They are admittedly crude, but they have more foundation than subjective classifications that have been used in the past and provide a common base for classification of all types of stands.

STAND DESCRIPTIONS

We used our system to describe five different stands. The selected stands were: (1) A 32-year-old red pine plantation (fig. 1), (2) a 32-year-old red pine plantation that had been commercially thinned 6 months prior to the date of data collection (fig. 2), (3) a 50-year-old red pine plantation (fig. 3), (4) a 40-year-old jack pine stand of natural origin (fig. 4), and (5) a 105-year-old jack pine stand with a well developed spruce-fir understory (fig. 5). Pertinent stand and fuel data for these examples are summarized in table 2. These five stands represent some of the more important coniferous fuel types in the Lake States region.

The undisturbed red pine plantations sampled were high density plantations on good sites. Crown closure had occurred and there was little surface fuel other than needle litter. The plantation that had been thinned differed due to the opening of the canopy and presence of slash. The 40-year-old jack pine stand was on a sandy site, and the ground fuels consisted of grasses, ferns, herbs, blueberry, and needle litter. The 105-year-old jack pine stand was on a rocky site and the stand was deteriorating rapidly. Surface fuels consisted of grasses ferns, herbs, needle litter, mosses, and a significant number of dead logs. The computer-generated graphs of fuels in those stands are shown in figures 6,7,8,9, and 10.

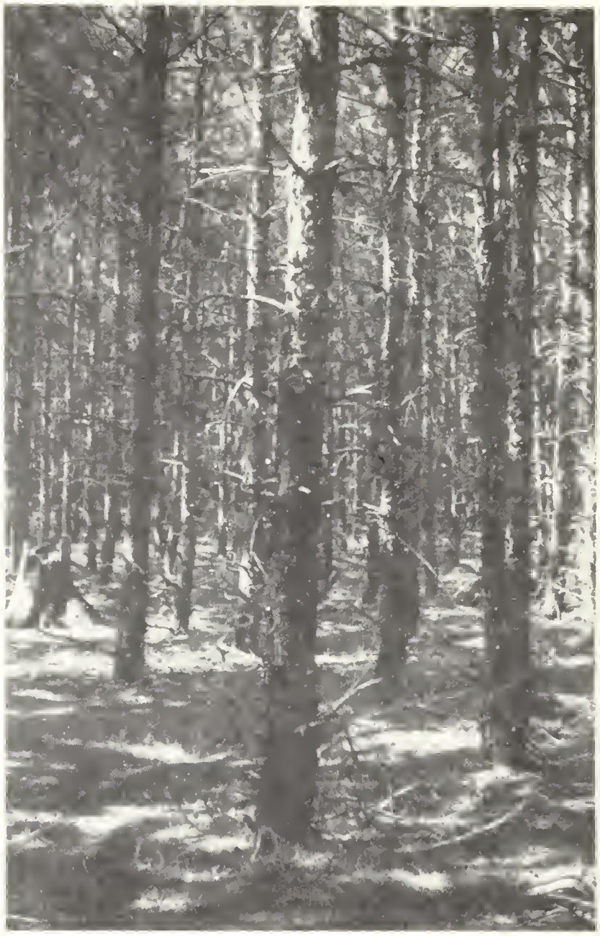

Figure 1.—Thirty-two-year-old red pine plantation.

MODELING APPLICATIONS

Another possible application of our system is for modeling stand changes. An examination of a red pine plantation that had been commercially thinned showed that the thinning operation had reduced the weight of crown material, increased the porosity of the stand, and reduced the vertical continuity. We then simulated several thinning methods by randomly selecting trees to be thinned from the stand. The resultant changes in the fuel complex were reflected by the indexes. For example, we simulated a commercial thinning in the 32-year-old red pine plantation that would randomly remove approximately half of the trees. We found this reduced the crown weight from 26,495 pounds per acre to 12,495 pounds per acre. This simulated thinning would

Figure 2. – Commercially thinned 32-year-old red pine plantation.

Figure 3. – Fifty-year-old red pine plantation.

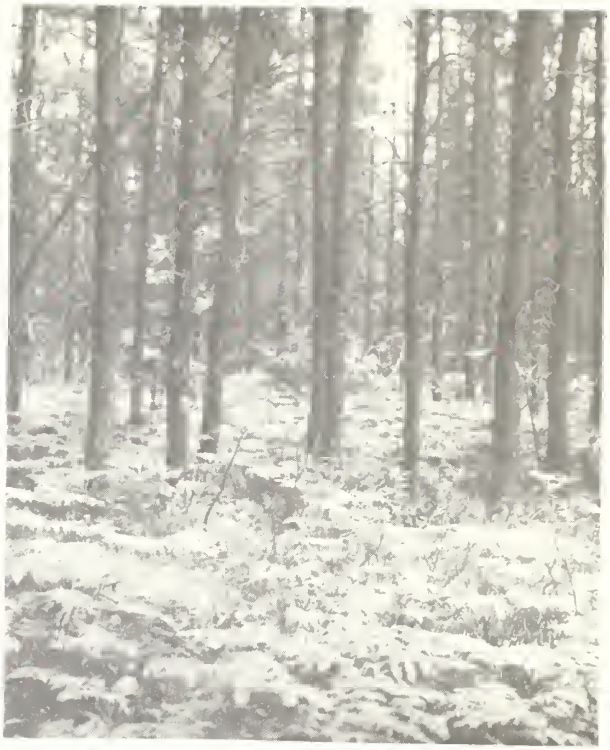

Figure 4. – Forty-year-old jack pine stand of natural origin.

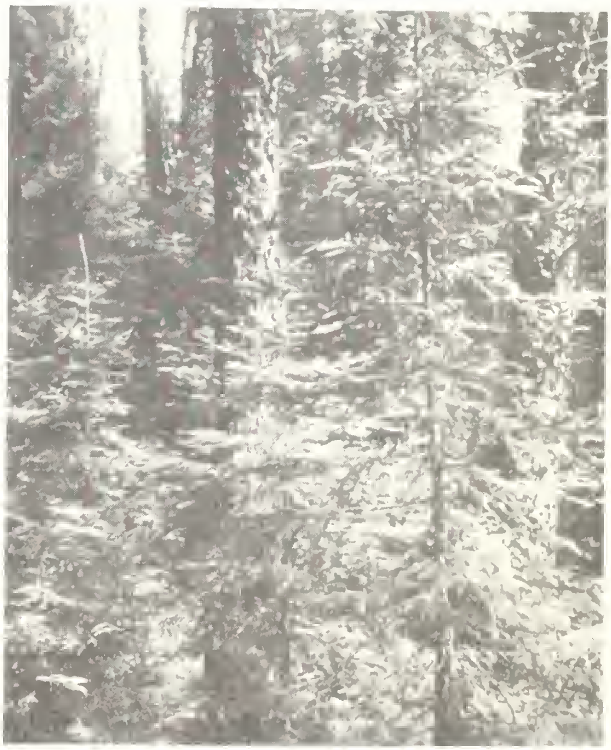

Figure 5. – One-hundred-five-year-old jack pine stand with spruce-fir understory.

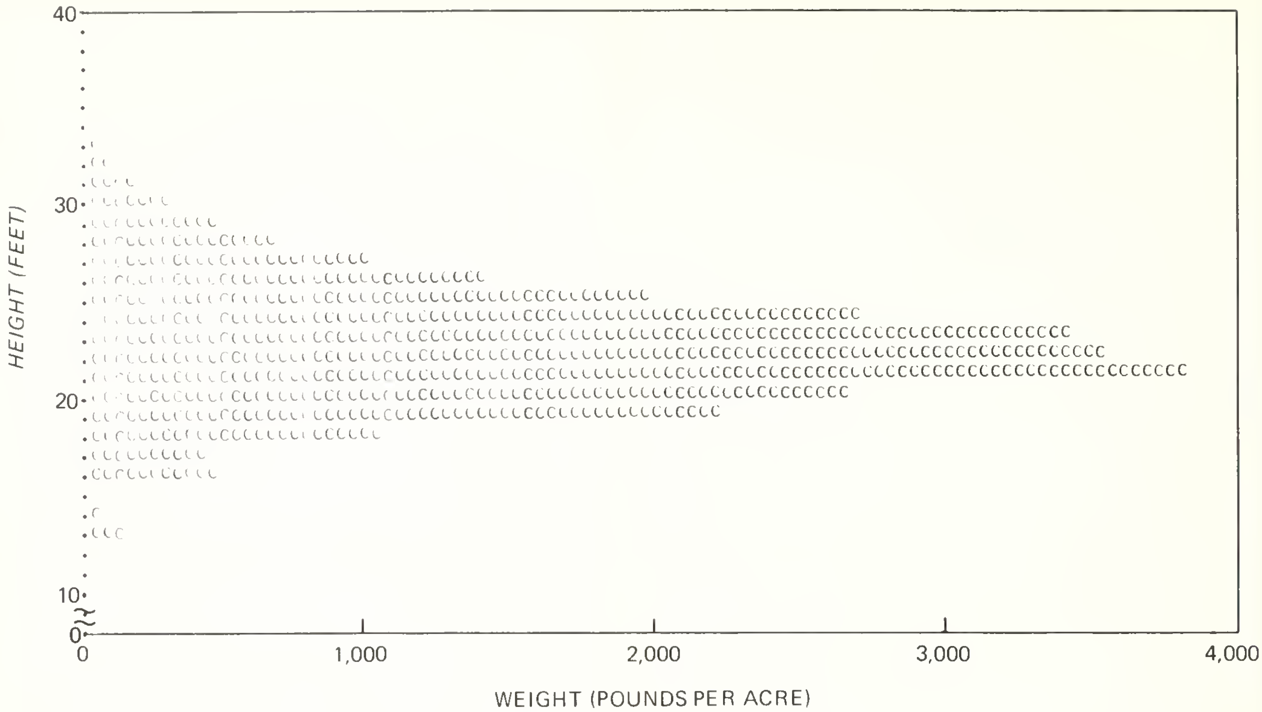

Figure 6.–Graph of crown weight in 32-year-old red pine plantation.

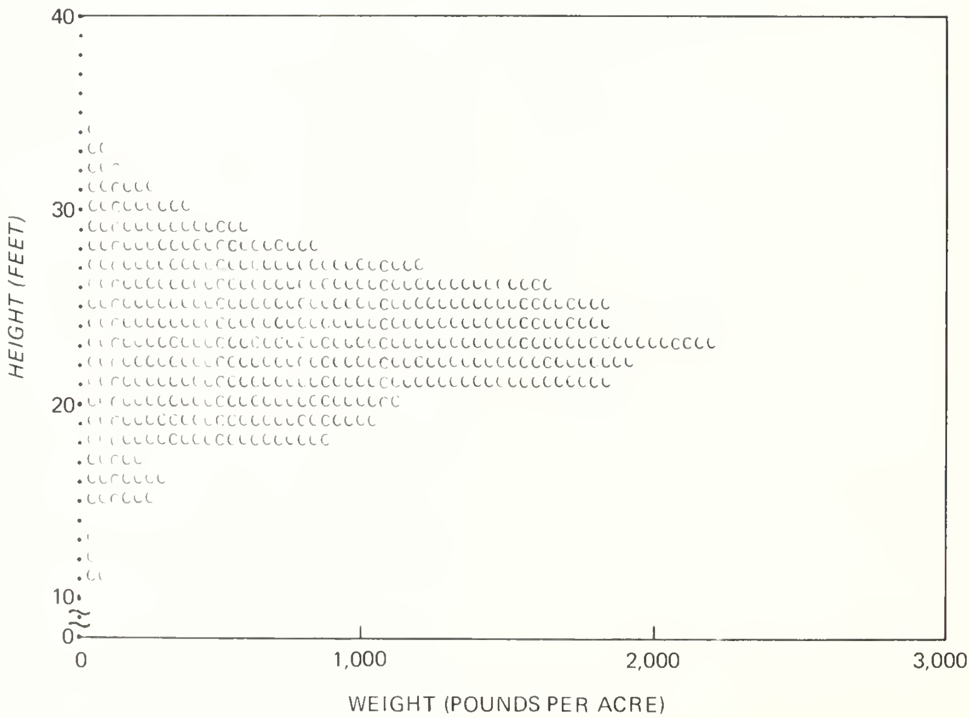

Figure 7.–Graph of crown weight in commercially thinned 32-year-old red pine plantation.

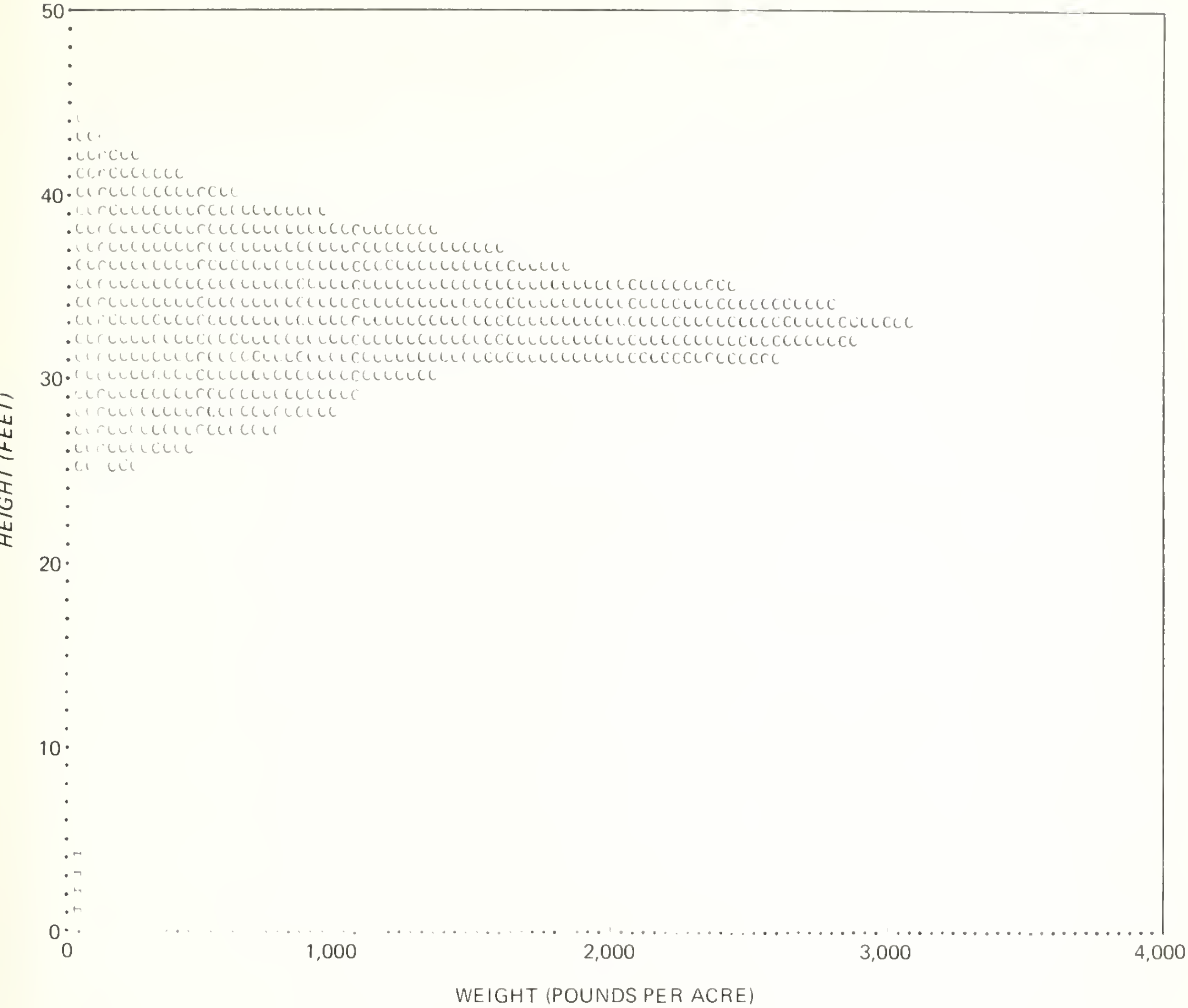

Figure 8.—Graph of crown weight in 50-year-old red pine plantation.

ave left 14,070 pounds per acre of slash on the ground. 'e then used the fire model developed by Rothermel 1972) to determine the impact this slash would have on re behavior. The fire model showed that a 35-fold icrease in fire intensity could be expected under the nbient conditions of 4-percent fine fuel moisture ›ntent and winds of 10 m.p.h. It is apparent that a wide iriety of forest management alternatives could be evalu- ed in the same manner. Some logical alternatives to 'aluate would be various levels of thinning, pruning to fferent heights, changing plantation species composition y including hardwoods or by mixing conifer species, id fuel reduction by prescribed burning. It is important to recognize that this method is dependent on the availability of regression equations that predict crown weights for the important species. There are many equations available in the literature; however, equations for some species may not presently be available.

It is also important to note that a complete fuel description method must emphasize the fuels at the ground surface. Our method does not describe these fuels. Therefore, it must be integrated with some means of describing these ground fuels before the fuel complex can be classified correctly. These methods are currently

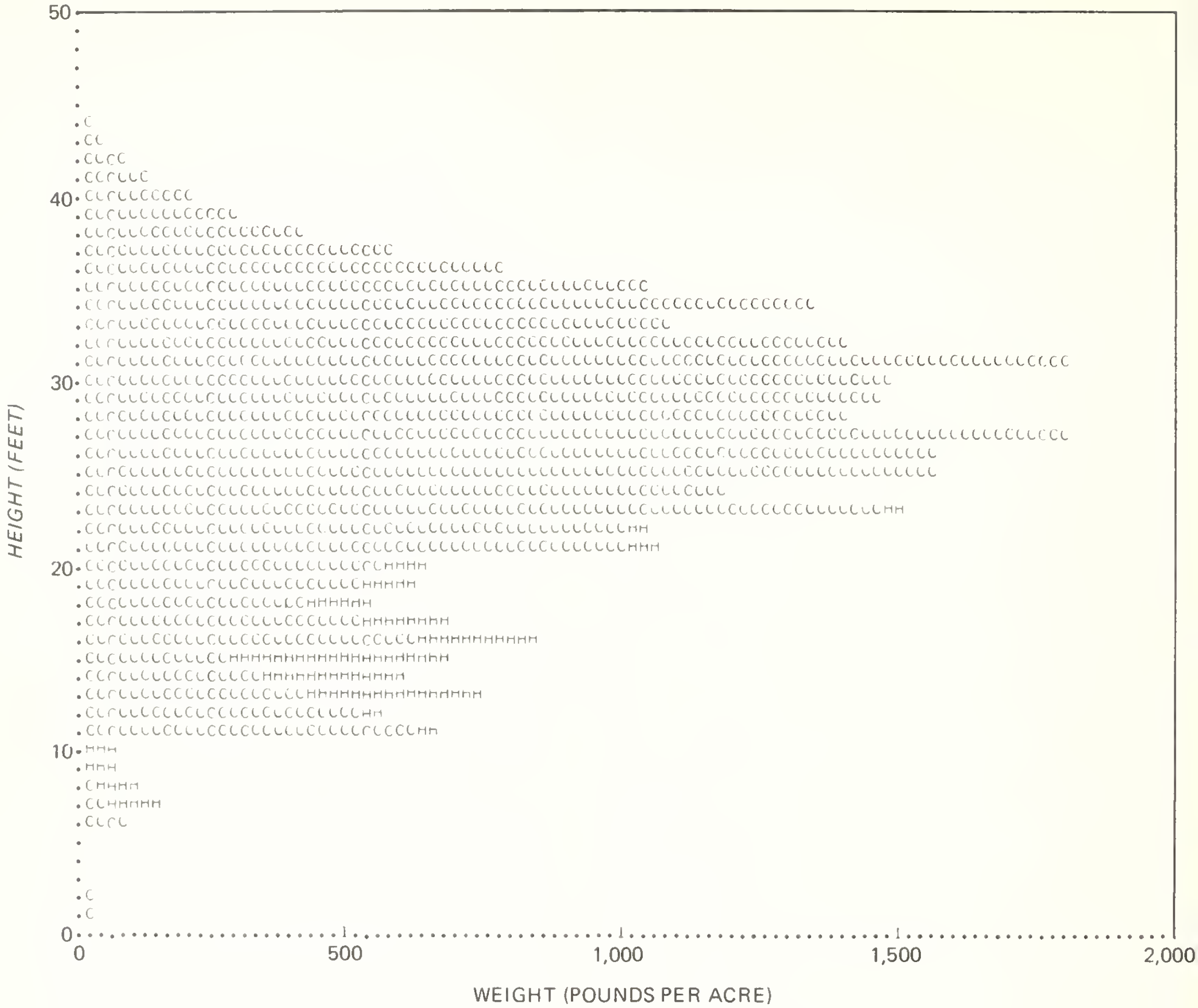

Figure 9. Graph of crown weight in 40-year-old jack pine stand.

available, however, and perhaps a complete quantitative description system will soon be available for use by fire control agencies.

SUMMARY

A system has been developed for describing the intermediate and crown fuels of forest stands that uses easily obtained measurements of the fuel complex. A computer program for summarizing the field data is an integral part of the system. A parameter, called the crow volume ratio, is calculated to characterize the fuel be porosity of the stand.

This system was used to describe five important fu types in the Lake States region and to evaluate th impact of a simulated commercial thinning operation i a red pine plantation. Testing under field conditions i a wide variety of fuel types is needed to fully evaluate th applicability of the method for predicting fire behavio

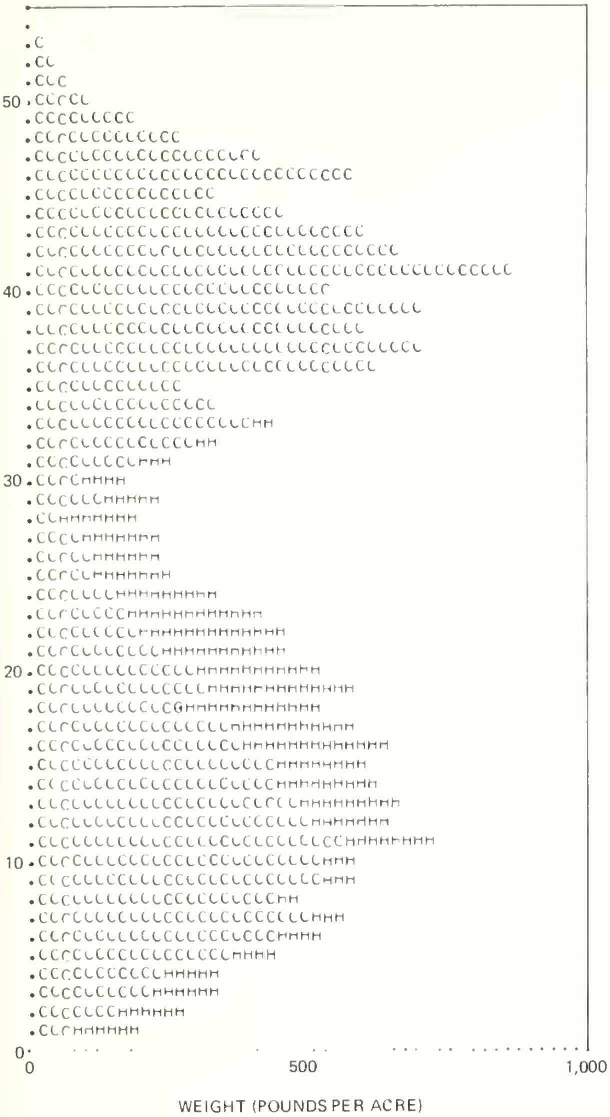

Figure 10.—Graph of crown weight in 105-year-old jack pine stand with spruce-fir understory. Note the important role of hardwoods in this stand.

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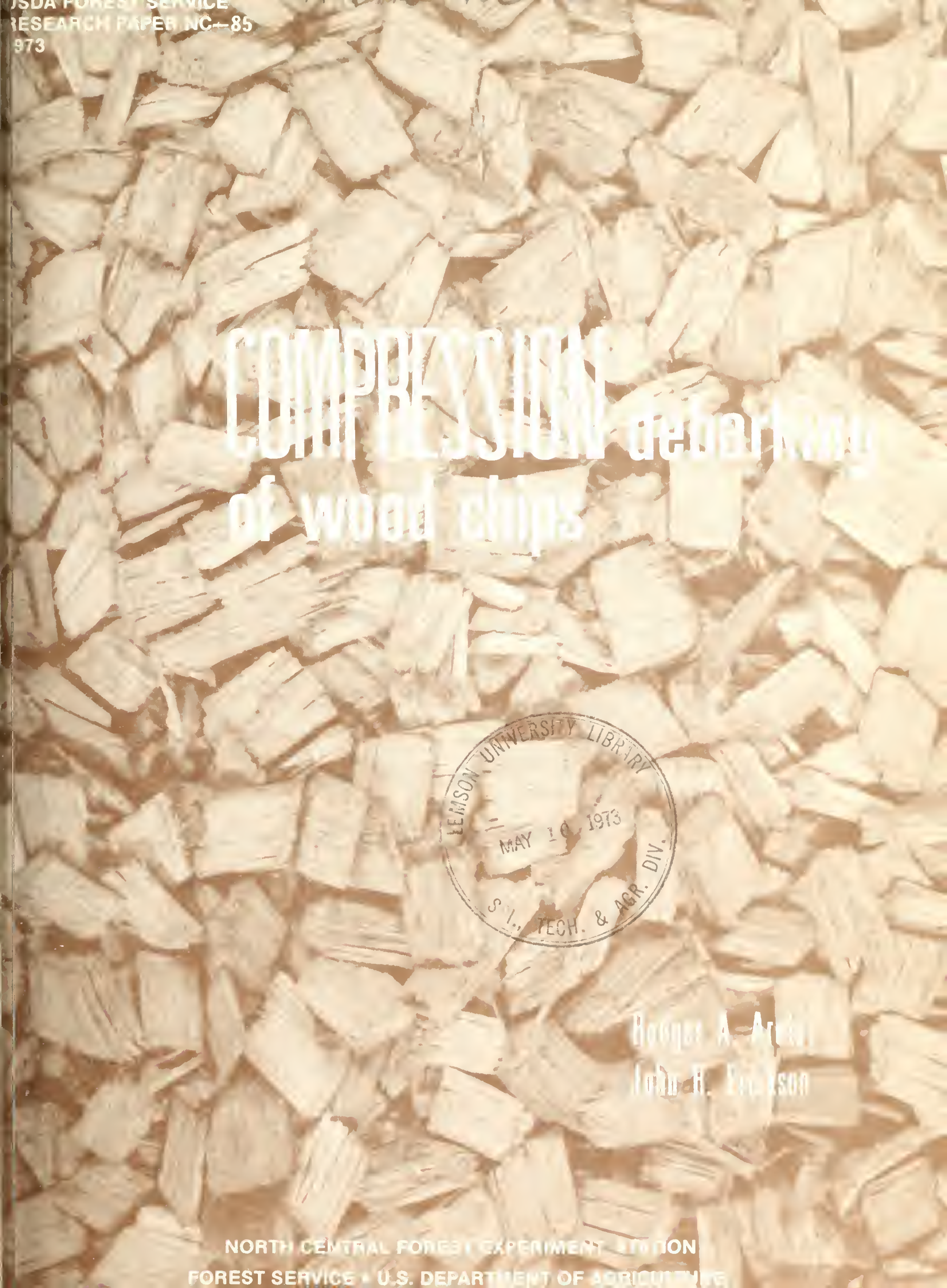

COMPRESSION debarking of wood chips

Rodger A. Arola
John R. Erickson

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

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CONTENTS

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Manuscript approved for publication October 24, 1972

COMPRESSION DEBARKING OF WOOD CHIPS

Rodger A. Arola and John R. Erickson

New timber harvesting methods are needed to improve the utilization of our forest resources, including logging residue. The gross volume of this material is estimated to be 2 billion cubic feet annually (excluding residual cull trees and thinnings) (Lassen and Hair 1970). This amount of wood fiber would fill more than 40 percent of our national pulpwood needs. Although economy is the major reason for leaving residue in the woods, the neglect of this material displays inefficient utilization standards.

In addition to the need for increased utilization, several environmental issues require attention. The Clean Air Act will impose restrictions on slash disposal by burning. We already have these restrictions in several areas of the country. Another environmental issue is "visual pollution." The public has voiced concern over the unsightly appearance of residue left after logging.

Before we can increase utilization standards and meet the impending environmental restrictions we must develop new technologies to remove sufficient levels of bark from residue wood. This is a major goal of the Forest Engineering Laboratory (F.E.L.) in Houghton, Michigan.

Bark removal after chipping is one promising approach that will help to improve the utilization standards of the forest industry. Bark removal after chipping is a two-stage problem: bark separation (the breaking of the bond between the bark and wood chip) and segregation (the removal of bark particles from the wood chips). We use the term bark removal to encompass both of these problems.

Compression debarking is a method that has shown considerable promise for removing bark from wood chips. The compression debarking principle involves passing a continuous single-layer flow of unbarked wood chips between two rotating steel rolls that have a nip spacing much smaller than the thickness of the wood chips. Due to the nip action, the bark particles either adhere to the surface of the rolls and are removed with roll scrapers into a waste area, or they fragment into smaller particles and are removed by screens.

The compression debarking process was initially developed by the Hosmer Machine Company (now HMC Corp.); however, the system was not developed commercially (Blackford 1961, 1965, 1966; Blanchard 1962). Because this concept showed promise, we decided that further work should be performed to evaluate the principle along with developing new methods to complement the process.[1] This paper discusses the results of an 18-month study of the compression debarking process as a single-pass system. Future publications will discuss complementary treatments.

STUDY OBJECTIVES AND TEST VARIABLES

Our study objective was to investigate the effect of several natural and machine variables on the amount of bark removal and wood recovery possible with the HMC experimental unit (fig. 1). The ultimate goal was to reduce the chip bark content to a residual of 1½ to 3 percent by weight (green) and to hold the wood loss to less than 5 percent.

Natural variables included species, season of cut, presized chips versus random mix, and fresh versus roundwood storage prior to chipping. Duplicate runs were made with chips produced from bolewood and tops and limbs.

The prime machine variables investigated were nip setting between two steel compression rolls, nip pressure in the chip compression zone, and adjustable baffle location beneath the rolls (fig. 2). Because of the large

[1] *Arola, R. A. State-of-the-art and analysis of bark-chip separation-segregation. (Unpublished report on file at the North Cent. For. Exp. Stn., USDA For. Serv., St. Paul, Minn. 1966)*

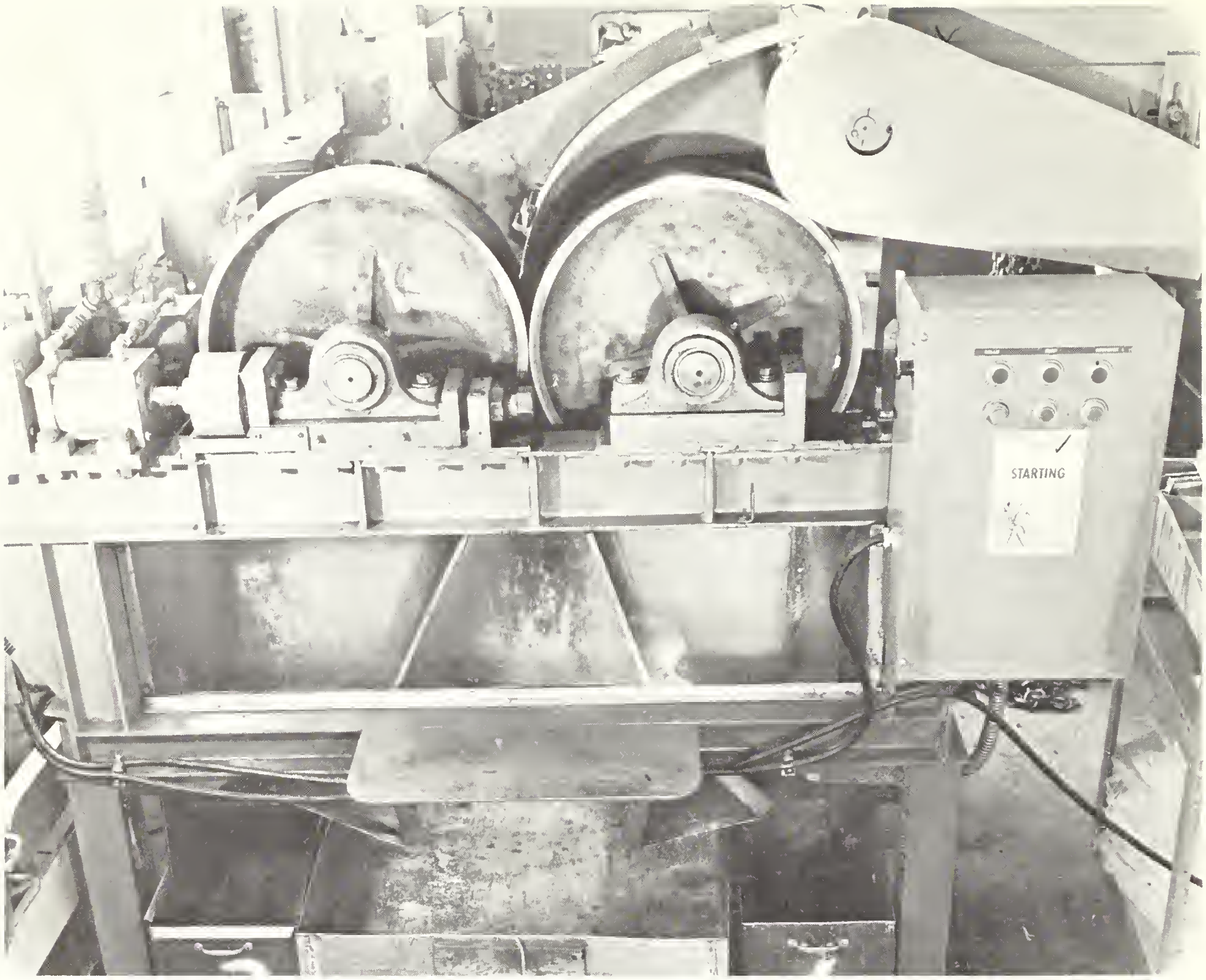

Figure 1. – The experimental compression debarker used for debarking wood chips.

number of tests required to complete the factorial experiments, roll speed and bulk feed rate (two additional prime variables) were kept constant for this study at respective values of 740 surface feet per minute and 1 cubic foot per minute.

MATERIAL DESCRIPTION AND ANALYSIS

We included three important Lake States species in our test program — aspen, which commands over 50 percent of the pulpwood market; hard maple, from the northern hardwood type; and jack pine. Southern pine was also tested. The total number of cuttings tested was as follows: fresh jack pine and aspen, five each; fresh hard maple, four; stored aspen, three; and stored jack pine and hard maple, two each (table 1). Three cuttings of fresh southern pine were also tested.

Unbarked chip samples were obtained from fresh bolewood, fresh tops and limbs, and stored bolewood (table 1). Bolewood was topped at approximately a 4-inch diameter and the topwood diameters were limited to approximately 2 inches. Foliage was not present in topwood.

All chips were produced with a Morbark Chip-Pac[2] and delivered to the F.E.L. by the following day. Within 1 week of chip delivery all material was classified

[2] *Mention of trade names does not constitute endorsement by the USDA Forest Service.*

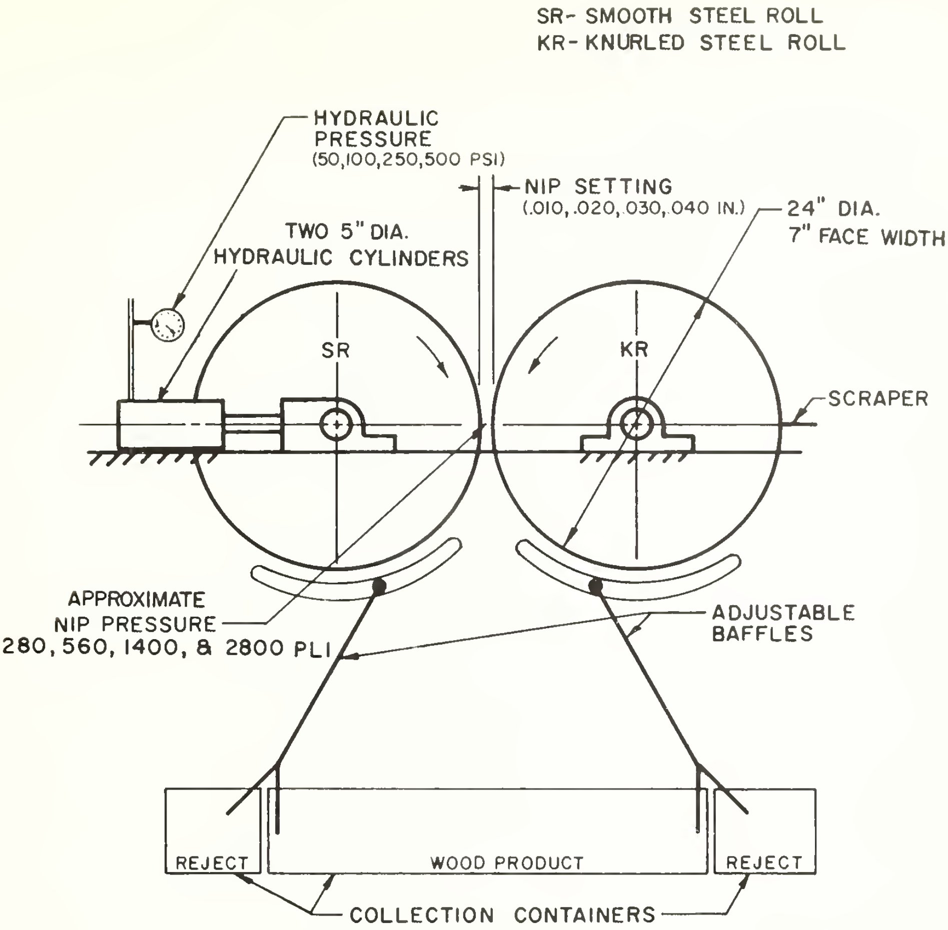

Figure 2. – Simplified compression debarker and machine variables.

and 25-pound charges were prepared and stored in plastic bags prior to compression debarking. During classification the chips were screened to remove those less than 3/16 inch and more than 1⅛ inches in size (round-hole screen), because we assumed fines would normally be discarded and oversize material rechipped and added to the input mix. The remaining chips were separated into three size classes with a SWECO[2] Classifier: 3/16 to ⅜ inch; ⅜ to ⅝ inch; and ⅝ to 1⅛ inches. Only the bark within these size classes was considered as input bark content in the compression debarking trials.

Two types of material were obtained for analysis from each debarking test — the residue removed from the compression rolls and the wood product output. The residue contained some wood fiber, which was considered as wood loss (methods to recover some of this wood are currently being studied). Conversely, the wood product output contained a residual bark content. Thus, both classes of material were sampled and analyzed to determine the amount of wood and bark in the output and in the residue material. The residual bark still adhering to the wood chips (called bark/wood) was also measured and compared with the input bark/wood fraction to evaluate the effectiveness of compression debarking in breaking the bark-to-wood bond. The output from the compression debarker was screened on a Williams Classifier[2] into the previously indicated size fractions and bark content determined within each chip size class.

RESULTS

Presized Chips Versus Random Mix

The chips were debarked both as a random mix and as separate presized fractions. In the latter, the best

Table 1. — *General information on species processed*

ASPEN

Material	Date cut	Date chipped	Inclusive processing dates	Age	Approximate wood temperature at chipping	Bark content		
						Free bark	Total bark	Separation
				Years		Percent	Percent	Percent
Bolewood (fresh)	17 Feb '70	19 Feb '70	3/3 -3/6	58	Frozen	13.1	15.8	86
	16 Apr '70	17 Apr '70	4/29-5/6	60	Unfrozen	13.4	20.1	67
	12 Aug '70	13 Aug '70	8/17-9/1	38	Unfrozen	14.5	15.3	95
	11 Dec '70	18 Dec '70	12/30-1/6	57	34° F	12.8	15.3	84
	23 June '71	24 June '71	6/31-7/12	36	61° F	18.2	18.2	100
Topwood (fresh)	16 Apr '70	17 Apr '70	4/29-5/6	32	Unfrozen	13.4	24.0	56
	12 Aug '70	13 Aug '70	8/17-9/1	21	Unfrozen	20.0	25.3	80
	11 Dec '70	18 Dec '70	12/30-1/6	32	34° F	17.0	21.0	81
	23 June '71	24 June '71	6/31-7/12	14	61° F	24.0	24.0	100
Bolewood (stored)	17 Feb '70	19 Nov '70	11/25-12/8	51	—	15.5	15.8	98
	16 Apr '70	20 June '71	1/25-2/2	46	24° F	15.8	16.1	98
	12 Aug '70	6 May '71	5/11-5/25	37	50° F	11.6	12.7	91
JACK PINE								
Bolewood (fresh)	23 Dec '69	30 Dec '69	1/30-2/4	48	Frozen	4.6	6.4	72
	23 Mar '70	24 Mar '70	4/20-4/21	31	Unfrozen	4.8	8.5	57
	25 Aug '70	26 Aug '70	9/11-9/24	30	Unfrozen	8.6	8.9	97
	15 Feb '71	17 Feb '71	2/17-3/5	50	28° F	3.9	7.8	50
	8 June '71	9 June '71	6/18-6/23	31	51° F	8.8	8.8	100
Topwood (fresh)	23 Dec '69	30 Dec '69	1/30-2/4	22	Frozen	7.5		
	23 Mar '70	24 Mar '70	4/20-4/21	14	Unfrozen	4.7	9.9	47
	25 Aug '70	26 Aug '70	9/11-9/24	13	Unfrozen	8.7	9.6	91
	15 Feb '71	17 Feb '71	2/17-3/5	23	28° F	4.7	10.3	46
	8 June '71	9 June '71	6/18-6/23	13	51° F	9.0	9.1	99
Bolewood (stored)	23 Dec '69	2 Nov '70	11/13-11/19	51	--	5.0	5.0	100
	23 Mar '70	6 June '71	1/11-1/20	29	8° F	6.1	6.2	98
HARD MAPLE								
Bolewood (fresh)	7 Mar '70	9 Mar '70	3/13-3/26	37	Frozen	10.9	11.6	94
	29 July '70	30 July '70	8/4 -8/14	54	Unfrozen	12.9	12.9	100
	21 Sept '70	2 Oct '70	10/19-10/28	63	Unfrozen	12.0	12.7	95
	17 May '71	20 May '71	6/2 -6/7	41	40° F	12.6	12.6	100
Topwood (fresh)	7 Mar '70	9 Mar '70	3/13-3/26	37	Frozen	13.2	14.3	92
	29 July '70	30 July '70	8/4 -8/14	20	Unfrozen	13.5	13.6	99
	21 Sept '70	2 Oct '70	10/19-10/28	41	Unfrozen	14.6	17.6	83
	17 May '71	20 May '71	6/2 -6/7	24	40° F	15.6	15.7	94
Bolewood (stored)	7 Mar '70	3 Dec '70	12/9 -12/21	88	--	10.7	10.7	100
	29 July '70	15 Apr '71	4/21-5/4	66	42° F	13.4	13.4	100

results (in terms of bark removal) within each size fraction were mathematically weighted and combined into a "reconstituted" mix to give an overall bark removal and wood recovery. This permitted us to compare the results with presized chips with the best results for chips processed as a random mix. The hypothesis was that a "best" combination of machine parameters existed for processing each of the three chip sizes, which would be an improvement over processing random-sized chips.

The compression debarking results did not improve when presized chips were processed (table 2). For example, the mean input bark content of presized aspen bolewood was reduced to 8.5 percent while that of the random mix was reduced to 8.6 percent. The mean wood

Table 2. — *Compression debarking results for reconstituted and random-mix bolewood chips (fresh)*[1]
(In percent)

Species	Input bark	Reconstituted mix			Random mix		
		Residual bark	Bark removed	Wood recovered	Residual bark	Bark removed	Wood recovered
Jack pine:							
Mean	8.5	3.2	62.3	95.3	2.4	71.8	92.2
Range	7.8- 8.9	1.8- 4.4	43.6-79.5	93.7-96.7	1.3- 3.6	57.6-85.2	86.7-96.6
Aspen:							
Mean	16.9	8.5	49.2	97.0	8.6	49.4	96.3
Range	15.3-20.1	5.4-10.8	29.4-70.3	94.4-98.3	5.0-10.3	32.7-72.5	94.0-97.7
Hard maple:							
Mean	12.4	5.2	57.5	97.5	4.7	61.5	97.4
Range	11.6-12.9	3.3- 7.4	36.2-74.4	93.6-99.5	2.3- 7.9	31.9-82.2	93.6-99.2
Loblolly:							
Mean	10.3	4.9	52.4	96.9	4.8	53.6	96.2
Range	10.0-10.8	4.0-5.8	43.1-63.0	96.2-98.4	3.5- 5.6	45.1-67.6	94.9-97.6

1/ Nip pressure set at 560 Pli.

recovery for presized aspen chips was 97.0 percent, compared with 96.3 percent for chips processed as a random mix. The mean residual bark content of the other species was slightly less for the random mix than the presized material.

Bolewood Versus Topwood

We found little difference between the compression debarking results of bolewood and topwood (table 3). The mean percent bark removal for aspen and loblolly topwood was slightly greater than for bolewood but was within the experimental seasonal range for bolewood. The percent of input bark content in topwood was 22 to 35 percent greater than for bolewood. Thus, the residual bark content in topwood was slightly greater than in bolewood. The wood recovery was about the same for both types of material — for bolewood it ranged from 92.2 to 97.4 percent, and for topwood from 92.4 to 98.1 percent.

Fresh Versus Stored Bolewood

Although good bark separation resulted when bolewood was stored for approximately 9 months prior to chipping (table 1), no consistent improvement in segregation occurred (table 4). Roundwood storage had no

Table 3. — *Compression debarking results for random-mix bolewood and topwood chips (fresh)*[1]
(In percent)

Species	Bolewood				Topwood			
	Input bark	Residual bark	Bark removed	Wood recovered	Input bark	Residual bark	Bark removed	Wood recovered
Aspen:								
Mean	16.9	8.6	49.4	96.3	22.9	10.7	52.4	95.9
Range	15.3-20.1	5.0-10.3	32.7-72.5	94.0-97.7	20.2-25.3	6.1-15.8	34.2-74.6	93.4-97.9
Hard maple:								
Mean	12.4	4.7	61.5	97.4	15.3	6.7	56.1	98.1
Range	11.6-12.9	2.3- 7.9	31.9-82.2	93.6-99.2	13.6-17.6	4.0- 9.9	30.8-72.4	97.1-98.8
Jack pine:								
Mean	8.5	2.4	71.8	92.2	10.7	3.8	66.5	92.4
Range	7.8- 8.9	1.3- 3.6	57.6-85.2	86.7-96.6	9.1-14.7	0.5- 7.2	44.4-94.5	88.6-95.1
Loblolly:								
Mean	10.3	4.8	53.6	96.2	12.6	5.1	59.7	95.8
Range	10.0-10.8	3.5- 5.6	45.1-67.6	94.9-97.6	11.9-13.3	4.4- 5.8	56.4-63.0	94.3-97.3

1/ Nip pressure set at 560 Pli.

Table 4. — *Compression debarking results for fresh and stored bolewood chips*[1]
(In percent)

Species, bolewood condition	Input bark	Reconstituted mix			Random mix		
		Output bark	Bark removed	Wood recovered	Output bark	Bark removed	Wood recovered
Aspen:							
Fresh	16.9	8.5	49.2	97.0	8.6	49.4	96.3
Stored	14.9	7.3	50.7	97.0	6.1	59.5	97.1
Hard maple:							
Fresh	12.4	5.2	57.5	97.5	4.7	61.5	97.4
Stored	12.1	5.2	57.8	92.5	6.5	46.1	96.4
Jack pine:							
Fresh	8.5	3.2	62.3	95.3	2.4	71.8	92.2
Stored	5.6	2.9	48.5	94.9	2.4	57.7	94.8

1/ Nip pressure set at 560 Pli.

effect on the average wood recovery. The aspen was cut in February and April, the hard maple in March and July, and the jack pine in December and March.

Long-term storage of wood chips in piles was not tested. However, we did observe a significant increase in bark removal when aspen chips were stored at room temperature in polyethylene bags for approximately 3 weeks. Regardless of the compression debarker nip and pressure settings we were able to remove approximately 90 percent of the input bark and recover 90 to 95 percent of the wood fiber. Because bark removal improved with bag storage, tests were run on aspen chips stored in a small pile in an unheated building during the winter and on chips stored in polyethylene bags at room temperature. Chips from each source were sampled for 2 months at 3- to 5-day intervals. The pile-stored chips did not yield an increase in bark removal over this period — the residual bark fluctuated between 57 and 73 percent of the input bark content with a mean value of 67 percent (fig. 3). The residual bark in bag-stored material showed a significant reduction with storage time — it decreased from 69 percent of the input at the start of storage to 11 percent after 55 days of storage. Wood recovery decreased slightly with prolonged bag storage.

The bag-stored aspen chips and bark were analyzed for moisture content at various intervals over a 43-day period. The wood chips started at about 53 percent moisture and decreased to 47 percent (wet basis) in that period while the bark started at 41 percent and increased to 53 percent. Thus, a transfer of moisture occurred between wood and bark stored in the plastic bags. The moisture content in wood and bark were equal in about 16 days, after which the cambial surface of the bark started to feel tacky. This explained why the bark readily adhered to the compression rolls.

The benefits of bag storage led to a search of "conditioning" treatments that would simulate the action in the polyethylene bags. One approach was to heat the chips with low-pressure steam. A study is now in progress to determine optimum steaming temperature, pressure, and time for aspen, hard maple, jack pine, and southern pine. Steaming prior to compression debarking to increase bark removal is definitely a beneficial treatment — particularly with aspen.

An interesting study that relates to the effect of bag storage on chips was conducted at the Forest Products Laboratory, where wood chips were covered with plastic membranes to limit chip deterioration by cutting down

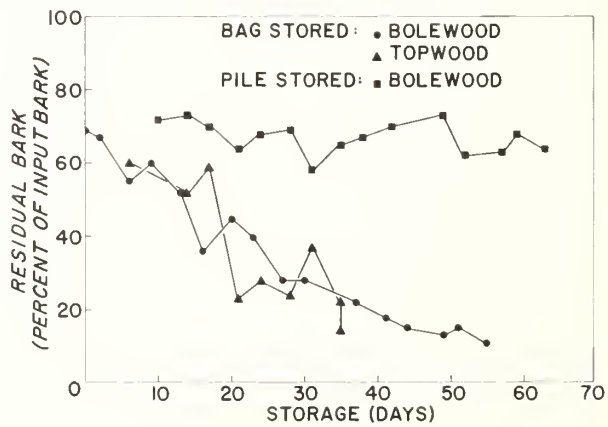

Figure 3. – Effect of bag storage at room temperature on bark removal.

the oxygen supply (Feist *et al.* 1971). Fresh aspen chips stored for 185 days under a 20-mil.-thick polyethylene sheet showed less deterioration and yielded a kraft pulp of comparable quality to fresh chips. The covered chips also showed slight staining and light mycelial growth. It is our opinion that this mycelial growth caused the tackiness of the cambial surface of the bark in our bag-stored chips, and we feel it desirable for improving the compression debarking process. Methods to artificially induce *controlled* mycelial growth in unbarked chip piles may be worthy of investigation.

Nip Spacing and Pressure

The tests to evaluate the combined effect of nip spacing between the rolls and the pressure per lineal inch of roll width did not result in a true "optimum" combination of the two. Bark removal decreased with increased nip spacing within the range of 0.010 to 0.040 inch, whereas wood recovery increased. Conversely, bark removal increased with increased nip pressure in the range of 280 to 2,800 pounds per lineal inch (pli), and wood recovery decreased.

The greatest bark removal and least wood recovery occurred at the 0.010-inch nip spacing and 2,800 (pli) nip pressure. Ideally, both bark removal and wood recovery would be maximized. However, conditions that lead to improved wood recovery also lead to reduced bark removal. Thus, a compromise had to be made between bark removal and wood recovery. We looked for a combination of nip spacing and pressure that gave approximately 50 percent bark removal and 95 percent wood recovery for all seasons of the year. For bolewood, a combination of 0.020-inch nip spacing and 1,400 pli of nip pressure yielded results closest to the desired bark removal and wood recovery levels for all species tested. Topwood was tested only at the 560 pli level and four nip spacings. However, based on the similarity in results between bolewood and topwood at this pressure level, it is felt that the 1,400 pli nip pressure would also be a good compromise for topwood.

Baffle Location

The original compression debarker employed stationary baffles under the compression rolls to segregate and collect bark and wood chips. Because the bark and wood chips of each species and season adhered to the compression roll with varying tenacity, we added adjustable baffles beneath the rolls of the compression debarker to control the bark removal or wood recovery for each species. As we moved the baffles closer to the mainstream of wood output more bark was removed, but at a sacrifice in wood recovery. As the baffles were moved away from the mainstream of wood output more wood was recovered, but the residual bark in the wood output also increased.

We were unable to determine the "best" baffle location because of mechanical limitations in the machine used in the original study. A more detailed study with a revised test setup is now underway to evaluate how much material adheres to each roll and the trajectory distribution of bark and wood particles that are thrown off the rolls. We plan to develop histograms of bark and wood trajectory from each roll and establish confidence limits for bark removal and wood recovery with varying baffle locations. These data will make it possible to recommend baffle locations in a production or pilot plant unit.

Season of Cut

Cutting season affected the amount of bark that separated from the wood chips due to chipping. With wood cut during the growing season, nearly all of the bark separated from the wood due to the chipping action. However, with wood cut during the dormant season, less than 40 percent of the bark of some species separated from the chips. We also found that compression debarking segregated more bark from wood cut during the growing season:

	Bark removal	
Species	*Growing season (Percent)*	*Dormant season (Percent)*
Aspen	70	41
Maple	70	43
Jack pine	80	57

This is probably due to two factors: (1) better separation of the bark/wood bond, and (2) the cambial layer of the bark is tackier and adheres better to the compression rolls.

Because of the strong influence of season on bark removal we have sought a "conditioning" treatment to offset the seasonal effects. Preliminary test results show that steaming of the bark-chip mass prior to compression debarking helps to offset seasonal effects. As previously indicated, steaming of unbarked chips prior to compression debarking is now under investigation.

Smooth Versus Knurled Roll

The compression debarker as tested was equipped with a smooth and a knurled compression roll (fig. 2). The amount of material that the smooth and knurled rolls removed from the mix varied by species (and, of course, by season as previously indicated) (table 5). For all cuttings the combined amount of material removed from both rolls was slightly over 10 percent of the input.

Table 5. — *Results of compression debarking with smooth and knurled rolls for random-mix aspen, hard maple, and jack pine*[1]
(In percent)

Species	Material removed from:					
	Smooth roll			Knurled roll		
	Percent of input	Wood	Bark	Percent of input	Wood	Bark
Aspen 2/	5.1	21.2	78.8	5.4	19.0	81.0
Jack pine 2/	7.0	39.6	60.4	5.8	42.2	57.8
Hard maple 3/	3.3	14.5	85.5	6.3	22.9	77.1

1/ Nip pressure set at 560 Pli.
2/ Mean test results for five separate cuttings.
3/ Mean test results for four separate cuttings.

For aspen, approximately 20 percent of the material removed was wood and 80 percent bark with both rolls. For jack pine there was a considerably greater proportion of wood fiber loss — approximately 40 percent wood and 60 percent bark. With hard maple the knurled roll residue had over 20 percent wood while the smooth roll residue had only 14 percent wood. The knurled roll contributed most to the wood loss in maple because it removed nearly twice as much material as the smooth roll.

These tests were run with fresh chips — thus the chips had a high moisture content. Later observations indicated that wood loss increases considerably as the wood chips become drier.

Bark Analysis by Chip Size Before and After Compression Debarking

As mentioned earlier, bark removal after chipping requires both separation (breaking of the bark-to-wood bond) and segregation (the removal of bark chips from wood chips). Compression debarking partially accomplished both jobs. Because compression debarking is a fairly severe mechanical treatment, it is of interest to compare the bark and chip sieve sizes before and after treatment.

Thus, we determined the percentage of free wood, free bark, and bark/wood[3] within each chip size before and after the compression treatment in addition to the percentage of the total mix that each size represents (table 6).

After compression debarking the percent of mix in each size fraction did not change much; however, the free wood, free bark and bark/wood percentages within each size fraction did change. For example, with aspen we found the ⅝ to 1⅛ inches fraction exceptionally clean — it had only 0.3 percent residual free bark and 0.9 percent bark/wood. The ⅜- to ⅝-inch fraction still had 11.0 percent free bark and 1.0 percent bark/wood. Most of the residual bark was concentrated in the two smallest chip sizes. Hard maple, jack pine, and loblolly pine yielded similar patterns.

We believe that much of the residual bark after compression debarking is bark that was originally attached to the wood chips in the input mix. In other words, the nip action broke the bark-to-wood bond but did not remove this bark from the mix. The bark/wood content was reduced in each size fraction after compression debarking. For ⅝- to 1⅛-inch aspen chips we were able to reduce the bark/wood content from 7.5 percent to 0.9 percent; for ⅜- to ⅝-inch chips from 2.5 to 1.0 percent; and for 3/16- to ⅜-inch chips from 0.5 to 0.4 percent.

The bark content in the input chips and the processed chips has been plotted by chip size for each species tested (fig. 4). Additionally, these figures illustrate the percentage that each size fraction represents in terms of total mix. The bark contents are illustrated in bar chart form, and the percent of material in each chip size is shown graphically.

CONCLUSIONS

The single-pass compression debarking process tested did not consistently reduce residual bark content to the goal of 3 percent for the species tested and for wood cut during all seasons. Additional processing

[3] *Free wood = wood chips with no bark adhering; free bark = bark particles with no wood adhering; bark/wood = wood chips with bark still adhering.*

Table 6. — *Free wood, free bark, and bark/wood percentages before and after processing by chip-size class*[1]

Chip-size class (inches)	Material	Total mix		Free wood		Free bark		Bark/wood	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
ASPEN									
5/8 - 1-1/8	Input	64.3	53.7-71.1	86.3	76.3- 91.4	6.2	4.2- 9.0	7.5	0.0-19.4
	Output	63.5	49.9-74.6	98.8	96.1-100.0	.3	0.0- .6	.9	0.0- 3.3
3/8 - 5/8	Input	29.2	24.8-36.1	69.5	66.2- 78.8	28.0	18.4-33.5	2.5	0.0- 6.7
	Output	27.2	20.0-34.7	88.0	84.6- 91.5	11.0	8.4-14.5	1.0	0.0- 2.7
3/16 - 3/8	Input	6.7	4.1-10.2	54.9	46.7- 68.9	44.6	30.8-53.3	.5	0.0- 1.7
	Output	9.3	5.4-15.4	64.7	56.3- 68.4	35.0	32.7-42.2	.4	0.0- 1.5
HARD MAPLE									
5/8 - 1-1/8	Input	65.4	64.7-66.5	95.5	95.0- 96.0	3.8	2.9- 4.5	.7	0.0- 2.1
	Output	67.1	65.6-69.0	99.2	98.9- 99.7	.7	.3- 1.2	.1	0.0- .4
3/8 - 5/8	Input	27.9	27.1-28.4	75.4	74.5- 76.0	24.2	23.2-25.4	.4	0.0- 1.0
	Output	25.2	24.0-26.3	93.8	92.4- 95.0	6.1	5.0- 7.4	.1	0.0- .2
3/16 - 3/8	Input	6.7	6.4- 6.9	50.7	46.0- 53.4	49.2	46.6-53.7	.1	0.0- .3
	Output	7.7	6.9- 9.2	70.4	58.6- 79.5	29.4	20.5-40.8	.2	0.0- .6
JACK PINE									
5/8 - 1-1/8	Input	58.5	52.5-62.5	87.6	80.3- 93.8	3.2	.8- 6.1	9.3	.1-18.9
	Output	49.4	45.4-53.4	97.7	93.8- 99.8	.4	.2- .6	2.0	0.0- 5.6
3/8 - 5/8	Input	33.2	31.4-37.0	86.8	83.1- 90.4	8.1	4.6-12.0	5.1	0.0-10.7
	Output	37.6	35.1-40.1	94.3	89.2- 97.8	3.5	2.2- 5.4	2.3	0.0- 5.4
3/16 - 3/8	Input	8.3	5.7-10.4	74.5	68.9- 82.1	24.4	16.4-30.8	1.1	0.0- 2.6
	Output	13.0	11.5-14.5	84.7	81.8- 87.6	14.0	13.4-15.3	1.3	0.0- 3.4
LOBLOLLY PINE									
5/8 - 1-1/8	Input	56.3	51.6-61.7	90.0	87.4- 93.8	4.1	3.3- 5.4	5.9	.8- 8.9
	Output	51.9	47.1-57.8	97.3	96.0- 98.1	1.5	.4- 2.4	1.3	.1- 1.9
3/8 - 5/8	Input	34.5	32.0-37.8	84.7	84.4- 85.3	12.7	11.9-14.1	2.6	.6- 3.7
	Output	36.2	32.5-40.4	91.4	88.7- 96.1	7.5	3.1-10.2	1.1	.3- 2.1
3/16 - 3/8	Input	9.2	6.3-10.8	71.2	68.0- 76.8	28.4	22.7-32.0	.5	0.0- .9
	Output	11.9	9.7-13.4	79.9	74.1- 84.5	19.6	14.9-25.9	.5	0.0- 1.0

1/ Nip pressure set at 560 Pli.

or conditioning treatments are necessary to help the compression process reach the established goal.

If secondary processing treatments are employed after compression debarking, they should concentrate on beneficiating the smaller chip size fractions that contain the majority of the residual bark. This secondary output would then be recombined with the clean chip fraction from the compression debarker. Another alternative is to utilize the chips passing the ⅜-inch sieve for other products that can tolerate high bark percentages.

Nip pressure, nip setting, wood storage, and season of cut all influenced bark removal with the compression debarker. But we feel that the most important variable affecting debarking efficiency is the season of cut. We were able to remove approximately 70 percent more bark from wood cut in the growing season than from wood cut in the dormant season. The percent of bark removal and wood recovery varied little between topwood and bolewood. More variation in bark removal was observed for material stored 9 months in roundwood form than for material chipped fresh.

Nip pressure and spacing had a significant effect on bark removal and wood loss. A compromise setting of 1,400 pounds per lineal inch nip pressure and 0.020-inch nip spacing should yield reasonable bark removal with limited wood loss for the species tested during most seasons of the year.

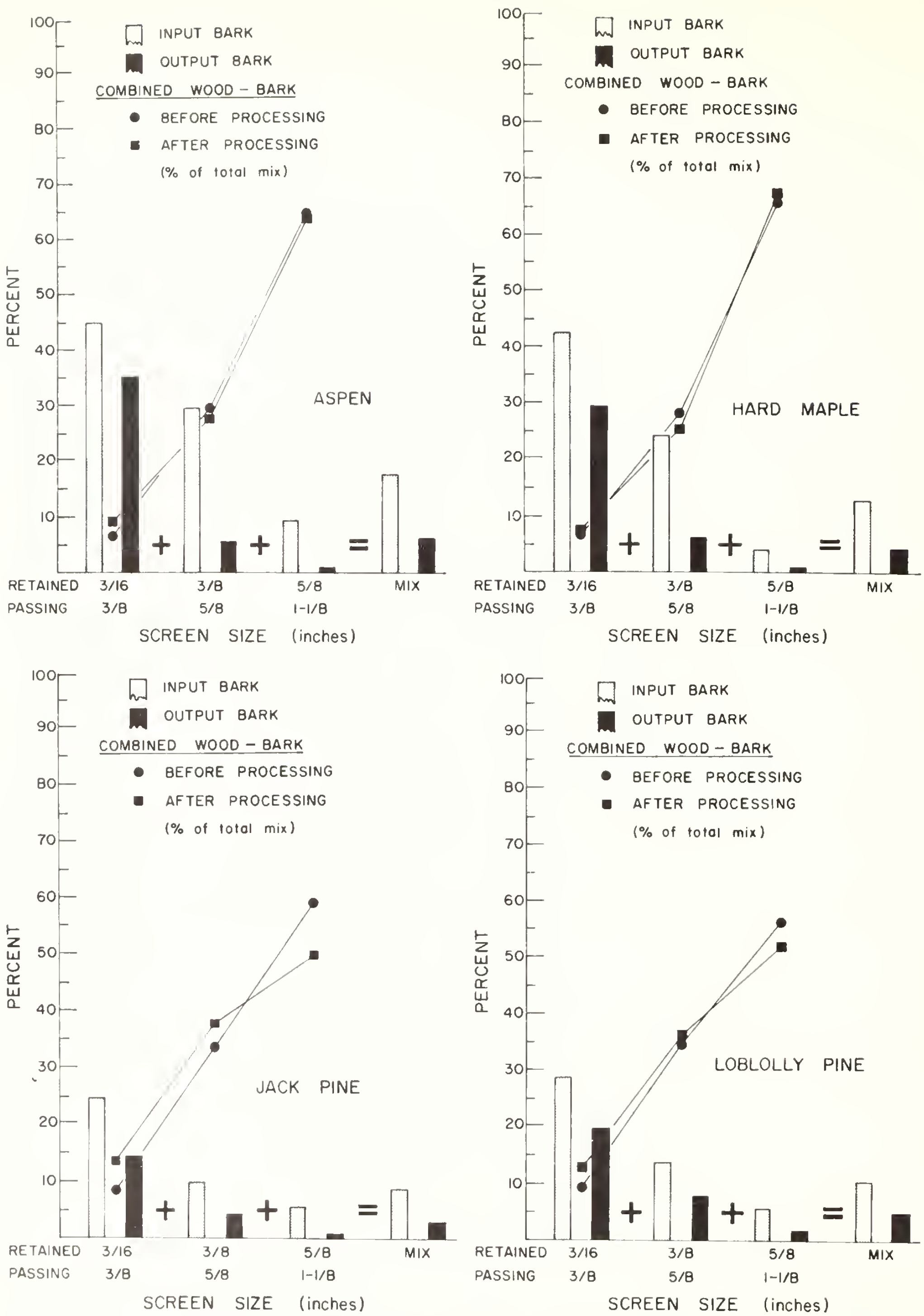

Figure 4. – Size breakdown and bark content before and after compression debarking.

Presizing or grading of the chips prior to compression debarking did not improve bark removal. Future tests will be run with random chip sizes.

Storage of chips in plastic bags at room temperature resulted in transfer of moisture to the bark after about 3 weeks, at which time the bark became tacky. We suspect micro-organic action caused the bark to become tacky and more susceptible to removal by compression debarking. Future compression debarking tests should include pile-stored bark-chip mixes that have begun to show signs of light micro-organic action. Additionally, research on methods to induce a tacky surface on the cambial side of the bark is recommended.

Bark removal and wood recovery can be altered with adjustable baffles beneath the compression rolls. Tests are now underway to allow specific recommendations to be made for pilot or production plants.

As a result of the research reported here, a new system has been developed and is being tested. It includes a device to presteam bark and wood chips prior to compression debarking. An abrasion treatment follows compression debarking and the abraded material is screened to remove bark fines. The outlook for this new system is very good, particularly with aspen and jack pine. Limited tests to date indicate that it is possible to remove up to 35 percent more bark with the new system, which would make it suitable for most pulping processes. If similar results are obtained with other primary pulpwood species and logging residues, the system could contribute to solving a major portion of our utilization problem.

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SOME SOIL PHASES IN THE MISSOURI OZARKS HAVE SIMILAR SITE INDEXES FOR OAKS

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Manuscript approved for publication November 20, 1972

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Some Soil Phases in the Missouri Ozarks Have Similar Site Indexes for Oaks

Richard F. Watt and Michael E. Newhouse

The classical and most widely used method of estimating forest site quality is to use the growth of the trees themselves as an integrator of the site's growth factors and microclimate. This method is based on the logical belief that the reaction of the tree over its lifetime is the surest indicator of the long-term levels of moisture, nutrients, heat, and light available. Heights and ages of several dominant and codominant trees are determined, and, by reference to height-age curves, the height of the tree at some standard age — the site index — is calculated. Naturally, trees selected for site index measurements must have grown without suppression or serious injuries that might have affected normal height-age relationships. When such trees are not present, we must resort to indirect methods of site index determination. These can be based on physical factors, such as soils, topography, and climate, or the presence and growth of other plants believed to indicate the site's ability to support the tree species in question.

Soils and topography, separately or combined, are often used to estimate site quality, because they are stable factors of the landscape that are relatively undisturbed by man's activities. Although soil types were found to be significantly correlated with site index of loblolly pine and shortleaf pine in Texas (Chandler *et al.* 1943), site index of black oak in southeastern Ohio varied too widely within soil series to have practical use in forest management (Carmean 1961). A number of additional studies (Graney and Ferguson 1971, Hannah 1968, Hartung and Lloyd 1969, Ike and Huppuch 1968, Smalley 1967, VanLear and Hosner 1967, and Yawney and Trimble 1968) have shown topography to be more important than soil classification in the indirect determination of site quality for hardwoods and conifers.

In this report, we will discuss one phase of a study designed to relate specific soil and topographic characteristics to site quality for black and white oaks in the Central Ozarks of Missouri. The results showed that soil series and phases, as presently defined, cannot be used as indicators of site quality for these tree species.

METHODS

This study was confined to the Salem Plateau of the southeastern portion of the Missouri Ozarks, an area of well dissected karst terrain heavily wooded with oak-hickory stands. Except for relatively small areas of colluvial slopes, the soils are residual and thin; they generally contain a large amount of chert, an insoluble silica stone left from the weathering of the parent material. Parent material is sedimentary rock from formations of the Lower Ordovician and Cambrian systems, largely cherty limestones and dolomites with some bands of sandstone in the Roubidoux formation. The low levels of phosphorus and potassium in the parent material, in conjunction with the long weathering period, have produced soils low in fertility and pH. Pleistocene loessal deposits approximately 3 feet thick have been largely eroded away, except for shallow remnants on the gentler slopes and level ridgetops. Hard, dense fragipan layers are found at shallow depths in some soil series. These fragipans limit penetration of roots and are slowly permeable to air and water.

A total of 179 black oak and 125 white oak plots was established in fully stocked, even-aged oak-hickory stands in the Ozarks of southeastern Missouri. On each plot five or more dominant or codominant trees were selected for site-index determinations. Three of these were felled for sectioning, height measurement, and detailed observations of height-growth patterns. The others were bored at breast height for ring counts; their total heights were determined optically. Care was taken to select only healthy trees that had grown without periods of suppression or damage. A number of trees that appeared normal externally were rejected later due to abnormalities disclosed by sectioning.

Equal numbers of plots were selected on the basis of aspect, slope position, and slope steepness for each soil phase and for both pan and nonpan soils. These topographic classes were selected after preliminary analysis of the partially completed sampling. This distribution of plots over the main topographic variables makes comparison of the pan and nonpan groups statistically valid.

Using a small backhoe, one to four soil pits were dug on each plot to a depth of at least 4 feet, bedrock permitting, and the large exposed profiles were then described by soil scientists. Bulk samples were taken for laboratory analysis of the chemical and physical properties of the soil horizon. Field descriptions and laboratory measurements were used to place each plot in the correct soil family, series, and phase. Independent verifications were later provided by a third soil scientist.[1]

RESULTS

The site index and soil phase analysis showed no statistical or practical difference in the average site quality of the seven soils studied. For example, the lowest average site index for black oak is 61.7 feet on the Clarksville cherty silt loam, and the highest is 65.1 feet on the Coulstone cherty loam. The range of differences for average white oak site indexes are equally small (fig. 1).

[1] *Soil descriptions for 125 black oak plots were made by John Millet, Soil Scientist, now with USDA Forest Service, Grants Pass, Oregon; descriptions for 54 black oak plots and 125 white oak plots were made by the junior author; verifications of a selected sample were made by Mack Miller, Soil Scientist, USDA Forest Service, Rolla, Missouri.*

Another major result, unexpected on the basis of our knowledge of the general physical characteristics of the two soil groups, was the almost identical site index averages and ranges for the pan and nonpan soils (table 1). A third finding was the uniformly lower site indexes obtained when white oak rather than black oak was used as the site-index species.

Table 1. — *Summary of nonpan and pan soil data for black and white oak plots*

Item	Nonpan soils	Pan soils
BLACK OAK		
Average site index	63.0	63.4
Standard deviation	± 4.4	± 7.2
Range	52-75	52-73
Number of plots	107	72
WHITE OAK		
Average site index	55.9	55.7
Standard deviation	± 5.2	± 5.4
Range	45-70	45-65
Number of plots	65	60

When the total range of site index for all soil phases is compared with the range for the individual soils, even more emphasis is placed on the impossibility of relating soils to site quality for growth of trees. For example, the total range of site index for all soils was 28 feet. The range of site index for most individual soil phases approaches this total range. Obviously, if all site indexes found in the study can also be found on most soil phases, it is impossible to predict site index from soil phases alone.

The fragipan soils have a dense, impervious layer 12 to 36 inches below the surface that restricts the downward movement of roots and moisture except for the occasional structural crack. Thus, pan soils are physiologically shallow and would be expected to be of lower site index than the nonfragipan soils (Krusekopf 1963). But, in fact, both pan and nonpan soils have nearly identical site index (table 1). How can this paradox of similar site index on soils of different effective depths be explained?

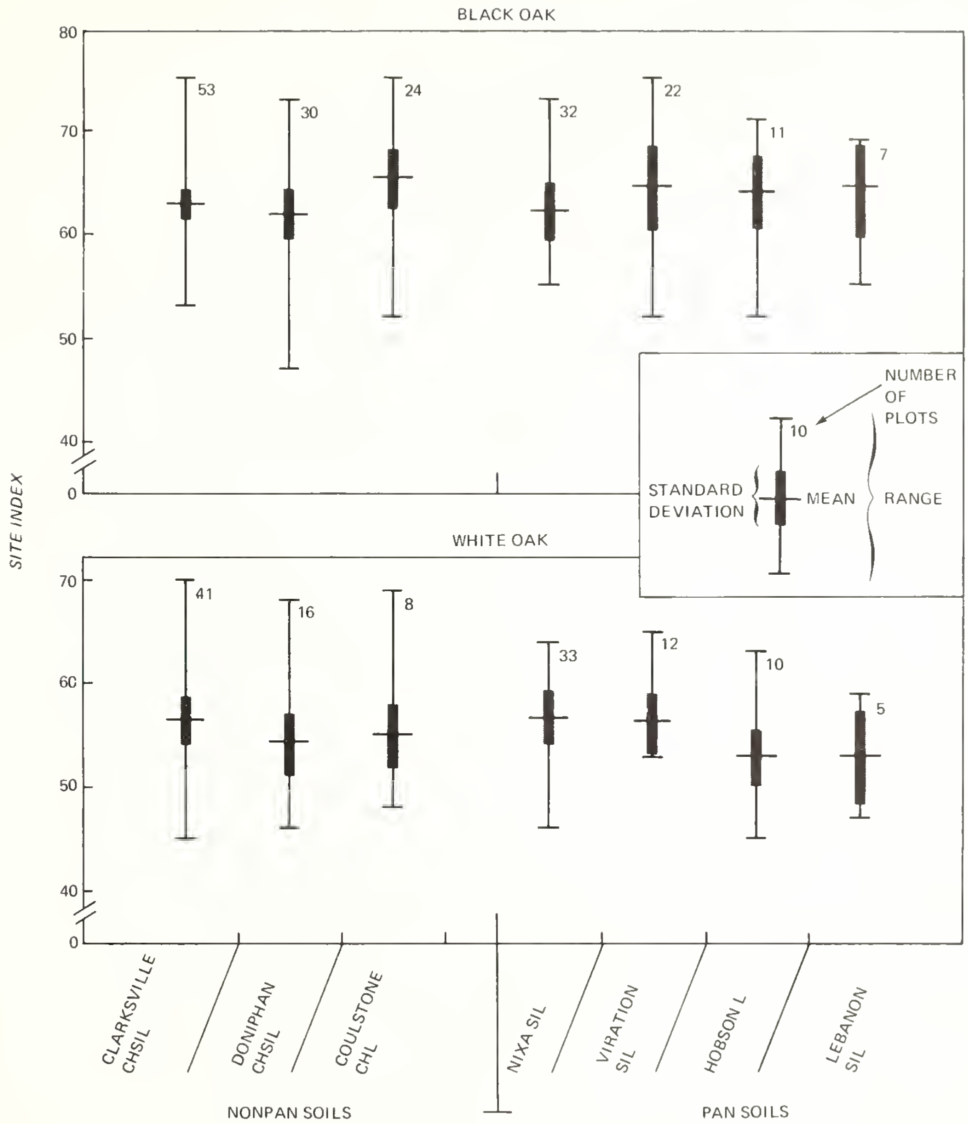

Figure 1. — *Site index for seven Ozark soils – mean, range, and standard deviation. CHSIL = cherty silt loam; CHL = cherty loam; SIL = silt loam; L = loam.*

Examining the available moisture capacity of the two groups may help to provide an answer, since moisture availability during the growing season may be a growth-limiting factor in this region of periodic hot, dry weather. Available soil moisture (the difference between moisture capacity at ⅓ and 15 atmospheres) was determined for the separate horizons with a pressure plate and pressure membrane apparatus. After making corrections for the presence of the chert fragments, the values were used to calculate available moisture either in the upper 36 inches of the profile or above the fragipan, as appropriate. These are the soil depths with the bulk of the tree roots.

The difference in available moisture between pan and nonpan soils to the depths calculated above was not as great as expected:

Soil phase	*Inches available water to pan or 36 inches*
Pan:	
Nixa silt loam	3.1
Viration silt loam	4.3
Lebanon silt loam	3.6
Hobson loam	3.1
Nonpan:	
Doniphan cherty silt loam	4.7
Clarksville " " "	4.2
Coulstone cherty loam	3.8

This additional moisture may be depleted in a short period during the summer months, for oak stands in Arkansas removed 0.19 inches of water per day from the upper 4 feet of the soil profile during a 6-week period (Zahner 1955). Thus, the small amount of additional water available in the nonpan soils is relatively unimportant. When the same data are averaged by site index classes, it is apparent that available moisture has little relationship to site quality:

Site Index Class	*Inches available water to pan or 36 inches*
50	3.8
51-55	4.0
56-60	3.8
61-65	3.8
66-70	4.0

Although fragipans have structural cracks that are occasionally penetrated by roots, moisture below the pan is probably of little help to the tree because of the slow percolation rate of water through the pan during periods of moisture recharge.

Foresters have often noted that young dominant and codominant white oak trees are frequently shorter than associated dominant and codominant members of the red oak group. The comparison of white and black oak site index for similar soils shows that this is indeed a well-founded observation; site index of white oak is 7 feet lower than site index for black oak. The difference in height growth between these two species has been well-documented using sectioned trees of both species from the Central States, including a good representation from Missouri (Carmean 1972). Carmean's site index curves indicate that black oak grows more rapidly than white oak during the early years, just as in our study.

CONCLUSIONS

This preliminary analysis of measurements from 300 sample plots indicates that soil phases, as presently described for the Missouri Ozarks, cannot be used to determine the site indexes for oak. As we have shown, a given soil phase will include a wide range of site qualities; average site qualities of the soil phases studied were essentially similar. This failure of soil classification to indicate the supply of soil growth factors has been found in other studies with oak.

Because soils research and taxonomic classification have historically been oriented toward agricultural uses, considerably more is known about the features that influence shallow-rooted, annual agricultural crops than about those that influence long-lived, relatively deep-rooted trees. Consequently, soils series used for intensive agriculture have been defined more narrowly than those describing soils on rough land suited only for extensive uses (Kellogg 1958). Carmean (1961) indicated that certain soil and topographic features closely related to the growth of forest trees in Ohio vary widely within soils types and soil mapping units, but are not included in their definition. Topographic features such as steepness and degree of erosion are sometimes included, but often in terms too general to be useful for forest site evaluation.

The wide range of slopes and aspects occupied by a given soil in Missouri suggests that the variability in site quality found in this study may be traced to factors not delineated in current soil classifications. As the relationships between forest soils and tree growth are studied more intensively, the way should be open for revision of soil mapping units to reflect to a greater extent the soil's ability to support tree growth.

Many physical characteristics, such as steepness of slope, aspect, soil texture, and depth, are important modifiers of site quality and may be used to improve estimates based solely upon soil phases (Carmean 1970). For example, working with Clarksville soils in a single county in the Ozarks, Hartung and Lloyd (1969) showed that topographic exposure could be used to give a better estimate of the soil's ability to support tree growth.

Preliminary analysis of the data in this study has disclosed that a combination of topographic features and some edaphic characteristics will provide the best estimate of site quality for sites that do not have trees suitable for direct site-index determination.

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RESEARCH PAPER NC— 87
1973

FOREST FIRES IN MISSOURI

Donald A. Haines, William A. Main, and John S. Crosby

FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE
NORTH CENTRAL FOREST EXPERIMENT STATION

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Manuscript approved for publication November 3, 1972

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Forests occupy more than one-third of Missouri's total land area (Gansner 1963). Most of this 15 million acres is capable of timber production. Missouri's forests also provide wildlife habitat, recreational opportunities, watershed protection, and jobs and economic security for rural residents.

Because wildfires cause degrade and volume loss in timber and impair the attractiveness of the forest for recreation, fire protection is a necessity if forest lands are to serve the people well. But even in 1970, a relatively light fire-year, Missouri had 3,000 fires in protected areas, the second highest of the 20 States in the Eastern Region of the USDA Forest Service. The 45,000 acres burned in Missouri in 1970 was much greater than the acreage burned in any other State in this Region (USDA Forest Service 1971).

Responsive fire management programs are based on accurate reporting and compiling of fire records. It is important, therefore, to make an in-depth examination of Missouri fire business as deduced from these records. This means trying to determine how the information might fit into an overall operational attack upon the problem of protecting the forests from fire.

DATA COLLECTION AND ANALYSIS

Tabulations of State and National Forest fire activity are published annually by the USDA Forest Service. Summary statistics from this source for the 1950 and 1960 decades are given in tables 1 and 2. Although both the State of Missouri and the Forest Service are guided by these data in planning fire prevention and suppression programs, no comparison between agencies is intended. The data in these two tables as well as following fire statistics cover somewhat different periods of time. Also, the problems of protection vary by locality due to dissimilar landownership patterns and activities of the residents. Therefore, it is impossible to make comparisons between State and Federal protection effectiveness from this information.

For the time interval covered in this study, protected State and private forest lands in Missouri ranged from a low of 7 million acres in 1951 to a high of 11 million in 1968. Consequently, the number of fire starts and acreage burned are normalized in table 1 for an average 10-million-acre protection unit. However, because the federally protected area in Missouri has remained fairly stable at about 1.39 million acres since the 1950's (table 2), no correction was necessary.

The State and Federal protection units show many similar trends (tables 1, 2). Both reveal a definite decrease in total number of fires over the two decades. A decided drop in fire numbers (33 percent) occurred on Missouri National Forests. A reduction of the incendiary fire problem during the 1960's was an important factor in that decrease, with acreage burned due to incendiarism down 61 percent within the National Forests. This shows that past prevention programs have been effective, although continued effort is certainly necessary.

A 33-percent reduction in large fires (Class C and larger) is evident on State protection areas, with a corresponding 50-percent drop in total burned acreage.

This background information is important input into the Missouri prevention and suppression programs. There are, however, a number of questions that cannot be answered with these data. For example, "What is the annual profile of fire activity?" "How much of a problem is the multiple-fire day?" "Is incendiarism a seasonal or a continuous year-round problem?" "Does fire actively fluctuate by day of week?" "How do weather elements such as wind affect fire occurrence?"

In an attempt to answer these and other related questions we analyzed data from three fire-protection areas in the major forested area south of the Missouri River. These areas (fig. 1), including both oak-hickory and oak-pine forests, are representative of the overall fire-protection problems in the State (table 3).

1. The Eminence State Protection District, predominantly private land, comprises 1,290,000 acres. Texas County contains more than 400,000 acres of

Table 1 — *Average annual fire activity on Missouri's State and private protected lands*

Item		1951-58	1961-68	Change
				Percent
Average protected acres	Million	8.06	10.60	+32
Number of fires per year	2/	3,567	3,227	-10
Number of Class "C" and larger fires	2/	1,202	801	-33
Number of fires by cause:	2/			
Incendiary		1,280	931	-27
Debris		1,716	1,512	-12
Camper		57	53	-7
Smoker		261	208	-20
Lightning		11	13	+18
Other		242	510	+111
Acres burned	2/	103,033	51,935	-50

1/ Compiled and normalized for a standard, 10-million-acre protection unit (USDA Forest Service).
2/ Per 10 million protected acres.

Table 2. — *Average annual fire activity within Missouri's National Forest protection boundaries*

Item	1950-59	1960-69	Change
			Percent
Number of fires per year	506	341	-33
Number of fires by cause:			
Incendiary	158	126	-21
Debris	68	--	--
Campfires	15	--	--
Smoking	92	45	-51
Lumbering	3	--	--
Railroad	3	--	--
Lightning	8	9	--
Miscellaneous	158	9	-94
Land occupancy	--	69	--
Recreation	--	67	--
Forest utilization	--	4	--
Equipment	--	12	--
All acres burned	6,315	3,596	-43
Acres burned by incendiary fires	3,499	1,354	-61
Acres burned by debris fires	1,101	--	--
Acres burned, land occupancy fires	--	1,157	--

1/ Averages compiled from data of USDA Forest Service--Division of Forest Fire Control.

forest land, and Shannon, with more than 500,000 forested acres, is the State's leading forested county (Gansner 1963). The Current and Jacks Fork Rivers flow through this district. Esthetic quality has been recognized by formation of the Ozark National Scenic Riverways, a popular recreation attraction.

2. The West Plains State Protection District comprises 1,428,000 acres. Although 10 percent larger than the Eminence District, it is less heavily forested and contains a greater area of farmland. The district encompasses portions of several noted Ozark streams, including the scenic Eleven Point River. It includes portions of Norfolk and Bull Shoals Lakes impounded from the White River. These water attractions, as well as the deer and quail populations, draw many recreationists. The district is almost entirely in private ownership.

3. The Rolla-Houston and Salem-Potosi-Centerville Districts of the Clark National Forest include 1,180,000 acres of land. These districts are more than half forested and have many farms; the dominant landownership is Federal.

Weather information used in this study was obtained from two sources: A Forest Service station at Salem, Missouri,[1] and a National Oceanic and Atmospheric Administration (NOAA) National Weather Service cooperative station located in the city of West Plains, headquarters for the West Plains District (fig. 1).

The fire data for the Eminence and West Plains State Districts include number of fires, acres burned, man-hours to control, and fire cause over the period 1961 to 1968. Fire data from the Clark National Forest Districts include number of fires and burned acreage over the years 1952 to 1961, with some supplemental data to 1969. Although these data make possible many statistical comparisons, we have included only those that provide an interpretive base for fire planning.

[1] *In cooperation with the USDC National Oceanic and Atmospheric Administration (NOAA) National Weather Service.*

Table 3 — *Yearly and seasonal averages for several measures of fire activity*

Fire business	Five districts of the Clark National Forest, 1952-1961			Eminence State District, 1961-1968			West Plains State District, 1961-1968		
	Spring season	All other seasons	Annual	Spring season	All other seasons	Annual	Spring season	All other seasons	Annual
Fires (all causes)	82	121	203	154	71	225	423	119	542
Incendiary fires	--	--	--	65	16	81	178	32	210
Debris fires	--	--	--	65	27	92	217	53	270
Class "C" and larger fires	17	11	28	45	18	63	124	26	150
Burned acres	998	832	1,830	2,857	921	3,778	8,498	1,262	9,760
Fire-days	33	63	96	47	43	90	59	60	119
Fires/fire-day	2.5	1.9	2.1	3.2	1.6	2.5	7.1	2.0	4.6
Fire-days as percentage of all days	38	23	26	51	15	25	65	19	33

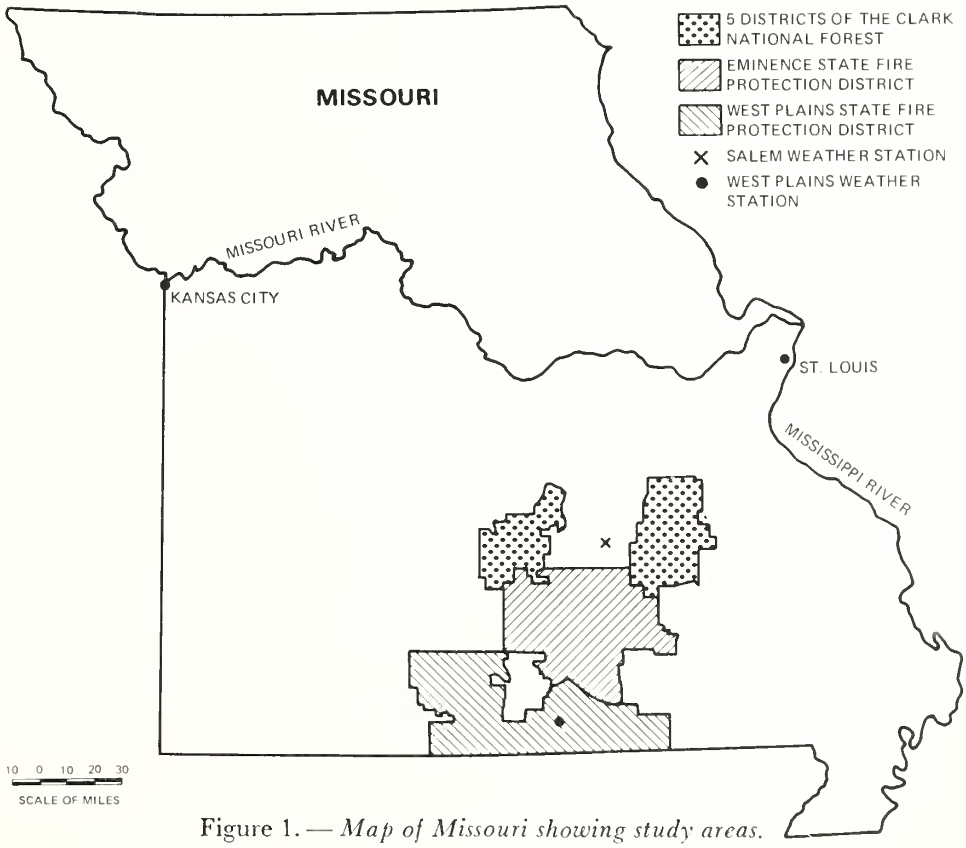

Figure 1. — *Map of Missouri showing study areas.*

THE ANNUAL DISTRIBUTION OF FIRES

Ten years of data from the Clark National Forest show that Missouri's spring fire season begins early in February and slowly increases in intensity to a peak in early April (fig. 2). The decline of fire activity is much more rapid, with the spring fire season ending by early May. A secondary fire season begins in early October and peaks in mid-November. Unlike northern forests where heavy snows end the fall fire season and snowmelt brings a definite spring start, Missouri may have fires throughout the year.

The peaks and lulls in fire occurrence are highly dependent upon seasonal changes in weather, fuels, and vegetation. Moreover, the life style and traditions

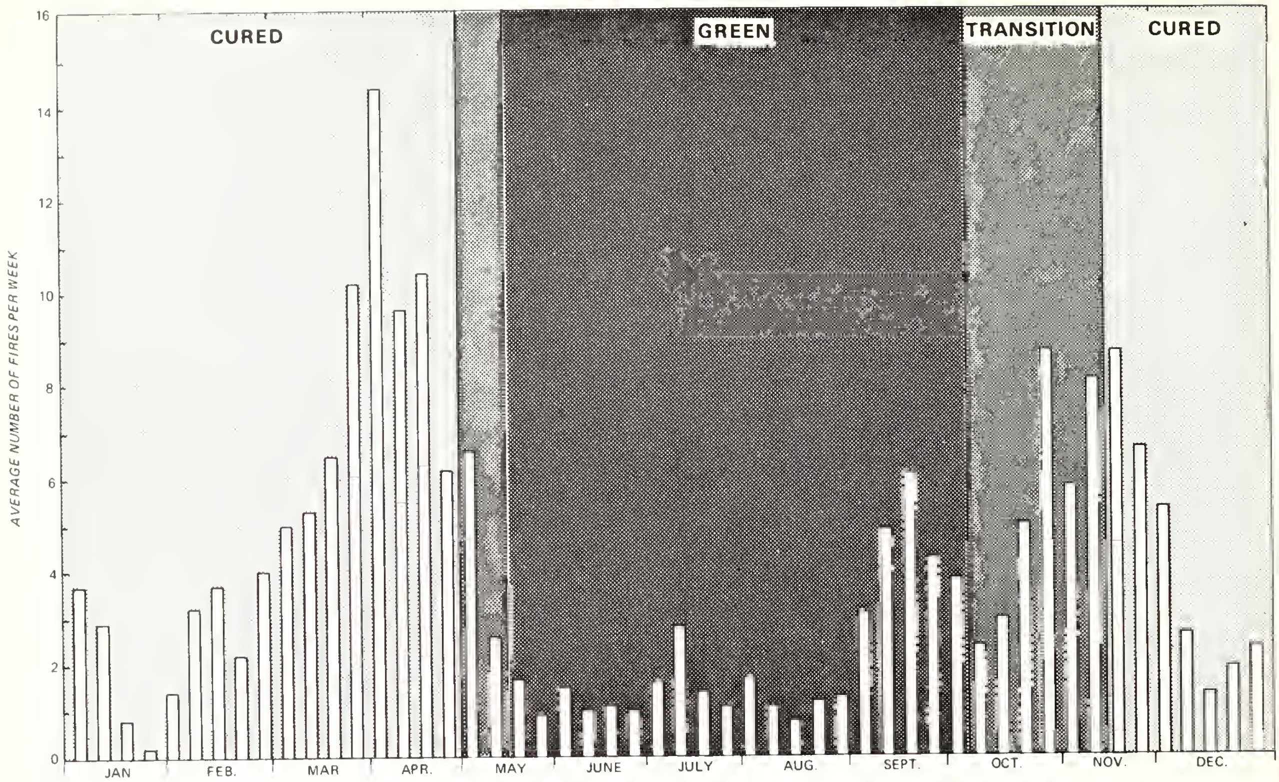

Figure 2. — *Average fires per week on five districts of the Clark National Forest and seasonal vegetative stages.*

of the rural people regarding woods burning affects the annual fire profile. During March and April incoming solar radiation is almost the same as it is during August and September in Missouri. However, because of greater spring cloudiness, measured radiation at the earth's surface is 20 percent less in March and April (Baker and Haines 1969). It might seem that with less available solar radiation in the spring months the forest fire potential would be less than in August and September. But in spring the hardwood forests are devoid of foliage, letting the available solar radiation through to the litter and slash.[2] The quantity of litter fuels is then at a maximum, and the slow shedding of dead foliage by some oaks is completed.

This is the time of year when strong cyclogenesis (low pressure areas) develops over the central United States, producing extended periods of strong winds in Missouri. March and April have low humidities coupled with the strong winds (tables 4, 5, 6, and 7), making this season optimum for fuel drying. In addition, spring is the traditional time for the residents to engage in woods burning. "Spring cleanup" also contributes to the problem.

Early May sees the hardwood forest suddenly turn green with a leafy canopy that greatly reduces solar radiation at the forest floor. The humidity increases and windspeed decreases. The change is especially apparent under the forest canopy. With these conditions litter fuels decay more rapidly, so that by the end of September the weight per acre of surface fuel has reached an annual minimum. Traditionally, cattle were turned into the woods to graze by May and then fire was unwanted. Consequently, in addition to poorer burning conditions during late spring and summer, there was and is less incentive for residents to burn.

[2] *The same conditions might apply in summer or early fall if the forests are seriously defoliated by insects or disease.*

Table 4 — *Frequency of windspeeds, Salem, Missouri, 1300 c.s.t.*
(In percent of days in month)

Month	Windspeed (m.p.h.)						
	≤5	6–9	10–13	14–19	20–23	24–29	≥30
Jan.	29.7	38.4	20.1	10.1	1.5	0.2	--
Feb.	25.6	38.9	24.8	8.8	1.4	.6	--
March	20.1	32.9	27.2	16.6	2.8	.4	--
April	20.4	36.6	23.2	15.9	3.3	.6	--
May	36.9	37.6	17.8	6.6	.9	.4	--
June	45.8	41.1	9.4	3.6	--	--	--
July	54.8	37.1	7.7	.4	--	--	--
Aug.	57.3	34.2	7.9	.6	--	--	--
Sept.	45.9	38.9	14.1	1.1	.2	--	--
Oct.	39.4	37.4	18.6	4.1	.2	.0	0.2
Nov.	28.8	33.9	23.9	11.3	1.9	.0	.4
Dec.	30.3	36.1	20.9	12.4	.4	--	--

Table 5.—*Frequency of windspeeds, West Plains, Missouri, 1200 c.s.t.*
(In percent of days in month)

Month	Windspeed (m.p.h.)					
	≤5	5–9	10–14	15–19	20–24	25–29
Jan.	25.2	52.7	16.1	5.2	0.8	--
Feb.	19.5	49.4	24.7	5.5	.6	0.3
March	12.1	47.6	28.8	8.5	2.7	.3
April	14.4	51.6	24.9	7.0	2.0	--
May	24.1	37.3	37.6	1.1	--	--
June	36.4	53.0	9.0	1.5	--	--
July	36.6	52.7	9.9	.5	--	--
Aug.	44.6	48.3	7.0	--	--	--
Sept.	38.2	50.6	10.0	1.2	--	--
Oct.	26.9	57.3	13.4	2.0	--	--
Nov.	21.2	55.4	19.6	3.0	.6	--
Dec.	26.6	45.7	23.7	2.3	1.4	--

As autumn approaches, the green vegetation[3] begins to mature (fig. 2). Following the first hard frost or sometimes even earlier, grasses and other herbaceous vegetation cure rapidly. By early November a large portion of the approximately 2 tons/acre canopy of hardwood leaves and pine needles have become part of the surface fuels. The days are shorter and temperatures lower; therefore, burning periods are normally short and infrequent. Den-tree fires started by hunters and debris-burning fires are occasionally a problem.

[3] *Conditions of vegetation or herbaceous stage have appropriately become an integral part of fire danger rating systems. The method used to describe this state of vegetation is given by Nelson (1964) and identifies three stages of curing condition for vegetation such as grass and forbs.*

Winter, of course, is colder with occasional snow. Surface leaves often dry to low moisture content, but the duff holds moisture, and fires that do start usually do little damage.

The West Plains District averaged less than one fire a week during most of the summer and experienced an insignificant September fire problem during the decade of the 60's (fig. 3). This more southerly district commonly has an earlier and more severe spring fire season than the Clark. The large number of fires shown during September on the Clark (fig. 2) is somewhat misleading, which reflects the hazard of drawing conclusions from relatively short time periods. Unprecedented late-summer droughts in 1952, 1953, and 1954 (fig. 4) caused major fall fire activity to occur much sooner and be stronger than usual (contrast figs. 2 and 3). In the late fall of 1952 a proclamation by the governor, followed by similar Forest Service action, closed all woods and forests in Missouri to the public, the only time this action has been taken. Other fall droughts have occurred, of course (fig. 4), but the 1952 to 1955 period was the worst in the memory of the people living in the eastern Ozarks. Drought can be expected to occur in the future, and prevention action will again have to be stepped up to counteract a potential large-fire disaster. On those occasions some measure of previous drought severity (fig. 4) will be helpful to back up the administrative decisions that officials must make.

Table 6. — *Frequency of relative humidity values, Salem, Missouri, 1300 c.s.t.*
(In percent of days in month)

Month	Percent relative humidity										
	≤14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–59	60–69	≥70
Jan.	0.2	0.4	1.9	2.7	5.7	4.8	7.8	9.5	15.0	12.2	39.9
Feb.	.4	.8	3.9	4.1	7.9	9.4	8.6	9.8	14.8	11.0	29.1
March	.8	2.0	4.5	8.0	9.9	11.6	8.1	8.7	11.2	9.4	25.8
April	—	3.0	8.0	11.7	10.0	10.2	9.6	7.4	11.7	8.4	20.0
May	--	.2	2.3	5.2	8.1	12.0	11.3	9.0	17.9	14.4	19.5
June	.2	.0	.2	1.3	2.8	6.3	9.1	15.2	30.9	19.1	15.0
July	--	—	.5	1.1	4.5	10.4	13.1	12.5	27.4	18.5	12.1
Aug.	--	.2	1.1	2.3	4.5	10.2	13.3	14.5	28.4	12.9	12.7
Sept.	.4	1.1	2.2	6.7	10.2	8.1	15.2	9.8	17.8	11.3	17.4
Oct.	.4	3.9	6.8	8.2	13.4	9.9	10.9	11.8	12.5	6.1	16.0
Nov.	.8	1.5	3.7	6.1	11.1	7.6	13.3	9.4	13.7	10.8	22.1
Dec.	.2	.7	1.1	2.3	4.3	5.2	8.6	10.1	16.0	14.0	37.6

Table 7. — *Frequency of relative humidity values, West Plains, Missouri, 1200 c.s.t.*
(In percent of days in month)

Month	Percent relative humidity										
	≤14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-59	60-69	≥70
Jan.	--	--	1.5	1.8	5.9	8.8	9.7	10.0	21.4	12.1	28.7
Feb.	--	0.3	.9	4.1	6.4	10.8	8.9	8.9	22.3	9.9	27.4
March	--	2.1	4.7	7.6	7.3	9.4	11.1	7.3	14.9	8.2	27.3
April	0.3	1.5	3.9	10.2	13.8	12.9	9.3	6.3	14.5	6.6	20.4
May	--	.2	.9	2.6	4.7	6.2	12.9	12.3	22.9	17.9	19.4
June	--	--	--	--	2.4	3.4	6.1	8.8	37.4	24.3	17.6
July	--	--	--	.5	2.3	3.8	6.6	11.3	34.9	22.5	17.9
Aug.	--	--	.5	1.4	2.3	5.5	6.7	11.3	34.8	20.9	16.3
Sept.	--	--	--	.3	2.6	6.9	8.1	13.4	25.3	20.3	22.9
Oct.	--	.3	3.1	6.3	10.4	11.0	10.1	9.4	17.6	16.4	15.7
Nov.	1.2	.9	4.5	4.8	6.0	6.6	12.1	12.1	15.4	11.4	24.8
Dec.	.5	.3	.8	2.1	4.5	5.6	8.3	11.0	16.4	15.5	34.8

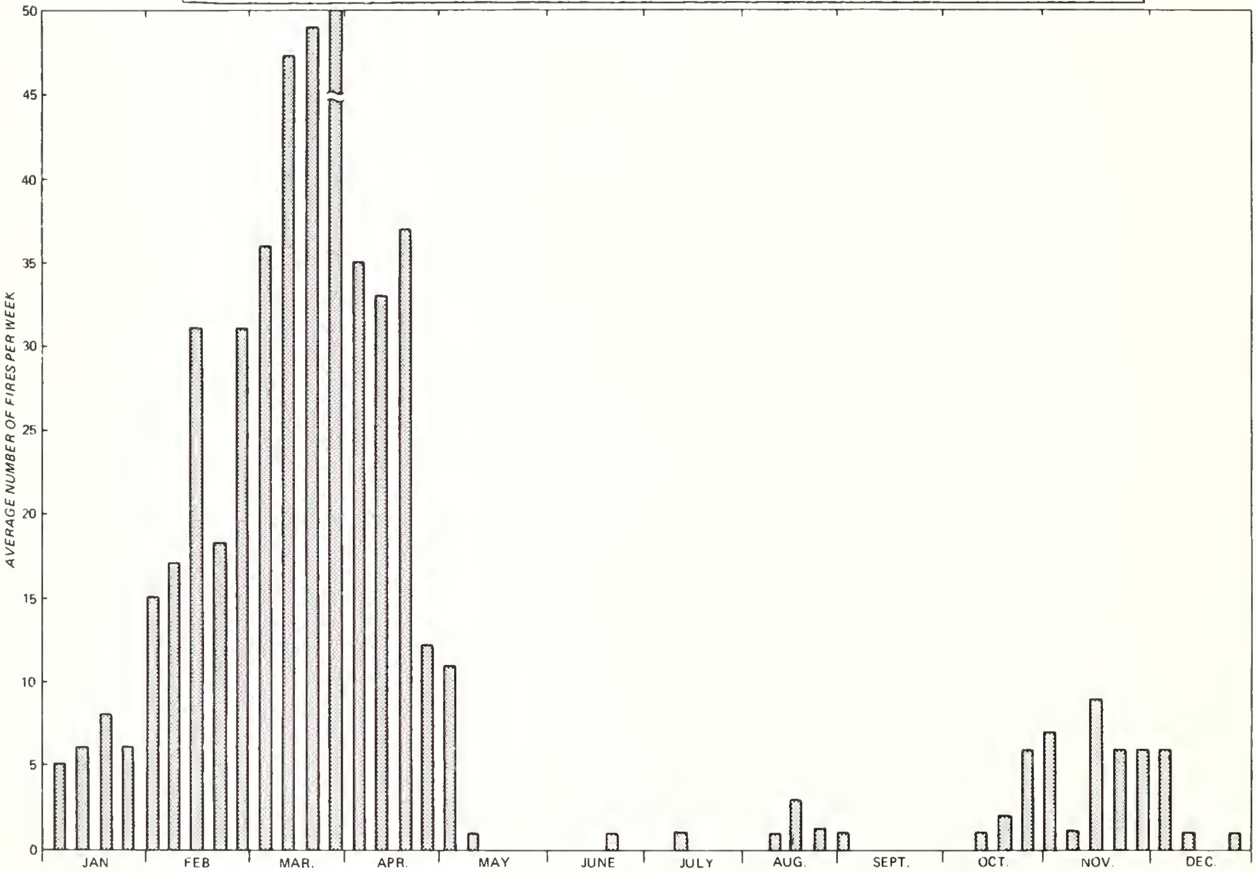

Figure 3. — *Average fires per week on the West Plains District. Weeks averaging less than one fire not indicated.*

THE MULTIPLE-FIRE DAY

In areas where fires are infrequent, fire control planning depends upon predicting days with high probability of a fire. Where fires are numerous, planning depends upon the ability to predict the number of fires that will occur each day. Examining the number of days having at least one fire (fire-days) and the number of fires per fire-day can provide managers with useful predictive information. The three protection areas show large differences in some measures of fire business, but the differences in the average annual number of fire-days are not extreme (table 3).

An indication of the suppression problem on the three areas is easily obtained by dividing the number

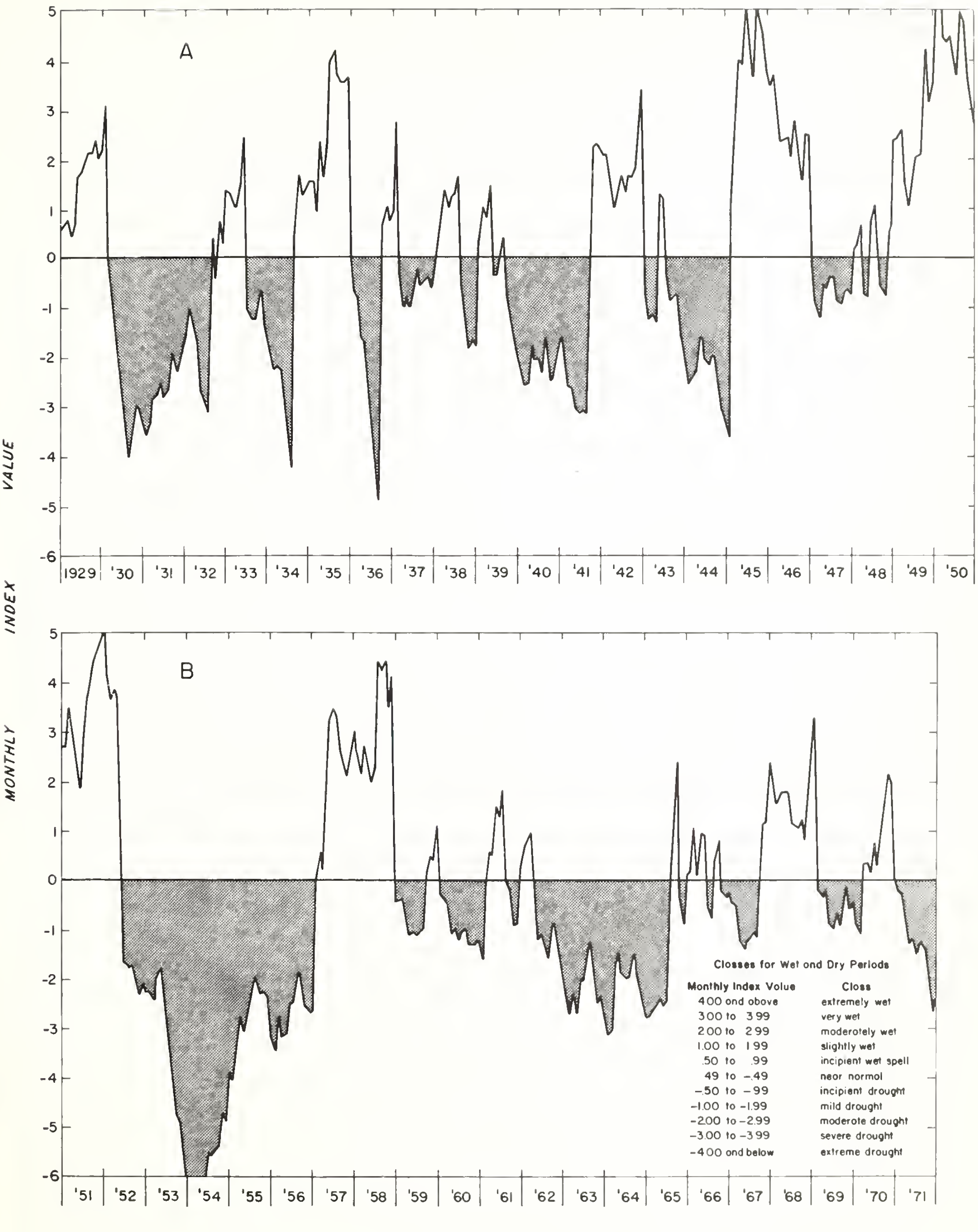

Figure 4. — *Monthly averages of the Palmer Drought Index for the Eastern Ozarks (Palmer 1965). A, 1929-1950; B, 1951-1971.*

of fires per year by the total number of fire-days, thereby finding the average number of fires per fire-day. The combined Clark Districts averaged two fires per fire-day, the Eminence District two and one-half, and the West Plains District more than four. Significantly, these values remain fairly constant year after year (fig. 5); this stability also holds true if only the fires of 10 acres and larger are included.

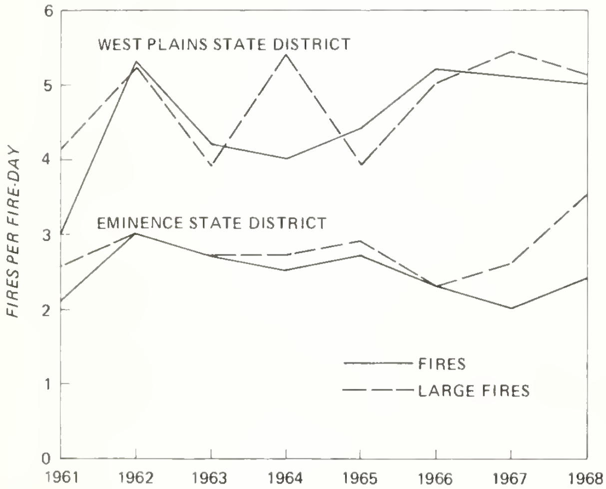

Figure 5. — *Average number of fires per fire-day and average number of 10-acre or larger fires per large fire-day.*

Of more managerial significance, however, is the distribution of fires throughout the year. The annual distribution of fire-days (fig. 6) shows the same pattern as fire numbers (fig. 2), except that the spring and fall seasons have more nearly the same number of fire-days per week.

Computing fire-days as a percent of all days in the year shows that 26 percent of the total were fire-days on the Clark Districts, 25 percent on the Eminence District, and 33 percent on the West Plains District (table 3). But during the spring fire season alone, the Clark National Forest Districts had fires on 38 percent of the days, the Eminence District on 51 percent, and the West Plains District on 65 percent. These percentages are much higher in spring than in the other seasons of the year.

The intensity of seasonal fire business is further indicated by comparing the number of fires per fire-day in spring with the number in all other seasons (table 3). These data again show the concentration of fires during spring. The concentration is most pronounced on the West Plains District, where 2 out of 3 spring days had fires, and fire numbers averaged more than seven per fire-day. This is a heavy suppression load by any standard.

Nevertheless, averages by themselves may be misleading; therefore, the number of fires per fire-day over all seasons should be examined (fig. 7). On the five districts of the Clark National Forest, 50 percent of the fire-days had only one fire. The Rangers in this area could expect to have two fires on about 20 percent of the fire-days. The chance of seven fires per fire-day is less than 1 percent, and 14 was the highest number of fires occurring in a single day on the Clark during the 1950's.

Eminence State District data are similar except that there are a significant number of days within the "10 or more" category. The maximum number of

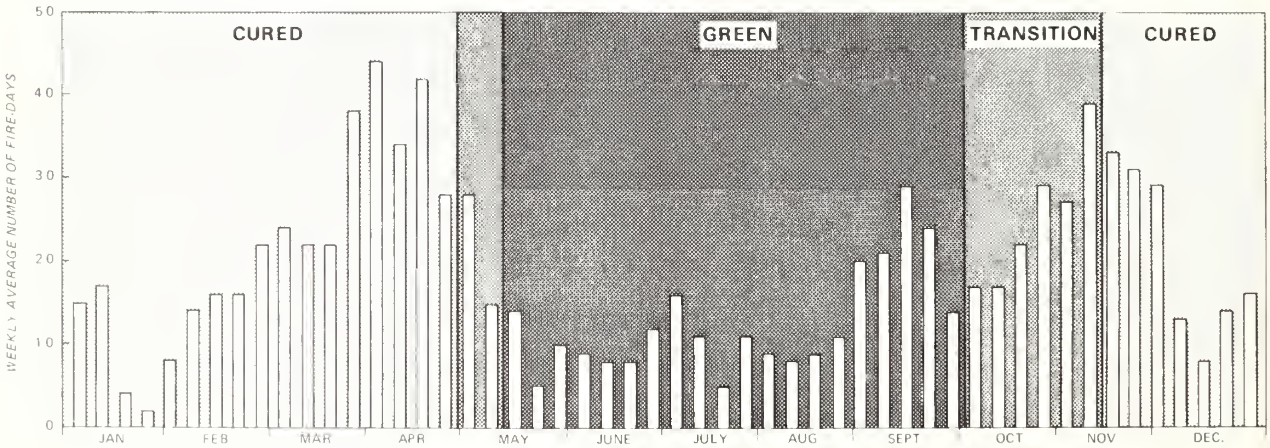

Figure 6. — *Average number of fire-days per week on the five districts of the Clark National Forest and seasonal vegetative stages.*

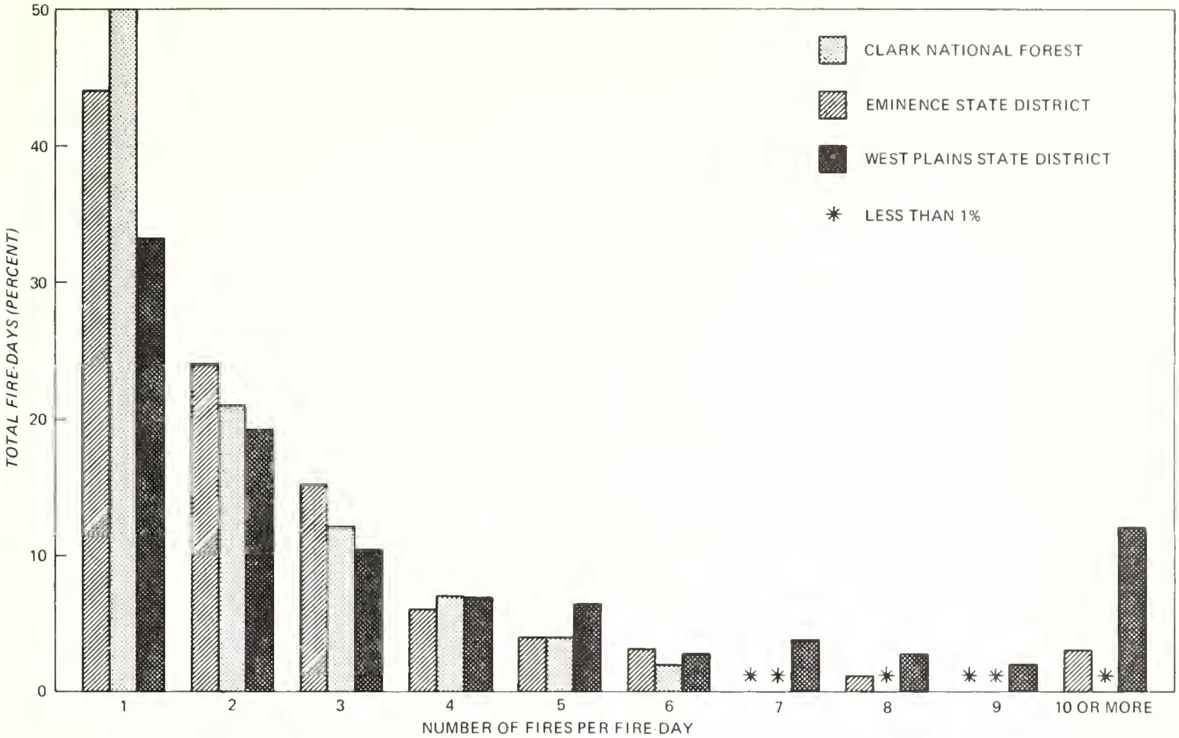

Figure 7. — *Percent of days having a given number of fires per fire-day, averaged for the year.*

fires for any one day on this district was 20 during the years examined.

The West Plains District displays a different pattern. Here only one-third of the fire-days had just one fire and 12 percent of the fire-days had 10 or more fires. The maximum number of fires on any one day, 43, was recorded on February 13, 1962. That day the district fought 21 debris-burning fires. There were 20 incendiary fires with only four set in a single string. Twenty-five of the fires grew to Class C size or larger, while a total of 5,346 acres burned.

Multiple-fire days call for skillful dispatching of men and equipment plus good communications. The decisions involved with the sudden mobilization necessary to fight large numbers of near simultaneous ignitions are vital. The number of men needed is the crux of the decision process. To help solve this problem, the average number of man-hours required to control fires were computed for days having different numbers of fires per fire-day on the West Plains District (fig. 8).

Roughly, 3 to 4 man-hours are required to control the average fire when one to six fires occur on the same day. Although the data are somewhat erratic, they show a general increase in manpower necessary for control as the number of fires per fire-day increases. At 15 and 16 fires per fire-day, it takes 7 to 8 man-hours to control each fire. There are probably two reasons for this. First, increased fires per fire-day should reflect increased weather severity, and consequently more control difficulty. Second, manpower resources are not inexhaustible. As the number of fires increases, there are fewer people available to fight

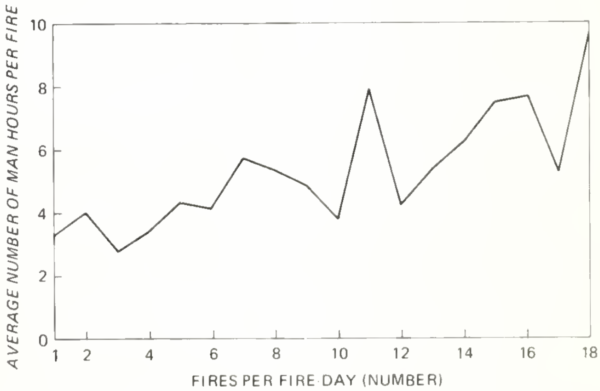

Figure 8. — *Average number of man-hours needed to control a fire relative to the number of fires per fire-day, West Plains State District.*

each one. Therefore, the insufficient force present at each fire requires a greater total suppression effort. Delays in initial attack contribute to increased control time. Rapid initial attack is often the difference between a small or large fire.

Combining numbers of fires per fire-day with data for average man-hours to control provides some additional information for manpower allocations. For example, at 18 fires per day, the average number of man-hours to control a fire is 10. On that day 180 man-hours will be needed for control action. At 8 work hours per man-day, 23 men are needed. But this is an unrealistically low number of men. The 18 fires may be scattered over three or four counties, requiring travel and search time. Thus, few men spend a full 8 hours controlling fires. The work force, even if optimally used, must be greater than 23 men. The number of men and their locations will probably be decided the previous day or during the morning of the fires. But even before the season starts, the administration must prepare a budget for anticipated suppression costs. The average man-hours for suppression can be estimated from these data for a season.

The concept of the multiple-fire day has other applications. In Missouri in 1970, 30 percent of the fires and 59 percent of the total acreage burned occurred on only 2 percent of the total days (USDA Forest Service 1971). Major fire control activity is usually concentrated within a short time span. Statistics compiled for the average year on the West Plains District bear this out (fig. 9), as follows:

(1) Slightly less than half of all fire-days had two or more fires.

(2) Half of all fires occurred on days when there were eight or more fires.

(3) Half of all large fires occurred on days when there were 11 or more fires.

(4) Half of all man-hours to control were used on days when there were 12 or more fires.

(5) Half of all acreage burned was on days when there were 13 or more fires.

Thus the fire control job is compressed into a relatively small number of days of intense activity, while over the season as a whole the organization handles a much smaller fire load. These data also illustrate the potential of past records as possible predictive tools in fire-control planning.

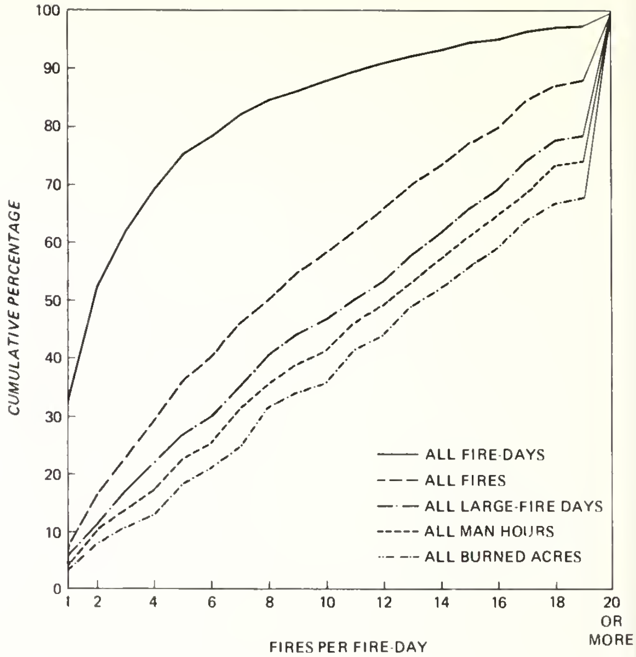

Figure 9. — *Cumulative percent of five measures of fire activity relative to the number of fires per fire-day, West Plains State District.*

One factor is especially important during the time of year when multiple fires are common. Much depends upon speed of control and this in turn is related to rapid initial attack. Men and equipment cannot be tied up on single fires for long periods. Personnel must have enough versatility to handle other fires. Optimum crew size and equipment, consequently, are critical considerations.

FIRE CAUSE

Weather, fuels, and vegetation stage are the factors commonly used to measure fire danger. Fire occurrence in Missouri is also strongly affected by the attitudes and habits of the people. Some residents accept woods burning as a normal practice. Customarily, spring is a favored time for burning; it is rarely done in other seasons. Much of today's wildfire activity stemming from debris burning and incendiarism is basically a carryover from traditional burning practices (Crosby 1960).

To examine the cause factor in more detail, fires were tabulated by cause for the West Plains and Eminence State Districts on an average monthly and yearly basis. Incendiary and debris burning fires accounted for the overwhelming majority of all starts. Consequently, fires originating from these two causes were tabulated separately, and the rest of the causes (lightning, campfire, machinery, smoking, miscellaneous, and unknown) were classified as "other."

Yearly Summaries

The distribution of fires by cause on the West Plains District does not appear to show an increasing or decreasing trend in the year-to-year data (fig. 10). However, there seems to be a falling off of total yearly fire activity on the Eminence District from 1963 through 1968, although there is no clear evidence that it is related to a change in fire cause (table 8). The year-to-year distribution appears random, although there may be a slight increasing trend in "other" starts on the Eminence District, with a corresponding decrease in the incendiary cause category. On the average, the Eminence District records 35 percent of fire causes as incendiary. About 42 percent of the fires are due to debris burning, and 23 percent are started by other causes. On the West Plains District 39 percent of the fires are incendiary starts, 50 percent are due to debris burning, and 11 percent result from other causes.

Table 8. — *Percent of fires and burned area by cause on the two State Districts*

WEST PLAINS STATE DISTRICT

Year	Debris burning		Incendiary		Other	
	Fires	Burned area	Fires	Burned area	Fires	Burned area
1961	53	57	31	32	16	11
1962	48	58	39	30	13	11
1963	47	41	39	52	14	7
1964	62	52	27	40	11	7
1965	50	52	36	35	14	14
1966	43	48	48	47	10	5
1967	58	47	33	46	9	8
1968	45	51	49	47	6	2
Average	50	51	39	41	11	8
EMINENCE STATE DISTRICT						
1961	48	68	36	22	17	10
1962	39	30	42	54	20	16
1963	35	21	40	62	25	16
1964	54	62	26	19	20	19
1965	37	48	40	36	23	16
1966	31	26	47	58	22	15
1967	47	60	24	29	29	11
1968	44	33	24	28	33	40
Average	42	44	35	39	23	18

Within each of the two State districts, the 8-year average percentages of fire numbers and area burned are almost the same for each fire cause. For example, incendiary starts accounted for an average of 39 percent of the fires and 41 percent of the burned area on the West Plains District. These averages are misleading, however. There are tremendous year-to-year differences in the percentages on both districts. As an example, incendiary starts accounted for about 20 percent of the burned area on the Eminence District in 1961 and 1964, but more than 50 percent of the lost acreage in 1962, 1963, and 1966. These latter 3 years were also the years of greatest area burned on that district (fig. 11), probably reflecting the fact that an active incendiarist can quickly overload the fire-control forces. The highest burned acreage occurred in 1962 on the West Plains District. More than 18,000 acres were consumed, with debris burning accounting for 58 percent of the starts. Surprisingly, even with the tremendous year-to-year variations shown in figure 11, the annual proportion of burned acreage caused by large fires is relatively constant at 80 to 95 percent.

For the most part, the percentage of incendiary starts (table 8) followed the same trend each year on both State districts. When one district showed a change in this cause category, so did the other. Area burned due to incendiarism did not follow this same pattern.

Monthly Averages

Both State districts record a small number of "other" fire causes throughout the year, which peak equally in the spring and fall. Incendiary and debris-burning fires, on the other hand, show a strong maximum in the spring and a weak secondary peak in the fall.

March is by far the worst fire month on the West Plains District, with an average of over 200 fires (fig. 12). On the Eminence District, however, the fire

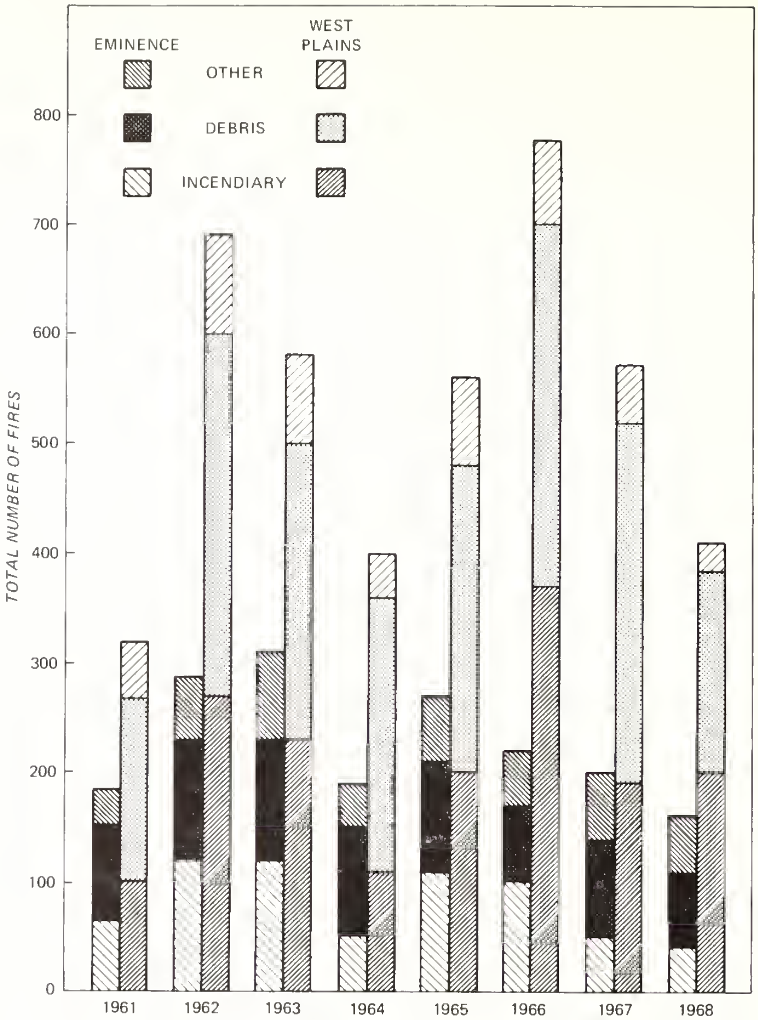

Figure 10. — *Total number of fires on the two State districts by cause.*

starts are almost evenly divided between March and April. If we consider only fires of 10 acres or larger, then April is a worse month on the latter district (fig. 13). It is notable that the large-fire problem in April on the Eminence District is primarily due to incendiarism, which accounts for 53 percent of the starts. When considering large fires this is the only major fire month on either State district when incendiary starts averaged more than one-half of the total.

FIRE ACTIVITY BY DAY OF WEEK

Many managers feel that day of the week is an important factor to consider in fire-control planning, because of social patterns that increase fire starts. Weekends, holidays, sale days, election days, and other special occasions all produce broad similarities in local social response, which may be related to variations in fire occurrence. As an example, on weekends more visitors are in the forests and parks, and large numbers of rural residents who work in the cities are home. One might argue that more people create a greater risk potential, therefore more fires.

Tabulation of day-of-week data in the northeastern United States is not often done. A 5-year summary of number of fires compiled by the Wisconsin Department of Natural Resources (1970) shows a small but

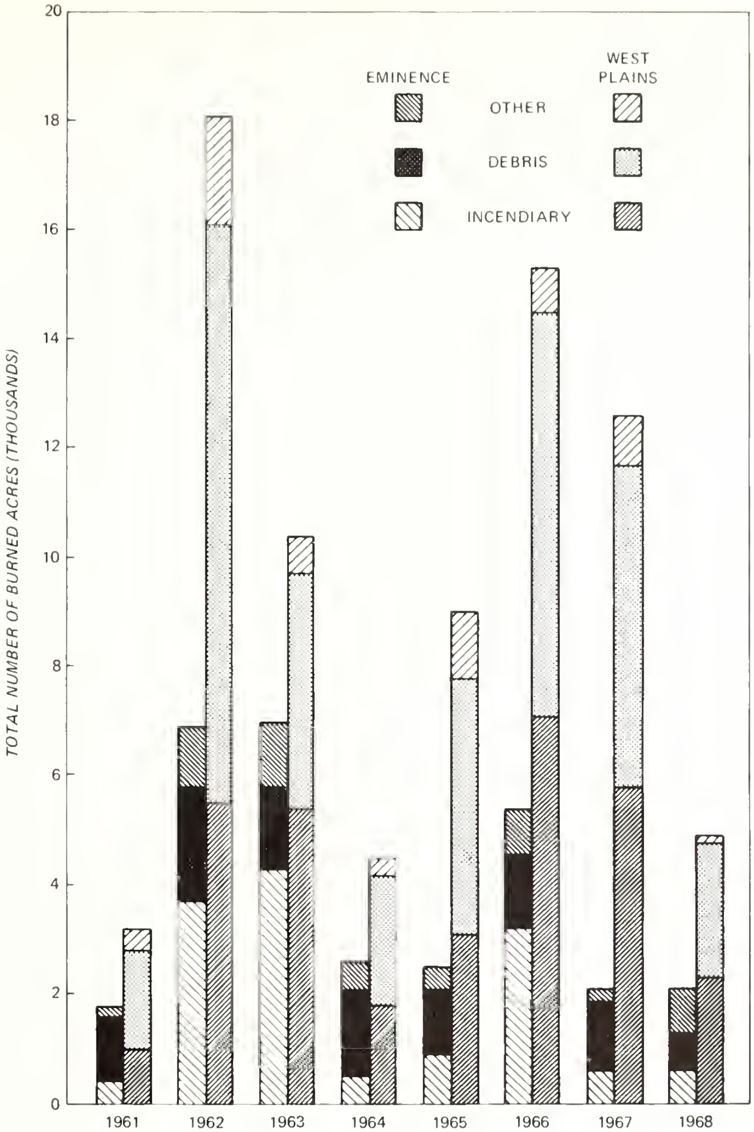

Figure 11.—*Number of acres burned by cause on the two State districts.*

fairly consistent year-to-year bias for Saturday fires. State of Pennsylvania data indicate a decided preference for weekend fires.[4] To test the hypothesis for Missouri, we tabulated available measures of fire activity by day-of-week. The tabulations were done as yearly averages for a given day of the week over the period of record. National Forest data were also compiled by individual years and seasons. Information for the two State districts was broken down still further into cause classification.

Few clear patterns emerged from this analysis. In terms of average acreage burned and man-hours to control, the only interesting feature occurred on the Eminence District. There the greatest acreage burned on Thursdays with 65 percent of the loss due to incendiarism. Correspondingly, the greatest amount of manpower was used on that day. On the average, 340 man-hours per year were used for fire control on

[4] *Personal correspondence with Mr. E. F. McNamara, Pennsylvania Department of Environmental Resources, 1972.*

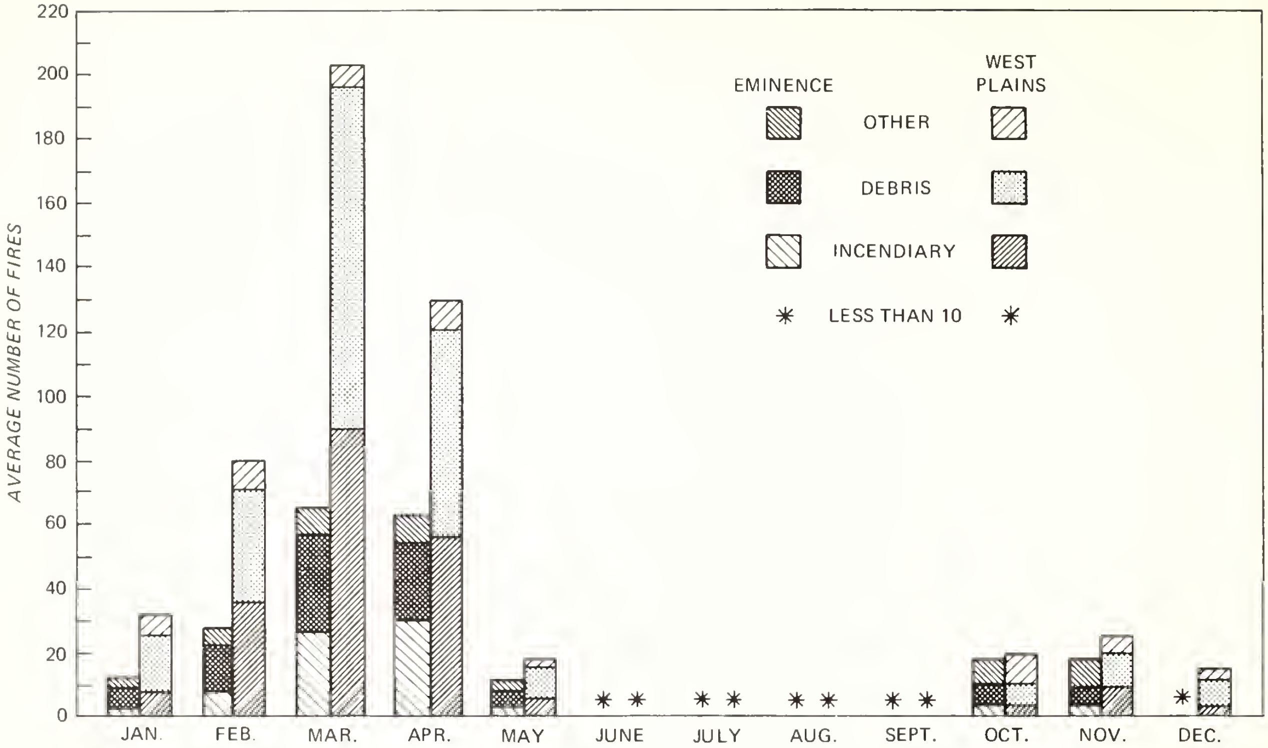

Figure 12. — *Average number of fires per month by cause groups on the two State districts.*

Thursdays at Eminence, more than one-half again as many hours as on the next worst day of the week. This certainly reflects the management problems inherent in dealing with incendiarism.

No obvious day-of-week trend is apparent in large-fire starts. The Eminence District had the greatest number of large fires on Saturday, while the West Plains District had the fewest number of large fires on that day.

Only when we examine average number of fires do some interesting weekend data emerge. This measure of fire activity shows that there are more fires on Saturday on the two State districts than on other days, although the difference is relatively small. The second greatest number of fires occurs on Tuesday on the West Plains District and Thursday on the Eminence District. These cause data do not appear to indicate a meaningful day-of-week pattern.

There is, however, an increasing trend in total fires through the weekend on the Clark. This may reflect a much higher weekend usage of Missouri's National Forests in comparison with State and private forest lands. To test this trend further, supplemental data from the Clark for the period 1960-1969 were also sorted by day of week. This showed by far the greatest number of fires occurring on Sunday, with Saturday fires not as prominent as they were during the 1950's. Fire-days occurred most often on Sundays with Saturdays second in this measure of fire activity.

No generalizations can be made from this analysis that would have meaning outside of the examined areas. It is apparent, however, that day of week can be a local factor affecting fire starts. It also may be only a coincident factor. The fire control manager should be alert to any day-of-week pattern that may be evidenced on his district. An analysis could well provide the basis for further investigation of both cause and characteristics of people responsible. This then would be an aid in fire prevention as well as in planning presuppression and suppression activities.

FIRE WEATHER

The climatic patterns that prevail in Missouri have been well described by Miller and Decker (1957), Decker (1963), and McQuigg and Decker (1963).

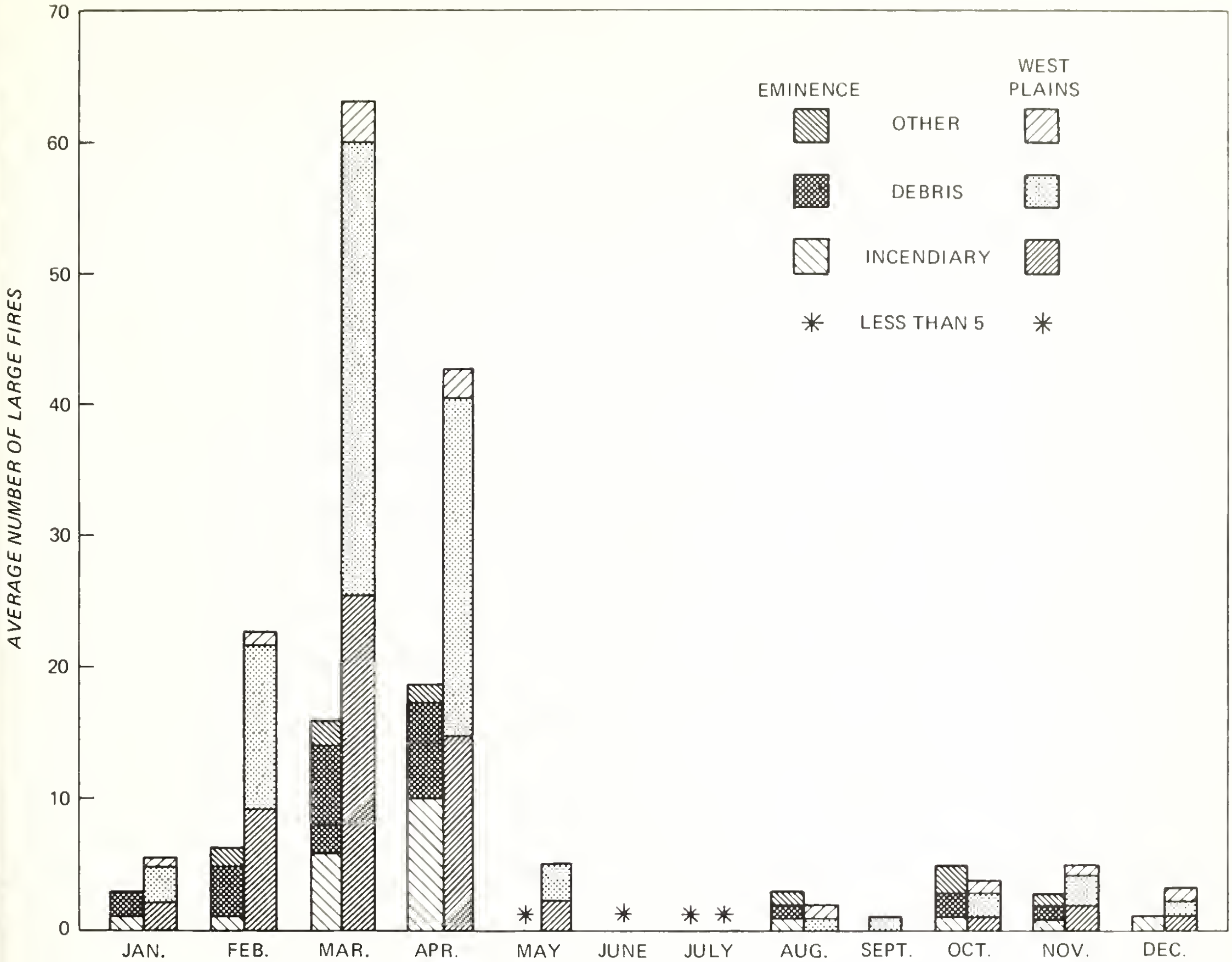

Figure 13. — *Average number of large fires per month by cause on the two State districts.*

Yearly precipitation varies from less than 34 inches in the extreme northwest to over 50 inches in the southeastern lowlands. During the height of the spring fire season (figs. 2 and 3), weekly precipitation normals vary from 0.6 inch in the northwest to 1.2 inches in the extreme south and southeast. During this same period, afternoon maximum temperatures average 60° F. in the north to 68° F. in the extreme southeast.

In Missouri the probability of a fire-day is usually a function of season, fuel availability, fine fuel moisture, windspeed, and human activity. The first four variables are relatively easy to measure; the fifth is more complex. Haines, Main, and Johnson (1970) found the Fine Fuel Spread Index in the 1964 version of the National Fire Danger Rating System (Nelson 1964) to be a surprisingly good predictor of the probability of a fire-day. This index assumes uniform fuel availability and essentially assigns a constant value to human activity. It is fundamentally a weighted composite of the fine fuel moisture (which is responsive to atmospheric temperature and relative humidity) and windspeed.

The index was computed for the spring season using the weather records at Salem, Missouri. By comparing this index with the fire activity on the five districts of the Clark National Forest it is possible to show both the probability of a fire-day and a large-fire day (fig. 14). Computations were done by using mean values over two-unit index increments. The coefficient of determination value (R^2) is high (fig. 14), but this is not unexpected. Like most fire danger rating systems, this index sorts days into classes with general levels of fuel moisture.

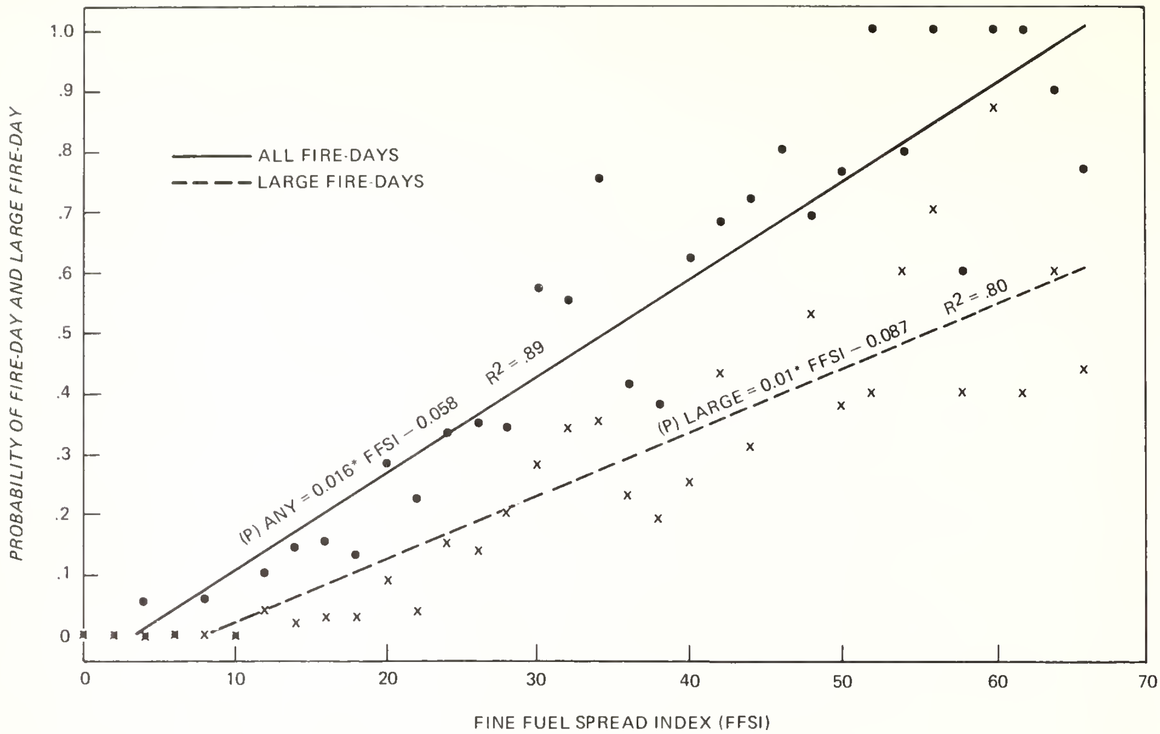

Figure 14. — *The relation between the Fine Fuel Spread Index and both the probability of a fire-day and the probability of a large-fire day. Clark National Forest, spring season.*

A knowledge of fuel moisture will provide information on expected rates of spread and energy release as well as the ignition potential. The ignition factor, by itself, answers the question, "Will it burn?" In level terrain the fire may need wind to act as a spread agent or it will go out. If the fire goes out quickly, there will have been a fire start, but not necessarily a *reportable* fire. Debris-burning fires offer a good example. If a firebrand from a trash burner ignites dry grass on a Missouri oak-hickory litter area during a calm afternoon, the fire should spread slowly and may be suppressed by the person maintaining the burner. On a windy day, however, the fire may escape and the operator will have to call for the assistance of a fire suppression unit.

We calculated the wind's effect in determining the probability of a fire-day (fig. 15). Spring days were divided into two categories for the Clark National Forest: those with winds above 5 m.p.h. and those with winds at or below this velocity. The fine fuel moistures in each group were then plotted against the probability of a fire-day. Even with this rather rough breakdown, the importance of wind as a factor in the computations is convincing. At low fine-fuel moisture the chance of a fire-day increased 25 percent with windspeeds over 5 m.p.h.

We also tabulated the frequencies of occurrence of various relative humidity, temperature, and windspeed categories for early afternoon, when fire danger observations are usually taken (tables 4-7 and 9-10). During March, the most severe fire month (fig. 13), wind velocity is at or above 5 m.p.h. 88 percent of the time at West Plains (table 5). At Salem it is above 5 m.p.h. 80 percent of the time during March (table 4). In late summer the same breakdown of wind puts the frequency nearer the 50 percent mark. Wind velocity is one of the reasons for the intense spring fire season in Missouri.

Fine fuel moisture values are usually calculated from atmospheric temperature and relative humidity readings. The included tables for these two meteorological variables give frequency of occurrence, and therefore indirectly describe the probable ignition features of this fuel.

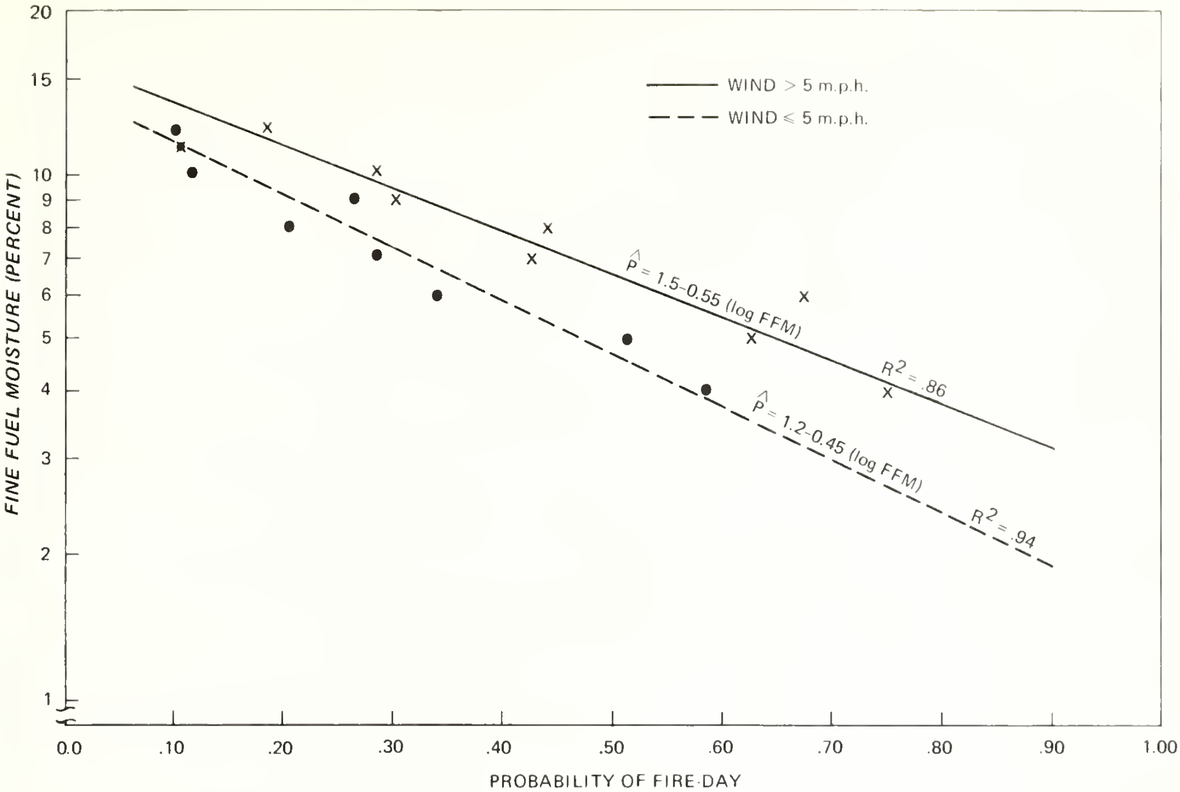

Figure 15. — *The relation between the Fine Fuel Moisture and the probability of a fire-day, with windspeeds at or below 5 m.p.h. and above 5 m.p.h. (for the Clark National Forest).*

Table 9. — *Frequency of temperature values, Salem, Missouri, 1300 c.s.t.*
(In percent of days in month)

Month	Temperature (°F.)									
	≤39	40-49	50-59	60-69	70-79	80-84	85-89	90-94	95-99	≥100
Jan.	59.1	20.6	14.6	5.3	0.4	--	--	--	--	--
Feb.	45.8	27.9	17.9	7.1	1.2	0.2	--	--	--	--
March	27.7	24.5	22.2	17.3	7.6	.7	--	--	--	--
April	2.2	12.6	21.9	27.6	28.2	5.9	1.5	--	--	--
May	--	1.5	10.1	25.7	35.8	20.6	5.9	0.4	--	--
June	--	--	1.7	6.5	31.1	24.1	27.4	6.1	3.1	--
July	--	—	.2	.7	18.8	27.4	30.6	16.7	5.4	0.2
Aug.	--	--	--	2.7	22.5	28.1	30.8	12.9	2.9	.1
Sept.	--	.2	1.8	17.7	40.6	18.7	14.4	4.6	1.8	.2
Oct.	.6	4.8	20.6	31.0	31.0	9.3	2.3	.4	--	--
Nov.	16.7	25.4	25.7	24.3	8.0	--	--	--	--	--
Dec.	49.8	25.0	18.8	6.3	.2	--	--	--	--	--

SUMMARY

Fire protection is critical in Missouri because of the large forest acreage. A tabulation of records on three fire protection areas shows that in much of the State the major fire season begins in early February. Activity peaks in early April and is over by early May. There is a second fire season in the fall with maximum activity in mid-November, but it is less severe than the spring season. There are also more multiple-fire days in the spring than in the fall.

The multiple-fire day is highly indicative of the problem that protection units face. The average number of fires per fire-day changes dramatically from district to district within Missouri, but stays fairly constant from year-to-year within a given area. This area stability is also evident when the measure is

Table 10 — *Frequency of temperature values, West Plains, Missouri, 1200 c.s.t.*
(In percent of days in month)

Month	Temperature (°F.)									
	≤39	40-49	50-59	60-69	70-79	80-84	85-89	90-94	95-99	100-104
Jan.	43.7	24.3	18.8	12.0	1.2	--	--	--	--	--
Feb.	31.1	28.7	22.6	12.9	4.2	--	0.3	--	--	--
March	10.4	22.1	24.2	23.6	16.4	2.4	.8	--	--	--
April	--	2.7	15.1	27.6	36.1	14.2	3.3	0.9	--	--
May	--	--	2.3	15.0	33.2	27.6	20.3	1.5	--	--
June	--	--	--	3.7	17.0	24.8	37.2	15.2	1.8	--
July	--	--	--	.2	3.2	17.1	33.1	31.4	11.5	3.2
Aug.	--	--	--	.6	10.6	14.4	30.7	33.9	7.4	2.3
Sept.	--	--	.8	7.8	34.7	24.2	20.6	8.7	2.9	--
Oct.	--	.5	8.8	29.9	35.1	16.7	7.3	1.4	--	--
Nov.	5.1	17.5	27.8	31.1	18.1	.3	--	--	--	--
Dec.	36.1	25.7	21.2	14.9	2.1	--	--	--	--	--

number of large fires per large-fire day, or the ratio of acreage burned by large fires to total acreage burned.

Incendiarism and debris burning are by far the most important causes of fire starts. These two factors account for 77 percent of the total fire starts on the Eminence District and 89 percent on the West Plains District. Incendiarism becomes an even greater concern if acreage burned and multiple-fire starts are used as the measure of fire activity.

Grouping the fire activity data by day of week does not produce many obvious patterns. Even average number of fires shows no discernible trend by day of week on the two State districts. On the five districts of the Clark National Forest, however, there is an increased number of total fires on weekends. This might reflect the high usage of the National Forests during these days.

Determining the probability of a fire-day in a protection area in Missouri can be done quite easily by combining the fine fuel moisture with the windspeed. The combination produces a good indication of fire potential, even though occurrence is also dependent upon the number of firebrands in an area.

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estimating slash fuel loading for several lake states tree species

peter j. roussopoulos and von j. johnson

NORTH CENTRAL FOREST EXPERIMENT STATION
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Manuscript approved for publication January 18, 1973

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THIS PAPER IS AN EXPERIMENT IN COMMUNICATION.

Realizing that the needs and interests of our two major ''clients'' — the scientist and the practitioner — are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better. You are about to sample the first fruit of this effort.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

The Documentation section describes the details of the research process. It is for the reader interested in laboratory and field procedures, tabulations, statistical analysis, and philosophical discussion. This section, too, is self-contained.

Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. *We would like to have your opinion.*

ESTIMATING SLASH FUEL LOADING FOR SEVERAL LAKE STATES TREE SPECIES

Peter J. Roussopoulos and Von J. Johnson

APPLICATION

Fire behavior is greatly influenced by the amount of slash fuel on the ground. So the land manager concerned about fire control needs to know what kind and how much slash is present before he can devise a plan to prevent or control fire. Especially, he needs to know the sizes of slash material present, because the smaller pieces are most critical to fire behavior. Current methods of slash appraisal range from visual "guesstimates" to complex measurements and computations.

Presented here is a slash fuel survey method that we feel is easy to use and yet reasonably accurate. It involves simple field measurements used in conjunction with some alignment charts.

Field Procedure

Planar intersect sampling simply involves tallying by size and species all the stems, branches, and twigs ("particles") that cross above or below a number of sample lines. Any number and length of lines may be sampled, but of course the reliability of the sample increases as the total sample length increases. The finer the material the less length of line needed. If you have a relatively homogeneous slash area, 80 feet of sample line will give you accuracy to within about half a ton per acre for the finer material. If you want greater accuracy, you'll need a longer line. Or if you want comparable accuracy for larger material, you will need a longer line than that used for the "fines."

To avoid bias, the direction each sample line is run should be determined randomly. A table of random numbers or a simple "spin-the-bottle" game can be used to select the direction for each line.

Once you have established line length and direction, stretch a string or tape between two stakes or chaining pins and begin tallying (fig. 1). A prepared tally sheet simplifies the process (fig. 2). You can measure fine material (up to 1½ inches in diameter) with a go-no-go gage (fig. 3); estimate diameter of larger fuel ocularly, periodically checking with a diameter tape.

Figure 1. Branchwood particles intersected by the sample line are tallied by species and diameter class. In this photograph the sample is only one meter long, and is delineated in 25 centimeter segments by plumbbobs suspended from a meterstick. A large number of these short samples must be taken to ensure reliable results.

Tally only those particles that actually cross the sample line. If a curved or angular particle crosses the line

Date________________ Observers____

Area Identification____

Sample Number__________________ Direction of Line (Azimuth)______________

Branchwood Tally Form

Diameter class (Inches)	Line length	Jack pine	Red pine	Balsam fir	Spruce	Aspen	Birch	Other decid.	Other conifer
0-.25									
.26-.75									
.76-1.50									
2*									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									

* Range: 1.51-2.50, etc.

REMARKS:

Figure 2. Field tally sheet for planar intersect fuel sampling.

more than once it should be tallied for each crossing. Ignore particles that merely touch or parallel the line.

Office Procedure

Summarize the data for the entire sample area:

1. Total all the individual sample line lengths.

2. Total the number of particles intersecting the sample lines by diameter class and species.

3. Divide the total number of particle intersections for each species-diameter class combination by the total length of sample lines to get the average number of particle intersections per foot of sample line.

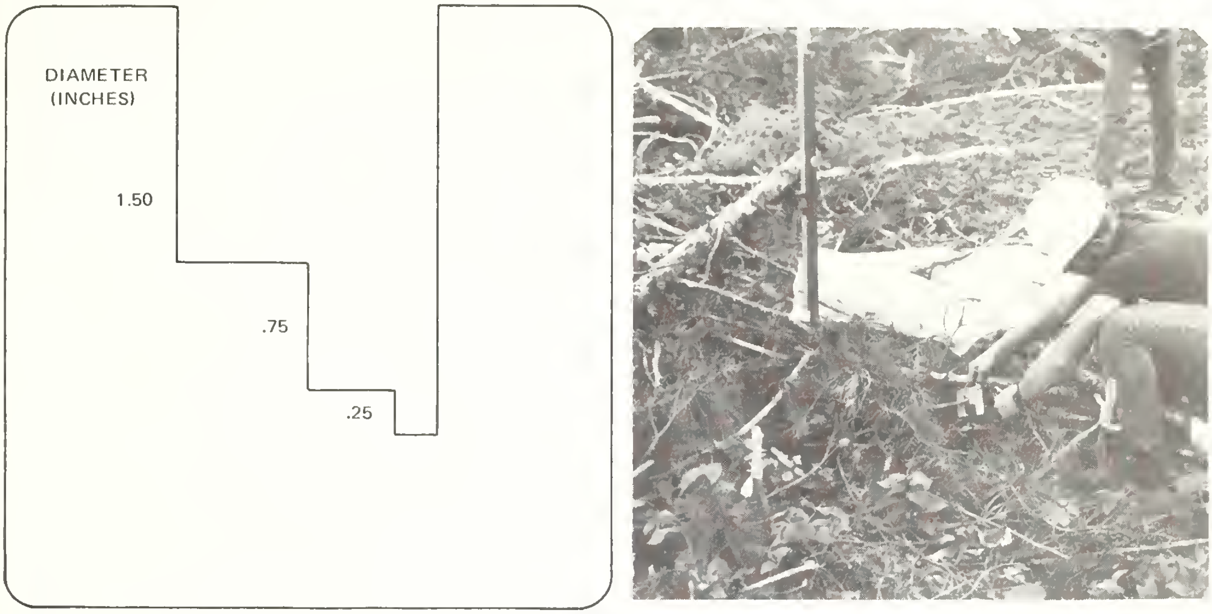

Figure 3. Sheet metal or plastic go-no-go gage may be used to determine fine fuel diameter classes.

Referring to the appropriate alignment chart (figs. 4 and 5):

1. On the far left scale find the point representing the number of intersections per foot of sample line for a certain species and diameter.

2. On the "Diameter Class" scale for the species in question, find the appropriate diameter.

3. Extend a straight line through these two points until it intersects the appropriate "Branchwood Fuel Weight" scale on the right.

4. Read the fuel weight in tons per acre at the intersecting point.

5. Repeat for all species-diameter combinations and add them all together to get total fuel weight per acre.

Example

Assume that ten 20-foot samples have been taken and that the numbers of ¼-¾-inch diameter jack pine particle intersections were 13, 54, 7, 22, 81, 42, 1, 132, 39, and 21. The total of these numbers (412) divided by the total sample line length (200 feet) gives an average of 2.06 intersections per foot of line. Locate this number on the left-hand scale of figure 4 and the ¼-¾-inch point on the jack pine Diameter Class scale and extend a line between these points to the jack pine fuel weight.

Estimating Foliage Weight

Foliage weight is directly related to the weight of the finest particles (¼ inch in diameter and smaller) and, for red pine, to the weight of particles as large as ¾ inch in diameter. Ratios of foliage weight to fine particle weight have been computed for three northern conifers — jack pine, red pine, and balsam fir — to facilitate calculating foliage weights for these species.

Three numbers are necessary to make the calculation:

1. Percent of foliage retained on the branches. (Obtained by ocular estimate.)

2. Ratio of foliage weight to branchwood weight. (For particles ¼ inch in diameter or less — jack pine - 1.6; red pine - 3.3; balsam fir - 0.9. Red pine was the only species having foliage on larger (¼-¾-inch) particles. Ratio for this size is 0.4.)

3. Branchwood fuel weight for the appropriate species and size. (Derived from alignment charts.) Multiply 1 by 2 by 3 and divide by 100 to get tons of foliage per acre. (For red pine this calculation must be done for both sizes of particles.)

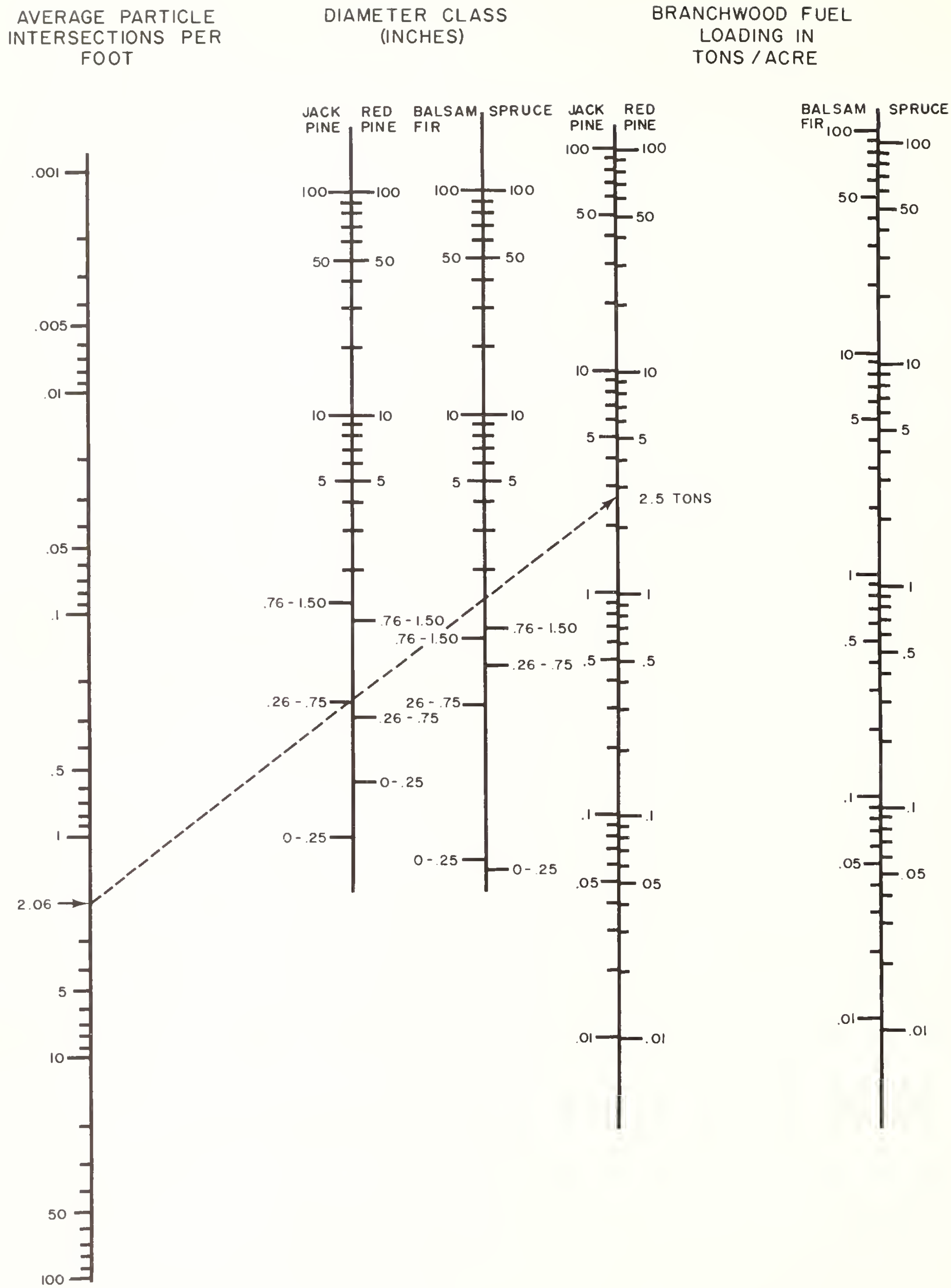

Figure 4. Nomograph determination of branchwood fuel loading for jack pine, red pine, balsam fir, and spruce.

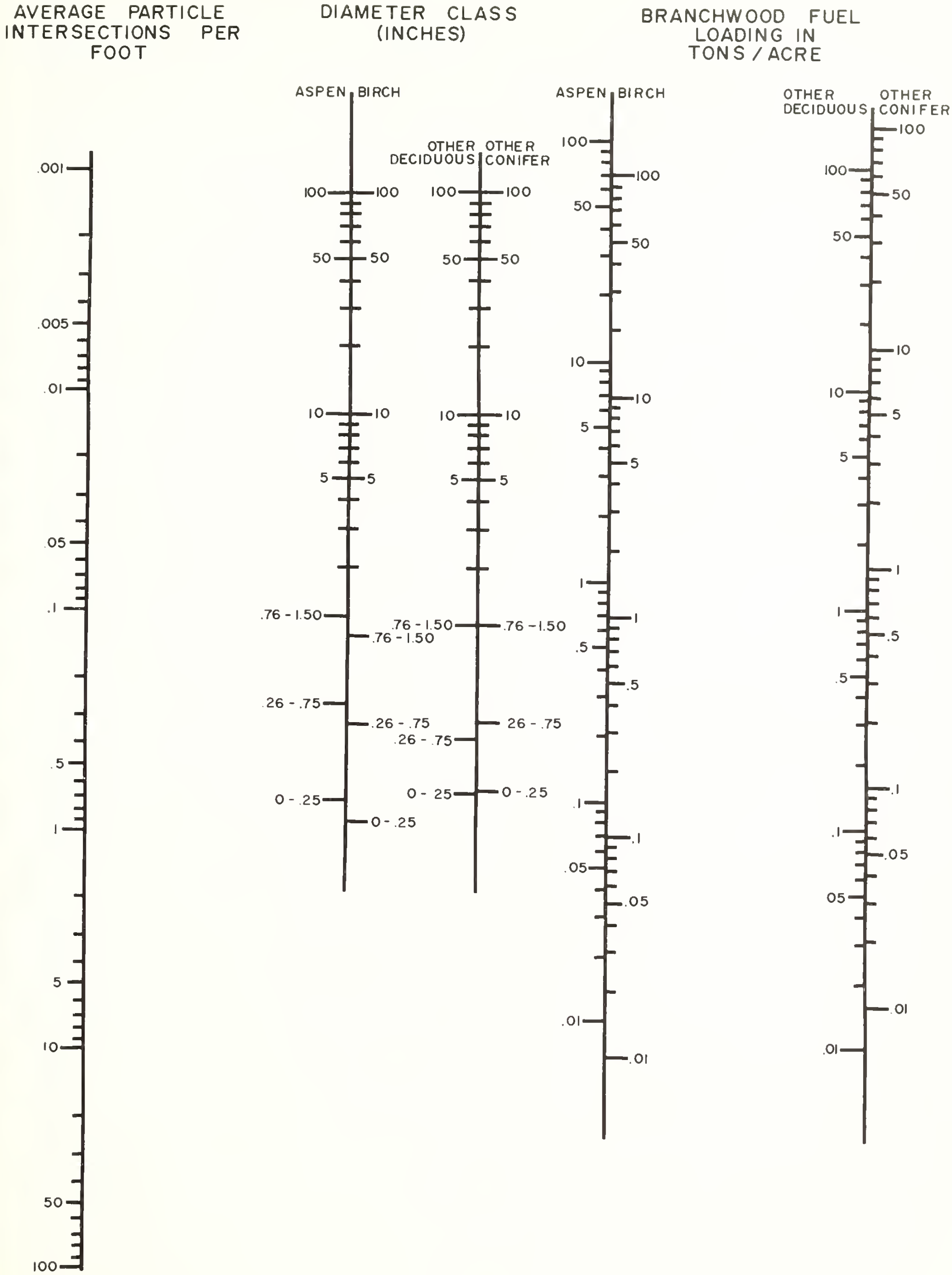

Figure 5. Nomograph determination of branchwood fuel loading for aspen, paper birch, other hardwoods, and other conifers.

DOCUMENTATION

Much of the recently published information on forest fire control, prescribed burning, and fuel management leans heavily toward quantified descriptions of forest fuels. Developments in fire control planning systems as well as the new National Fire Danger Rating System (Deeming *et al.* 1972) involve fuel descriptions of this nature. Loading of slash fuel (its weight per unit of ground area) is perhaps the measurement appearing most often in the literature. Usually it is expressed in tons per acre, but commonly in pounds per square foot as well. Because fire behavior is influenced greatly by fuel loading, sound decisions among alternative fuel management strategies require knowledge of the existing fuel load. Needed is a quick but reliable method of estimating slash fuel loading usable by field personnel at low cost. Availability of such a technique would not only provide a sound basis for fuel management decisions, but it also would allow "on-the-ground" decisionmakers to develop an intuitive "feel" for quantitative fuel descriptions.

Classic techniques for determining fuel loading involve weighing ovendry samples extracted from known plots and are expensive and time consuming. Crown weight tables have been helpful for slash weight estimates in conifer plantations, but in natural stands, where the fuel array includes many species, these are not totally satisfactory.

One promising alternative involves planar intersect sampling originally developed by Warren and Olsen (1964) to assess logging waste in *Pinus radiata* plantations in New Zealand. Detailed discussions of the theory, applications, and evaluations of this procedure have been reported by Bailey (1969, 1970), Beaufait,[1] Brown (1971), Dell and Ward (1971), and Van Wagner (1968). Since first applied to forest fuel sampling by Van Wagner (1968), the technique has been used successfully by many specialists to estimate fuel loading. With only a few simplifications it can be used by forest land managers as well. Advantages of this method include speed and simplicity in the field, minimal equipment requirements, and the relative ease with which fuel can be classified by species and size (important in view of the influence of the finer fuels on fire behavior).

[1] *Beaufait, W. R. Prescribed fire cooperative study. Study Plan N. 2102-12 on file at Int. For. & Range Exp. Stn., North. For. Fire Lab., USDA For. Serv., Missoula, Mont. 1967.*

One big disadvantage is the need for a bank of supplementary information on physical characteristics of the fuel components, such as particle specific gravities and diameter distributions within chosen size classes. We have overcome this objection locally by compiling the necessary data for several Lake States species and constructing alignment charts to facilitate their use.

Alignment Chart Development

The alignment charts were constructed to graphically represent the following equation.[2]

$$L_{ij} = 11.65\ N_{ij}\ S_{ij}\ \delta_{ij}$$

where L_{ij} = fuel loading in tons per acre of wood particles of the i^{th} species in the j^{th} size class.

N_{ij} = the number of particles intersected per foot of sample line in the ij^{th} species-size class category.

S_{ij} = the representative specific gravity of fuel particles in the ij^{th} species-size class category.

δ_{ij} = the representative squared diameter for fuel particles in the ij^{th} species-size class category.

11.65 = a constant of proportionality to express loading in tons per acre.

To satisfy the equation, the values of S_{ij} and δ_{ij} had to be determined for a number of species-size class combinations. The fieldwork for these determinations was conducted in a tornado blowdown area on the Virginia District of the Superior National Forest. The predominant species existing in this area were jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), balsam fir (*Abies balsamea*), spruce (*Picea*), aspen (*Populus*), and white birch (*Betula papyrifera*). The "other deciduous" and "other conifer" categories were created to represent less frequently encountered species.

Representative squared diameters (δ_{ij}) for the three smallest size classes were determined by measuring to

[2] *A modification of that given by Van Wagner (1968).*

the nearest 0.01 inch, the diameters of all particles of these sizes intersecting a number of planar intersect samples. Each measurement was squared and the squared diameters averaged for each species-size class combination to obtain the values of δ_{ij} (table 1). The data for ¾-1-½-inch "other conifers" were insufficient to determine δ, so a value of 1.25 in.[2] was subjectively assigned to this class.

Because the frequency distribution of particle diameters resembles a highly skewed gamma curve, it is assumed that diameters within the larger size classes (2 inches and larger) are distributed with nearly equal probability, and that δ_{ij} is equivalent to the square of the class midpoint. Although this assumption introduces a bias, it is considered negligible within such narrow (1-inch) size classes.

Evidence suggests that particle specific gravities (S_{ij}) become greater in smaller diameter particles.[3] This can be attributed to higher concentrations of pitch and extractives, and the larger proportion of volume occupied by bark in smaller particles. However, specific gravities were assumed to be relatively constant in the larger diameter classes.

For these classes (2 inches and larger) specific gravities given in the *Wood Handbook* (U.S. Department of Agriculture 1955) were used. For the smaller classes values were determined empirically. Air-dry volumes were measured by a mercury displacement technique and weights were found after ovendrying 24 hours at 105° C. (table 2). Data were insufficient for estimates of ¾-1-½-inch spruce and "other deciduous" and all "other conifer" specific gravities. The *Wood Handbook* value 0.40 was used for the spruce and a value of 0.50 was assigned to the "other deciduous." As a compromise between *Wood Handbook* values for eastern white pine (*Pinus strobus*) and northern white-cedar (*Thuja occidentalis*), "other conifer" species were assigned a specific gravity of 0.32 for all classes.

Using equation 1, then, the values given in tables 1 and 2 were built into the logarithmic scales of the alignment charts (figs. 4 and 5).

Estimating Foliage Loading

Good loading estimates for foliage are slightly more elusive than for branchwood fuels. It is not practical to count foliage intersections in the planar intersect sample, and large-scale extractive sampling of foliage would be too time consuming and expensive. Brown (1970) estimated foliage loading in spruce-fir logging slash in western Montana by determining the ratio of foliage weight to the weight of ¼-inch or less branchwood. This was done by stripping the foliage from sample branchwood, weighing the ovendried needle and branchwood components, and dividing the former by the latter. The product of this foliage weight ratio and the ¼-inch branchwood loading estimate, furnished by the planar intersect sample, is the estimate of foliage loading.

[3] *Personal communication with James K. Brown, Northern Forest Fire Laboratory, dated October 2, 1970.*

Table 1. — *Representative squared diameters (δ_{ij}) for small size classes (Square inches)*

Species	Size class (j) (inches)					
	0-.25		.26-.75		.76-1.50	
	Mean	Standard error	Mean	Standard error	Mean	Standard error
Jack pine	0.012	0.001	0.230	0.012	1.197	0.056
Red pine	.034	.003	.150	.031	1.309	.044
Balsam fir	.005	.001	.225	.019	.822	.010
Spruce	.005	.002	.304	.067	1.108	.155
Aspen	.022	.002	.211	.019	1.165	.184
Birch	.016	.003	.160	.025	1.237	.397
Other deciduous	.028	.004	.100	.013	1.254	.034
Other conifer	.041	.017	.169	.018	***	***

*** Insufficient data.

Table 2. — *Particle specific gravities (S_{ij}) for small size classes*

Species	Size class (inches)					
	0-.25		.26-.75		.76-1.50	
	Mean	Standard error	Mean	Standard error	Mean	Standard error
Jack pine	0.554	0.025	0.510	0.023	0.441	0.042
Red pine	.607	.017	.548	.020	.460	.008
Balsam fir	.695	.029	.404	.050	.408	.006
Spruce	.601	.029	.644	.042	***	***
Aspen	.591	.034	.444	.036	.490	.017
Birch	.685	.021	.545	.020	.484	.008
Other deciduous	.654	.034	.576	.014	***	***
Other conifer	***	***	***	***	***	***

*** Insufficient data.

If the time and equipment are available, this procedure provides good foliage loading estimates. Fifteen or twenty sample branches for each species should provide reasonably reliable ratio estimates.

When the time or equipment is not at hand and a foliage loading estimate is desired for jack pine, red pine, or balsam fir, refer to the alternative procedure described on page 3. Ratios of foliage weight to ¼-inch or less branchwood weight were determined for these species. The samples were collected near Virginia, Minnesota, from branches retaining all of their foliage. No needle fall had occurred prior to sampling. To apply these ratios, a subjective estimate of the proportion of needles retained on the branches is required for each coniferous species in the sample area. This may be expressed as the percent of the total possible needles (assuming no needle fall) remaining on the branches.

Summary

The current trend toward increasingly sophisticated forest management planning systems indicates a need for better methods of obtaining required inputs to these systems. If fuel management is to be practiced intelligently, managers must be able to assess fuel hazard in quantitative terms. A set of alignment charts has been presented to aid in assessing slash fuel loading, one component of fuel hazard. Use of planar intersect sampling with the associated fuel loading alignment charts provides a rapid and fairly reliable method of estimating slash fuel weights by species and diameter class.

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LIGHT, SOIL MOISTURE, and TREE REPRODUCTION in HARDWOOD FOREST OPENINGS

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Manuscript approved for publication May 11, 1973

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LIGHT, SOIL MOISTURE, AND TREE REPRODUCTION IN HARDWOOD FOREST OPENINGS

Leon S. Minckler, John D. Woerheide, and Richard C. Schlesinger

Much research has been done in recent years to quantify the available light in forest openings and its influence on regeneration. This research has been approached both from a theoretical and an empirical basis. Our studies, conducted in mixed-hardwood stands in southern Illinois, show that the amount of light reaching the forest floor is related to size of openings, aspect, position in the opening, time of day, and season. Although exact quantification of available light in these openings was limited by the experimental setup and sampling methods, the results clearly demonstrate that light and soil moisture are related in complex ways to the above variables. Some of these relationships are discussed in this report.

METHODS

The study was conducted in several mixed-hardwood stands on the Kaskaskia Experimental Forest in southern Illinois. White oak (*Quercus alba*) and hickory (*Carya* spp.) were the dominant species on the southerly slopes, while oaks and yellow-poplar (*Liriodendron tulipifera* L.) were the dominant species on northerly slopes and in the coves. The stands were approximately 100 to 125 years old and were well stocked (80 to 100 square feet basal area per acre).

Circular openings of six different sizes were created on each of three topographic positions in the forest stands in the spring of 1959. The diameter of these openings ranged from one-fourth to twice the height of the surrounding trees.[1] The three topographic positions included a northeast slope, a southwest slope, and a cove.[2] Thus, our study encompassed 18 openings (six sizes x three topographic positions). There was only one replication of each size x site combination and therefore statistical analysis of the data was not possible.

Five light measurements per sample day were made at each station in 1959 at 1½ hour intervals, beginning at 9:00 a.m. c.s.t. The measurement period extended from the last week in June to the first week in September, each opening being sampled on 3 to 6 separate days during this period. Additional light measurements were taken in the ½-tree height and 1-tree height openings on north and south aspects during the 1960 growing season. Light at the center stations in these four openings was measured periodically from June 1 to September 21, every 2 hours from 5:45 a.m. to 5:45 p.m. c.s.t.

All light measurements were made with a Brockway light meter, which gives instantaneous readings in foot-candles (Minckler 1961).[3] In all cases, the meter was held in a horizontal position at about waist level, thus avoiding the variation in light readings caused by understory vegetation (Gatherum 1961).

Soil moisture was meaured in only six of the openings (north and south ½-, 1-, and 2-tree height plots), and under the canopy. Samples were taken at depths of 6 and 18 inches near the light stations three times during the summer of 1959. The same stations

[1] *The overstory trees in the coves and on the north and south slopes averaged approximately 90, 80, and 60 feet in height, respectively.*

[2] *Slope steepness was 20 to 30 percent on north and south aspects, and cove sites were nearly level.*

[3] *This type of meter is to be contrasted with an integrating light meter which records the sum of the illumination received during its exposure period. The average of the five daily instantaneous readings was highly correlated ($r^2 = 0.93$) with readings from an integrating light meter placed at the center of the openings (Minckler 1961). The average difference between observed and predicted values was 10 percent. The meter was used with a hemispherical receiving sensor.*

were resampled once during the summer of 1962 at the 6-inch depth only. Soil moisture was determined gravimetrically and expressed as a percent of ovendry weight. Available soil moisture is the difference between this value and the percent soil moisture at the permanent wilting point (taken to be the moisture content at 15 atmospheres pressure).

The soils were derived from thin loess underlain by sandstone. The south aspect soils contained more sand and clay than the north aspect soils. Average texture for the 6-inch depth was 12 percent sand, 62 percent silt, and 26 percent clay, and for the 18-inch depth, 7, 62, and 31 percent, respectively.

Reproduction was measured in the openings during August 1959 and remeasured in October 1964. All stems were tallied in 1959 and stems considered "free to grow" were tallied in 1964. The ¼-tree height openings were sampled with five 1.15 milacre plots centered at the light stations. The other openings were sampled with 4.5 milacre plots centered at the light stations, and for the 1-, 1½-, and 2-tree height openings an additional four plots were located halfway between the edge and center plots.

RESULTS

The 1959 data show two distinct effects of opening size on the light received at specific points within the opening. The amount of light on clear days generally increased as opening size increased for all positions except south (fig. 1). Since readings were taken facing the sun, the observer effectively shielded the light meter from the diffuse light from the opening, and the south edge readings reflect differences in the density of the surrounding stand rather than opening-size differences. Opening size also apparently affected the relative amount of light received at the five positions within an opening. For openings of ¾-tree height and less, the north position received the most light, followed by the center, west, east, and south. For openings of 1-tree height and larger, the center position generally received the most light, followed by the north, west, east, and south.

For openings of all sizes, light intensity was greatest on south slopes, coves, and north slopes, in that order. Because the measured light was that received on a horizontal surface, the slope effect is one of shadow

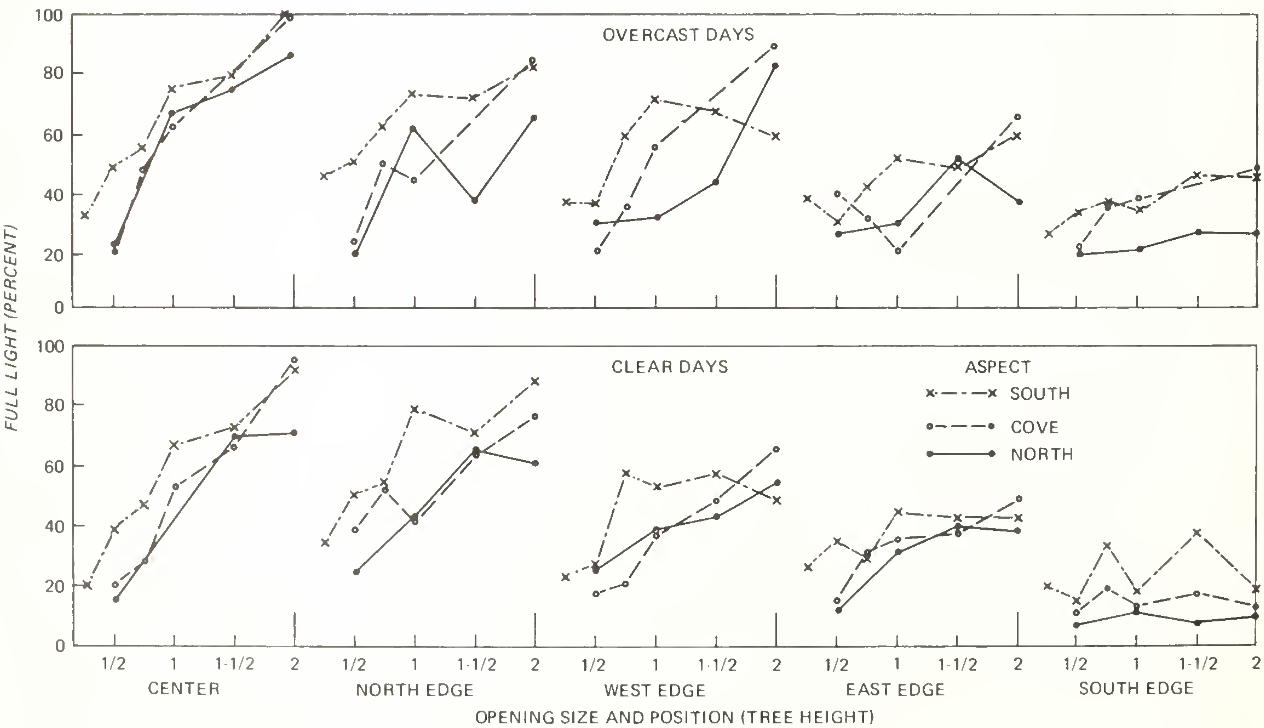

Figure 1. — *Average light as related to opening size, aspect, and position in opening.*

length. The shadow-casting trees are in effect below the opening on south slopes and above the opening on north slopes.

Light in the openings on overcast days, expressed in percent of full light, was greater than on clear days, but the total light in foot-candles was only 55 percent as much as on clear days. On overcast days there is greater light dispersal, so stations at the edges of openings received relatively more light.

The 1960 data showed that little information was lost by not measuring light as early or as late in the day during 1959. The measurements earlier and later in the season indicate that the differences between the center of the north and south 1-tree height openings increased as the season progressed (fig. 2). The centers of the ½-tree height plots received nearly equal illumination throughout the season.

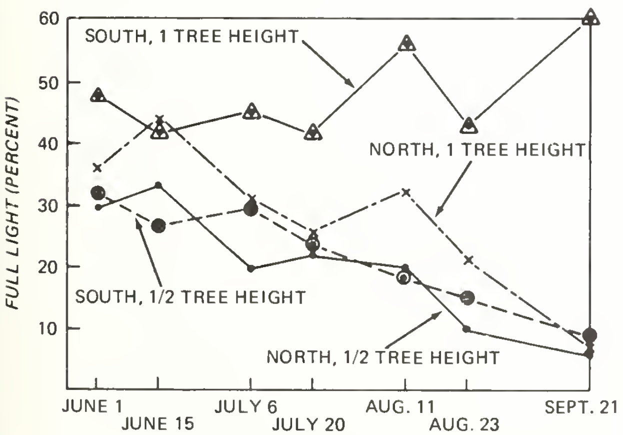

Figure 2.—*Light in center of openings during the 1960 growing season.*

Measurements on July 14, 1959, showed that the center of the openings had from two to eight times more available soil moisture than the adjacent forest soil (table 1). Fletcher and Lull (1963) found a similar moisture advantage of open areas over forested areas. There were slight differences in soil moisture between the two soil depths, but no consistent differences between opening sizes or aspects. Soil moisture content at the edges of the openings, in all cases, was intermediate between that in the center of the opening and under the stand.

Repeat measurements 3 years later (July 27, 1962) showed that the centers of the openings still had more moisture than soils under the adjacent canopy (table 2). However, the differences had decreased, especially for the smaller openings. Soil moisture at the opening edges was about the same as under the canopy at this time.

When the openings were created in March 1959, all stems greater than 18 inches tall were removed. In August 1959 the reproduction on north aspects was generally less than a foot tall, consisting of new seedlings, advanced seedlings, seedling sprouts, and stump sprouts, depending on species (table 3). On south aspects, the mean heights were less than on north aspects. There were no consistent differences in the abundance of reproduction by opening size in either August 1959 or October 1964. The number of stems "free to grow" (not overtopped) in 1964 was about half of the total number of stems present in 1959 (table 4). On north aspects, the proportion of desirable species had increased, while on cove and south aspects, this proportion had decreased. In 1964 the mean height of the tallest stems free to grow increased as opening size increased, and within an opening the tallest trees were generally found in the center plots (table 5, fig. 3).

DISCUSSION

These results demonstrate the variability in the amount of light received at several points in forest openings. Although the measurements are not precise enough to establish absolute differences in the light received as it is influenced by location within an opening, by opening size, or by aspect, they do indicate the general relationships involved. The least light was recorded at the south edge of a ¼-tree height opening on a north slope, while the most was recorded at the center of a 2-tree height opening on a south slope. Other positions, sizes, and aspects provided the full range of intermediate conditions. Soil moisture was greatest in the center of the openings, but the difference between the openings and the uncut stand decreased as the demands of the new vegetation for moisture increased. In general, the edges of the smallest openings were least favorable for new growth, while the center of the largest openings were most favorable.

Table 1.—*Average available soil moisture in openings and adjacent forest stand; first summer after cutting openings*
(In percent)

NORTH ASPECT

Opening size (tree height)	Days since 1-inch rain	6-inch soil depth: Center of opening	6-inch soil depth: Edge of opening	6-inch soil depth: Adjacent stand	18-inch soil depth: Center of opening	18-inch soil depth: Edge of opening	18-inch soil depth: Adjacent stand
1/2	4	24.6	17.6	12.3	19.1	14.9	11.0
	19	18.5	8.6	3.1	14.9	8.6	3.5
1	4	23.6	20.6	15.1	20.4	20.3	11.1
	19	19.2	13.2	6.1	16.4	13.0	4.8
2	4	25.6	18.5	15.4	19.9	16.2	14.5
	19	20.1	9.7	5.1	18.1	10.5	7.7
SOUTH ASPECT							
1/2	1	22.0	21.6	16.4	19.4	18.4	16.1
	19	20.1	14.7	8.6	17.3	13.4	9.4
1	1	23.6	21.0	18.2	20.1	18.7	15.2
	19	15.2	12.4	7.6	15.5	9.8	5.1
2	1	23.5	20.4	19.3	19.8	18.3	15.1
	19	19.3	11.9	4.7	18.8	11.1	2.2

Table 2.—*Average available soil moisture*[1] *at 6-inch depth in openings and adjacent forest stand; fourth summer after cutting openings*
(In percent)

NORTH ASPECT

Opening size (tree height)	Center of opening	Edge of opening	Adjacent stand
1/2	2.2	1.6	1.3
1	6.0	2.2	2.3
2	10.8	3.3	3.4
SOUTH ASPECT			
1/2	5.0	2.7	3.1
1	5.5	3.4	3.8
2	7.4	2.9	3.2

1/ Taken on July 26, 16 days after a 1.1-inch rain.

Table 3. — *Mean height and description of reproduction on north slopes at start of study in 1959*

Species	Mean height of all reproduction in openings in August 1959 after complete cutting in March	Description of reproduction
	Feet	
Yellow-poplar	0.18	New seedlings
Hickory	.78	Mostly advanced regeneration
White oak	.97	Mostly seedling sprouts
Black and red oaks	.67	Mostly seedling sprouts
Miscellaneous undesirable[1/]	1.38	Most advanced reproduction and sprouts
Non-timber[2/]	.92	New seedlings, advanced reproduction, and sprouts

1/ Chiefly sugar maple, black gum, elm, and beech.
2/ More than 90 percent sassafras, but some sumac and dogwood.

The revegetation of the openings is dependent upon many micrometeorological and biological factors not examined in this study. Nevertheless, the general trends of height growth and species composition differences within the openings demonstrate the importance of understanding the complex environment of openings as a basis for controlling the regeneration of forest stands.

Table 4. — *Number of seedlings per acre in openings in 1959 and 1964; all opening sizes combined*

Aspect	Total number seedlings, August 1959		Number of seedlings free to grow, October 1964	
	Desirable[1/] species	Undesirable[2/] species	Desirable[1/] species	Undesirable[2/] species
North	4,400	6,600	2,200	2,500
Cove	6,900	9,200	1,600	2,200
South	2,800	2,600	1,200	1,300

1/ Chiefly yellow-poplar; white, black, and red oaks; and hickory. Yellow-poplar occurred only rarely on the south aspects.
2/ Chiefly sugar maple, black gum, elm, beech, and nontimber species such as sassafras, sumac, and dogwood.

Table 5. — *Height of tallest trees*[1] *6 years after creating openings*

(In feet)

COVES AND NORTH SLOPES

Species and opening size[2]	Position in opening: Center	North edge	East and west edges	South edge
Yellow-poplar:				
1/4 to 1/2	--	--	--	--
3/4 to 1	7.5	--	--	2.0
1-1/2 to 2	14.3	--	--	1.8
White oak:				
1/4 to 1/2	5.3	2.4	3.7	4.2
3/4 to 1	6.7	5.3	6.0	6.9
1-1/2 to 2	10.4	--	6.2	3.3
Black and red oaks:				
1/4 to 1/2	1.8	1.9	1.9	2.1
3/4 to 1	3.9	--	3.7	3.3
1-1/2 to 2	6.3	5.8	4.5	2.4
Hickory:				
1/4 to 1/2	4.1	4.2	5.1	2.7
3/4 to 1	6.3	6.2	5.7	6.2
1-1/2 to 2	7.4	5.6	5.0	4.5
Nontimber species:				
1/4 to 1/2	5.6	4.2	5.4	3.5
3/4 to 1	10.5	8.1	5.3	6.3
1-1/2 to 2	12.8	10.7	6.2	2.9
SOUTH SLOPES				
White oak:				
1/4 to 1/2	--	3.1	2.4	3.2
3/4 to 1	8.2	7.0	--	--
1-1/2 to 2	7.9	6.5	--	--
Black and red oaks:				
1/4 to 1/2	--	--	1.3	--
3/4 to 1	4.4	5.3	4.0	2.5
1-1/2 to 2	6.5	--	4.4	2.8

1/ Based on two tallest trees in each sample plot.
2/ In tree-height.

Figure 3. — *Regeneration in a 2-tree height opening on a north aspect, 9 years after cutting.*

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☆U.S. Government Printing Office: 1973 — 761-969

NORTH CENTRAL FOREST EXPERIMENT STATION

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PREDICTING SEGREGATION OF WOOD AND BARK CHIPS BY DIFFERENCES IN TERMINAL VELOCITIES.

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Manuscript approved for publication May 15, 1973

PREDICTING SEGREGATION OF WOOD AND BARK CHIPS BY DIFFERENCES IN TERMINAL VELOCITIES

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Research is now in progress both in industry and government on developing methods of bark removal after chipping. Reasons for supporting this research have been listed and elaborated on in previous publications (Arola 1968, 1970; Erickson 1968, 1970, 1971). Briefly stated, fuller utilization of our existing forest resources must take place in order to meet the projected demands for pulpwood. One method of utilizing more of the standing tree is to chip the tops and limbs presently left as residue, or chip the whole tree and remove the bark after chipping.

Bark removal after chipping is a twofold problem: it consists of separating the attached bark from the wood chips (breaking of the wood-bark bond) and segregating the "free" bark chips from the "free" wood chips. Air flotation is one process being investigated to segregate bark from wood once it has been separated. The air segregation process depends on basic differences in terminal velocities of the wood and bark chips. The terminal velocity of a particle is defined as the maximum (constant) velocity the particle attains while falling freely through a viscous medium such as air (Korn 1951). This occurs the moment equilibrium is attained between the accelerating force (gravity) and the upward resisting force (drag) acting on the particle. An upward air flow can raise a particle only if the air velocity is greater than the terminal velocity of the particle. Thus, in order to design an efficient air flotation process, it is necessary to know the terminal velocities of the wood and bark chips of the various pulpwood species.

A variety of equipment exists for sorting materials according to differences in size, shape, specific gravity, and color. Such methods are used extensively in the agricultural, mining, and food-processing industries. However, none have proven capable of segregating bark and wood chips on a commercial scale. It therefore is necessary to design and develop new equipment for bark-chip separation-segregation. The first step is obtaining basic engineering data on the physical, mechanical, and chemical properties of wood and bark. Data on bark especially are very limited. This paper presents data on some of the physical properties of wood and bark chips for eight important pulpwood species: aspen, sugar maple, jack pine, red pine, white spruce, balsam fir, slash pine, and loblolly pine. The physical properties measured were length, width, thickness, moisture content, specific gravity, and terminal velocity. Differences in the terminal velocities of the wood and bark chips caused by differences in the other physical properties were used to predict the degree of segregation possible by air flotation.

EXPERIMENTAL PROCEDURE AND APPARATUS

Data were obtained on wood and bark chips made by chipping unbarked logs with a Morbark Chip-Pac[1] chipper (48-inch diameter disc with three knives). The chips were classified on a Sweco classifier and the following three chip sizes were measured and tested: less than 1-1/8 inch and greater than 5/8 inch (passed through the 1-1/8 inch screen and retained on the 5/8 inch screen); less than 5/8 inch and greater than 3/8 inch; and less than 3/8 inch and greater than 3/16 inch. Random samples of 100 wood and bark chips in each size

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

class were tested. The laboratory procedure on the individual chips was as follows:

1. The chips were weighed as received.
2. Length, width, and thickness were measured (length was measured along the grain).
3. Terminal velocity was determined.
4. Specific gravity[2] was determined.
5. Chips were ovendried.
6. Ovendried chips were weighed (for moisture content determination).

Terminal velocity was determined in a vertical wind tunnel with the wood or bark chips initially at rest on a stationary screen. When the terminal air velocity was reached, the chip floated in the air stream just above the screen. This technique has been described in detail in a previous publication (Sturos 1972). A unique flow straightener was designed to give a uniform air velocity distribution in the center portion of the vertical tube and a higher velocity near the tube wall, thus preventing the chip from moving up on its edge against the wall. A calibration curve correlating the air velocity to the voltage applied to the blower motor eliminated the need of the pitot tube and manometer in each velocity measurement.

Two density-gradient columns of different ranges were used to measure the true specific gravities of the wood and bark chips. The preparation of the density-gradient columns used in this study have been described in detail previously (Julien *et al.* 1971). The technique is based upon the fact that when two immiscible liquids of different specific gravities are placed in a cylinder, the liquids diffuse and form a density gradient whose upper and lower limits are equal to the densities of the two liquids. Petroleum ether and chlorobenzene were used for one of the columns, and toluene and bromobenzene were used for the other. The columns were calibrated by small glass beads whose specific gravities were accurately determined according to ASTM standards. The gradients of the two columns as prepared were 0.67 to 1.09 and 0.93 to 1.28. When carefully placed in the column, a wood or bark chip having a specific gravity value between these limits would sink to the level at which its specific gravity equaled that of the surrounding liquid mixture. The position of the chip was compared with the standardized beads for determining the specific gravity. Linear interpolation was used between the beads. A limiting factor of the density-gradient column technique is that specific gravity values less than 0.67 could not be determined. Therefore the specific gravities of chips that floated in the lower range column were determined by using their calculated moisture contents. Specific gravity-moisture content relationships developed in a cooperative study by Conder (1971) were used. These relationships were linear prediction equations. The data were obtained by soaking ovendried wood and bark chips for time intervals ranging from 2 minutes to 12 days. The moisture content and specific gravity were measured at the end of each interval.

For each of the 100 chips, the weight, length, width, thickness, blower motor velocity required to float the chip, specific gravity, and ovendry weight were recorded on prepared data sheets from which the data were keypunched on computer cards. A computer program calculated the terminal velocities from a predetermined velocity vs. voltage calibration equation and also determined the moisture content of each chip.

RESULTS AND DISCUSSION

The tabular output from the computer program gave the mean, standard deviation, the upper and lower 95-percent confidence limits on the mean, and the minimum and maximum values for each of the measured variables. The summary statistics for each species tested are given in tables 1 through 8. Comparing the differences in the mean terminal velocities between the wood and bark chips in each size shows that the four most promising species tested were aspen, sugar maple, balsam fir, and white spruce. The mean terminal velocities of the wood and bark chips of these species differed by 2.9 to 8.9 feet per second. Comparing the values of the other chip variables shows that the differences in terminal velocities are highly correlated to differences in the surface density (the product of specifc gravity and thickness) of the wood and bark chips.

By assuming a normal distribution as an approximation to the terminal velocity, the percentages of the total wood and bark chips in each size that one would expect to be lifted at any given air velocity were calculated for

[2] *Specific gravity as used in this study is the true or "natural" specific gravity defined as the green weight per green volume.*

Table 1. – Mean measurements of aspen wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.78	1.14	0.13	49	0.78	13.9	2.0
5/8	Bark	.81	.90	.24	44	1.07	21.4	2.7
3/8	Wood	.72	.54	.11	39	.73	13.2	2.3
3/8	Bark	.77	.40	.19	43	1.06	20.3	3.3
3/16	Wood	.68	.30	.08	42	.75	11.9	2.7
3/16	Bark	.62	.24	.11	48	1.06	17.0	3.6

* Green weight over green volume.

Table 2. – Mean measurements of white spruce wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.85	1.05	0.13	30	0.61	11.6	2.1
5/8	Bark	.78	1.28	.20	52	.92	19.4	2.2
3/8	Wood	.79	.50	.10	37	.67	11.8	2.5
3/8	Bark	.81	.66	.17	51	.91	19.1	4.2
3/16	Wood	.76	.29	.08	32	.64	10.5	2.3
3/16	Bark	.46	.33	.09	39	.92	13.4	2.1

* Green weight over green volume.

Table 3. – Mean measurements of sugar maple wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.86	1.43	0.15	35	0.94	16.2	1.8
5/8	Bark	.86	.78	.20	35	1.04	21.8	2.1
3/8	Wood	.74	.64	.11	29	.86	14.6	2.3
3/8	Bark	.77	.49	.18	40	1.01	21.3	3.1
3/16	Wood	.65	.30	.08	43	.83	13.6	2.1
3/16	Bark	.57	.27	.12	24	1.05	18.9	3.2

* Green weight over green volume.

Table 4. – Mean measurements of balsam fir wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity: Mean value	Terminal velocity: Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.90	1.09	0.15	54	0.77	14.7	1.3
5/8	Bark	.91	1.26	.27	45	.97	23.6	1.9
3/8	Wood	.76	.54	.11	54	.77	14.3	2.6
3/8	Bark	.70	.55	.21	46	1.00	22.8	2.6
3/16	Wood	.73	.28	.08	30	.69	12.6	2.5
3/16	Bark	.55	.29	.09	36	1.00	16.5	3.1

* Green weight over green volume.

Table 5. – Mean measurements of jack pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity	
							Mean value	Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.91	1.06	0.14	32	0.72	13.0	2.1
5/8	Bark	.74	.94	.12	46	.92	15.4	2.7
3/8	Wood	.72	.50	.11	39	.76	12.8	2.4
3/8	Bark	.70	.61	.10	50	.93	14.5	3.0
3/16	Wood	.69	.27	.08	38	.79	11.9	2.2
3/16	Bark	.54	.28	.07	33	.89	11.4	2.8

* Green weight over green volume.

Table 6. – Mean measurements of red pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity	
							Mean value	Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.85	0.96	0.14	52	0.84	15.7	1.9
5/8	Bark	1.04	.81	.11	36	.95	13.4	3.4
3/8	Wood	.81	.47	.12	47	.83	15.2	2.2
3/8	Bark	.80	.53	.08	36	.96	12.2	3.3
3/16	Wood	.72	.26	.09	41	.80	12.9	2.3
3/16	Bark	.56	.28	.04	37	1.09	8.5	3.1

* Green weight over green volume.

Table 7. – Mean measurements of slash pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity	
							Mean value	Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.86	0.84	0.15	45	0.92	15.6	2.1
5/8	Inner bark	.76	.77	.09	70	.98	15.1	2.3
5/8	Outer bark	.80	.81	.19	27	.71	14.6	2.6
3/8	Wood	.74	.52	.12	32	.88	14.3	2.2
3/8	Inner bark	.68	.42	.09	71	1.00	17.0	2.8
3/8	Outer bark	.76	.52	.15	24	.71	14.4	2.8
3/16	Wood	.68	.24	.08	39	.89	13.0	2.3
3/16	Inner bark	.71	.19	.07	65	.96	15.0	3.2
3/16	Outer bark	.46	.28	.08	21	.72	11.1	1.9

* Green weight over green volume.

each of the above four species (fig. 1, tables 9-12). The 0.95 upper confidence limit on the wood chip mean and the 0.95 lower confidence limit on the bark chip mean were used to position the wood chip and bark chip distributions (fig. 1). This would lead to more overlap of the wood and bark terminal velocity distributions and result in more bark being lifted with the wood, approximating a lower limit on system effectiveness. In tables 9 through 12, the output bark content in the wood product (that is, the chips that were lifted)

Table 8. – Mean measurements of loblolly pine wood and bark chips

Nominal chip size (inches)	Chip type	Length	Width	Thickness	Moisture content (wet basis)	Specific gravity *	Terminal velocity	
							Mean value	Standard deviation
		Inches	Inches	Inches	Percent		Ft./sec.	Ft./sec.
5/8	Wood	0.94	1.01	0.18	51	0.92	16.2	2.1
5/8	Inner bark	.92	.72	.07	66	.93	13.8	1.9
5/8	Outer bark	.96	.73	.22	24	1/ <.67	13.8	3.3
3/8	Wood	.73	.47	.12	47	.86	14.8	2.5
3/8	Inner bark	.90	.37	.06	68	.97	13.3	1.9
3/8	Outer bark	.61	.44	.15	7	1/ <.67	13.2	3.2
3/16	Wood	.60	.26	.07	27	.80	10.9	2.3
3/16	Inner bark	.58	.21	.05	55	.96	11.6	2.2
3/16	Outer bark	.40	.27	.08	46	1/ <.67	10.6	2.2

1/ All outer bark particles floated in the density-gradient column. Therefore the mean specific gravity is less than 0.67.

* Green weight over green volume.

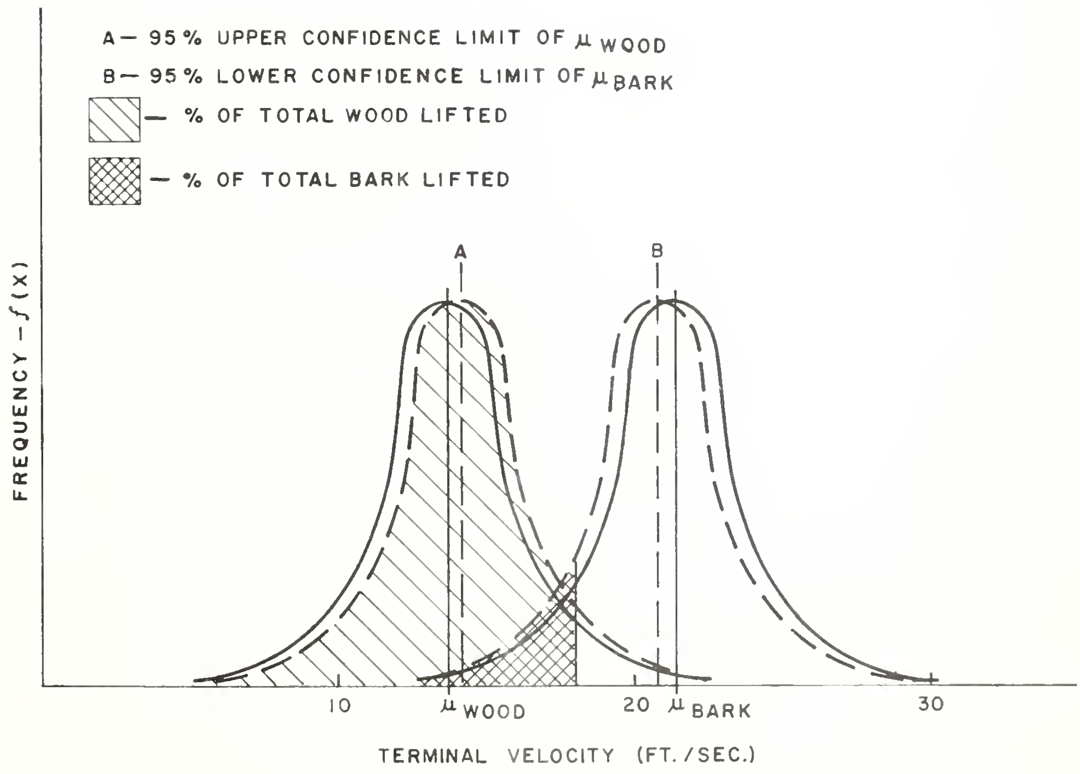

Figure 1. – Normal distributions of the terminal velocity of 5/8-inch aspen wood and bark chips. The distributions have been positioned at the 0.95 upper confidence limit on the wood mean and at the 0.95 lower confidence limit on the bark mean.

Table 9. – Possible results of segregating aspen wood and bark chips by air flotation methods

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	7.2	16.0	81.4	3.8	0.4
5/8	7.2	17.0	92.0	7.9	.7
5/8	7.2	18.0	97.2	9.5	.8
3/8	32.4	14.0	55.9	4.4	3.6
3/8	32.4	15.0	71.9	7.9	5.0
3/8	32.4	16.0	84.4	13.4	7.1
3/16	53.9	11.0	30.1	7.0	21.3
3/16	53.9	12.0	43.9	11.5	23.5
3/16	53.9	13.0	58.6	17.8	26.3

Table 10. – Possible results of segregating sugar maple wood and bark chips by air flotation

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	1.5	18.0	78.6	5.5	0.1
5/8	1.5	19.0	91.2	13.0	.2
5/8	1.5	20.0	97.3	25.6	.4
3/8	22.1	15.0	48.7	3.4	2.0
3/8	22.1	16.0	65.5	6.7	2.8
3/8	22.1	17.0	79.7	11.9	4.1
3/16	52.7	13.0	32.1	5.1	15.0
3/16	52.7	14.0	50.8	9.3	17.0
3/16	52.7	15.0	69.3	15.6	20.1

Table 11. – Possible results of segregating white spruce wood and bark chips by air flotation

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	16.3	14.0	82.7	1.1	0.3
5/8	16.3	15.0	92.3	3.3	.7
5/8	16.3	16.0	97.2	8.5	1.7
3/8	10.8	14.0	75.1	15.8	2.5
3/8	10.8	15.0	86.0	22.2	3.0
3/8	10.8	16.0	93.1	29.9	3.8
3/16	22.5	10.0	34.4	7.4	5.9
3/16	22.5	11.0	51.1	17.0	8.8
3/16	22.5	12.0	67.6	31.9	12.1

Table 12. — Possible results of segregating balsam fir wood and bark chips by air flotation methods

Nominal chip size (inches)	Input bark content	Air velocity	Total wood lifted	Total bark lifted	Output bark content in wood product
	Percent	Ft./sec.	Percent	Percent	Percent
5/8	14.8	19.0	99.8	1.5	0.3
5/8	14.8	20.0	100.0	5.0	.9
5/8	14.8	21.0	100.0	12.8	2.2
3/8	12.8	17.0	80.7	2.0	.4
3/8	12.8	18.0	89.6	4.8	.8
3/8	12.8	19.0	95.0	10.1	1.5
3/16	7.5	12.0	32.9	10.6	2.6
3/16	7.5	13.0	48.1	17.8	2.9
3/16	7.5	14.0	63.7	27.4	3.4

was calculated for each of the three air velocities chosen for each chip size. The degree of bark removal possible by air flotation methods is realized by comparing the output and input bark contents. Also, the percent of the total wood chips lifted gives an indication of the amount of wood recovery in each size class. The optimum air setting for each size would not be determined solely on output bark content but on a combination of bark removal and an acceptable wood recovery.

The data would suggest that in an industrial process, a minimum of three air flotation machines would be operating simultaneously — at least one machine for each nominal chip size. The wood product from each machine (chip size) would ultimately be combined to form a single wood product. Based on this assumption, typical combined wood products were calculated for aspen, sugar maple, white spruce, and balsam fir (table 13). For each species an air velocity was selected for each chip size. Also, realistic weighted fractions of the total chip mix were assumed for each size. These were based on actual classification tests of the random mix as received from the chipper. As table 13 shows, the calculated wood recovery ranged from 91 to 93 percent for the four species and the residual bark content from 1.8 to 2.6 percent.

Numerous pulpmills accept chips with 3 percent or less bark — thus, the above results indicate that air flotation is a promising method of segregation with the four species mentioned above. Also, similar results would most likely occur with the species whose wood and bark chips have similar differences in specific gravity and shape.

Table 13. — Results obtained by combining the wood product from the three size classes in each species

Species	Air velocities selected for each chip size (inches)			Percent of total chips assumed in each chip size (inches)			Combined input bark content	Combined wood product	
	5/8	3/8	3/16	5/8	3/8	3/16		Wood recovered	Bark content
	Ft./sec.	Ft./sec.	Ft./sec.				Percent	Percent	Percent
Aspen	18	15	12	72	22	6	15.5	91	1.8
Sugar maple	20	17	15	69	23	8	10.3	92	2.0
White spruce	16	16	11	65	26	9	15.4	92	2.6
Balsam fir	21	19	14	48	38	14	13.0	93	2.1

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NORTH CENTRAL FOREST EXPERIMENT STATION

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OWTH OF
ACK WALNUT TREES
EIGHT MIDWESTERN STATES—A PROVENANCE TEST

calvin f. bey

NORTH CENTRAL FOREST EXPERIMENT STATION

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Manuscript approved for publication May 16, 1973

GROWTH OF BLACK WALNUT TREES IN EIGHT MID-WESTERN STATES — A PROVENANCE TEST

Calvin F. Bey

Black walnut (*Juglans nigra* L.) is native to a large geographic area in the eastern United States. Within the natural range, climate varies from wet to dry, with hot to cool summers and mild to severe winters. As expected, a lot of genetic variation in black walnut exists over this wide range (Bey 1970, Bey *et al*. 1971). We have shown that the geographic variation (among stands) is greater than local variation (among trees within stands) (Bey *et al*. 1972a).

In planning tree improvement and reforestation projects, maximum gain will be made only if we take advantage of the natural variation of the species. Ideally, nurserymen want to provide the "best" seedlings, from the "best" parent trees, from the "best" geographic area. In this study, we have observed how trees from widely separated geographic areas survive and grow at eight locations in the midwestern United States. Results of this early test can be used as an interim guide for geographic selection in black walnut tree improvement and reforestation projects.

METHODS

In 1967, 1-year-old black walnut seedlings from 15 to 25 geographic sources were planted at each of eight locations in midwestern United States (table 1). Each source consisted of seedlings grown from seed collected from an average of six parent trees generally located within the same stand. Although most of the sources were represented in two or more plantings, no two plantations contained trees from all of the same sources. Each planting consisted of a randomized complete block design with six replicates of four-tree plots.

Weeds were controlled in all plantations for at least the first 3 years. Some corrective pruning was done to develop straight central stems, but the amount and type varied among plantations. Site quality was originally considered to be good to very good for walnut.

In the fall of 1971 (6 years from seed), data were collected on survival, height, and diameter at 12 inches

Table 1. —*Location of plantation, number of sources, and cooperating agencies for eight black walnut seed source plantations*

State	County	Latitude °N	Longitude °W	No. sources	Cooperating agency[1/]
Illinois	Alexander	37.3	89.3	20	Shawnee N.F.
Missouri	Pulaski	37.8	92.2	15	Clark N.F.
Indiana	Lawrence	38.7	86.6	15	Wayne-Hoosier N.F.
Kansas	Pottawatomie	39.2	96.5	15	Kansas State Univ.
Ohio	Wayne	40.8	81.9	25	OARDC
Iowa	Johnson	41.8	91.7	25	U.S. Army Corps of Engineers
Michigan	Kalamazoo	42.3	85.4	20	Michigan State Univ.
Minnesota	Winona	44.2	92.0	15	Minnesota Div. of Forestry

1/ The author greatly appreciates the help of all cooperators in establishing these studies and collecting data.

above ground for all trees. Because each plantation at least partially represented a different population, only comparisons of trees from sources within plantations were made.

RESULTS

Survival

Survival ranged from 41 percent for trees in the Minnesota plantation to 87 percent for the Missouri plantation (table 2). About 10 percent of the seedlings died during the first growing season. The loss was concentrated in a few sources and was presumably associated with root rot, which was observed when the seedlings were planted. The biggest loss (17 percent) occurred during the first winter and second growing season. For the next 3 years (1969-1971), only 5 percent of the trees died. From the survival standpoint, the first winter is probably the most severe.

In the Indiana plantation, survival was unexpectedly low. The area was flooded briefly in the spring during the first 2 years and some mortality may be attributed to the flooding.

Except for the Ohio and Minnesota plantations, survival of trees was not related to the latitude of the source. Wright (1954) also reported no correlation between survival and origin of source. In the Ohio plantation, the trend was for generally higher survival from the southern sources (fig. 1). Thirty percent of the variation in survival was accounted for by the latitude of the seed source.

In the Minnesota plantation, there was a strong continuous trend with latitude, with higher survival in trees from the northern sources (fig. 1). Trees from sources within 250 miles south of the planting site had

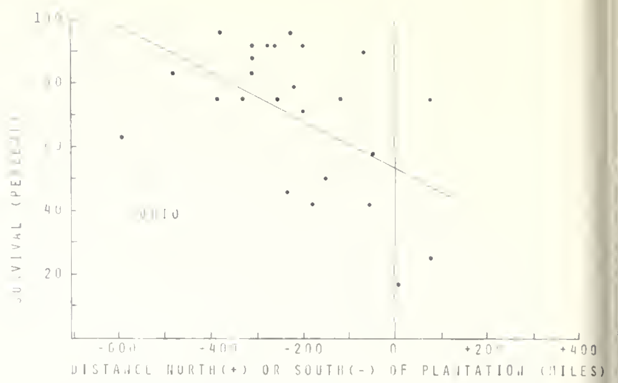

Figure 1. – *In the Ohio test, trees from southern sources generally survived better than trees from northern sources.*

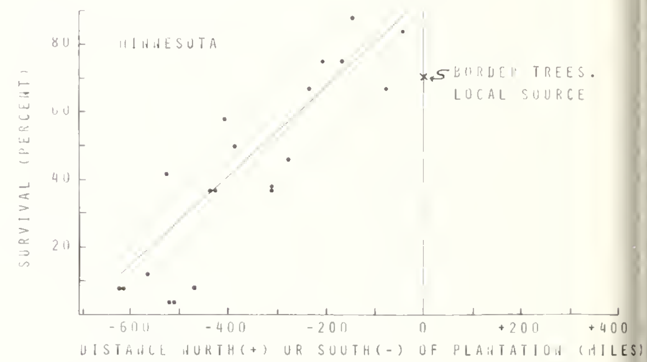

Figure 2. – *In the Minnesota test, trees from the northern sources generally survived better than trees from the southern sources.*

76 percent survival while trees from sources 250 to 650 miles south had only 29 percent survival. Seventy-one percent of the Minnesota-source border trees survived. Seventy-nine percent of the variation associated with survival can be accounted for by latitude of seed

Table 2. – *Average survival, growth, correlation coefficient (for height and diameter), and gain by selection for each plantation*

State	Survival by year					Diameter at 12 inches above ground	Height	Height (ft.) divided by diameter (in.)	Correlation coefficient between ht. and dia.	Average gain in height by selecting tallest sources	
	1967	1968	1969	1970	1971					Tallest 40 percent	Tallest 20 percent
	Percent	Percent	Percent	Percent	Percent	Inches	Feet			Percent	Percent
Illinois	94	88	85	85	85	2.0	8.1	4.1	0.93	14.8	21.0
Missouri	92	--	88	87	87	1.4	5.9	4.2	.74	9.4	13.4
Indiana	86	64	61	61	61	2.7	11.6	4.2	.95	10.5	13.9
Kansas	88	77	--	--	75	3.5	12.0	3.4	.52	5.4	7.2
Ohio	—	83	79	71	70	1.8	8.1	4.6	.79	7.8	10.3
Iowa	92	--	--	76	76	1.8	6.6	3.6	1.00	12.4	18.1
Michigan	90	85	--	--	82	1.1	5.4	4.8	.92	12.3	18.4
Minnesota	92	50	--	41	41	1.6	6.8	4.4	.78	9.3	14.6

source. In a Nebraska test, Emerson (1906) also showed that the trees of southern provenances suffered more cold injury than those of northern provenances.

Although we did not run a combined analysis (all sources at all locations) for survival, there were obvious interactions that had practical significance. For example, trees from one North Carolina source had 92 percent survival in Missouri and 8 percent survival in Minnesota. In contrast, trees from one Iowa source had good survival in both plantations: 96 percent in Missouri and 75 percent in Minnesota. These and other examples demonstrate the need for conducting provenance tests at many locations.

Growth Differences Among Plantations

Average tree height and diameter varied from 12.0 feet and 3.5 inches for the Kansas plantation to 5.4 feet and 1.1 inches for the Michigan plantation (table 2). Although the Kansas and Michigan plantations have only six sources in common, the distribution of sources (north and south of the planting site) was similar for both plantations. The growth differences between these two plantations (and others) probably reflect site productivity differences. In addition to the site factors, differences among plantations may also be due to the particular sources included at each plantation. The Kansas plantation is on a well-drained alluvial soil below Tuttle Creek dam. It is obviously an excellent site for walnut. Trees from one Mississippi source grew, on the average, 0.9 inch in diameter per year. The Michigan plantation is on a level hilltop with a sandy loam soil. Although the site might be described as a typical upland in southern Michigan, it is not considered a good site for walnut.

From our original estimation of site productivity, we anticipated that trees in the Illinois, Missouri, and Indiana plantations would grow at about equal rates. Such has not been the case. Trees in the Illinois and Missouri plantations grew less than expected. The Illinois plantation is on a well-drained silt loam soil. Late summer leaf yellowing and early leaf drop on trees in the Illinois plantation in 1970 suggest the site may be droughty and therefore less than ideal for maximum growth. Although the soils at the Missouri and Indiana sites were considered to be similar (slightly heavy for walnut), trees in the Indiana plantation are about twice as large as those in Missouri. Climatic conditions and cultural treatments, although not identical in both plantations, probably are not responsible for the major growth differences. Although soil texture is similar, other soil properties are presumably different and responsible for the growth differences. A fertilizer experiment in an adjacent plantation in Missouri suggests that the soil is deficient in nitrogen and phosphorus.[1]

Growth Differences Among Trees From Various Sources

At all locations tested, trees from sources as far as 200 miles south of the planting site generally grew as large or larger than trees from local or northerly sources. The data suggest that seed can be safely moved 200 miles north of the collection area. At some locations, seed may be safely moved as far as 400 miles north of the collection area. Trees from seed collected north of the planting site will usually be smaller than trees of local origin.

Growth of trees from particular sources was dependent on the source and plantation location. For example, trees from one Texas source were tallest (25 percent above plantation mean) in Illinois and shortest (26 percent below plantation mean) in Iowa. In contrast, trees from one Tennessee source were 7 percent below the plantation mean in Illinois and 3 percent above the plantation mean in Iowa. Again, this genotype x location interaction demonstrates the need for conducting provenance tests at many locations.

Illinois, Missouri, and Indiana

Trees from sources south of the planting site were generally taller and larger in diameter than trees from local and northern sources (figs. 3-6). On the average,

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[1] *Phares, Robert E. 1972. Fertilization of young black walnut plantations with nitrogen, phosphorus, and lime. File report for study CH-433 dated June 8, 1972.*

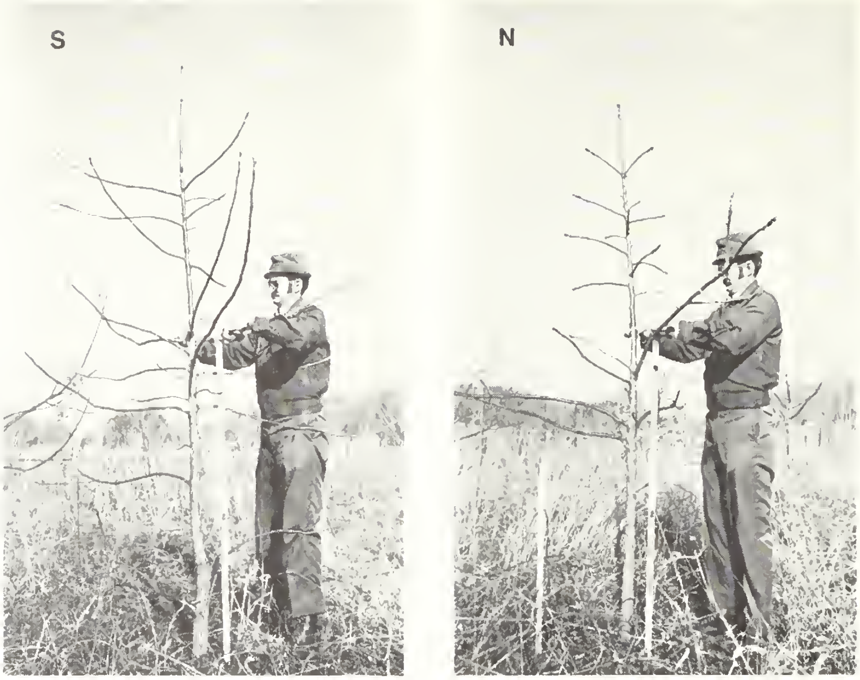

Figure 4. – *In an Illinois provenance test, trees from sources 300 miles south (S) were generally 20 percent larger than those 300 miles north (N) of the planting site.*

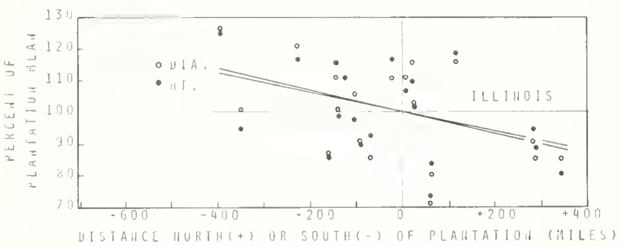

Figure 3. – *In Illinois, trees from sources south of the planting site were generally larger than trees from local and northern sources.*

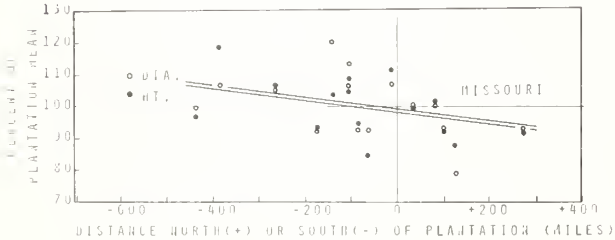

Figure 5. – *In Missouri, trees from sources south of the planting site were generally larger than trees from local and northern sources.*

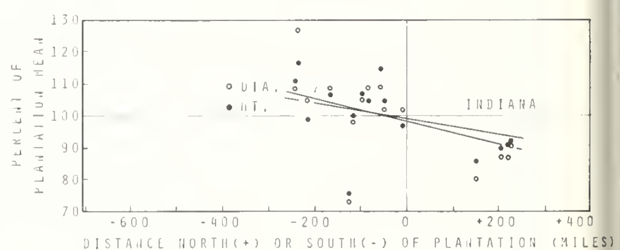

Figure 6. – *In Indiana, trees from sources south of the planting site were generally larger than trees from local and northern sources.*

trees grown from seed collected 300 miles south of the planting site were 10 percent taller and larger in diameter than trees of local origin. In the Indiana and Missouri plantations, height and diameter were average or below for trees from eight of the nine sources located north of the planting site.

There is no apparent explanation for the exceptionally poor growth of trees from one source in the Indiana plantation. The source (Kentucky 2001) is located 125 miles south of the plantation and is 25 percent below the mean. Trees from this source grew about average in Michigan and 10 percent below average in Missouri. The danger of drawing conclusions based on too few trees is illustrated by this oddball example.

Kansas and Ohio

Trees from local sources grew about as much as those from sources farther north and south of the plantation (figs. 7 and 8). Straight-line regressions for height and diameter over latitude were not significant. Nothing in the data suggests that it would be unwise to collect seed from 200 to 300 miles south of the plantations. However, in the Ohio plantation, trees from three of the four sources located more than 350 miles south of the planting site had less than average growth. Seed collection for Ohio should probably be limited to not more than 300 miles south of the planting site.

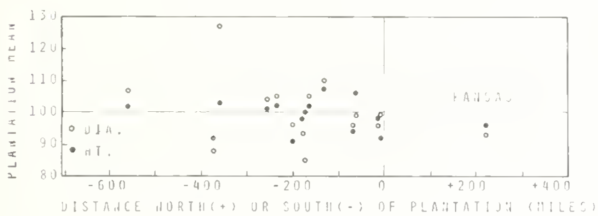

Figure 7. – *In Kansas, tree size was not associated with latitude of seed source.*

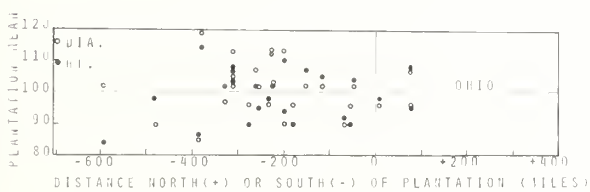

Figure 8. – *In Ohio, tree size was not associated with latitude of seed source.*

Iowa

There is a definite limit on how far walnut trees can be safely moved northward (fig. 9). Trees from northern sources were generally larger than trees from southern sources. The evidence is strong that movement of seed into Iowa from the south should be limited to areas within 200 miles of the planting site. Within a zone 200 miles north and south of the planting site, there was no apparent trend in size of trees from various sources. The sources with the tallest trees generally also had the highest survival. The correlation coefficient between height and survival was 0.61.

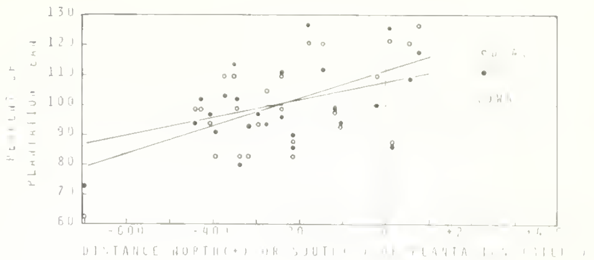

Figure 9. – *In Iowa, trees from northern sources were generally larger than trees from southern sources.*

Michigan

Trees from sources south of the planting site were generally larger than those from local and northern sources (fig. 10).[2] Trees from sources 300 to 500 miles south of the planting site (especially Virginia, West Virginia, Kentucky, Tennessee, and North Carolina) grew about 15 percent larger than those from local sources and had 93 percent survival. Although the results are not consistent with results from Ohio, Iowa, and Minnesota, the black walnut trend seems to parallel that of white pine grown in southern Michigan (Wright 1970). Persons planning to plant walnut farther north than the lower half of Lower Michigan and in the Upper Peninsula should probably use seed from not more than 200 miles south of the planting site. This

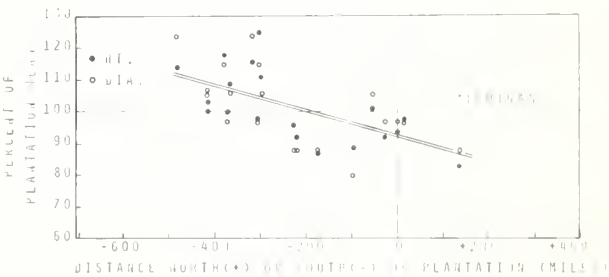

Figure 10. – *In a southern Michigan plantation, trees from sources 300 to 500 miles south of the planting site grew about 15 percent larger than those from local sources.*

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[2]*One source from Indiana (1708) was badly infected with root rot at the time of planting and was not included in the analysis.*

would be in line with results from other black walnut provenance tests in Iowa and Minnesota.

Minnesota

Trees from northern sources generally grew larger than those from southern sources (fig. 11). In this test, border trees of Minnesota origin were measured for comparison purposes. Trees from all sources within 300 miles south of the planting site survived about as well as and grew larger than border trees of Minnesota origin. For trees from the 15 sources in the Minnesota test, the coefficient between height and survival was 0.54 and significant. Although the trend in growth and survival is distinctly continuous from north to south, it appears that we can safely move seed into Minnesota from areas up to 200 miles south.

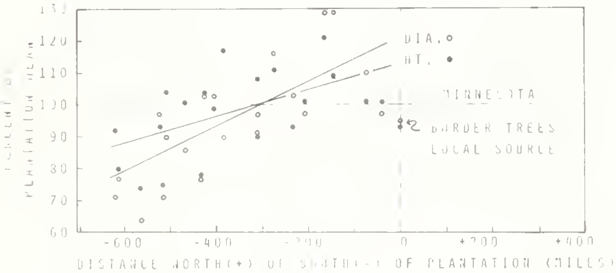

Figure 11. – *In Minnesota, trees from northern sources were generally larger than trees from southern sources.*

Height-Diameter Ratio

The average height-diameter ratio, an expression of the stockiness of a tree, differed among plantations. Trees in the Kansas and Iowa plantations were consistently stockier (3.38 and 3.63) than trees in the other plantations. Trees in the Michigan plantation were the least stocky; they had the highest ratio (4.81). Values for the remaining five plantations varied from 4.12 to 4.56.

Within each plantation, a correlation coefficient was computed between height-diameter ratio and latitude of the source. The correlation coefficient was positive for the Indiana (+ 0.52) and Ohio (+ 0.99) plantations, indicating that in these tests the southern sources were the most stocky. The correlation coefficients were negative for the Iowa (− 0.47) and Minnesota (− 0.46) plantations, and nonsignificant for the other plantations. The negative correlations for the Iowa and Minnesota plantations indicate that the northern sources were the most stocky.

Selection

Perhaps the best character for evaluating the value of sources at this early age is height. Although merchantable volume and quality will undoubtedly provide a better estimate of value at a later date, height is an estimate of potential size and indirectly reflects winter dieback and susceptibility to late spring frosts. Trees that have their tops killed back by severe winters and/or late spring frosts will be shorter than those not affected. Trees with multiple tops (poor form), from whatever the cause, are not likely to be as tall as trees with single central stems.

Selecting for height generally also means selecting for diameter. Based on source means, the correlation coefficients between height and diameter for each plantation averaged 0.83 and varied from 0.52 for the Kansas plantation to 1.00 for the Iowa plantation. There was no apparent relationship between the correlation coefficient and either the geographic location of the plantation or the size of trees in the plantation.

Although provenance tests are designed primarily to show regional or geographic variation patterns, the value of using fast-growing seed sources can also be demonstrated from these tests. If each plantation now under study were thinned to leave only the trees in the tallest 40 percent of the sources, the average height for all plantations would increase 10 percent (table 2). By selecting the tallest 20 percent of the sources the average height would increase about 15 percent. Plantations with the greatest variation offer the greatest opportunity for improvement through source selection. Additional gains could also be made by selecting the tallest trees within the tallest sources and perhaps the tallest trees in some of the shorter sources (Bey *et al.* 1972b).

DISCUSSION

This report is intended as an interim guide for those concerned with tree improvement and planting of black walnut in the Midwest. Although the experiment will not define the best geographic sources for all areas where walnut is grown, it is adequate to rule out some geographic origins for specific areas. Thus it reduces the size of the geographic area to be considered in future provenance and progeny tests.

In the six plantations where straight-line regressions for height and diameter over latitude were significant, latitude accounted for an average of 25 and 32 percent of the observed variation for height and diameter. The unaccounted for variation is attributed to genetic aspects related to longitude, altitude, and locale, and the variation due to the test environment. The amount of variation appears to be about the same for sources from the various latitudes in each plantation. This suggests that there is an approximately equal opportunity within any defined area for genetic gain for height and diameter growth through additional selection. Progeny testing, with roguing and conversion to seedling seed orchards, has been recommended; such orchards should be established within the geographic constraints shown in this report (Funk 1966, Bey *et al.* 1972b).

Recommendations are based on results from 6-year-old trees and are valid to the extent that 6-year-old performance represents future performance. The reader is cautioned against applying the results from any single plantation to an entire State. Results from a single or several adjacent States may be more appropriate. For example, for northern Illinois the results from Iowa are likely to be more meaningful than the results from southern Illinois. Although source names and numbers are not presented in this paper, the author would be glad to furnish additional details for those interested.

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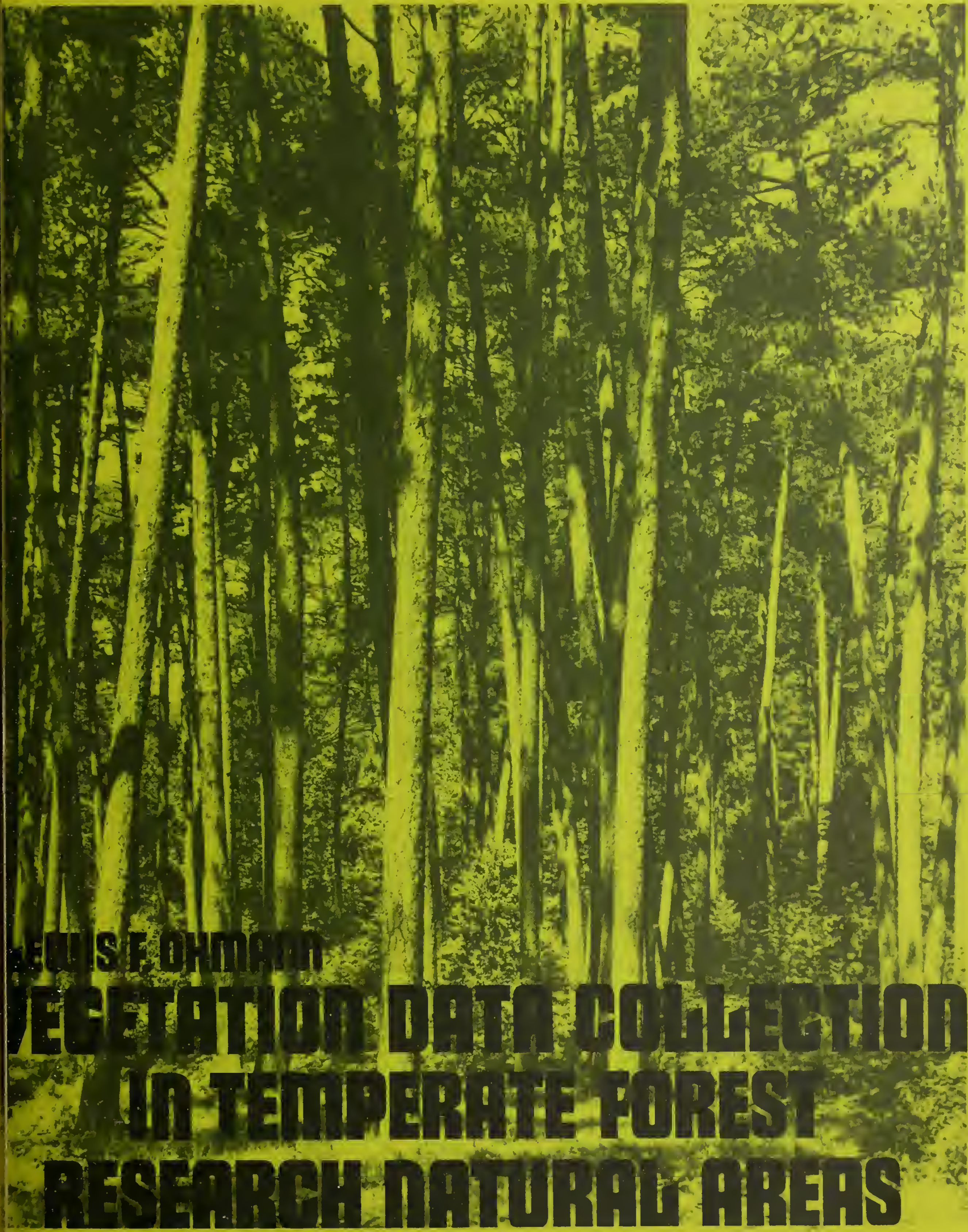

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VEGETATION DATA COLLECTION IN TEMPERATE FOREST RESEARCH NATURAL AREAS

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CONTENTS

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(Maintained in cooperation with the University of Minnesota)
Manuscript approved for publication June 5, 1973

VEGETATION DATA COLLECTION IN TEMPERATE FOREST RESEARCH NATURAL AREAS

Lewis F. Ohmann

Since 1927 more than 300 research natural areas ıve been reserved by Federal land management agencies. any more have been preserved for science and eduıtion by State and local governments, and public and ivate organizations.

A major goal in reserving research natural areas is to ıve them serve as comparisons with managed, utilized, ıd artificial ecosystems. This goal cannot be met withıt some baseline from which to determine what (if any) ıanges are occurring or have occurred in natural areas.

Surprisingly, despite long advocacy of research natural ea reservation by scientists and conservationists in neral, and actual reservation by governmental agencies particular, it is difficult to find reports of significant search performed in established natural areas. As wan (1968) points out, ". . .few people have appreated the unique research opportunities presented by ır existing preserved areas."

The glaring lack of knowledge about reserved areas came apparent when uniform and comparable informan about national parks, nature reserves, etc., was llected on checksheets in accordance with the instrucns of International Biological Program (IBP) Handok No. 4 (Peterken 1967). We found that many deral natural areas had little or no qualitative or ıantitative description and, in fact, the plant and ıimal communities of most nonfederal natural areas ıve not been adequately described either. It is apparent ıat some framework or system is needed to encourage ıseline description of natural areas so that they may rve the purpose for which they were established.

Obtaining baseline data for the Federal research ıtural areas alone could be costly. However, if a framerk could be provided through which interested nonofessionals under the consulting supervision of prossional ecologists, foresters, or botanists were enuraged to collect such data, these collections could be made at minimal cost. And if a framework would be provided so that these data would be generated in a rather standardized way, they would be even more valuable. This manual is intended to serve as such a framework for the collection of baseline vegetation data.

Most concerned individuals agree that the minimum information that should be available for each area is a description of the biotic communities and environmental factors such as soil, landform, geologic complex, etc. As much data should be accumulated as time and talent will permit. Each additional piece of information will build a base for further work and may stimulate further studies. If circumstances permit only the collation of all currently available research information for an area, this will serve as a valuable base for future studies and is, therefore, worthwhile. If circumstances permit a reconnaissance survey of the vegetation, that is further progress. But we will not make full use of our natural areas until the processes governing production of organic matter, the flow of energy, and the cycling of nutrients have been worked out for each area. At least for the immediate future, productivity and nutrient cycling will probably remain in the realm of the professional ecologist. The eventual achievement of these goals will, however, depend on the availability of sound baseline data. A necessary start toward this goal can be provided by nonprofessionals utilizing this manual under the supervision of professional ecologists.

OBJECTIVES

The focus of this manual is on temperate forest vegetation.[1] The specific objectives of the manual are to:

[1] *There is a recognized need for a similar framework for the collection of information on water, wildlife, soils, etc.*

(1) identify qualitative and quantitative information, especially regarding vegetation, important for research natural areas, and (2) describe methods by which this information can be obtained.

The manual is intended primarily for interested individuals who have training in the biological sciences to the baccalaureate level or above who are not professional ecologists, but who are willing to work under the consulting supervision of professionals. In particular it is hoped that high school and junior college biology teachers will be stimulated to work on research natural area their localities through the use of this manual.

Identical sampling techniques cannot always be u successfully to characterize all types of vegetat While the specific methods presented are inten primarily for temperate forest communities, the rem der of the background material and discussion of ty of information pertinent to research natural areas general applicability. Some of the methods might also modified for use in the collection of quantitative dat nonforest vegetation.

PART I – METHODS

This part of the manual presents procedures and methods for sampling a natural area to provide information that can be used to monitor vegetation changes over time. The following steps are presented in a checklist format as a convenient outline that should normally be followed.

1. Read the entire handbook ( ).

Some readers will want, and need, much more elaboration of both the prefield and field procedures, or will want to consider alternative methods that might be used (or recommended by the supervising ecologist). Pertinent details on prefield and field procedures, and on some alternative methods are contained in Part II.

2. Obtain permission to conduct study ( ).

One may not work in a research natural area without the permission of the managing agency. Natural areas may be managed by a Federal agency, such as the USDA Forest Service, or by State, county, or local government, or by a foundation, such as the Nature Conservancy. After the agent responsible for the area is satisfied that you are working under adequate consulting supervision, agrees with your objectives, and has granted approval, you are ready to begin.

3. Gather information pertinent to the area ( ).

3a. Check natural area file ( ).

The only starting place you may have is the natural area file of the managing agency. Some information will be available from records of the procedural establishment of a scientific research natural area, and more information may have been brought together during completion of the International Biological Program (IBP) checksheet for the area. Figure 1 shows a portion of a completed checksheet for an area.

3b. Check with government agencies (persor and files), colleges, knowledgeable inc duals, nature clubs, etc. ( ).

Your consulting ecologist may be able to give y valuable leads to follow. The object is to determine history of this unit of land, including both natural man-caused events. First sources to be checked Federal, State, county, and local governmental agenc dealing with any aspects of land management in region and the nearest center of higher education. C sult the life science and natural science departments these institutions for leads to further informati Members of these departments can often provide infor tion about private clubs and nonprofessional natural who can be valuable sources of documents, maps, repo flora and fauna lists, and historical activities.

Look also to the experts in the science departme for advice on sampling, taxonomic problems, and pl collection and storage facilities.

3c. Answer basic questions about the area (

Before you enter the natural area for purposes sampling and description, you should have answers to following questions (the details of background infor tion collection are contained in Part II):

1. Who initiated the action that resultec reservation of the natural area?
2. Why was it reserved?
3. What is the most unique characteristic the area?
4. Where and exactly how big is it?
5. What work has already been done in area? What information has already b gathered by agencies or individuals?
6. What is known about the geology a soils of the area?

Figure 1. — Sample pages from a completed IBP Natural Area Check Sheet.

INTERNATIONAL BIOLOGICAL PROGRAMME

SECTION CT : CONSERVATION OF TERRESTRIAL BIOLOGICAL COMMUNITIES

CHECK SHEET (Mark VII) FOR SURVEY OF IBP AREAS*

To be completed with reference to the GUIDE TO THE CHECK SHEET

Serial Number

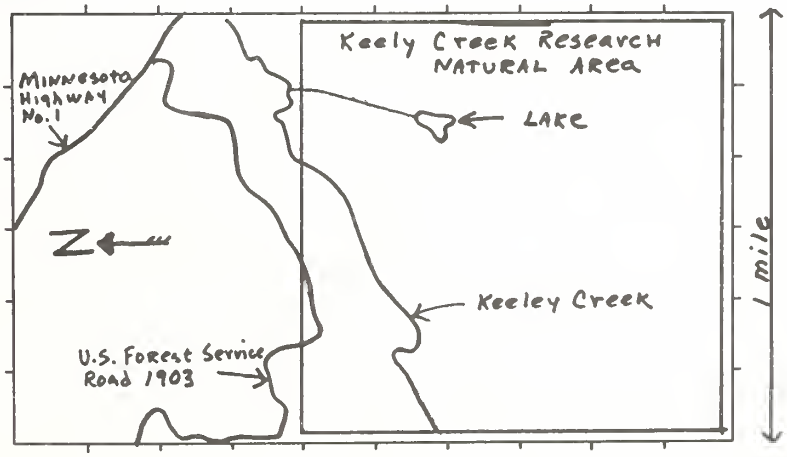
For Data Centre Use only

1.

1. Name of surveyor ....Robert R. Ream and Lewis F. Ohmann....
2. Address of surveyor ....U.S. Forest Service....
   North Central Forest Experiment Station
   St. Paul, Minnesota, U.S.A. 55101
3. Check Sheet completed (a) on site ....✓.... (b) from records ....✓....
4. Date Check Sheet completed ....10 June 1968....

2.

1. Name of IBP Area ....Keeley Creek Natural Area....
2. Name of IBP Subdivision (or serial letter) ....—....
3. Map of IBP Area* showing boundaries attached? Yes ....✓.... No ....
4. Sketch map of IBP Area*. Please mark direction of north, the scale and grid numbers where applicable.



* For " IBP Area ", read IBP Area and/or IBP Subdivision.

For Data Centre Use only

3. **Location of IBP Area***

1. Latitude 47° 47' N Longitude 91° 42' W
2. Country U.S.A.

State or Province Minnesota County Lake

(State or Province .... County ....)

4. **Administration**

National 1. Official category Research Natural Area (USDA Forest Service)

2. Address of administration Director,
North Central Forest Experiment Station
Folwell Ave.,
St. Paul, Minnesota, U.S.A. 55101

International Class

3.

Included in U.N. List	Rejected from U.N. List	Area with formal conservation status	No formal cons. status
(A)	(B)	(C)	(D)

5. **Characteristics of IBP Area***

1. Surface area (state units of measurement) 640 Acres
2. Altitude (state units of measurement) Maximum 1580 feet

Minimum 1500 feet

6. **Climate**

Nearest climatological station :

1. Name Duluth (nearest Class-1 station)
2. Climatological station on IBP Area*? Yes .... No ✓
3. If (2) not, distance from edge of IBP Area* (state units) 80 miles
4. Direction from IBP Area* SSW
5. Additional data sheet attached? Yes .... No ✓

For Data Centre Use only

7. **Vegetation and Soil**

1 **Vegetation**

Community Reference Number	Vegetation Code: Primary Structural Group	Class	Group	Formation	Sub-Formation	Plant communities (give usual name using full Latin names of a species where applicable)	Area (state units) Acres
1	1	A	1	7	a	Pinus banksiana (SAF-1)	284
2	1	A	1	7	a	Picea mariana (upland) (SAF-7)	52
3	1	A	1	7	a	Abies balsamea - Betula papyrifera (SAF-5)	80
4	1	A	2	1		Populus tremuloides (SAF-11)	42
5	1	A	1	2	a	Picea mariana (lowland) (SAF-12)	108
6	1	A	2	2		Larix laricina (SAF-38)	8
7	1	C	1	3		Open sedge bog (A-25)	32
8	1	B	2	2	e	Alnus lowland shrub	34
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Please give information about further communities on a separate sheet.

7. What is the recent (Pleistocene) history of the area (i.e., glacial, volcanic, coastal emergence or submergence, etc.)?
8. What direct or indirect influences has man had on the area?

3d. Establish a working file ( ).

Set up an organized working file of all background information. It will be of value in designing the sampling procedure, evaluating results, and describing the area. At the completion of the study, copies of this file should accompany each set of data that is deposited for future comparison.

3e. Compile background information ( ).

Only after the above kinds of background information have been synthesized should you plan to undertake extensive fieldwork.

4. Conduct preliminary fieldwork ( ).

4a. Reconnoiter the area ( ).

The first preliminary fieldwork should be an extensive reconnaissance of the area, preferably with your consulting ecologist or individuals who know the area well. You should be equipped with airphotos (if they exist), and topographic, geologic, and soils maps; these will help to familiarize you with all aspects of the landscape. Look for gross vegetation differences.

4b. Check plant collection regulations ( ).

In checking the flora, how many plant species can you already identify? If a collection for the area is not already available, perhaps this is the proper time to begin collecting plant species for identification and voucher specimens. Be sure to check regulations pertaining to collection procedures for the area.

5. Design sampling procedure ( ).

The next step is to design the sampling procedure you will use to provide baseline information for future comparison. You will have to decide if you should sample the entire natural area as one unit, or if it should be split into several uniform areas on the basis of soil, topography, or vegetation differences that will make the sampling more meaningful. In stratifying you will want to consider such things as upland versus lowland vegetation, forest versus nonforest vegetation, and soil or bedrock differences that may have influenced species distributions. Here is where much of the background material you have collected, especially history of disturbance and vegetation and soils maps, will be of value.

5a. Obtain professional advice ( ).

At this point you should (if possible) also obtain advice from ecologists, botanists, and zoologists in educational institutions and land management agencies in the area. Take the time to show as many qualified individuals as possible what information you have about the area and what possible stratifications you and your consultant think could be useful. Obtain opinions on suitable sample stratification, complexity of vegetation, separation of vegetation components, and number and size of sample plots. You, in consultation with your supervisor, will have to consider the expert opinions in the context of time, manpower, and finances available to do the sampling.

5b. Locate sample stands ( ).

On a suitable map (U.S. Geological Survey topographic or vegetation map, for example) plot the location of stands to be sampled within the uniform unit(s) you have decided to sample. Use a grid and random numbers to locate a point within the area for each stand to be sampled. You will have to decide how many stands you can sample and how many will give you an adequate representation of the structure and composition of the vegetation present. The number of sample stands can be increased or reduced as the sampling proceeds. Be sure to record the location of the sample stands on airphotos and maps so the stands can be found again for future sampling.

5c. Check for homogeneity of sampling area vegetation ( ).

Before you begin actually locating sample plots in the stands you should be sure the stand vegetation is uniform (homogeneous) over a large enough area to contain the sample plots. It should be uniform in the sense that it contains no obvious changes in plant composition. If the stand is located on a uniform slope of one aspect and has had a uniform history, it will usually be a reasonably homogeneous unit of vegetation (but not necessarily in a statistical sense). It would be inaccurate to present sample data as representative of a single stand when the sample plots were placed within two quite different types of vegetation. For example, if the sample area covered the north slope, the top, and part of the south slope of a hill, the plots could represent strongly differing environmental and vegetational conditions. Or, if half the sample area was coniferous and through some historical event (such as repeated wildfire) the other half was broadleaf deciduous, sampling plots in each and combining the data as representative of one stand would be describing a vegetation type that doesn't really exist.

6. Select sampling methods ( ).

Once you are ready to begin establishing sample units, decisions must be made concerning plot versus plotless techniques, and size and number of units for each component of the vegetation. The extensive reconnaissance will have helped you become familiar with the flora and vegetation. This familiarity, along with the advice you obtained from local botanists or ecologists, will be the basis for your decision. Your advisers will base their opinions on knowledge of similar areas and how they were sampled, and on the reliability of the results. Thus, they can provide a good estimate of which techniques will do the job most efficiently.

Some possible plot numbers, shapes, sizes, and vegetation components to be sampled in the plots, are given in table 1. Which, if any, of these you choose will depend on the general characteristics of the vegetation being sampled. The 1/100-ha. (1/40-acre) plot size traditionally used by ecologists was shown to be inefficient in terms of both statistics and time when tested in one forest type (Lindsey *et al.* 1958). Thus, a mature hardwood forest of all-aged trees might be best sampled using relatively few large, rectangular plots. On the other hand, a larger number of smaller plots is generally preferred over a few large plots from a statistical point of view. Thus, a dense, mature even-aged conifer stand might be sampled more efficiently with a relatively large number of small (1/100 ha.) plots.

Sampling the less numerous large-diameter trees with a large plot and the more numerous small-diameter trees with smaller plots should also be considered.

Under restricted time and manpower conditions (assuming forest vegetation) a minimum of 20 nested plots for sampling the various stand components is recommended. The number of plots used, however, should be a function of both the size of the area being sampled and the complexity of the vegetation. The plot sizes given in table 1 are based on a 10-percent sample for the tree component on a minimum stand size of 5 acres. For complex vegetation as many as 40 or more plots may be necessary to do the job. One could measure 10 plots and examine the data; if the data for the common species are quite variable, another 10 plots can be measured, etc., until the variability in the data for the common species seems reasonable.

Unless time efficiency is more critical than statistical reliability, most ecologists agree that the plot shape should be rectangular and that the long axis of the plot should cross any contours and soil or vegetation banding (Bormann 1953).

6a. Prepare forms for field notes ( ).

Systematic data collection dictates the use of well-designed data forms. Whenever possible, species names and other appropriate items should be preprinted on the data forms so that as few entries as possible need be made in the field. This will tend to reduce errors of data omission as well as recording errors. Ideally, the data form should be designed so that most of the blanks will be filled; blanks remaining after sampling will then be readily noticed as possible omission errors and can be corrected while still in the field. Another common source of error is transposing numbers when recording values, or placing values in the wrong row or column of the data form. Try not to use code numbers for species names while in the field, even though you plan to use them in later automatic data processing, because code numbers are easily misrecorded. To shorten the process of recording species names (if not preprinted on the form) write the species name the

Table 1. Possible plot shapes and sizes

Vegetation component sampled	Minimum number of plots	Plot shape: Circular radius		Plot shape: Rectangular dimension		Plot area	
		Meters	Feet	Meters	Feet	Hectares	Acres
Trees over 2.54 cm. d.b.h.1/	20	5.65	18.62	15 x 6.66	50 x 21.78	1/100	1/40
	10	7.98	26.33	30 x 6.66	100 x 21.78	1/50	1/20
	5	11.29	37.24	60 x 6.66	200 x 21.78	1/25	1/10
	3	15.96	52.66	120 x 6.66	400 x 21.78	1/12	1/5
Trees under 2.54 cm. d.b.h. and tall shrubs	20 or more	1.13	3.72	4 x 1	13.2 x 3.3	1/2,500	1/1,000
Low shrubs, forbs, ferns, fern allies, and ground characteristics	20 or more	.56	1.86	2 x 0.5	6.6 x 1.6	1/10,000	1/4,000

1/ Larger diameter size classes may be sampled using larger plots and smaller diameter size classes using smaller plots.

first time you enter it on a data sheet, place an abbreviated form of the name alongside the full name, and use the abbreviated form when entering that species again. Wherever possible, design the data form to allow preprinting of the most common species. Data collected from each size plot should be recorded on a separate form. If data are collected for different plant groups (tree seedlings and the tall shrubs, for instance) on one plot, either record them on separate forms or separate them on one form.

In addition to the data form for plot sampling, prepare a general information data form to record the date of sampling, stand and plot identifications, airphoto identification, stand elevation, percent slope, age of dominant trees, height of canopy, other components (if desired), and your impressions of the stand (fig. 2). If you are collecting information on soils or soil samples, you might include this information on the general information data form. Another item to include here is plant species that you observed in the stand but which did not occur within any of the sample plots.

7. Conduct fieldwork ( ).

7a. Locate plots ( ).

Each sample plot should be randomly located within the stand if time and manpower are not critical, or if the sampling is intensive on a rather small area. If possible, the extra time and effort required for plot randomization is worthwhile from the standpoint of statistical analysis. When plots are located randomly, extra care should be taken in describing their position; random plots are much harder to relocate than plots spaced equidistant from each other.

The most workable method for randomization may be to lay down baselines at right angles along two edges of the stand. Using these as axes and pairs of random numbers as coordinates, position each sample plot within the space between the two axes. Measurement of the

GENERAL INFORMATION DATA FORM

Col.		
1	E I _ 1	Card Identification
5		Stand Number
8		Air Photo No.
17		Township
19		Range
21		Section
23		¼ Sect. NE-1 SE-2
24		40 SW-3 NW-4
25		Crew Leader + Crew
26		Month (Oct.=0)
27		Day
29		Year
31		Elevation
35		Per Cent Slope
37		Aspect_______
40		Position on Slope: 1=ridgetop 3=midslope 5=valley 2=upper 4=lower
41		Location: 1=interior 3=peninsula 2=island 4=lake shore

	Col.	
Distance to water body of over 5 acres (meters)	42	
Geologic Type: 01=Slate 03=Redrock 05 02=Gabbro 04=Granite 06	45	
Surface Material: 01=Ground Moraine 04=Lacustrine 02=Outwash 05=Bedrock 03=End Moraine	47	
Insolation	49	
Ages of larger trees in stand		
	Height 53	
Species__________	Age 55	
	Height 58	
Species__________	Age 60	
	Height 63	
Species__________	Age 65	
	Height 68	
Species__________	Age 70	
	Height 73	
Species__________	Age 75	

Figure 2. — Form for recording general environmental data within each sample stand.

distances from the axes to the sample site need not be exact, for initial location pacing the distances will be sufficient (Greig-Smith 1964). But for relocation purposes you may want to determine the distances more exactly after the plot has been established.

If randomization of plot location is not a practical alternative in your situation, use some random procedure to select the location of the first sample plot. You can devise your own method for doing this; the point is that you want to select your first sample plot without bias. You can, for example, use random numbers to select the direction and distance from the original random point you used to select the stand location. After the first sample plot is located, space each of the remaining plots equidistant from the first plot. The spatial configuration will depend on what the sample area is like. Many workers prefer to distribute the plots in blocks; for 20 plots you might use five rows of four plots each. Space the plots to cover most of the stand but leave a buffer zone between the plots and the edge of your sample area.

7b. Establish plots and permanently mark locations (   ).

Laying out sample plots can be a time-consuming procedure, but it needs to be done with care to ensure accuracy in sampling and relocation.

Rectangular plots are probably best established by using a long steel measuring tape (200 ft./60 m.) to determine one side of the plot and by permanently marking the two corners. Plot width can then be determined during each sampling by using a line (or rod, etc.) held perpendicular to the established side. Be sure to record the bearing of the established side. Once the side for the largest plot is known, the lengths and widths of other plots nested within it can be determined by measurement along the established side. The smaller plots should be nested within the larger plots in a consistent manner so that permanent marking can be restricted to one or two corners of the large plot and the nested plots can be relocated by measurement (fig. 3).

If time is critical, establishing circular plots may be faster than rectangular plots. Find the plot center and determine the outer limits of the large plot by use of a rangefinder or, less efficiently, by use of a line. The nesting of the smaller plots in this case can be around the center point of the large plot, or where more than one of each size nested plot is desired, they may be established along one or more cardinal axes through the large plot (fig. 4). If the smaller plots are nested around the center point of the large plot, it is probably better

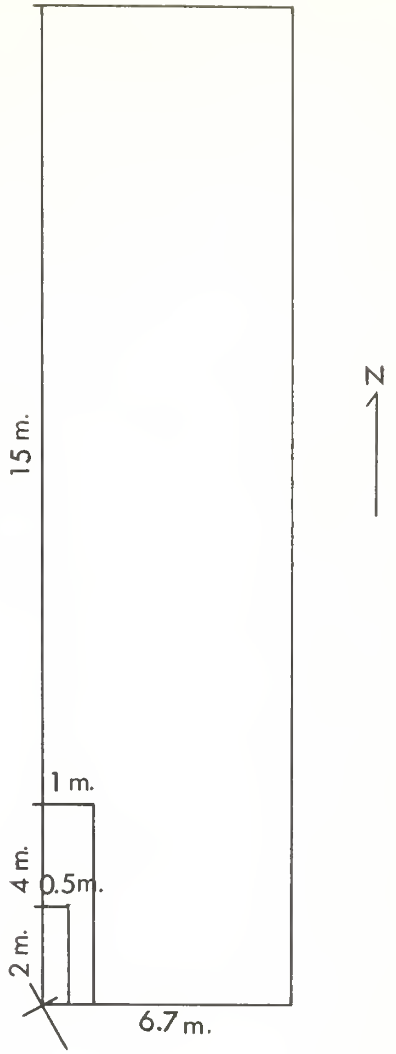


Figure 3. — Nest of rectangular plots with permanent marker at one corner of all three plots. Long axis of this nest is north-south for ease in relocation.

not to place the permanent marker at the center but at some standard distance from the plot center to avoid disturbing the low vegetation (fig. 5).

Because this type of survey is designed to generate baseline data, that is, data that can be used to compare changes occurring in the natural area over time, it is essential that plots be permanently marked and their location recorded in detail so they can be sampled in the future. Mark with aluminum pipe or cedar post the plot corner(s) or center. The plot number should be marked on the pipe or post. This number, along with location distances and directions, should be filed with

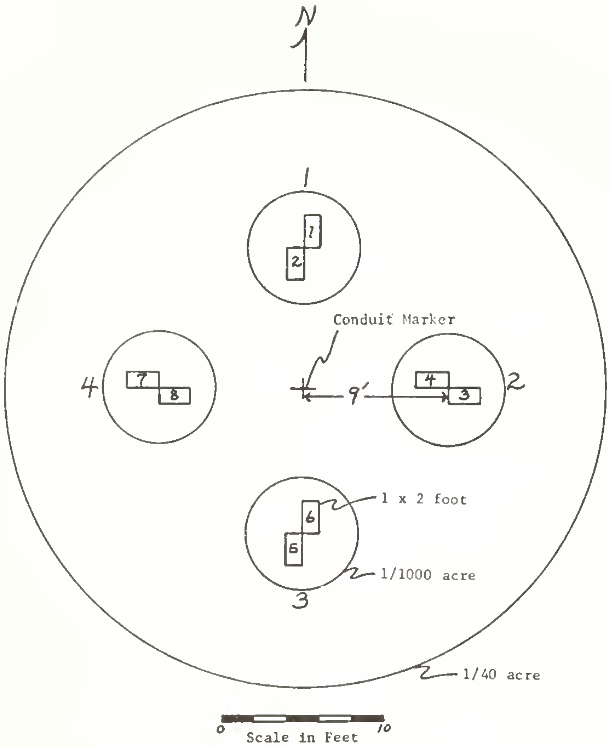


Figure 4. Subplot location and numbering sequence. The numerals outside the circular plots are the milacre plot numbers; those inside the rectangular plots are the 1- by 2-ft. plot numbers.

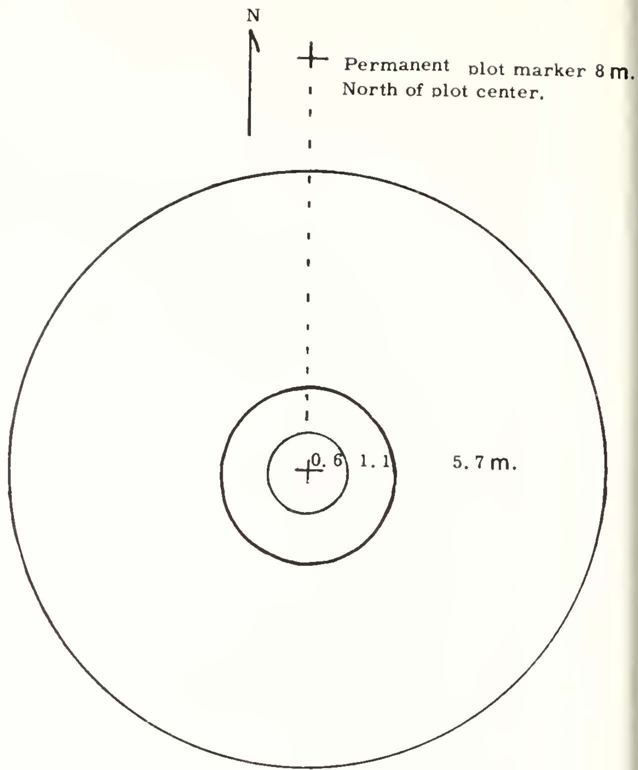


Figure 5. – Nest of circular plots with permanent marker 8 m. due north of plot center for use in relocation.

each copy of the data. The plot identification number should also appear on the completed data sheets for the plot. A diagrammatic representation of the plot distribution and nesting for each stand is a good document to include with the records. However the plots are marked – plot center, corner, or standard distance and direction – all should be marked the same. Consistency is vital in vegetation sampling for baseline purposes.

7c. Sample the vegetation ( ).

In practice, the smallest plots should be measured first, then the intermediate, and finally the largest. The reason is that the most delicate plants are recorded in the smallest plots. Moving through the area in measuring the woody plants in the larger plots will result in damage to the plants in the small plots, making cover estimates and species identification difficult.

A major problem in sampling will be plant identification. You may have trouble identifying some species because not every plant will be in fruit or flower during the sampling period. As a general rule, identify every plant to the species level where possible; but if there is a chance of frequent misidentification, go only to the level where identification is positive.

7c-1. Sample the trees ( ).

Depending on the vegetation being sampled, one or more plots may be used to record, by species name, the diameter at breast height (d.b.h.) to the nearest 0.25 cm. (1/10 in.) of each individual stem over 2.54 cm. (1 in.) in d.b.h. (fig. 6). If it seems best to use different-sized plots to sample the trees over 2.54 cm., you will have to decide at what diameter to split the class. Ecologists often use two classes: 2.54 cm. to 10 cm. (saplings), and more than 10 cm. (trees).

If the administering agency has no objection, spray a spot on each stem with a durable paint at the time of diameter measurement. This accomplishes two objectives: it assures that each tree stem is measured once and only once, and it also makes the plot easier to find in the future, as long as the paint remains visible. Nonpermanent marks can also be used to ensure measurement; for example, a small cloth sack filled with crushed chalk will leave a mark visible for days when

TREE STRATUM DATA FORM

Stand No. 01 Plot No. 09 Uniform Area No. 01
Plot size 1/10 Acre Plot shape circular Date 7/3/69 Crew OHMANN-KARNES
Permanent Plot Identification Number 01-01-09
Permanent plot location description: (see map).
Coordinate Q 337 feet south on stand Baseline I - Plot located 83 ft west from Q.
Coordinate R 83 feet west on stand Base Line II - Plot located 337 ft south from R.

species	dbh in.	area ft^2	species	dbh in.	area ft^2	species	dbh in.	area ft^2	species	dbh in.	area ft^2
(JP) Jack Pine	9.0	0.442	(F) Balsam Fir	2.0	0.022	(B) Paperbirch	1.5	0.012	(BS) Blackspruce	5.2	0.147
JP	11.0	0.660	F	1.8	0.018	B	1.6	0.014	BS	2.3	0.029
JP	10.0	0.545	F	1.3	0.009	B	1.7	0.016	BS	3.0	0.049
JP	10.2	0.567	F	3.6	0.071	B	1.1	0.007	BS	7.0	0.267
JP	8.9	0.432	F	6.3	0.216	B	1.7	0.016	BS	4.1	0.092
JP	10.7	0.624	F	6.2	0.210	B	6.8	0.252	BS	5.9	0.190
JP	8.7	0.413	F	2.3	0.029	B	1.1	0.007	BS	5.7	0.177
JP	11.7	0.747	F	1.3	0.009	B	2.2	0.026	BS	1.2	0.008
JP	9.5	0.492	F	3.5	0.067	B	1.6	0.014	BS	2.0	0.022
JP	9.2	0.462	F	1.6	0.014	B	1.5	0.012	BS	2.0	0.022
JP	12.1	0.798	F	4.6	0.115	B	4.4	0.106			
JP	7.8	0.332	F	1.8	0.018	B	1.8	0.018			
JP	10.2	0.567	F	2.3	0.029	B	7.3	0.291			
			F	4.1	0.092	B	6.3	0.216			
			F	2.5	0.034						
			F	4.3	0.101						
			F	4.1	0.092						
Total	no.	area	sub/total	no.	area		no.	area		no.	area
TREES	13	7.081		6	0.826		4	0.865		5	0.873
SAPLINGS	—	—		11	0.320		10	0.142		5	0.130

Figure 6. – Example of completed tree stratum data form.

hit against a tree. There is, however, a legitimate question about the advisability of introducing any unnecessary materials into a research natural area.

7c-2. Sample seedlings and tall shrubs ( ).

An intermediate-sized plot should be used to record (1) by species name, the number of individual stems of all tree species under 2.54-cm. (1-in.) d.b.h., and (2) by species name, the number of stems of the tall shrub species. An estimate of species dominance can also be obtained by placing stems over 15 cm. (6 in.) tall into diameter classes (measured at 15 cm. (6 in.) above ground) by use of a template (fig. 7). While the diameter classes can be of any desired range, 1-cm classes have been used with some success (Ohmann and Ream 1971b). Data sheets for recording seedling and tall shrub numbers by diameter class are difficult to preprint because one cannot readily predict how many diameter classes will occur in any one plot. A form can be

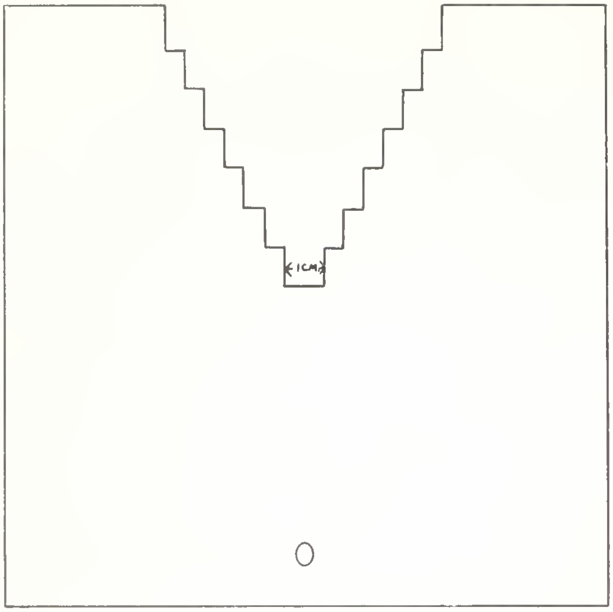


Figure 7. – Template of 1 cm. size class determination of tall shrubs.

prepared that has a limited number of diameter classes and provision for adding additional ones. It is probably best to enter the species name and diameter class for this stratum as the sample is taken (fig. 8).

Another satisfactory way of obtaining a measure of species dominance is to read the amount of cover each species projects onto a tape measure stretched along one edge of the large plot. Start at the zero end of the tape and record, by species name, the cover to the nearest cm. along the tape. Record the actual cm. covered by each species; for example, *Corylus cornuta* 0 to 6; 11 to 22; 123 to 131 cm.. etc. The direct readings can be later converted to percent cover. There is likely to be overlap as more than one species can occupy the space above the tape. You will need to devise a separate data form if you choose to measure dominance through this line intercept of cover method.

7c-3. Sample the low shrubs, forbs, etc. ( ).

The smallest plots are used to record, by name, the percent projected ground cover for each species of low shrub, forb, fern, and fern ally, and actual cover of selected ground surface characteristics (fig. 9). Estimate the cover of the largest plant species first; you may then wish to move or bend some of the taller stems to better estimate the cover of the smaller species and the ground surface characteristics.

An object of known percent cover is often a valuable aid in making estimates. One can determine the projected cover his hand will have, or the amount of cover the diameter class template of the shrub stratum projects. The reason for estimating cover is to obtain some measure of dominance in addition to frequency. After a bit of practice you will become reasonably proficient at estimating cover, at least for the common species. If you feel your results would be more reproducible by assigning species to cover classes than by trying to estimate cover more closely, you can use the following (or some other) classes: (1) less than 1 percent cover, (2) 1 to 5 percent, (3) 6 to 25 percent, (4) 26 to 50 percent, and (5) 51 to 100 percent.

After percent cover is recorded for the low shrub and forb species, record the percent cover for the ground surface characteristics. This is good practice for estimating cover because these characteristics normally add up to 100 percent (there is negligible overlap in their foliage or area).

Cover for items measured in this plot can also be estimated through use of the line-intercept method just as for the tree-seedling and tall-shrub categories.

If cover estimates of the plant species in the small plots are deemed unnecessary and if frequency is the only characteristic recorded, sampling can be done more rapidly and two or more plots per nest can be established.

7d. Complete sampling of first plot ( ).

After the sample has been taken, take a few minutes to look over the data forms for obvious errors. Then proceed to the next plot.

8. Summarize data ( ).

The objective of data reduction is to summarize the raw data collected for the various vegetation components on all sample plots.

8a. Summarize tree stratum data ( ).

Examples of how the raw data for this component can be summarized are shown in figures 6 and 10 and table 2. The area equivalents were added after sampling by reference to a conversion table. Ten 1/10-acre plots were used to sample the stratum. To save space, not all the raw data from the plots are shown. For instance, figure 6 would actually be continued on another form for plot 01 because there were more stems of balsam fir than would fit on this sheet, and also more species. Figure 10 was produced later as a worksheet on which to summarize for the tree size class by species, occurrence in plots, number of stems, and basal area. Another worksheet would be prepared for the sapling size class. This step is not essential – one could transfer totals

SHRUB STRATUM DATA FORM

Stand No. 01 Plot No. 09 Uniform Area No. 01
Plot size milacre Plot shape circular Date 7/3/69 Crew OHMANN & KARNES

Permanent location within nest: milacre plot center located 15 feet due east of 1/10 acre plot center of permanent plot 01-01-09.

TALL SHRUB Species	Diameter class	Number stems	TREE SEEDLING Species	Diameter class	Number stems
Green alder	00	01	Balsam fir	00	08
	01	03		01	01
	02	01		03	01
Round-leaf dogwood	00	02	Red maple	00	01
	01	05			
Mountain maple	00	01	Aspen	00	01
	01	02			
	03	01			

Figure 8. — Example of completed shrub stratum data form.

directly to the summary sheet, but this method facilitates separation of the values for the two size classes and also helps to ensure accuracy. Table 2 presents the data summarization process for the tree component of the stand. Another table would be produced in the same manner for the sapling component.

The number of plots each species has occurred in, the number of total stems counted in the plots, and the total basal area those stems represent are the basic data brought forward from the tree stratum forms and work-sheet for each species. All other information on the summary sheet is derived from these three values.

8a-1. Summarize percent frequency data ( ).

The calculation for percent frequency is simply the percent of plots in which the species occurred as a rooted individual. Thus, in the summary table for the tree size class, jack pine (*Pinus banksiana*) occurred in 10 out of a possible 10 plots and therefore has a frequency percent of 100 (10/10 x 100 = 100 percent), while aspen (*Populus tremuloides*) occurred in only 1 of the 10 plots examined and so has a frequency value of 10 (1/10 x 100 = 10 percent).

8a-2. Summarize average density data ( ).

Plot size in this example was 1/10 acre, and thus it is easy to express density on a per-acre basis. One hundred eight jack pine trees occurred on the 10 plots; the average is 10.8 stems per plot, or 108 stems per acre. Only 19 black spruce (*Picea mariana*) stems occurred on the 10 plots, for an average of 1.9 stems per plot or 19 stems per acre. Since this example is too easy, let's suppose only eight 1/10-acre plots were used and the same number of stems were counted. The value for jack pine would then be (108/8) or 13.5 stems per 1/10-acre plot or (13.5 x 10) 135 stems per acre. The average

Stand No. ________ Uniform Area No. ______________

Plot Size _____ Plot Shape _________ Date _______ Crew _____________

Permanent location within nest:

SPECIES Name	Code	PLOT NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Not Rooted in Plot No.	
ADP CARD Col.	8-10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53
Arcto uva	031																						
Chima umb	032																						
Gaulth hisp	033																						
Gaulth pro	034																						
Rosa acic	035																						
Rubus idae	036																						
Rubus pub	037																						
Vaccin Ang	038																						
Vaccin myr	039																						
Aralia nud	050																						
Aster mac	051																						
Clint bor	052																						
Coptis groe	053																						
Cornus can	054																						
Epilob ang	055																						
Frag vesca	056																						
Galium tri	057																						
Goodye rep	058																						
Goodye tes	059																						
Lathy ochro	060																						
Linn bore	061																						
Maianth can	062																						
Lyco annot	020																						
Lyco clavat	021																						
Lyco compla	022																						
Lyco lucidu	023																						
Lyco obscu	024																						
Bare Rock	001																						
Live Wood	002																						
Dead Wood	003																						
Bare Ground	004																						
Litter	005																						
Call. schr.	006																						
Clad. alpest	007																						
Clad. rangif	008																						
Clad. mitis	009																						
Clad. sylv.	010																						
Dicranum sp	011																						
Hylo splend	012																						
Hypnum cris	013																						
Polytri sp.	014																						

Figure 9. — Example of low shrub, herb, and moss-lichen strata data form.

TREE SIZE-CLASS WORK SHEET

Stand No. 01 Uniform Area No. 01

Item	Jackpine		Balsam fir		Paperbirch		Black spruce		Red maple		Aspen	
Plot no.	Stems no.	Area ft^2	Stems no.	Area ft^2	Stems no.	area ft^2	Stems no.	Area ft^2	Stems no.	Area ft^2	Stems no.	Area ft^2
01	13	7.081	6	0.826	4	0.865	5	0.873	–	–	–	–
02	10	5.999	13	1.598	3	0.752	–	–	4	0.930	–	–
03	10	5.369	11	1.234	1	0.352	–	–	–	–	–	–
04	15	6.621	9	1.218	–	–	–	–	1	0.398	–	–
05	14	7.617	17	2.311	–	–	2	0.239	–	–	–	–
06	7	3.465	5	0.631	–	–	1	0.226	–	–	–	–
07	8	4.096	14	1.990	2	0.293	4	0.902	–	–	1	0.326
08	8	4.044	10	1.375	2	0.185	7	1.552	–	–	–	–
09	10	5.333	14	1.806	4	0.889	–	–	–	–	–	–
10	13	7.074	4	0.528	4	0.739	–	–	1	0.102	–	–
Number of plots	10		10		7		5		3		1	
Number of stems	108		103		20		19		6		1	
Basal area	56.699		13.517		4.075		3.792		1.430		0.326	

Figure 10. -- Example of completed tree size-class worksheet.

Table 2. -- Tree stratum summary sheet for Stand No. 01, Uniform Area No. 01

Species	Plots occurred in	Stems	Basal area	Frequency	Density	Basal area	Relative frequency	Relative density	Relative dominance	Importance value
	Number	Number	Ft.^{2}/acre	Percent	Stems/acre	Ft.^{2}/acre	Percent	Percent	Percent	Percent
Jack pine	10	108	56.699	100	108	56.7	27.8	42.0	71.0	46.9
Balsam fir	10	103	13.517	100	103	13.5	27.8	40.1	16.9	28.3
Paper birch	7	20	4.075	70	20	4.1	19.4	7.8	5.1	10.8
Black spruce	5	19	3.792	50	19	3.8	13.8	7.4	4.7	8.6
Red maple	3	6	1.430	30	6	1.4	8.3	2.3	1.8	4.1
Aspen	1	1	.326	10	1	.3	2.8	.4	.4	1.2
Total		257	79.839	360	257	79.8	99.9	100.0	99.9	99.9

density of all tree-sized stems in this stand is 257 stems per acre. This is derived by dividing the total number of stems (257) by the number of plots (10) to get the average per plot, and then multiplying by the expansion factor (10) to derive stems per acre (257/10 x 10 = 257). The total stems per acre could also be derived by adding the values for the individual species; computing both ways will provide a cross-check on computations.

8a-3. Summarize dominance (average basal area) data ( ).

Each stem diameter can be converted to its area equivalent through reference to a conversion table, or through use of the equation: Area = $\pi \left(\frac{\text{d.b.h.}}{2}\right)^2$, where π = 3.1416. The area values have been summed for each species in all 10 plots on the worksheet (fig. 10). The total measured basal area for jack pine is 56.699 $ft.^2$. The average basal area per 1/10-acre plot is then 5.67 (56.699/10) $ft.^2$, or 56.7 (5.67 x 10) $ft.^2$ per acre. The one stem of aspen equals 0.33 $ft.^2$ of basal area for an average of 0.033 $ft.^2$ per 1/10 acre or 0.3 $ft.^2$ per acre. As with density, the total basal area per stand can be determined, and computations cross-checked, by adding the individual species values or by dividing the total measured basal area of all sample plots (79.839 $ft.^2$) by the number of plots (10) and multipying by the expansion factor for an acre (79.839/10 x 10 = 79.8 $ft.^2$ per acre).

8a.-4. Summarize relative frequency (RF) data ( ).

In addition to the three absolute values for density, frequency, and dominance described above, one can calculate relative values for each. Percent relative frequency is computed from the percent frequency column of table 2 as follows:

$$\text{Species RF} = \frac{\text{percent frequency of EACH species}}{\text{percent frequency of ALL species}} \times 100.$$

This value represents the percent of total frequency that is contributed by each species. The RF for all species should total 100 percent. In our example jack pine has a frequency value of 100; this is 27.8 percent of the total frequency for the stand:

$$\text{Jack pine RF} = \frac{100}{360} \times 100 = 27.8 \text{ percent.}$$

8a-5. Summarize relative density (RD) data ( ).

This value represents the percent of total stems that is contributed by each species. It is computed as follows:

$$\text{Species RD} = \frac{\text{number of stems counted for EACH species}}{\text{number of stems counted for ALL species}} \times 100.$$

Thus, in our example, 108 of a total of 257 stems in the tree class were jack pine, or:

$$\text{Jack pine RD} = \frac{108}{257} \times 100 = 42.0 \text{ percent.}$$

Note that relative density values also total 100 percent and thus may serve as a cross-check on the computation for each species.

8a-6. Summarize relative dominance (basal area (RDom) data ( ).

This value represents the percent of total basal area there is contributed by each species. It is computed as follows:

$$\text{RDom} = \frac{\text{basal area of EACH species}}{\text{basal area of ALL species}} \times 100.$$

In our example, jack pine has a measured basal area of 56.669 $ft.^2$ out of a total of 78.839 $ft.^2$ for all species, thus

$$\left(\frac{56.669}{79.839} \times 100\right) \text{RDom} = 71.0 \text{ percent.}$$

8a-7. Summarize importance value (IV) data ( ).

The relative values of frequency, density, and dominance can be combined as an overall importance value by averaging them:

$$\text{IV} = \frac{\text{RD} + \text{RF} + \text{RDom}}{3};$$

or, in our example,

$$\text{Jack pine IV} = \frac{27.8 + 42.0 + 71.0}{3} = 47.5 \text{ percent.}$$

This can be interpreted as meaning that, based on the characteristics measured, jack pine is the most important species in the tree size class.

When the same calculation has been performed for the sapling size class stems, the tree-stratum summary for the stand may look like that in the upper part of table 3.

8b. Summarize shrub stratum data ( ).

The raw data to be summarized for this stratum include those for the tree seedlings (0 to 0.25 cm. (0- to 1-in. d.b.h.)) and the tall shrubs on intermediate-sized plots. The data can be recorded on two separate forms or on one form (see fig. 8). The 00 class represents stems under 15 cm. (6 in.) tall, which are not placed in a diameter class for basal area estimate.

Table 3. – Stand data summary for Stand No. 01, Uniform Area No. 01

Item	Plot frequency	Density	Basal area	Cover	Relative frequency	Relative dominance	Relative density	Importance value
	Percent	Stems/acre	$Ft.^2$/acre	Percent	Percent	Percent	Percent	Percent
Tree size class:								
Pinus banksiana	100.0	107	57.1	--	28.2	71.8	42.4	47.5
Abies balsamea	100.0	103	13.5	--	28.2	17.0	40.6	28.6
Betula papyrifera	72.7	19	3.8	--	20.5	4.8	7.6	11.0
Picea mariana	45.5	17	3.4	--	12.8	4.3	6.8	8.0
Acer rubrum	27.3	6	1.4	--	7.7	1.7	2.2	3.9
Populus tremuloides	9.1	1	.3	--	2.6	.4	.4	1.1
Total	354.6	253	79.5	--	100.0	100.0	100.0	100.0
Sapling size class:								
Abies balsamea	100.0	502	15.3	--	23.9	81.5	79.8	61.7
Acer rubrum	90.9	47	.6	--	21.7	3.2	7.5	10.8
Betula papyrifera	72.7	46	1.3	--	17.4	6.8	7.2	10.5
Picea mariana	72.7	24	.7	--	17.4	3.7	3.9	8.3
Picea glauca	45.5	4	.1	--	10.9	.6	.7	4.1
Sorbus americana	27.3	4	.8	--	6.5	4.1	.7	3.8
Pinus banksiana	9.1	1	.1	--	2.2	.1	.1	.8
Total	418.2	629	18.8	--	100.0	100.0	99.9	100.0
Seedling size class:								
Abies balsamea	40.0	950	3.3	--	47.1	69.1	57.6	57.9
Sorbus americana	20.0	200	1.3	--	23.5	25.8	12.1	20.5
Betula papyrifera	15.0	350	.1	--	17.6	3.1	21.2	14.0
Acer rubrum	5.0	100	.1	--	5.9	1.0	6.1	4.3
Populus tremuloides	5.0	50	.1	--	5.9	1.0	3.0	3.3
Total	85.0	1,650	4.8	--	100.0	100.0	100.0	100.0
Tall shrub class:								
Corylus cornuta	55.0	5,100	3.5	--	21.6	33.0	26.4	27.0
Diervilla lonicera	65.0	7,250	1.5	--	25.5	14.3	37.5	25.8
Alnus crispa	30.0	3,900	4.2	--	11.8	39.4	20.2	23.8
Amelanchier spp.	30.0	950	.9	--	11.8	8.2	4.9	8.3
Acer spicatum	40.0	1,150	.3	--	15.7	3.1	5.9	8.2
Lonicera hirsuta	15.0	400	.1	--	5.8	.8	2.1	2.9
Lonicera canadensis	10.0	150	.1	--	3.8	.3	.8	1.7
Cornus rugosa	5.0	350	.1	--	2.0	.7	1.7	1.4
Cornus stolonifera	5.0	100	.1	--	2.0	.2	.5	.9
Total	255.0	19,350	10.7	--	100.0	100.0	100.0	100.0
Low shrub class:								
Vaccinium angustifolium	100.0	--	--	13.6	47.6	55.7	--	51.7
Gaultheria procumbens	90.0	--	--	7.6	42.9	31.4	--	37.1
Vaccinium myrtilloides	15.0	--	--	2.8	7.1	19.7	--	9.4
Rosa acicularis	5.0	--	--	.3	2.4	1.2	--	1.8
Total	210.0	--	--	24.4	100.0	100.0	--	100.0
Forbs, ferns, and fern allies:								
Pteridium aquilinum	50.0	--	--	23.5	14.7	48.9	--	31.8
Aster macrophyllus	85.0	--	--	16.4	25.0	34.0	--	29.5
Gramineae	75.0	--	--	2.4	22.1	5.0	--	13.5
Maianthemum canadense	65.0	--	--	3.2	19.1	6.5	--	12.8
Aralia nudicaulis	30.0	--	--	1.6	8.8	3.3	--	6.1
Trientalis borealis	10.0	--	--	.4	2.9	.7	--	1.8
Cornus canadensis	10.0	--	--	.3	2.9	.6	--	1.8
Melampyrum lineare	10.0	--	--	.2	2.9	.4	--	1.7
Clintonia borealis	5.0	--	--	.2	1.5	.5	--	1.0
Total	340.0	--	--	48.1	100.0	100.0	--	100.0
Ground surface characteristics:								
Litter	100.0	--	--	77.2	29.9	77.1	--	53.5
Other mosses	85.0	--	--	12.9	25.4	12.9	--	19.1
Caliergonella schreberi	50.0	--	--	4.8	14.9	4.8	--	9.9
Dead wood	40.0	--	--	3.2	11.9	3.1	--	7.5
Other lichens	25.0	--	--	1.2	7.5	1.2	--	4.3
Dicranum spp.	20.0	--	--	.6	6.0	.6	--	3.3
Hypnum cristacastrensis	10.0	--	--	.1	3.0	.1	--	1.5
Cladonia rangiferina	5.0	--	--	.2	1.5	.1	--	.8
Total	335.0	--	--	100.2	100.0	100.0	--	100.0

The data for each group are then transferred to a worksheet for summarizing by species the number of stems, basal area, and number of plots in which a rooted individual occurred. A worksheet (fig. 11) is very useful for this stratum because it will allow easy compilation of the data required on the summary sheets. The number of plots on which a species occurred in this case is based on the rooted presence of at least one stem (of any diameter class) of that species per plot. In this example, 20 milacre plots, two within each 1/10-acre plot, were used to sample the stratum. The number of stems counted were summed by species and by diameter class for the entire 20 plots.

To determine the total estimated area for green alder (*Alnus crispa*) in the example:

Class	*Stems*		
00	10	–	–
01	27	x 0.00021135 =	0.0059 ft.^{2}
02	41	x 0.00190220 =	0.0780 ft.^{2}
Total	78		0.0839 ft.^{2}

The values from the worksheet are transferred to the summary sheet (table 4). For each species the number of plots on which it occurred, the number of stems counted (regardless of height or diameter class), and the total basal area estimate of stems over 15 cm. (6 in.) tall is recorded. As in the tree stratum, these three values are used to determine the summary characteristic values for the species in the stand. Frequency is the percent of the plots in which each species occurred; thus, beaked hazel (*Corylus cornuta*) was rooted in 11 of the 20 plots for 55 percent frequency. Density per acre is determined by averaging the total number of stems of each species per 1/1,000-acre plot and expanding to an acre; for example, bush honeysuckle (*Diervilla lonicera*) had a total of 145 stems in 20 plots (145/20) = 7.25 per 1/1,000-acre plot = 7,250 stems per acre. Basal area is derived in the same way; for example, green alder had a total basal area estimate of 0.0839 ft.^{2} for 20 plots $(\frac{0.0839}{20})$ = 0.004195 ft.^{2} per 1/1,000-acre plot = 4.2 ft.^{2} per acre.

TALL SHRUB WORK SHEET

Stand No. 01 Uniform Area No. 01

Species	Green alder				Beaked hazel					Round-leaf dogwood			Moutain maple					
Plot number / Diameter class	00	01	02	total	00	01	02	03	total	00	01	total	00	01	02	03	total	
01	01	03	01	05						02	05	07	01	02	–	01	04	
02	–	05	–	05	03	08	05	01	12				03				03	
03	03			03	06	02	03		08				01				01	
etc.									etc.				etc.					
18	02			02		06			06				01	01			02	
19		06	08	14		01			01				01	01			02	
20		04		04	02	03	01	01	07				01				0	
Total stems	10	27	41	78	46	31	20	05	102	02	05	07	17	05		01	23	
Total plots				6					11			1					8	
Total basal area	–	0.0059	0.0780	0.0839	–	0.0066	0.0380	0.0264	0.0710	–	0.001	0.001	–	0.0011	–	0.0053	0.0064	

Figure 11. – Example of completed tall shrub worksheet.

Basal area (in ft.^{2}) is determined for stems over 15 cm. (6 in.) tall by multiplying the total number of stems in each diameter class (01, 02, 03, etc.) by the appropriate area value for a stem of the class. The area values presented below are based on the midpoint of the class; thus, the value for the 01 diameter class is based on a diameter of 0.5 cm.

Diameter class (cm.)	*Basis of area value (cm.)*	*Area per stem (cm.^{2})*	*(ft.^{2})*
01 (0-1)	0.5	0.19636	0.00021135
02 (1-2)	1.5	1.76721	.00190220
03 (2-3)	2.5	4.90891	.00528390
04 (3-4)	3.5	9.62146	.01035644

Table 4. — Tall shrub summary sheet for Stand No. 01, Uniform Area No. 01

Species	Plots occurred in	Stems	Basal area	Frequency	Density	Basal area	Relative frequency	Relative density	Relative dominance	Importance value
	Number	Number	Ft.^{2}/acre	Percent	Stems/acre	Ft.^{2}/acre	Percent	Percent	Percent	Percent
Beaked hazel	11	102	0.0710	55	5,100	3.53	21.6	26.4	33.0	27.0
Bush honeysuckle	13	145	.0301	65	7,250	1.53	25.5	37.5	14.2	25.8
Green alder	6	78	.0839	30	3,900	4.20	11.8	20.2	39.4	23.8
Juneberry	6	19	.0172	30	950	.88	11.8	4.9	8.2	8.3
Mountain maple	8	23	.0064	40	1,150	.33	15.7	5.9	3.1	8.2
Hairy-climbing honeysuckle	3	8	.0021	15	400	.08	5.8	2.1	.8	2.9
Fly honeysuckle	2	3	.0010	10	150	.04	3.8	.8	.3	1.7
Round-leaf dogwood	1	7	.0010	5	350	.07	2.0	1.7	.7	1.4
Red osier dogwood	1	2	.0005	5	100	.02	2.0	.5	.2	.9
Total		387	.2132	255	19,350	10.68	100.0	100.0	100.0	100.0

In computing this value, be sure to recognize that it is derived from the class midpoint and is not an absolutely accurate estimate of basal area. The total number of stems and total basal area can be used to estimate density and basal area for all stems just as in the tree stratum. Here too, it can serve as a cross-check on species computations.

Relative values for each characteristic can be computed using the formulae as for the tree stratum. When all summary calculations are completed, the stand summary sheet will contain sections headed tree seedlings and tall shrubs (table 3).

Basal area values could also be carried forward to the summary sheet as cm.^{2} per m. or ha. Divide cm.^{2} per acre values by 929.034 to convert them to ft.^{2} per acre.

8c. Summarize low shrub, forbs, etc. data ( ).

Because the raw data for the low shrub, forbs, ferns, and the ground surface characteristics were collected in the same manner on the same sample plots, we can discuss data reduction procedures for all simultaneously. Although the data may be collected at the same time, they should be recorded either on separate forms or at least separated to facilitate computation (fig. 9).

The measurement recorded in the field is the estimated percent of plot covered by projection of foliage onto the ground. The percent cover of a species can also be used to indicate the species presence in the plot for frequency computation. Occasionally a species may cover part of a plot and yet not be rooted in the plot. The data sheet, therefore, must contain some method for indicating when this occurs so that all recorded values are used for average percent cover computation but not for frequency computation. Note that in fig. 9 this situation was indicated by recording in columns at the far right of the data sheet the plots where only cover and not frequency is to be included for the species.

A worksheet is not needed to derive the totals for the summary sheet for these two strata. Sum the values for cover in the 20 plots across the data sheet for each species and bring this total forward to the summary sheet. Count the number of plots where cover was recorded, subtract those which were noted as not to be included for frequency purposes, and bring this total forward to the summary sheet. Summarize data separately for (1) the low shrubs, (2) the forbs, ferns, and fern allies, and (3) the ground surface characteristics. Because computations are the same for all three groups, only a few examples from the low shrub group will be used.

The species name, frequency, and total estimated percent cover are represented in the first three columns of the summary sheet (table 5). Frequency is computed as it was for the other strata; i.e., the percent of the plots in which a species occurred. Thus, late sweet blueberry (*Vaccinium angustifolium*) was present in 20 plots out of a possible 20 plots for 100 percent frequency. The average percent cover is used as the characterization of dominance for these strata. Average percent cover is the total estimated cover averaged over the number of plots; thus, the cover of wintergreen (*Gaultheria procumbens*) was estimated at 153 percent in the 20 plots (153/20), o

Table 5. – Low shrub, herb, and moss-lichen strata summary sheet for Stand No. 01, Uniform Area No. 01

Species or characteristic	Plots occurred in	Total cover	Species frequency	Average cover	Relative frequency	Relative dominance	Importance value
	Number	Percent	Percent	Percent	Percent	Percent	Percent
Low shrubs:							
Late sweet blueberry	20	272	100	13.60	47.6	55.7	51.7
Wintergreen	18	153	90	7.65	42.9	31.4	37.1
Velvet-leaf blueberry	3	57	15	2.85	7.1	11.7	9.4
Wild rose	1	6	5	.30	2.4	1.2	1.8
Total		488	210	24.40	100.0	100.0	100.0
Herbs:							
Bracken fern	10	470	50	23.50	14.7	48.9	31.8
Large-leaf northern aster	17	327	85	16.35	25.0	34.0	29.5
Grasses	15	48	75	2.40	22.1	5.0	13.5
Clinton's lily	1	5	5	.25	1.5	.5	1.0
Total[1/]		962	340	48.10	100.0	100.0	100.0
Mosses-lichens:							
Litter	20	1,732	100	86.60	29.4	86.6	58.0
Dicranum spp.	12	83	60	4.15	17.6	4.2	10.9
Other mosses	11	48	55	2.40	16.2	2.4	9.3
Total[1/]		2,000	340	100.00	100.0	100.0	100.0

1/ For brevity, totals include species not listed.

an average of 7.65 percent projected ground cover. Relative frequency and relative dominance (percent cover), as in the other strata, are computed as the percent of each species contribution to the total for these values. The importance value is computed as the average of these two relative values.

Note that cover values for the low shrub and forb, fern, and fern allies groups can average more or less than 100 percent cover due to overlap or openings in the foliage, but the total for ground surface characteristics cover will usually average 100 percent. The reason is that the latter includes all ground surface characteristics and there is normally no overlap.

The data derived from this summary will be reported in the last three parts of the stand summary (table 3).

If cover estimates are assigned by classes, the data must be summarized differently than in our example. A frequency chart will show the number of times each species was assigned to each cover-class value. One can also use the cover-class identification numbers to derive an index value for the species. For example, assume that a species was assigned the following cover-class values:

(1) *Class identification number*	*(2)* *Number of times assigned*	*(1) x (2)*
1 (less than 1%)	0	0
2 (1 to 5%)	1	2
3 (6 to 25%)	4	12
4 (26 to 50%)	10	40
5 (51 to 100%)	5	25
Total	20	79

Summing the products of the class identification numbers (1) and the number of assignments for the species (2) and dividing by the total number of assignments (79/20 = 3.95) provides an index of the class-cover assignments. This could be done for each species and reported as a part of the stand summary.

An additional useful summary for tree species is a chart or table indicating the number of stems of each diameter encountered in the sample.

8d. Summarize stand characteristics ( ).

Values for the characteristics computed from the raw data comprise four major parts of the stand summary. Copies of this summary sheet (table 3) should be placed in several files.

This section explains in greater detail the steps involved in collecting information on natural areas. Hopefully, it will benefit nonprofessionals who are not familiar with vegetation sampling techniques. Those who wish more information than is provided here are invited to consult the literature references cited. Some general reading of ecology texts would be particularly helpful, especially Cain and Castro (1959), Greig-Smith (1964), and Kershaw (1966).

What is a Research Natural Area?

According to the statement on policy and standards by the Federal Committee on Research Natural Areas, such an area may be defined as ". . .a physical or biological unit where natural conditions are maintained insofar as possible. These conditions are achieved by allowing ordinary physical and biological processes to operate without intervention, but on certain Areas, by deliberate manipulation intended to maintain the unique features that the Research Natural Area was established to protect."

What is the Value of Such an Area?

Many views have been stated on the value of natural area preservation (Shanklin 1951, Shanklin *et al.* 1952, American Association for the Advancement of Science 1963, Lawrence 1963, Spurr 1963, Cowan 1968, Darnell 1968, Franklin and Trappe 1968, Wellner 1969). Buchinger (1969) stressed six values of such areas – patriotic, scientific, economic, educational, recreational, and moral. Nicholson (1968) listed the following reasons why natural areas will be important to both biological and human welfare:

1. The maintenance of large, heterogeneous gene pools.
2. The perpetuation of samples of the full diversity of the world's plant and animal communities in outdoor laboratories.
3. Opportunity for comparison with managed, utilized, and artificial ecosystems.
4. Outdoor museums for study, especially in ecology.
5. Education in the understanding and enjoyment of the natural environment and for the intellectual and esthetic satisfaction of mankind.

Background Information

The first step in characterizing a natural area might best be to collect information already available about the area. Some of these data may have been gathered in conjunction with the reservation procedures for the area. Additional information may have been gathered during completion of IBP checklists. But for most areas, previous data collection will not be as complete as it can or should be. Therefore, a thorough search for background materials is needed. Background information is useful in at least three ways: (1) It sets the stage for selecting a sampling scheme that will adequately describe the vegetation. It may dictate sample stratification. (2) It will aid in interpretation of study data. (3) It may foster further research within the natural area – a major goal in the establishment of these areas. Unique conditions may be brought to light, and future researchers may want to examine these conditions in relation to the biotic communities. Researchers are more willing to work in areas where the historical and environmental aspects are well documented.

Listed below are some kinds of general information that might be sought. We cannot predict which types of information will be most important; any data that add knowledge and promote greater insight will be valuable.

Maps

The landscape features of a natural area are important to its description and study. Most topographic features are the result of the interraction between the erosion and the underlying bedrock. The main forces of erosion are wind (atmospheric), water (fluvial), and ice (glacial). Topographic features are basically the product of four factors: the agent of erosion and its mode of operation (e.g., a river cutting into its valley); the degree to which an agent has completed its work (stage); the physical and chemical character of the rock being eroded (determining those physiographic features that are due to differential erosion); and length of time that an agent has been operative (as well as interruptions to its normal activity).

Landscape features are represented on two types of maps:

(1) *Flat (planimetric).* — A two-dimensional projection of an area that shows only positions of and distances between objects.

(2) *Relief.* — A three-dimensional depiction of the topography as well as the details included in flat maps. Topography may be shown in a variety of ways, including shading, color, hachures (lines drawn in the direction of slope of mountains, hills, and valleys), and most commonly by contours (lines through points of equal elevation).

The existing file for a natural area will usually have a flat map available, and it may also have a relief map. However, the scale may not be well suited for fieldwork. A scale of 1:250,000 (4 mm. per km. (0.25 in. per mile)) may be adequate for general location purposes, but 6.4 cm.^{2} (1 in.^{2}) at this scale will cover almost 4,032 ha. (10,000 acres). A scale of 1:24,000 (4.2 cm. per km. (2.64 in. per mile)) is much more useful because 6.4 cm.^{2} (1 in.^{2}) on this scale will cover only about 37 ha. (90 acres). U.S. Geological Survey quadrangle topographic maps are available at this scale. Surface topography is often shown by 3.04-m. (10-ft.) contour intervals. Another useful scale, if maps are available, is 1:7,920 (12.7 cm. per km. (8 in. per mile)). One in.^{2} (6.4 cm.^{2}) will cover an area of about 4 ha. (10 acres) and thus the map is useful for detailed work on the ground.

In addition to those showing land surface features, there are maps and diagrams (or reports) that deal with the underlying mineral material. Unfortunately, these maps are often unavailable or are too small in scale to be of much help. However, the following related types of maps can be useful.

Bedrock geology. — Maps showing the consolidated materials underlying the area (which may protrude above the surface in places). At least small-scale maps of this type have often been produced (many bedrock geology maps for States are available). Some areas have been mapped in great detail, especially where economically important minerals may be present. Bedrock geology maps may also include topographical and cultural features of the area.

Block diagram. — Illustrations of the geology and physiography of an area. They are especially useful in demonstrating the relationship between geological structure and topography. Such diagrams are usually found in geological reports for an area.

Surface geology. — Maps of the unconsolidated materials above the bedrock. These materials may be derived from the bedrock below or may have been transported into the area by wind, water, or ice. These maps may conform to the bedrock geology maps only where bedrock reaches the surface.

Soil. — Maps of unconsolidated surface materials that have undergone differential weathering and organic matter incorporation. There may be several soil types mapped on the same unconsolidated surface material. Most agricultural soils have been mapped in the United States, but few forest soils have been mapped. If soil maps are available, they represent an especially useful aid to vegetation interpretation.

Glacial geology. — Maps or diagrams showing the extent of the various ice advances and retreats and the resulting landforms, such as moraines, eskers, etc. These are only available where glaciation has been important.

Bathometric. — Lake bottom contour maps. Where lakes are an important part of the natural area, these maps are useful. They are sometimes available in areas where commercial or sport fishing, navigation, or hydroelectric power development has been important.

Vegetation. — Maps of the vegetation of an area. In recent years such maps have become important and are now available for all parts of the world (Kuchler 1967). Most are on a very small scale; for example Kuchler's (1964) map of the United States (1:3,168,000). These maps are useful for showing the relationship of the natural area vegetation to that of the surrounding region, but larger-scale maps are better for fieldwork. The California vegetation-soil survey maps are a good example of such large-scale maps. These maps are based on a minimum mapping area of 4 ha. (10 acres). They are available on a scale of 1:31,680 (3.2 cm. per km. (2 in. per mile)), which is about the same scale as the 7-1/2-minute quadrangle topographic maps of the U.S. Geological Survey. Forest land management agencies (e.g., USDA Forest Service) frequently have timber-type maps available. They are relatively large-scale maps generated by interpretation of aerial photographs and based on commercial important tree species. A common scale is 1:31,680.

Photographs

Aerial. — Photographs taken from above the vegetation by aircraft. One of the most productive sources of information is the aerial photograph. Although few airphotos were taken prior to the 1920's, many areas have been photographed about once per decade since then, providing good visual evidence of major land use and vegetation changes over time. Most natural areas on federal lands have been photographed from the air one or more times. These photos are available in stereographic pairs and will provide a three-dimensional view of the area. Natural areas located in the vicinity of agricultural land may have been photographed from the air frequently in recent years by governmental agencies in their administration of land bank and crop production programs.

Ground. – Photographs taken of the vegetation from ground level. Useful photos from the past that were taken from an established point are difficult to find. Such things as historical documents and land survey party notes occasionally contain photos. If found, they are especially useful to document general plant cover changes that have occurred.

Historical Documents

A part of "analyzing" vegetational data and other observed phenomena is simply relating them to past history. Biotic communities are greatly influenced by what has happened to them in the past. What can one look for to help determine past influences on the area?

Official land surveys. – Land survey records are available for most of the continental United States, and they may be available for other areas, too. The metes and bounds surveys of the colonial States can provide some insight to vegetation changes, but the rectangular surveys of the General Land Office include definitive observations of the vegetation at the time of survey. Thus, they are usable for quantitative as well as qualitative analyses (Bourdo 1956). These surveys have been used to construct maps of forest type distributions, or to determine structure and composition of forests at the time of survey (Davis 1907, Marschner 1946, Cottam 1949, Brown 1950, Bourdo 1956, Lindsey *et al.* 1965, Ward 1956).

Geomorphology. – Geomorphic processes leave their distinct imprint on the land and each develops its characteristic assemblage of landforms. In some regions these processes have been studied and published as reports of the State geologist or in scientific journals. Any literature of this type should be included in the natural area file. This information is best located through contact with local college or university geology or geography departments, or through government agencies that deal with geology, minerals, or land planning.

Climate. – A knowledge of past and present climatic conditions prevalent in the region of the natural area is important in understanding both vegetation and flora. The annual precipitation pattern, seasons of adequate moisture, direction of prevailing winds, frost-free season, and length of growing season are all important and have been documented for most areas through official weather station data (U.S. Weather Bureau Climatological Data – National Summary and also monthly State Reports). Some of these data have been included in the IBP checksheet. Long-term climatic history can be deduced by observation of vegetation change through fossil pollen analysis. A history of the regional vegetation from pollen analysis may be available, especially if the region has been glaciated. Some information may also be available on the historical aspects of the flora in plant geography books. Any such information will help future workers to understand how the present vegetation developed, and it may help to predict what the future vegetation will be. Literature pertinent to the natural area should be added to the file.

Disturbance Records

Natural disturbance. – A record of severe regional disturbances caused by natural agents such as fire, wind, disease, and insects may exist. This kind of information is best sought from area colleges, universities, and land management agencies. Wildfire history, at least for recent periods, can be obtained from the records of the agency that is responsible for protecting the area from fire. Evidence of fire may be found in charcoal presence at the surface of the mineral soil, but will not provide a date for the fire. More exact dates for some vegetation may be obtained by looking for fire-resistant trees with scars on their bases from past fires – these trees can be bored into with an increment borer to obtain an annual ring core showing years of past fires (Heinselman 1969).

Information on wind damage by hurricane or tornado may be obtained through interview of nearby residents, or the former owners of the natural area, if any. Stump evidence of salvaged dead and down trees may be traced to severe wind damage.

History of disease and insect epidemics can probably best be obtained from land management agencies near the natural area. Both of these influences are usually regional in character and thus well known. They can have an important influence on the vegetation present at any given time through setting back succession; for instance, oak wilt (*Ceratocystis fagacearum*) can have a major influence on components of oak forest communities of eastern North America, and the spruce budworm (*Choristoneura fumiferana* Clem.) has drastically altered fir-spruce communities in the northern United States and Canada. Although set back, the plant communities recover in time. Apparently such epidemics have recurred periodically through time.

Human disturbance. – This influence may operate either directly on the natural area (usually not extensive or it probably would not have qualified as a natural area), or indirectly (most natural areas have been affected to some degree). In either case these conditions should be documented so that they are considered in analysis of present or future vegetation studies.

Some of man's direct influences are roads, agriculture, drainage, salvage logging, or other obvious disturbances not present when the area was reserved. Some other direct disturbances such as removal of dead or blown-down trees, trapping, hunting of animals, recreational harvest of forest products (berries, mushrooms, seed cones), plant collecting, and pesticide or herbicide application (as part of a larger regional program) are hard to detect, and may be discovered only through interviews of nearby residents or former owners of the area, if any.

Indirect influences may be more insidious and difficult to document. These are activities that occur on lands surrounding the natural area. Industrial, mining, or agricultural practices may produce materials that find their way into the natural area or utilize substances that would normally move through the natural area. Included in this category are pollutants, both atmospheric and waterborne; dams that influence water levels or flow patterns; irrigation practices; and horticultural or agricultural activities that introduce exotic plant species or diseases, such as the chestnut blight (*Endothea parasitica*), white pine blister rust (*Cronartium ribicola*), and Dutch elm disease (*Ceratocystis ulmi*).

Vegetation Description

In the early years of ecology, subjective observations by trained personnel were considered adequate for describing the characteristics of a plant community (Oosting 1956). Time has shown that few observers view things alike. It became apparent that ecological description would have to become more precise through accurate measurement and detailed records. This has led to the predominant use of quantitative methods of sampling and describing vegetation.

Qualitative Techniques

Floristics. – The flora is the total of all the kinds of plants that exist within an area. The identification and collection of voucher specimens of the flora in a natural area is a useful contribution. This will require some taxonomic ability. Identification "keys" for most areas are available. A hand lens and a dissecting microscope are useful tools to aid in identification. Specimens (including the root system if possible) should be collected, dried in a plant press, mounted on herbarium paper, and properly identified. Collections should be made throughout the growing season. Some natural areas are set aside for the protection of rare or unusual species. If the area being described is one of these, workers should be aware of the rare species and refrain from collecting them without permission of the managing agency. Some plants are also protected by government statute; these too should not be collected without a permit. Rare or unusual plants within natural areas may be indicated on IBP checksheets that have been filled out for most areas. If a copy of the completed checksheet is not in the natural area file, one can be obtained from the Biological Records Centre, The Nature Conservancy, Monks Wood Experiment Station, Abbots Ripton, Huntingdon, England.

Most potential investigators toward whom this manual is directed will have had some experience in collecting and preserving plant specimens. A recent book by Klein and Klein (1970) contains an up-to-date description of the procedures and equipment required.

The problem of where to deposit voucher specimens is still unresolved – it is hoped that eventually some central location will serve as a data bank for all natural areas and that voucher collections will be deposited in an herbarium within this data bank. Meanwhile, the best solution is to house the collection at a nearby educational institution with herbarium facilities. Be sure a list of the plant collection with the collector's identification number is maintained in the natural area file of the managing agency. Duplicate lists should be filed wherever data from the area are deposited as well as with the herbarium where the specimens are deposited. These collections require a great deal of work, but they are necessary. As the vegetation of a natural area matures, certain abundant species may become rare and even disappear, while others may invade and change from rare to abundant. Proper identification through voucher specimens is necessary to prove that a species is present now, even though it may not be found when the area is surveyed again at some future time.

Permanent Photographic Points

Gross changes in vegetation can be recorded by photographic evidence. Photos should be taken from permanently marked locations along recorded compass bearings. Appropriate information as to season, location of permanent points, and compass bearing needs to be recorded for each photo. Marking and describing permanent photo points must be as accurate as marking and describing permanent vegetation sampling plots.

Mapping

Vegetation, at least dominant forest cover types, can be mapped on a qualitative basis by running lines (transects) and recording obvious changes in cover or vegetation characteristics. Vegetation can also be mapped through airphoto interpretation with ground spot-checking. Detailed vegetation mapping is usually best done after one is familiar with the vegetation or after the various plant communities have been distinguished through objective quantitative techniques.

Individual species distributions may also be mapped; this will require an intensive search of the natural area. For certain very rare or unusual species this might be a useful contribution, but often natural areas will be small enough so that most species will be found throughout. Both kinds of mapping are time consuming if done properly and are probably best done after the area's vegetation has been well described.

Physiognomy

Vegetation can be described qualitatively in terms of its physiognomy, or general outward appearance. Dansereau (1958) presented such a method that does not require detailed knowledge of the species present. It involves using symbols as a pictorial representation of the vegetation. The procedure includes five steps, which have been presented in detail by Phillips (1959): *Step 1.* The number of different life forms present is ascertained, and the various symbols necessary to separate these life forms are devised. *Step 2.* The size of the different plants of each life form is estimated or measured. *Step 3.* Leaf shape, size, and texture is recorded for each life form. *Step 4.* Percent coverage is estimated for each life form. *Step 5.* A diagram of the vegetation is prepared on graph paper using the appropriate symbols.

Quantitative Techniques

Time, money, and manpower availability are important considerations in sampling and description. They have a direct bearing on the considerations of what, and how, to sample. Ideally a natural area's plant and animal populations, and the environmental factors that influence them, will be simultaneously described so that future changes can be monitored. The eventual goal, however, should be to describe the processes governing production of organic matter, the flow of energy, and the cycling of nutrient resources. The assumption of this manual is that most potential users will, as a minimum, be interested in sampling to provide a quantitative description of the major plant communities in a natural area. Along with quantitative vegetation data, sufficient environmental information should be collected so that the vegetation can be related to its surroundings.

Obviously, the most accurate way to quantitatively describe the vegetation of an area is to document every plant. However, this is only feasible for very small areas, and is probably unnecessary even there. The customary method of describing vegetation is by sampling — that is, by selecting parts of an area for data collection and then extrapolating for the whole area.

The most critical aspect of sampling is the design — the subsequent data collection is mostly hard work. The suitable design for quantitative description is best derived through consultation with statisticians, biometricians, professional botanists, or ecologists. This should be done after the background information is as complete as possible, and after the natural area has been examined by a thorough field reconnaissance. The vegetation should be sampled in such a way that the results can be projected as accurately as possible for a specific part of the whole natural area. A series of samples that properly represent the vegetation of the area under consideration must be obtained. This should be done efficiently to result in as accurate a description as possible for the time, money, and effort expended.

Most ecology textbooks contain a section on sample design and sampling. Some books that deal entirely with vegetation sampling are: Brown (1954), Phillips (1959), Cain and Castro (1959), and Greig-Smith (1957, 1964). Most natural areas will already have had some aspects of what Cain and Castro (1959) refer to as a "primary survey" completed through the checksheet filled out for IBP in accordance with Handbook No. 4 (Peterken 1967). This information, along with other background information, described in the previous sections, should serve as the basis for what Cain and Castro (1959) refer to as the "intensive survey" of the area. This survey can deal with all the communities in an area, or it can treat a particular community. The major problem with this approach is that it assumes one already has knowledge of the communities.

Sample Design

What is the procedure for setting up the sample design? From the preceding paragraphs you have probably surmised that there is no pat answer. This section details some ideas and practices that should help make the sample design as valid as possible.

Stand Selection

On the basis of background information and reconnaissance, the design should treat as separate units those parts of the area that are similar in history, geology, topography, or other features that strongly affect the vegetation (e.g., forest versus nonforest, upland versus lowland, etc.). Within each uniform area (only rarely will the entire natural area be uniform) a random procedure should be used to select stands to be sampled. Perhaps the best method is to sketch on a topographic map or aerial photograph of workable scale the uniform areas from which the sample stands will be drawn. Then establish a grid by drawing baselines at right angles to each other on two sides of each uniform area. Finally, by drawing numbers from a random numbers table, a hat, or a deck of cards, establish the distance along the baselines for each stand to be sampled. Plot the coordinates of the two distances as a point on the map or photo to represent the center of areas (stands) to be sampled (fig. 12).

Each stand is then a random sample of the vegetation within the uniform area. How many such stands are required to adequately describe the vegetation of each

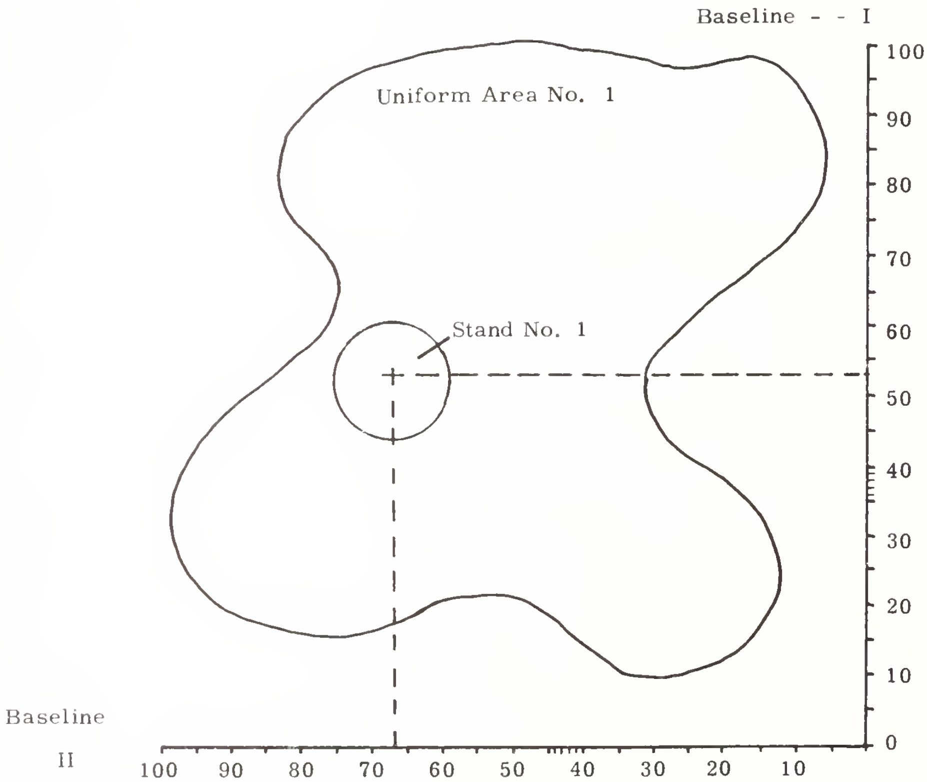


Figure 12. — Random selection of sample stands in Uniform Area No. 1. Number from table of random numbers was 5,367.

uniform area? How many plots need to be sampled to adequately describe the vegetation of each stand? These two questions are related and discussed below.

Number of Samples

The basic objective of sampling is to obtain data for comparison with future data. To do this one can treat each stand (even each plot) as a discrete unit. This is a valuable approach, but another useful approach is to combine data from all sampled stands within a uniform area to describe similar stands; that is, to summarize the stand data to describe the naturally occurring plant communities. For example, of 20 stands sampled on a uniform area, objective methods of comparison may show that they segregate into three groups of 10, four, and six stands. If we have selected enough random samples from the uniform area, we can assume with some degree of confidence that we are describing the three major plant communities in the area. The cause of the differences must be determined. Much of the background information may be of value here.

In other cases, primary interest may be in obtaining baseline data to monitor change and not in summarizing stand data. The baseline data obtained, however, should be such that others can later synthesize them, and use them to describe and analyze the plant communities. Thus, the number of plots should be sufficient to completely describe each stand, and the number of stands sampled within a uniform area should be sufficient to provide information on all the major plant communities present and to allow meaningful summaries of each community type.

How many samples are sufficient depends partly on the nature of the vegetation to be sampled, on its complexity, and on the number of community types present. In the past many authorities recommended using the "species-area curve" as an estimate of the number of samples to take. The general philosophy behind this idea was that when additional samples do not add new species or do not greatly refine the information already obtained, the effort required to obtain further samples is better spent elsewhere. Another method is to compute the standard error of the mean for the plots or stands sampled, and when this error is within the limits of accuracy you wish to obtain in your survey, the sampling is terminated. Methods like these suffer from the fact that they cannot be determined prior to sampling and they cannot be used to determine sample numbers for the next unit to be sampled. A further drawback is that while the error might be low for some species (perhaps the most common), it would not be for other species in the sample. One might use some composite characteristic such as tree density for all species, and by a running computation of the mean and its standard error, terminate sampling when this parameter is at acceptable limits. This is not a useful technique to determine the number of stands to sample until the community types have been defined, and the accuracy of their definition depends on the number of sample stands used. There thus appears to be no good objective way to determine how many samples are sufficient, and the methods proposed in the literature do not go beyond a rough guide as to whether most of the species present have been recorded or not. Greig-Smith (1964) summarizes the problem this way: "The validity of determining, other than empirically, any precise area to be used in describing vegetation depends on whether or not there is at some point, a sudden decrease in the amount of additional information obtained."

Distribution of Samples

Selection (by random means) of areas (stands) to be sampled has already been discussed. Distribution of the sample plots within the stand needs also to be considered.

Within a stand, plots might be distributed in three ways: (1) by arbitrarily selecting plots considered typical of the stand as a whole, (2) by selecting plots randomly, or (3) by selecting plots on some regular pattern. Selection of "typical" sites is generally not the approach used in vegetation description unless the objective is to describe "typical" stands – i.e., the modal characteristics of a predetermined community – through use of a limited number of plots.

If the plots are selected randomly, one can calculate the mean for any characteristic measured, and also measure the precision of this mean through the standard error. This is desirable in comparing sampled stands because unless we know the accuracy of estimated values for vegetation characteristics, it is impossible to assess the likelihood of their differences arising from chance.

Random selection of sample plots is time consuming in the field and many workers prefer to use some systematic method of selection. Systematic sampling is also thought to be more representative of variation over the sample area and thus likely to give better estimates of vegetation values than will random sampling. Some studies have shown little difference in data when both of these methods were used on the same area (Cain and Castro 1959).

The most workable method for randomizing sample plots, like selecting sample stands, is to lay down two perpendicular lines as axes at the edges of the stand, and by using a pair of random numbers as coordinates, position each sample plot along the two axes. Measurement of distances from the axes to the sample plots need not be exact (Greig-Smith 1964); pacing will be adequate and more efficient. However, the plots must be easily relocated in future years.

If systematic location of sample plots is used, it is important that the distribution pattern give a uniform representation of the area. Other considerations must also be met – for example, in some sampling techniques the points must be far enough apart so that individual trees are not sampled from two different points.

For intensive studies of a few stands on small natural areas where extra time and effort are worthwhile, a random location of stands and sample plots within the stands is recommended. On more extensive surveys of many stands, random location of stands and systematic plot distribution after randomly locating the first plot within the stand are desirable.

Sampling Units

Beyond the problem of location and distribution of sample units, a further consideration is the sampling units themselves. Some possible units are plots, plotless units, transects, or some combination of these techniques.

Plots

A plot is an areal sampling unit, traditionally square in shape. Rectangular plots have been found to be statistically more efficient than other shapes, while circular plots are more efficient in terms of measurement time. This is especially true if the outer limits of the plot are established with a rangefinder, thus eliminating the need for establishing plot boundaries.

Rectangular plots are statistically superior for sampling species showing a clumped distribution; the plot intercepts more clumps, thereby reducing the variability of the data. This advantage must be weighed against the advantages of square and circular plots, which are ease and speed of establishing and measuring and having to make fewer decisions on whether a stem is inside or outside the relatively shorter perimeter. Therefore, where time is critical, circular plots might be preferred, and where reduction in data variability is of primary concern, rectangular-shaped plots might be preferred.

Plot size is related to the size of the plants to be sampled and thus should be fitted to the various vegetational strata in the stand. In the section on components I have suggested some plot sizes that might be appropriate for the various strata of a forest stand. Curtis and McIntosh (1950) recommend that plot size be four times the mean area occupied by the most abundant species.

Plant density, frequency, and dominance (basal area or cover) can all be determined through use of plots. Frequency varies with the size of the plot and thus can be compared only for plots of the same size. If large plots are used, percent frequency values for the less numerous species will be inflated. Density and dominance are independent of plot size except in terms of efficiency of sampling.

Plotless Techniques

Some of the newer plotless sampling techniques are generally more efficient than using plots for sampling large woody plants. In forest communities it is often best to use a plotless technique for sampling trees and saplings, and plots for the other strata (Ohmann and Ream 1971a).

In plot sampling, density is determined by counting the number of stems in the plots and expanding this value to a larger area. Another way of characterizing density is to determine the reciprocal of the number of plants per unit area – that is, to determine the mean area each stem occupies within the stand. This value, the mean area, can be computed by assuming that trees are spaced so that the distance between them is equal to the square root of the mean area. In the field, measurements are taken at established points instead of plots within a stand. The points are regularly spaced (the first point may be randomly selected), and the distance between the trees is measured by one of several methods. The point-centered quarter method for measuring density is presented below; other methods of plotless sampling are detailed by Cottam and Curtis (1956).

Although the point-centered quarter method has been applied to sampling shrubs and grasses, it is probably most applicable to the tree stratum. The direction of movement from point to point within the stand constitutes one line, and a hypothetical line is drawn perpendicular to the line of movement (fig. 13). These two lines drawn through the point define four quadrants (note that this term differs from the quadrat). The distance to the nearest tree stem, its species name, and its d.b.h. are recorded in each quadrant at each point. When working with two size classes, trees and saplings, the nearest stem in each class is measured and recorded in each quadrant. The distances are usually measured to the nearest 30 cm. (1 ft.) or 15 cm. (1/2 ft.), and the d.b.h. to the nearest 0.25 cm. (1/10 in.), as in the areal plot methods.

The same information collected on areal plots can be determined by use of the plotless technique. In fact, relative values for frequency, density, dominance, and their summation, the importance value, originated with the plotless techniques. Thus, density, basal area (as a measure of dominance), and frequency (although different from plot-derived frequency) can all be determined through use of the point-centered quarter method.

If basal area is the primary concern, the variable radius sampling method introduced by Bitterlich (Grosenbaugh 1952) is a useful technique. A sighting gage is used to count trees that are within a distance of not more than 33 times their stem diameter from the sampling point. This tally multiplied by 10 results in a direct conversion to $ft.^2$ of basal area per acre. More recently (Bruce 1955), prisms have been used in place of the sighting angle gage, but the theory remains the same.

Lindsey *et al.* (1958) have assessed the efficiency of several plot and plotless techniques for sampling density and basal area in forest stands. The time required to reduce the standard error of the estimate to 15 percent was the basis of comparison. They concluded that variable radius sampling is superior for basal area estimation and that a 400 $m.^2$ (1/10 acre) circular plot defined by a rangefinder is more efficient for density determination.

Stand Vegetation Characterization

What parameters will provide useful information about the composition and structure of forest stands? How does one characterize vegetation? This section will

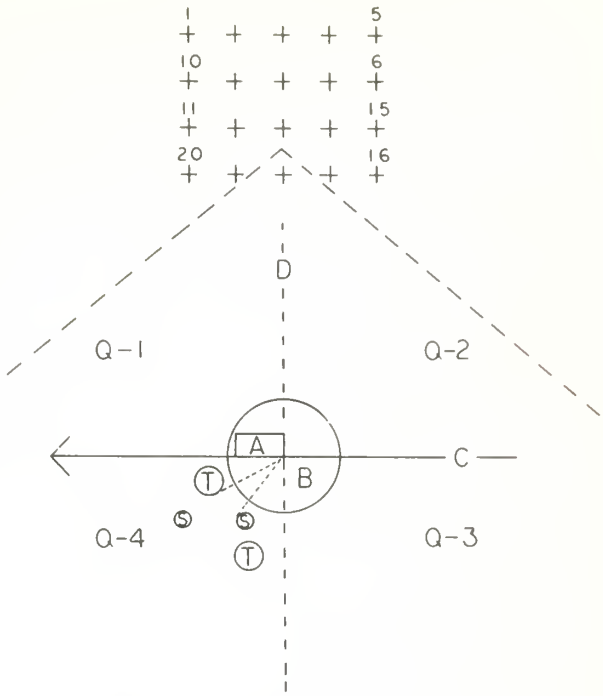


Figure 13. The upper portion of the figure shows the distribution of sample points within a stand. The lower portion is a diagrammatic representation of the sampling system at one sample point. A is a 1- by 2-ft. plot for sampling herbs and low shrubs. B is a milacre plot for sampling tall shrubs and tree seedlings. C is the line of travel and D is an imaginary line perpendicular to it, forming the four quadrants (Q) of the point-centered quarter method. S is a sapling. T is a tree.

describe some types of quantitative information often collected to describe vegetation.

Density

The number of individuals of each species present in the stand is an important way to characterize vegetation. Density is determined by counting the number of individuals of each species growing on each sample plot, and then estimating the average number of stems of each species per unit area sampled. Density is usually expressed as the number of stems per acre, square meter, hectare, or some other convenient unit.

When number of stems is based on estimation rather than counting, the characterization is referred to as abundance and is expressed by assigning each species to an abundance class. The concepts of density and abundance have been discussed in detail by Cain and Castro (1959).

Density can also be expressed on a relative basis as the percentage that a species makes up of all species. In general, relative density should be used only in conjunction with absolute density or other absolute measures of the species importance because relative density alone may overemphasize the importance of a species. For example, seedlings of prolific seed-producing trees may be very numerous following a good seed crop, but most of these individuals may not survive the first growing season. These may not be as important to the community as another species whose relative density is smaller but which is represented by older individuals.

Density is usually expressed in stems per unit area rather than in individual plants. It is often restricted to woody plants (usually tree and shrub species). With non-woody plants (and some woody plants, too) there is often a problem of determining what constitutes an individual. Even if all species could be adequately separated as individuals, counting small herbaceous plants would be very time consuming. Some tree species exhibit a clonal nature whereby the individuals are connected through underground root sprouts or other species by above-ground runners, and one cannot distinguish (in the normal sense of the term) an individual plant. One can, however, usually distinguish individual stems above the ground although sometimes stems are fused for some distance above the ground. Where does the fusion represent a stem and its branch and where does it represent two separate stems? This should be decided in advance; then the situation should be consistently treated each time it occurs. A convenient way to treat these cases is to consider any fused trees that separate below breast height (1.4 m. (4.5 ft.)) as individual stems, and to consider any shrubs that separate below 15 cm. (6 in.) as individual stems. The procedure used should be recorded in the description of methods that will accompany the data for the natural area.

Density of tree seedlings (stems per unit area) might best be categorized by height class. This is because certain species produce many small seedlings that may live for only one or two growing seasons. These seedlings quickly pass out of the picture in terms of stand succession. Other tree species may not produce many individuals, but more of the seedlings survive and are able to replace canopy trees as they die. Thus, a species with a rather low density but with individuals in several height classes might be ecologically more important than a species that has a high density but individuals only in the smallest height class.

Cain and Castro (1959) warn against obtaining density data as an arbitrary or standard procedure. I agree with their recommendation in part. I would advise density determination only for the tree (all size classes) and tall shrub species.

Frequency

Another method of characterizing the composition and structure of vegetation is to describe how widely each species is distributed within a stand. Frequency is expressed as the percent of sample plots in which a species is represented by at least one stem. The concept of species distribution patterns is discussed in detail by Greig-Smith (1957, 1964), Cain and Castro (1959), and Pielou (1969). Frequency is a measure of the homogeneity of the species distribution when used in conjunction with density and dominance (basal area or cover). Frequency values alone are somewhat unsatisfactory because they may not reflect numerical importance. There are, for instance, plant communities that have the same overall species density but when sampled with equal area, plot size, and plot number, will yield frequencies that vary 25-fold due to differing types of plant distribution (Greig-Smith 1957). To be recorded for frequency, a species needs only be present in a plot; one stem counts the same as many.

Most American ecologists require a stem to be rooted in the plot to count as present. Frequency in this case is technically called rooted frequency. A plant could project over a plot, or because of growth form (such as a trailing stem) be physically present but not rooted. However, these cases do not constitute presence for frequency computation if no other stems of the species are rooted in the plot.

Frequency values cannot be directly compared unless they are determined from plots of equal size and shape because the probability of a given species being present in the plot is dependent on the relationship between the plot area and the plant size. Thus, a plot size appropriate for determining frequency of large trees is not appropriate for small herbs, etc. This in itself is an argument for using different plot sizes to sample the various plant components of a stand. Even within a particular component stratum, frequency will depend on plot size. McGinnies (1934) concluded that larger plots give a better determination of frequency for the less abundant species and smaller plots give a better determination for the more abundant species.

Like density, relative frequency can be expressed as the percent a species makes up of all species.

Dominance

As Cain and Castro (1959) have pointed out, dominance is a term that is used in many contexts. As used here, it refers to the mass that a species contributes to stand structure. Through density and frequency characterization we derive knowledge of species numbers and distributions within a stand. Through dominance we add another dimension–the volume of space occupied or area of ground covered or shaded. Because volume is difficult to measure or even estimate for most species (Cain and Castro 1959), projected coverage of the foliage onto the ground surface or basal area are the measures most often used.

Cover is expressed as a percent. Obviously plants overlap each other in space within a stand; cover therefore may total more than 100 percent. An exception is the lowest stand layer (see section on components) which will normally have a total cover of 100 percent.

A limited number of cover classes are often used to assign cover percentages. Cover can also be estimated to the nearest 10 percent or even to the nearest percent. The smaller the estimated interval of cover, the poorer is the reproducibility of the measurement. The final estimate may not be any more crude, however, than is an estimate made by broad classification.

Cover is most easily estimated for low-growing vegetation because one can project foliage to the ground easily when standing above. It is also easier to estimate projected cover over smaller plots or over a tape laid on the ground than over large plots. For these reasons, cover characterization is often restricted to stand components that are low growing and sampled on small plots. When cover estimates for larger components are desired, some type of sighting device and a combination of mirrors is used to read percent cover projected over a tape laid on the ground. For cover estimates over small plots a piece of material of known area can be used as a standard to aid in estimation.

A more readily obtainable measure of dominance for the larger components of a stand is basal area. Basal area is the cross sectional area occupied by the stems of a species. For trees this is typically measured at breast height (1.4 m. (4.5 ft.)) above the ground surface. For tall shrubs and tree seedlings basal area has been reported at 15 cm. (6 in.) above ground. Tree seedling and tall shrub diameter measurements have also been made in the field by 1-cm. size classes to facilitate sampling. Tree estimates are usually based on diameter measurements using tapes that measure diameter equivalent of tree circumference. The diameter is recorded in the field and the data are converted to area by reference to a table. In the past, diameter has also been measured by use of a caliper. Measuring tapes are also available that measure area equivalent of circumference directly.

Basal area can also be characterized by a plotless technique in which trees surrounding a sampling point are counted by sighting over an angle gage (Grosenbaugh 1952) or through a calibrated prism (Bruce 1955).

Basal area is expressed as ft.^{2} per acre, cm.^{2} per m., or m.^{2} per ha. Diameter in the field is usually measured to the nearest 0.25 cm. (1/10 in.) at the same time the stem is counted for density characterization.

Both relative cover and basal area can also be expressed as the percentage that each species contributes to the total cover of basal area for all species.

Determining the volume occupied by a species, though difficult, can be done. A method for shrub species, which involves removing shrubs from sample plots and immersing them in water to calculate volume by the amount of water displaced, has been described by Buckman (1966). Volume estimates of standing usable timber are made by foresters interested in the amount of merchantable wood available in a stand. The d.b.h. and the height of the usable part of the stem are measured. By reference to appropriate tables the cubic- or board-ft. estimates of wood are determined.

Productivity

Another method of characterizing the stand vegetation is to estimate the standing crop or biomass yield on an annual basis. This is a destructive sampling method because it requires the clipping and removal of the vegetation from the sample plot (ideally including the root system) and thus may not be permitted in some natural areas. The procedure involves drying and weighing the material either by species, groups of species, or other category. The details of this method of vegetation sampling have been described in IBP Handbook No. 2 (Newbould 1967) entitled "Methods for Estimating the Primary Production of Forests."

Age

In temperate climates trees lay down increments of wood that can be differentiated as annual rings when the stem is observed in cross section. The rings can be counted from the center of the tree (pith) to the outermost ring to determine the age of the tree at the height of the cross section. Rather than cutting the stem to count these rings, a core of wood can be taken from the tree with an instrument called an increment borer. As the borer moves into the tree it cuts a small core. The core is removed and the rings are counted. Additional years can be added to the ring count to allow for the time required for the tree to grow to the height at which the core was removed. This addition is only important if one is seeking an absolute age for the tree. By comparing the ages of trees forming the canopy, one should be able to determine if the stand is even-aged (all the canopy trees started growing at about the same time following some past disturbance such as wildfire), or if it is all-aged (suggesting that the forest is mature and has undergone some period of canopy replacement). An all-aged canopy implies that the site has been forested for some time and that there has been replacement of trees that have died. This information can provide an indication of successional trends and capabilities of various species.

Increment borers are available in various lengths from science equipment and forestry suppliers. Most tree species can be aged; however, some species when mature have rotten centers, making accurate ring counts impossible. With a little practice one should be able to remove a core that will include the pith of the tree. Certain hardwood species are difficult to bore, and it is even more difficult to extract the borer after a core has been removed. Applying soap to the outside of the borer when working with difficult species may help. Some species have annual rings that are difficult to distinguish. Smoothing the core on one surface by shaving or sandpapering, and then wetting it with water or kerosene may make the rings appear more pronounced. Cores of nonporous woods are best counted by cutting a thin slice of core and projecting light through the wood so the rings composed of larger, thinner-walled cells laid down in spring are more visible.

Canopy Height

When tree age in a stand is combined with tree height, one can make deductions regarding the site quality. Canopy height can be measured by use of a clinometer or abney level. The directions for doing this are included with the instrument. In general the procedure involves walking a measured distance from the tree and determining the angle, or percent, from your eye to the top and bottom of the tree. Simple tabular or computational conversions then express the tree height as a percent of distance the observer stands from the tree. General canopy or supercanopy height can be estimated by doing this for several trees in a stand.

Vegetation Strata

It is efficient to reduce the stand into components for sampling. Consideration should be given to sampling the various components with different methods and/or with different-sized plots. The data collected for the various components are often reduced to an equivalent base for quantitative description even though they have been collected differently. This section describes a forest stand consisting of four components: the tree, shrub, herb, and ground surface strata. Other stands may not contain all of these strata.

Tree Stratum (Supercanopy, Canopy, and Subcanopy)

This category includes woody stems capable of becoming canopy, supercanopy, or subcanopy trees, which at the time of sampling are at least 2.5 cm. (1 in.) in diameter at breast height (d.b.h.).

Many ecologists use some arbitrary rule to separate "saplings" from "trees"–thus one might consider individuals between 2.5 and 10 cm. (1 and 4 in.) d.b.h. as saplings and all stems over 10 cm. (4 in.) d.b.h. as trees. Separate estimates of density and other parameters would would be made for saplings and trees of each species.

If the vegetation consists of many large and few small trees, and if sampling is by plots, plot size should be rather large–up to 400 m.^{2} (1/10 acre) or 800 m.^{2} (1/5 acre). However, if there are many smaller trees, plots of 40 m.^{2} (1/100 acre) may suffice. Often 100-m.^{2} (1/40-acre) plots are a useful compromise for forest stands. The number of plots may vary with both the size of the plot and the complexity of the vegetation. As few as ten 400-m.^{2} plots or as many as forty 40-m^2 plots may be necessary. Twenty 100-m.^{2} plots may be adequate for some forest types.

Shrub Stratum

Individuals in the seedling size class (under 2.5-cm. (1-in.) d.b.h.) of trees and tall shrub species are included in this component. Tall shrub species, in contrast to low shrubs, are those capable of growing above the surrounding forbs. They may even attain more than 2.5-cm. d.b.h. and enter the subcanopy. This breakdown of the shrubs is an arbitrary procedure that allows more efficient sampling. It is not equivalent to the half-shrub/shrub differentiation of other workers based on dormant season stem dieback.

Where tall shrubs and tree seedlings are numerous, sample plots might be as small as 2 $m.^2$ (1/2 milacre). Where these plants are not especially numerous, or numerous in only some stands, the plot should be at least 4 $m.^2$ (1 milacre). An adequate sample may require as few as 15 plots or as many as 30 plots (or more) per stand.

Herb Stratum

Low shrubs, forbs, ferns, and fern allies are considered to be members of this component. A convenient plot size for this stratum is a quarter-milacre (1 $m.^2$). This plot, however, may range from 0.25 $m.^2$ (2 $ft.^2$). to 4 $m.^2$ (1 milacre). The objective should be to have a plot size such that the most widely distributed species has a frequency of about 90 percent. Ohmann and Ream (1971b), working in a wilderness area, used a 0.25-$m.^2$ (2-$ft.^2$) plot with fair success. At least one herb-stratum plot per tall-shrub plot should be used.

Ground Surface Stratum

Information on the characteristics of the ground surface within a stand is valuable. The area of mosses, lichens, litter, bare rock, dead wood, and bare soil is an easily measured aspect of stand structure. Since mosses and lichens are difficult to identify to the species level, they can be treated as groups and will still provide valuable information. A 0.25-$m.^2$ (2-$ft.^2$) plot will work well for obtaining this information, and will also allow accurate ocular estimates of percent cover. If the plot used to sample the herb stratum is not too large, the ground-cover stratum can also be sampled in that plot.

Data Evaluation and Analysis

Units

Although the examples used in this manual are in English units, one should consider the possibility of using metric units or at least reporting the metric equivalents. Most countries use the metric system. These data may eventually be part of a world data bank that would likely operate under the metric system. Any procedure that will make the natural area data more compatible with other data available in a data bank system is worthwhile.

Errors

Discussion of statistical error has been included throughout the manual. Wherever possible one should use random-sampling procedures. This allows estimates of the standard error of the mean (average) to be made, as well as statements that (within a selected probability) the true value of the mean lies within a certain range on either side of the computed value (Greig-Smith 1964). Because generation of baseline data from individual stands is the primary objective of this manual, statistical tests are not presented. Look to any basic statistical textbook for the necessary statistical treatment, or for more specific examples regarding testing of vegetation data, see Greig-Smith (1964) or Freese (1967). The point to remember is that someone will want to apply statistical treatment to the baseline data for future comparisons. Thus, the nature of the data collection should allow valid comparisons to be made.

Errors in recording data and in computations are also important areas of concern. Review data forms in the field for obvious errors of omission or commission. Set up computing procedures that provide cross-checks on value totals. Retain all field data forms and computation worksheets (properly identified) as part of the natural area files.

Computations

In reporting the data use reasonable numbers of significant figures. Since many of the measurements are made in whole numbers, the resulting values from the computations should also be presented rounded off to the nearest whole number. Mean values are often presented to one or more decimal places, variability measures to two places (Sokal and Rohlf 1969). If summary data are presented to many decimal places for some reason, detail the units of original measurement in the report so that the proper importance may be attached to the reported values.

Analysis and Syntheses of Data

The stand summary data can be used as a baseline for later comparison of vegetation changes. It can also be used to describe the plant communities of the natural area through classification procedures. Finally, the data can be used in other ways, such as examining environment-vegetation relationships, or aiding in mapping vegetation of the area through airphoto interpretation and ground checks. Description of these and other techniques of analysis and synthesis is beyond the scope of this manual, but one should be aware of the possibility that others will become interested in carrying the baseline work forward to a complete description of the natural area.

Data Storage and Use

Be sure to record a complete, detailed description of the methods used to sample the natural area. An accurate description of the location of each stand and the location and marking of each sample plot within the stand should be included.

Devise and use a systematic method of identifying field data forms, worksheets, and summary sheets. The collection of papers mounts quickly and if each sheet is not properly identified, some may be lost or misfiled. Data that cannot be identified as to origin have no scientific value.

Several copies of data and natural area reports should be stored. The original reports should remain in the natural area file deposited with the managing agency. Perhaps one copy should be filed with a local or regional educational institution. Hopefully, there will soon be a national depository for these data where one or more copies of the report should be placed.

In addition to providing baseline data for future comparisons, natural area studies should make data available for use by other scientists. Such data provide a base for studies of productivity, species autecology, and influence of environmental factors on flora or vegetation. One way to make others aware that these basic data are available is to publish (with approval of the managing agency and perhaps with their help) a summarized version of the natural area report.

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☆ U.S. Government Printing Office: 1973 – 762-046

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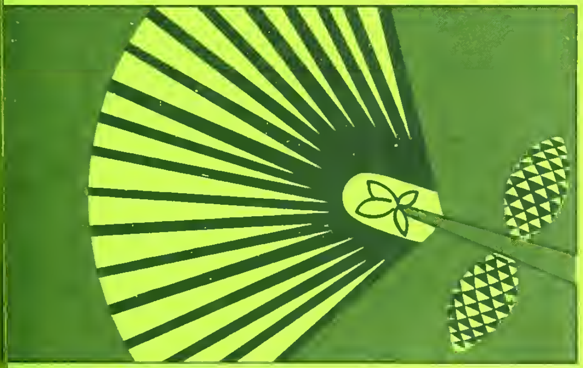

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EFFECTS OF THINNING ON YOUNG SHORTLEAF PINE PLANTATIONS IN INDIANA

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CONTENTS

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Manuscript approved for publication July 19, 1973

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EFFECTS OF THINNING ON YOUNG SHORTLEAF PINE PLANTATIONS IN INDIANA

Howard M. Phipps

Shortleaf pine (*Pinus echinata* Mill.) has been planted in southern Indiana and neighboring areas in the Central States Region since the late 1930's; today these plantations represent an important timber resource. This species has a wide natural range and usually establishes on dry upland soils and eroded sites. It is noted for its ability to resprout, up to the age of 8 to 10 years, if the main stem should be destroyed by fire or cutting. Many of the older stands were planted at close spacings; if they are allowed to remain so, tree crowns may become too small to maintain satisfactory growth, and mortality due to overcrowding may ultimately reduce total yield.

Two studies were established on the Hoosier National Forest in southern Indiana to determine if thinning young plantations will increase growth or quality of the residual stand, and if so, what residual density may be most appropriate.

THE STUDIES

The first study was established in a 14-year-old plantation near Tell City in an area known as German Ridge during the winter of 1950-51.[1] The pretreatment spacing was 6 by 6 feet with an average basal area of 127 square feet per acre. Treatments consisted of plots thinned to 120, 100, and 80 square feet of basal area and an unthinned control. Each treatment was replicated four times on one-tenth-acre plots. Plots were thinned again to the same basal areas in 1958.

A second study was begun in 1956-57 in a 17-year-old plantation near Houston, approximately 100 miles north of German Ridge. Average basal area per acre before thinning was 165 square feet. Plots 1/5-acre in size were thinned to basal areas of 130, 110, 90, and 70 square feet, and unthinned plots were left as controls. There were two replications of each treatment. A second thinning was made in the winter of 1961-62. In 1958 permanent sample trees (dominant or codominant) were selected in each treatment plot so that the effects of various thinning treatments on potential crop trees could be evaluated. Average sample tree height in both plantations was about 48 feet at age 25, which indicates a site index of 80 at 50 years (USDA Forest Service 1929). Plots were last measured in 1969.

RESULTS

Mortality

Fomes annosus had caused some losses in the heavily thinned plots at German Ridge after the initial thinning, and its presence was suspected at Houston. Subsequent observations and mortality counts did not indicate that the disease was becoming more widespread or increasing in severity, but potential losses — especially of the larger trees — is a factor to be considered in thinning decisions. For the 7-year period between the first and second thinnings, mortality from all causes at German Ridge was 28, 22, 56, and 48 trees per acre for the heavy, medium, light, and control treatments, respectively. For the 11-year period after the second thinning the counts were 30, 87, 86, and 262 for the same treatments. At Houston total losses 5 years after the first thinning ranged from 20 trees per acre in the heaviest thinning to 50 trees per acre in the control, and from 14 to 146 trees per acre 8 years after the second thinning.

Basal-Area Growth

The rate of basal-area growth declined in all treatments of both plantations from the time of the first

[1] *For early reports of this study refer to Clark (1956), Limstrom and Deitschman (1953), and Williams (1959).*

hinning measurements (tables 1 and 2). Although lifferences in growth rate among the treatments were iot great, there is evidence that plots thinned to 110 quare feet at Houston and 120 square feet at Gernan Ridge grew somewhat better than the other reatments. It is interesting to note that although nortality in the unthinned plots of both plantations luring the last 8 years of the study was about seven imes greater than in the most heavily thinned plots, he decline in average net basal area growth was simiar for all treatments. The unthinned plots still maintained the largest basal areas among treatments. Thus t does not appear that plots left unthinned to age 30 ire in danger of becoming stagnant or that mortality lue to competition would result in a serious loss of basal-area growth.

Diameter and Height Growth

Thinning caused increases in average d.b.h. ranging rom 1.9 to 0.5 inches at Houston and from 0.7 to 0.2 inches at German Ridge (tables 3 and 4). The effects of thinning on size class distribution were most evident at Houston. For example, at the last meaurement the most heavily thinned plots produced about 90 trees per acre in the 10- to 12-inch class, as opposed to about 15 trees per acre of that size in the control. However, the number of trees per acre in the 8- to 9-inch class was greatest in the control and least in the most heavily thinned plots. At German Ridge none of the thinning treatments increased the number of trees in the 10- to 12-inch class over that of the control, and thinning to 80 and 100 square feet of basal area reduced the relative number of trees in the 8- to 9-inch class. Effects of thinning on the diameter of permanent sample trees were similar to those reported above. There were small differences among treatments at German Ridge and 2.1 inches difference between the heaviest thinning and control at Houston. The average sample tree in both plantations measured 9.0 inches in 1969.

Table 1. — *Periodic annual basal area growth and residual basal area by thinning treatment at German Ridge*
(In square feet per acre)

Thinning treatment (sq. ft. of basal area per acre)	Annual basal-area growth at age:			Basal area at age 32
	0 to 14	14 to 21	21 to 32	
80	9.1	6.4	3.4	118
100	8.9	6.6	2.7	130
120	9.4	7.4	4.1	165
Control	8.9	7.4	2.9	208

Table 2. — *Periodic annual basal area growth and residual basal area by thinning treatment at Houston*
(In square feet per acre)

Thinning treatment (sq. ft. of basal area per acre)	Annual basal-area growth at age:				Basal area at age 29
	0 to 17	17 to 19	19 to 22	22 to 29	
70	9.4	7.3	6.3	4.1	99
90	9.4	6.2	6.1	4.3	123
110	10.3	9.4	7.0	5.4	150
130	9.7	8.5	6.6	4.3	162
Control	9.9	8.2	5.5	2.7	220

Table 3. — *Average stand d.b.h. by thinning treatment at German Ridge*
(In inches)

	Basal area 80	100	120	Control
1969	8.6	7.9	8.0	7.6
1951	5.2	5.0	5.1	4.9
Change	3.4	2.9	2.9	2.7

Table 4. — *Average stand d.b.h. by thinning treatment at Houston*
(In inches)

	Basal area 70	90	110	130	Control
1969	9.0	8.2	8.4	7.4	7.1
1956	5.6	5.7	5.8	5.4	5.6
Change	3.4	2.5	2.6	2.0	1.5

According to pole measurements of sample tree heights at Houston, average annual height growth from 1958 to 1969 ranged from 2.0 feet in the control plots to 1.7 feet in the most heavily thinned plots. Average tree heights on these plots in 1969 were 56 and 54 feet, respectively. Control-plot trees at German Ridge grew 1.7 feet per year as opposed to 1.3 feet in the most heavily thinned plots, with average heights in 1969 of 59 and 53 feet, respectively. Measurements taken during the first 7 years of the study at German Ridge indicated no differences in average height growth among the treatments (Williams 1959).

Volume Growth

Regardless of treatment, volume growth rate began to decline in both plantations after about 20 years. However, some thinning treatments evidently increased total cubic-foot volume or merchantable cubic-foot volume at different stages in stand development (tables 5 and 6). Generally, the first thinnings were more effective than the second thinnings in increasing growth rate. At German Ridge, thinning to 120 square feet increased merchantable volume growth after the first thinning and total cubic-foot volume after the second thinning. Thinning to 80 and 100 square feet accelerated merchantable volume growth after the first thinning but reduced both total and merchantable volume after the second. At Houston, after the first thinning both merchantable and total volume growth rates were best in plots thinned to 90 square feet, with an indication of slight benefit from thinning to 110 and 130 square feet. After the second thinning only the plots thinned to 110 square feet showed better growth than the control plots.

Table 5. — *Periodic net annual volume increase in the Houston plantation*[1]
(In cubic feet[2] per acre)

Thinning treatment (sq. ft. of basal area per acre)	Age (years) 0-17	17-19	19-22	22-29
70	146	174	162	129
	(126)	(166)	(181)	(133)
90	144	185	243	148
	(124)	(190)	(249)	(153)
110	158	244	197	188
	(136)	(239)	(210)	(193)
130	147	234	206	168
	(124)	(241)	(215)	(181)
Control	151	231	199	174
	(128)	(240)	(207)	(187)

1/ Thinned at ages 17 and 22.
2/ Top figure is total cubic-foot volume; lower figure in parentheses is merchantable cubic-foot volume.

Table 6. — *Net annual volume increase in the German Ridge plantation*[1]
(In cubic feet[2] per acre)

Thinning treatment (sq. ft. of basal area per acre)	Age (years) 0-14	14-21	21-32
80	107	158	120
	(79)	(165)	(122)
100	102	170	107
	(75)	(177)	(110)
120	106	194	174
	(79)	(203)	(155)
Control	101	204	143
	(75)	(152)	(192)

1/ Thinned at ages 14 and 21.
2/ Top figure is total cubic-foot volume; lower figure in parentheses is merchantable cubic-foot volume.

Form class[2] measurements of sample trees showed nly minor differences among treatments in either lantation by the end of the study period. In the Iouston plantation the form class increase in the ontrol was .18, as opposed to .21 for the other treatments. At the end of the study form class ranged from .833 in the 70-square-foot treatment to 0.800 in the ontrol. There was little difference among treatments t German Ridge, where the average form class for all ensities was 0.817.

Live crown percent (i.e., the percent of total tree eight in live crown) showed a definite correlation to hinning intensity in both plantations. In 1969 the igher the residual density, the shorter the live crown. Crown percents in the German Ridge plantation anged from 36 in the most heavily thinned plots to 0 in the check control, and at Houston from 43 to 8. For satisfactory growth in the loblolly-shortleaf ine type, Westveld (1949) recommended thinning eavily enough to maintain an average live crown ercent of about 40. However, results of our studies howed that thinning heavily enough to maintain a ve crown percent of 40 benefited growth very little, ut reduced total yield considerably.

Net Volume Yield

At German Ridge the highest productivity in terms f total cubic-foot volume[3] was obtained in the plots hinned to 120 square feet and in the control — 4,491 nd 4,418 cubic feet per acre, respectively. Thinning o 100 and 80 square feet produced total yields of ,793 and 3,922 cubic feet per acre. The light thinning and control treatments also produced the greatest merchantable volume.[4] Total yield for each of hese treatments was 4,226 cubic feet per acre, which xceeded yields for the most heavily thinned treatments by about 1,600 cubic feet per acre (fig. 1).

At Houston the greatest yields in terms of both otal and merchantable volume were obtained by thinning to 110 square feet. Total volume yield per acre for this treatment was 5,065 cubic feet, compared with 4,846 for the control and 4,590 and 4,220 for the plots thinned to 90 and 70 square feet, respectively. Merchantable volume yield in the control plots exceeded the yield in plots thinned to 70 square feet by about 600 cubic feet, and in plots thinned to 90 square feet by about 200 square feet. Thinning to 110 square feet produced about 180 cubic feet more of merchantable volume than no thinning. Similar results were obtained in a study in southern Illinois (Boggess *et al.* 1963), where it was found that heavy thinning in 15- to 17-year-old shortleaf pine plantations did not improve either growth or total yield during the following 5 years, and as site quality increased, thinning became less advantageous.

Hardwood Invasion

There has been considerable hardwood invasion in the study plantations, with an approximate two-fold increase in number of stems in the last 10 years of the study. In the German Ridge plantation the most hardwood stems 0.6 to 5.5 inches in d.b.h. were found in the more open plots. This was not evident, however, for stems less than 0.6 inches d.b.h. In the Houston plantation, residual density had no apparent effect on number of hardwood stems. The predominant hardwood species in both plantations was dogwood. Other species frequently encountered were white ash, elm, red and sugar maple, sassafras, yellow-poplar, black cherry, and black oak. A comparison with sampling results obtained 10 years previously in species frequency. Elm and redbud in the control the German Ridge plantation indicates a change in plots and sassafras and persimmon in the more open plots have been replaced largely by dogwood and white ash, although sassafras continues to be abundant.

The more common species and their relative abundance are listed for the two plantations in table 7. In the German Ridge plantation the average number of hardwood stems per acre on the thinned plots was about 6,400 and on the control plots about 4,850. Hardwoods were somewhat more abundant in the Houston plantation, with an average of 8,550 seedlings per acre.

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[2] *Girard form class.*

[3] *Total stem volume inside bark, including stump nd top.*

[4] *Volume to 3-inch top inside bark, excluding tump.*

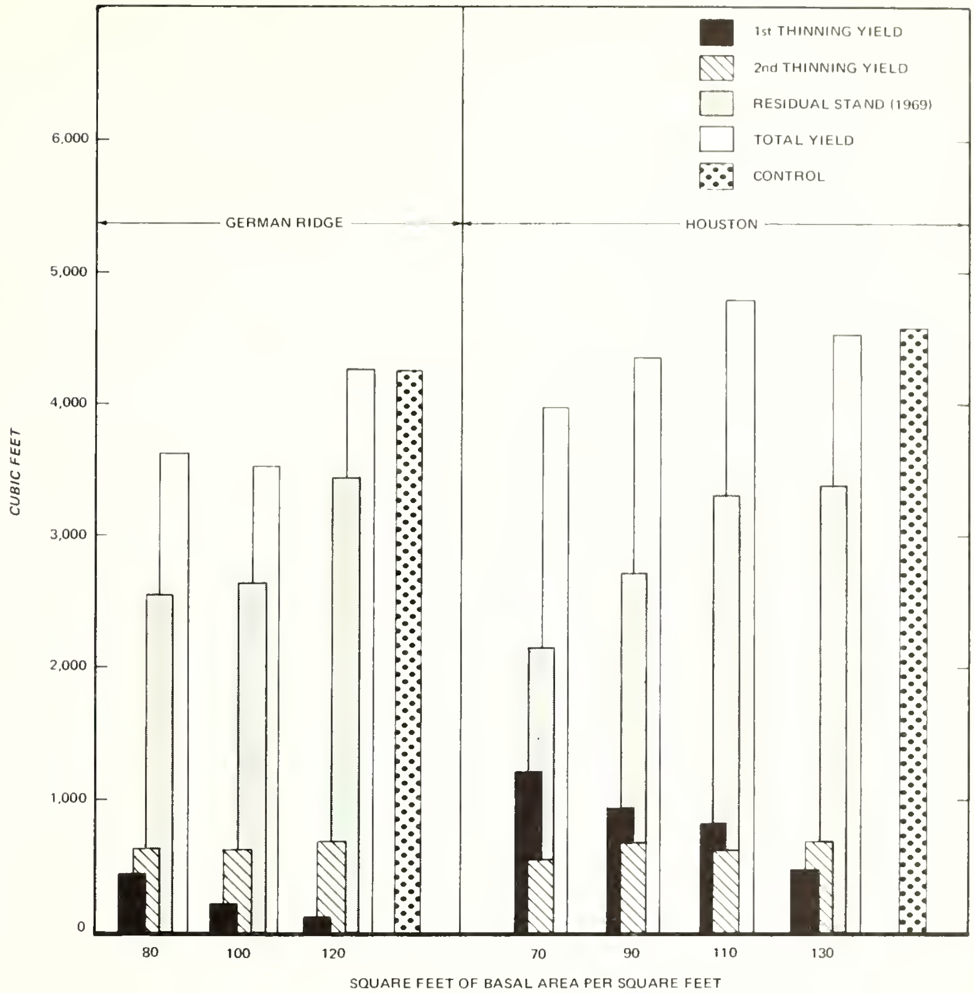

Figure 1. — *Net merchantable volume yield for the German Ridge and Houston plantations.*

SUMMARY

The results of studies in two shortleaf pine plantations in southern Indiana suggest that thinning before age 30 would be of questionable value in improving growth and yield. Thinning to 70 and 90 square feet of basal area at Houston increased average d.b.h. by 1.9 and 1.0 inches. As a result of these treatments, however, merchantable volume yields were reduced by about 5 percent and 13 percent, respectively. Yields were also substantially reduced at German Ridge by the two heaviest thinnings. Thinning lightly to 120 and 110 square feet produced slight increases in basal area growth rate and yield. Form class was changed little by thinning, but differences in live-crown ratio were evident, with the greatest reduction occurring in the unthinned plots. Thinning may increase losses due to *Fomes annosus*.

Without control measures it appears that hardwood species will succeed shortleaf pine in these plantations. If it is desired to convert these stands to hardwoods, it is likely that some level of thinning would aid in encouraging the more desirable but less tolerant species.

Table 7. — *Invasion of shortleaf pine plantations by hardwood treatments, 1968*

Species	German Ridge: Average stems/acre	German Ridge: Percent of total	Houston: Average stems/acre	Houston: Percent of total
High commercial value:				
White ash	1,193	20.2	107	1.3
Black oak	316	5.4	279	3.3
Sweetgum	304	5.2	---	---
Black cherry	276	4.7	1,011	12.0
Yellow-poplar	245	4.2	---	---
Miscellaneous	104	1.8	51	0.6
Total	2,438		1,448	
Low commercial value:				
Dogwood	1,244	21.1	4,919	58.5
Sassafras	664	11.1	338	4.0
Elm	509	8.6	103	1.4
Red maple	289	4.9	517	6.1
Sugar maple	234	3.9	395	4.7
Redbud	188	3.2	---	---
Spicebush	81	1.4	---	---
Sumac	80	1.4	199	2.4
Hazel	---	---	95	1.1
Beech	75	1.3	117	1.4
Miscellaneous	93	1.6	280	3.3
Total	3,457		6,963	

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☆U.S. Government Printing Office: 1973 — 762-244

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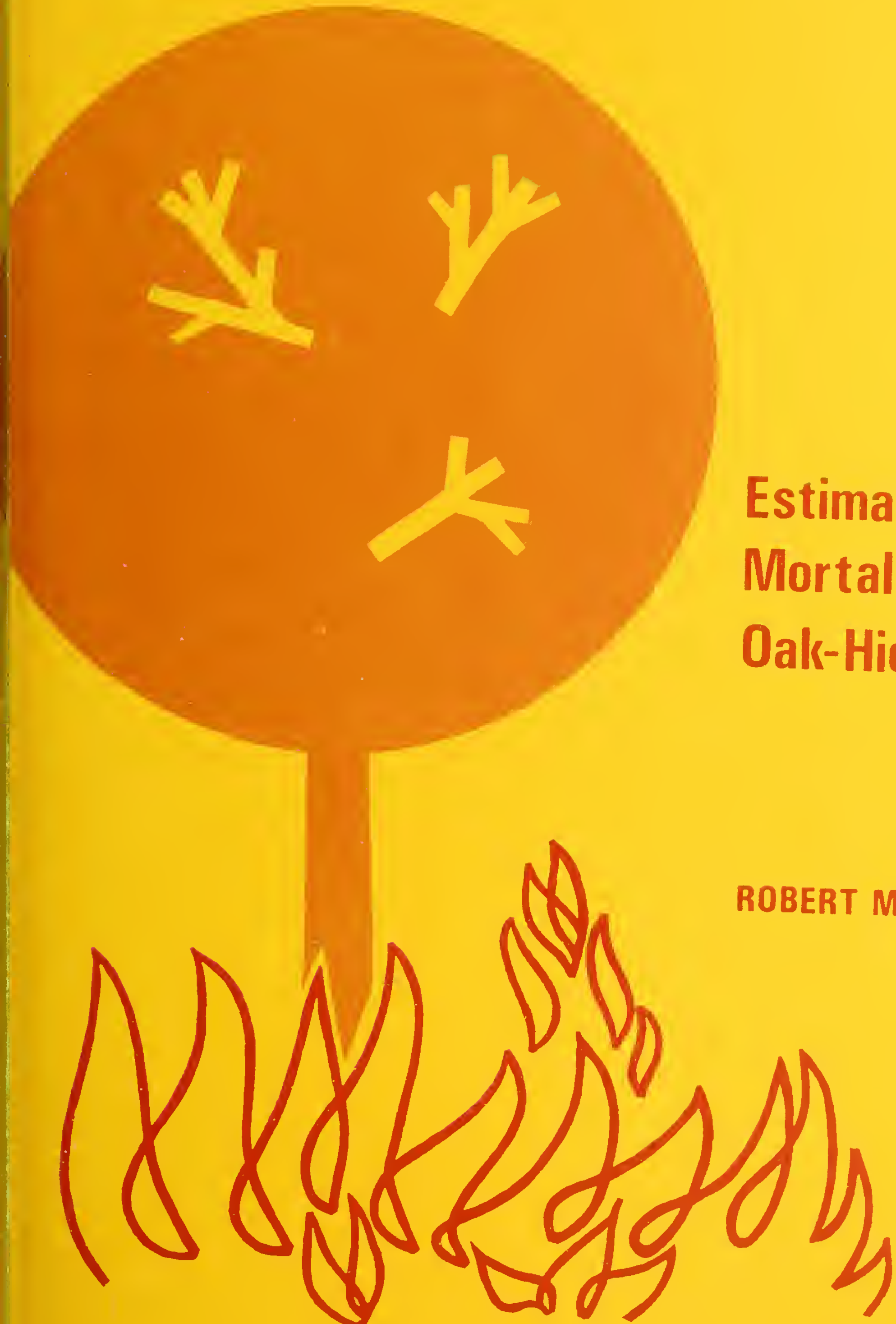

Estimating Fire-Caused Mortality and Injury in Oak-Hickory Forests

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Manuscript approved for publication June 18, 1973

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THIS PAPER IS AN EXPERIMENT IN COMMUNICATION.

Realizing that the needs and interests of our two major "clients" — the scientist and the practitioner — are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

The Documentation section describes the details of the research process. It is for the reader interested in laboratory and field procedures, tabulations, statistical analysis, and philosophical discussion. This section, too, is self-contained.

Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. *We would like to have your opinion.*

ESTIMATING FIRE-CAUSED MORTALITY AND INJURY IN OAK-HICKORY FORESTS

Robert M. Loomis

APPLICATION

The effects of fire on trees in the central and eastern hardwood forests are variable. Some trees are unaffected, some are injured but survive, some are killed immediately, and others die a year or more later. The most accurate damage appraisal can be made after one or two growing seasons have passed. By this time most delayed mortality has occurred and wounding is evident. But appraisals are often needed immediately after a fire for estimating damages, for planning and scheduling timber salvage or rehabilitation operations, for statistical reporting, and for possible legal action (fig. 1).

Figure 1.--*Appraisals are often needed immediately following fire.*

A method is presented here, applicable to the oak-hickory forest, for immediately predicting tree mortality and estimating basal wound size for surviving trees. This method can be used at any time of year; it requires only observations or measurements of (1) tree species, (2) tree d.b.h., (3) height of bark blackening,[1] and (4) width of bark blackening at 1 foot above ground (stump height). It is best applied to trees from 1 to 16 inches d.b.h. However, with caution it can be used for larger trees.

Mortality equations (table 1) were derived for black oak, white oak, post oak, and scarlet oak. The black oak formulas are also applicable to hickory and northern red oak. The mortality curves define the division between mortality and survival (figs. 2 and 3).

Equations for estimating wound dimensions on black and white oak are shown in table 2. The black oak equations may also be used for scarlet oak, northern red oak, hickory, and ash, and the white oak equations may also be used for post oak and chestnut oak.

The mortality graphs may be used to predict whether a tree will live or die. If survival is expected, then wound size equations may be used to estimate wound dimensions.

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[1]*Bark blackening (scorch) includes all degrees of discoloration from a bark surface only slightly browned or blackened or where scattered discontinuous pitting has occurred, to a bark surface that has been reduced in thickness or consumed.*

Table 1.--*Equations for estimating mortality probability of eastern oak-hickory forest species by season of fire*

Species	Season	Number of trees	Mortality probability (M%): Equation[1]	R^2	Standard error
Black oak[2]	Dormant[3]	424	M% = 87.7 + 13.6 Sh - 121.3 Log d.b.h.	0.72	15.9
	Growing[4]	317	M% = 93.6 + 20.4 Sh - 125.2 Log d.b.h.	.77	17.6
White oak	Dormant	331	M% = 84.8 + 9.2 Sh - 121.3 Log d.b.h.		
	Growing	333	M% = 90.6 + 13.7 Sh - 125.1 Log d.b.h.	.71	19.7
Post oak	Dormant	89	M% = 51.4 + 8.7 Sh - 92.6 Log d.b.h.		
	Growing	69	M% = 54.9 + 13.1 Sh - 95.5 Log d.b.h.	.49	27.8
Scarlet oak	Dormant	156	M% = 108.4 + 14.0 Sh - 127.1 Log d.b.h.		
	Growing	109	M% = 115.7 + 20.9 Sh - 131.1 Log d.b.h.	.66	19.7

[1]/D.b.h. = diameter breast height in 0.1 inch; Sh = height of bole blackening in 0.1 foot. When d.b.h. ≥ 11.0 inches, use 11.0 inches in equation.

[2]/Also applicable for northern red oak and hickory.

[3]/Dormant season--after leaves turn color in fall until they begin emerging in spring.

[4]/Growing season--from time leaves begin emerging in spring until they turn color in fall.

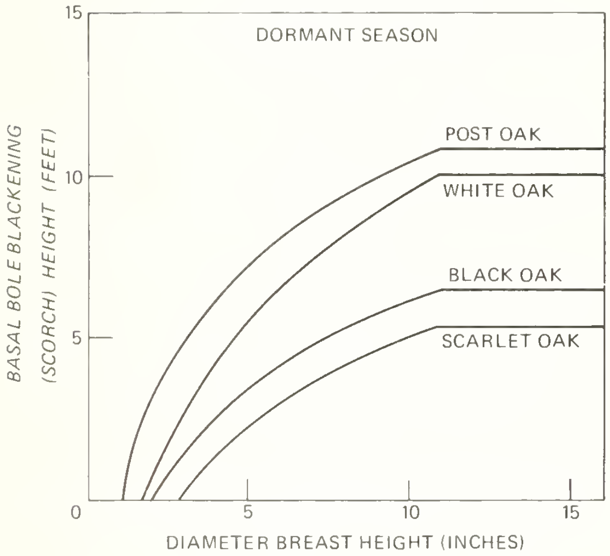

Figure 2.--*Fifty percent mortality probability for upland oaks after dormant-season fire. Probability greater than 50 percent above (mortality) and less than 50 percent below (survival) curve.*

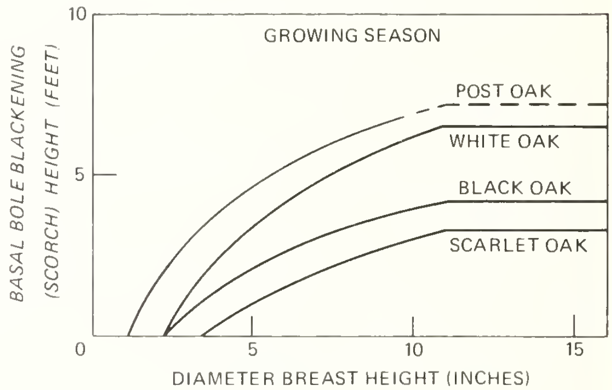

Figure 3.--*Fifty percent mortality probability for upland oaks after growing-season fire. Probability greater than 50 percent above (mortality) and less than 50 percent below (survival) curve.*

For example, assume a tree from a dormant-season fire is a black oak 9 inches d.b.h. with a basal scorch height of 5 feet and a scorch width at 1 foot of 1.3 feet. Select the mortality curve for dormant-season and black oak (fig. 2). Locate 5 feet (scorch height) along the left axis and 9 inches (d.b.h.) along the base. The point of intersection of these values is beneath the black oak curve, thus predicting tree survival.

Wound size can now be estimated by using formulas from table 2. By multiplying the observed scorch height of 5 feet by the factor 0.9, a wound height of 4.5 feet is obtained. By multiplying the observed scorch width of 1.3 feet by the factor 0.6, a wound width of 0.8 foot is obtained.

Mortality equations and graphs are not reliable for trees less than 3 inches d.b.h. The observer should depend more on his judgment, considering the general appearance of the fire area and indicated fire intensity.

Table 2.--*Equations to estimate wound dimensions for eastern oak-hickory forest species by season of fire*

Species	Season	Number of trees	Wound height (Wh)		Wound width (Ww)	
			Equation[1]	Standard error	Equation[1]	Standard error
Black oak[2]	Dormant[3]	170	Wh = 0.9 Sh	2.1	Ww = 0.6 Sw	0.5
	Growing[4]	104	Wh = 1.2 Sh	1.8	Ww = .7 Sw	.4
White oak[5]	Dormant	174	Wh = .7 Sh	1.5	Ww = .6 Sw	.4
	Growing	70	Wh = 1.0 Sh	.9	Ww = .7 Sw	.3

1/Sh = height of bole blackening in 0.1 foot; Sw = width of bole blackening in 0.1 foot at 1 foot above ground.

2/Also applicable for scarlet oak, northern red oak, hickory, and ash.

3/Dormant season--after leaves turn color in fall until they begin emerging in spring.

4/Growing season--from time leaves begin emerging in spring until they turn color in fall.

5/Also applicable for post oak and chestnut oak.

DOCUMENTATION

Methods

Observations and measurements were made on about 2,100 trees from 28 fires in Missouri, Pennsylvania, and West Virginia. Trees selected had good vigor before the fire and were free from prior basal injury. Some of the variables observed or measured were: bark blackening, tree species, d.b.h., and season of fire occurrence. We recognized the following degrees of bark blackening:[2]

1. *Burn.*--Continuous blackening of bark ridges; outstanding reduction in bark thickness. White ash on bark surface and black fissures (very recent fires).

2. *Char.*--Continuous charring and, in some instances, reduced thickness of ridges or bark scales. Little or no fissure discoloration. Also includes the areas classified as burn.

3. *Scorch.*--Slightly browned or blackened bark surface; scattered or discontinuous pitting of bark ridges; fissures usually unchanged in color. Also includes areas classified as char and burn.

Analysis showed the scorch degree to be best for prediction. However, awareness of the other degrees can be helpful in field appraisal.

Black oak and white oak had the best overall distribution of sample trees and variables (tables 3 and 4). Thus they were used in developing the equations for all species.

Mortality has immediate significance in damage appraisal, but wounding has delayed effects related to wound size. For example, fire scars are often the entry point for decay fungi (fig. 4).. Berry (1969), in studying decay in the upland oak stands of Kentucky, found fire scars to be the most important means of entry for decay fungi. He also found that more than one-fourth of all infections came from fire scars, and almost one-third of the total decay volume was associated with fire scars in the 30- to 110-year-old even-aged oak or oak-hickory stands he observed.

The trees having a single dominant wound larger than 2 inches in length or width were used in developing the wound size estimating equations.

[2]*These three degrees of bark blackening are similar but not identical to those described by Nelson* et al. *1933.*

Discussion

The standard errors of estimate associated with the equations indicate the wide range of prediction response. The response is, of course, due to interaction of many variables, with a limited number of the more significant used for prediction. Thus, the estimated damage for individual trees or fires may vary greatly from the actual. Reliability increases with increase both in number of sample trees and number of fires.

Table 3.--*Summary of data used in developing the fire-caused mortality predictions*

Species	Season	Number of fires	Number of trees, D.b.h. (inches) 1.0-4.9	5.0-10.9	11.0-15.9	16.0+	Total	D.b.h. (inches) Mean	Range	Height of bark blackening (feet) Mean	Range	Mortality percent Mean	Std. dev.
Black oak	Dormant[1/]	16	98	274	44	8	424	7.5	1.9-22.5	4.2	0.6-12.0	43	30
	Growing[2/]	10	122	160	35	0	317	4.8	1.1-15.8	2.7	.2-13.0	52	37
White oak	Dormant	14	161	155	14	1	331	5.5	1.5-16.5	4.6	.4-18.0	23	27
	Growing	8	273	57	2	1	333	3.6	1.1-17.7	3.4	0-34.0	69	36
Post oak	Dormant	9	52	35	2	0	89	5.0	1.7-15.3	4.4	.6-14.0	38	40
	Growing	7	53	16	0	0	69	4.2	1.4- 9.9	3.1	.4-10.5	39	38
Scarlet oak	Dormant	8	9	123	24	0	156	8.3	3.1-15.9	2.9	.7- 9.1	25	33
	Growing	6	56	46	6	1	109	5.9	2.2-20.5	2.5	0-14.0	69	33
Northern red oak	Dormant	3	23	37	15	8	83	8.4	1.8-19.1	4.2	.7-12.0	36	37
Hickory	Dormant	9	50	16	3	0	69	4.4	1.4-14.5	2.3	.5- 9.0	26	24
	Growing	4	17	5	2	0	24	4.4	1.7-13.8	1.9	.5- 6.5	75	36

1/Dormant season--after leaves turn color in fall until the new ones begin emerging in spring.

2/Growing season--from time leaves begin emerging in spring until they turn color in fall.

Table 4.--*Summary of data used in developing the equations for estimating fire-caused basal wound dimension*

Species	Season	Number of fires	Number of trees	D.b.h. (inches)			Height of bark blackening (feet)			Width of bark blackening at 1 foot (feet)			Wound height (feet)			Wound width at 1 foot (feet)		
				Mean	Std. dev.	Range	Mean	Std. dev.	Range	Mean	Std. dev.	Range	Mean	Std. dev.	Range	Mean	Std. dev.	Range
Black	Dormant[1]	14	170	7.7	3.5	3.2-22.5	3.8	1.8	0.9-12.0	1.6	0.9	0.0-5.0	3.6	2.3	0.2-15.0	1.1	0.8	0.0-4.[illegible]
oak	Growing[2]	9	104	7.2	3.1	2.2-15.6	2.4	1.3	.2- 6.0	1.2	.9	.0-3.8	3.0	2.1	.3-12.0	.9	.8	.0-3.3
White	Dormant	11	174	5.6	2.7	1.8-15.8	4.4	2.8	.8-14.0	1.0	.6	.0-3.7	3.4	2.4	.4-14.0	.6	.5	.0-3.3
oak	Growing	8	70	4.6	2.0	1.1-10.7	2.2	1.6	.4- 7.3	.7	.6	.0-2.8	2.4	1.6	.4- 7.3	.5	.4	.0-1.9
Post oak	Dormant	7	35	5.4	2.4	2.2-11.6	4.0	1.9	.7- 8.5	1.3	.6	.0-2.6	2.8	1.7	.3- 8.2	.8	.5	.0-1.8
	Growing	6	33	4.3	1.8	1.7- 9.5	2.7	1.9	.8-10.5	.8	.5	.0-2.4	2.3	1.8	.3-10.0	.5	.4	.0-2.2
Scarlet	Dormant	5	46	8.1	2.3	4.6-12.9	2.7	1.2	.9- 6.2	1.5	.7	.0-3.3	3.0	2.4	.4-10.0	.9	.6	.0-2.6
oak	Growing	5	30	6.5	3.6	2.5-20.5	1.9	.8	.9- 4.2	.8	.6	.0-2.1	4.9	2.7	.6- 9.0	.8	.4	.0-2.1
Northern red oak	Dormant	3	49	8.2	4.3	2.0-19.1	3.7	2.2	.7-11.0	1.7	1.4	.0-6.0	5.9	3.4	.3-13.0	.9	.7	.0-3.4
Chestnut oak	Dormant	2	47	7.8	2.8	2.5-14.0	4.6	2.5	1.2-11.0	1.4	.7	.3-3.2	2.5	1.8	.4-10.0	.5	.4	.0-1.6
Hickory	Dormant	7	36	4.3	2.5	1.9-14.5	2.3	1.6	.5- 9.0	.6	.4	.0-2.2	3.6	3.3	.4-11.0	.4	.3	.0-1.7
Ash	Dormant	1	6	4.0	1.0	2.6- 5.0	4.2	2.3	1.6- 7.5	.8	.4	.4-1.5	4.0	2.6	1.4- 7.3	.5	.2	.3- .9

1/Dormant season--after leaves turn color in fall until the new ones begin emerging in spring.

2/Growing season--from time leaves begin emerging in spring until they turn color in fall.

Figure 4.--*Fire scars are often the entry point for decay fungi. In this tree heartrot followed wounding, and the wound face never closed.*

Independent Variables

Heat-killing temperature varies inversely with exposure time; the relation between time and temperature is exponential within the biokinetic (living temperature) zone according to Hare (1961). Hare also states: "...a fairly high temperature may cause no apparent injury during comparatively long exposures, whereas a few degrees higher will kill in a brief time." Bark blackening is a visible expression of time and temperature. Thus, blackening or its absence is a good indicator regardless of season.

Trees may be killed by heat either in the crown or on the lower bole. Obviously, the taller the tree, the less likely it is to be killed by heat in the crown. The lower bole also becomes less subject to fire injury with increase in tree size and age because the bark is thicker, offering more protection to the cambium. Thus, d.b.h. relates to heat injury both because of bark thickness and tree height.

D.b.h., although a significant variable for predicting mortality, was not found to contribute enough to estimating wound size when added to scorch dimension to warrant its use.

Some prediction variation is due to physiological and anatomical differences. Kayll (1968), working primarily with conifer seedlings, found dormant seedlings generally more heat tolerant than those physiologically active. He also found heat tolerance differences between species. Species may account for bark differences as well as heat tolerance differences. Season may also account for some differences in heat tolerance.

Radiant solar energy is another interacting variable. This heat energy is probably most effective in raising initial cambium temperature of the lower bole just before hardwood leaves emerge, when the angle of the sun is high, and the boles are not shaded by leaves. The data suggest that the highest mortality and greatest injury may occur when buds are breaking and small leaves are emerging. Radiant energy is partly accounted for by season. Air temperature at time of fire is only recognized to the extent that season is accepted as a variable.

Season is also a significant variable because within the eastern hardwood forest, convective heat dispersal from a fire is probably much less effective when hardwoods are in leaf than during the dormant season. This could mean longer exposure of the tree to high temperatures when trees are in leaf.

Air movement and heat dispersal are also affected by topography, slope, aspect, and wind speed and direction. Bark blackening is related to these as well as to other variables. The bark blackening pattern is usually found on the leeward or uphill side of trees.

Additional Observations

A helpful observation possible following growing-season fires is the height to which foliage, buds, and small branchwood cambium are killed. This can assist in mortality prediction. Although the amount of kill in the crown was not included as a predictor, because it is not evident at all times of the year, it should be observed and considered whenever possible.

Wounds are often evident if growth has occurred since the fire. Cracking of bark along wound margins or unevenness of the bole may show where new callus growth is forming. Cutting through the bark to the cambium layer can show whether the cambium area is white and living or discolored and dead. Discoloration may not be evident immediately after a fire.

The degrees of bark blackening are helpful in anticipating dead cambium. The more severe (from scorch to char to burn) the greater the probability of underlying dead cambium. Also, dead cambium is more likely to be present and to extend vertically on the tree bole more than horizontally. Bark blackening that indicates cambium kill for the full circumference of a tree (girdling) would indicate mortality.

Our data showed that, as a general rule, the width of "char" at 1 foot (stump height) defined the width of the wound for the species observed. Toole (1959) had similar results with southern bottomland oaks and hickory.

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☆U.S. Government Printing Office: 1973 — 762-199

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COST-PRICE: A USEFUL WAY TO EVALUATE TIMBER GROWING ALTERNATIVES

ALLEN L. LUNDGREN

per
cubic foot,

per
cord,

or per
thousand
board feet.

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CONTENTS

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Manuscript approved for publication July 26, 1973

COST-PRICE: A USEFUL WAY TO EVALUATE TIMBER GROWING ALTERNATIVES

Allen L. Lundgren

INTRODUCTION

There are several ways to look at an investment. We can ask:

1. Will income be greater than cost?

2. At what rate will our invested capital increase?

3. What will we get back for every dollar we put in?

4. How long will it take to get our invested capital back?

5. What will it cost us to produce a unit of output?

These questions suggest several financial criteria to judge investments by:

1. Present net worth (or future net worth)

2. Internal rate of return

3. Benefit/cost ratio

4. Payback period

5. Production cost per unit of output

Each of these criteria measures an investment in a different way. All have their place in evaluating investment alternatives. The wise manager will not rely solely upon one criterion (that is, ask only one question about an investment); he will want answers to several questions and use several investment criteria, if possible, before making his final decision.

Many investment criteria are well known to forest managers and owners. Present net worth (with its related land or soil expectation value), internal rate of return, and benefit/cost ratio, have been widely used in forestry. Computer programs that calculate all three are available (Chappelle 1969, Lundgren and Schweitzer 1971). Payback period, widely used by business in practice, is not generally recommended as an investment criterion by economists, although it is recognized as one useful measure of an investment (Weingartner 1969).

One other investment criterion, the production cost per unit of output, has been available for decades but has not been widely used in forestry. For many purposes the cost of producing a unit of output may be a more useful guide for the forest manager than the traditional ones. In this paper this production cost per unit of timber output will be called "cost-price" (Lundgr 1966). This concept has been used by others: Kirkland (1915), Kittredge (1929), Hiley (1930, 1956), Buttrick (1943), Chapman and Meyer (1947).

This paper explains how this cost-price criterion is derived, shows how it can be used in making management decisions, and provides some charts useful in estimating the cost-price of timber for some general timber-growing activitie It also demonstrates how this criterion can be ex tended to nontimber outputs.

COST-PRICE: WHAT IT IS

The cost-price of growing timber is the pric at which timber would have to be sold at some future time in order to earn a specified average rate of return on all the capital and resources used in growing the timber. Thus, it is the cost (including a return on invested capital) of producing a unit of output, usually expressed as dollars per cubic foot, per cord, or per thousand board feet. Cost-price may apply to actual past costs of production and yields of timber products but this paper will be concerned primarily with calculating cost-prices for estimated future cost and yields.

The formula for calculating cost-prices is derived from the same discounting-compounding formulas used in other investment calculations, using the same concepts of discounted incomes and costs.[1/] The sum of discounted incomes for one rotation may include the sum of discounted income from the sale of different timber products at dif ferent times, the discounted value of other singl incomes from nontimber sources at different times and the discounted value of annual incomes.

To illustrate the concept of cost-price we will start with the simplest case. Assume that the only income will be from the sale of stumpage for a single product (measured in cubic feet)

1/ Procedures for compounding and discounting incomes and costs are widely available and will not be reviewed here. Interest rate tables are also available from many sources (for example Lundgren 1971).

at the final harvest or rotation age. This we can represent by P_nV_n where P_n is the price in dollars per cubic foot at the rotation age n, and V_n is the volume in cubic feet per acre sold as stumpage at the rotation age n. Later we will show how this can be expanded to consider multiple products harvested at more than one time.

The sum of discounted costs for one rotation may include the sum of discounted periodic costs (including initial costs of stand establishment, timber stand improvement, timber sale costs, etc.), the discounted value of annual costs and expenses in growing the timber, and the net discounted value of the land used for growing the timber for one rotation. For our purposes we will assume that all discounted costs over the rotation can be represented by one symbol, C.

In general, the present net worth (PNW) is the sum of discounted incomes minus the sum of discounted costs. For our simple example:

$$PNW = P_nV_n(1+r)^{-n} - C,$$

where r is the stated interest rate.

It will be more convenient to express this in terms of future net worth (FNW) at the end of the rotation.

$$FNW = PNW(1+r)^n = P_nV_n - C(1+r)^n .$$

This is the basic formula used to derive the cost-price expression.

First we ask, "At what price (P_n) would the expected volume (V_n) have to be sold at the rotation age (n) in order to earn the stated rate of return (r) on the invested capital (C)?" At this price, future incomes would just equal compounded costs:

$$P_nV_n = C(1+r)^n ,$$

and FNW = 0.

From this we derive the formula for the cost-price (P_n):

$$P_n = C(1+r)^n \div V_n .$$

For example, suppose we expect to grow 1,200 cubic feet of merchantable timber per acre in 20 years, with a total discounted cost of \$30 per acre, and wish to earn 6 percent on this \$30/acre investment. The cost price would be:

$$P_n = \$30/\text{acre}\ (1.06)^{20} \div 1,200 \text{ cu ft/acre}$$

$$= \$96.21/\text{acre} \div 1,200 \text{ cu ft/acre}$$

$$= \$.0802/\text{cu ft}.$$

This tells us that if we can grow 1,200 cu ft of merchantable timber per acre in 20 years, and can sell it at \$0.080 per cubic foot, then we will get just enough income (\$96) at the end of 20 years to have earned 6 percent on our initial investment of \$30 per acre. Including a return on our invested capital, it will have cost us \$0.080 per cubic foot to grow this timber, hence the term cost-price. The cost-price is the break-even price.

USES OF COST-PRICE

Cost-price can be used to compare the economic efficiencies of alternative investments in much the same way as other investment criteria, such as discounted net worth, are used. We calculate the cost-price for each alternative and choose the one offering the lowest cost-price, if we wish to use that as our selection criterion. In this way we can compare the per-unit cost of growing timber on different sites, between different rotations, between different species, and for different cost levels, to cite some illustrations.

For example, jack pine (*Pinus banksiana* Lamb.) yield tables are available for well-stocked stands in the Lake States on site index (SI) 60 for a range of alternative rotation ages (table 1). Using the formula developed earlier,

Table 1.--Volume yields and average diameters of site index 60 jack pine1/ and illustrative cost-prices2/ for alternative rotation ages

Stand age	Volume per acre	Average d.b.h.	Cost-price per cord
	Cords	Inches	Dollars
20	8.3	4.0	9.58
30	17.7	5.9	7.32
40	25.6	7.5	8.24
50	31.1	8.7	11.07
60	34.6	9.7	16.22

1/ Unpeeled gross volume per acre in standard cords in trees 5.0 inches d.b.h. or more to a 4.0-inch top d.i.b., in well-stocked stands of jack pine in the Lake States. Interpolated from p. 29, Eyre and LeBarron (1944).

2/ Illustrative only; assumes discounted costs of \$30 per acre and a 5-percent rate of return on this investment.

$P_n = C(1+r)^n \div V_n$, illustrative cost-prices per cord were calculated for each rotation age, assuming an initial investment of $30 per acre to cover all discounted costs and a 5-percent rate of return on this invested capital. These average cost-prices per cord were graphed to show the trend in cost-price with increasing rotation age (fig. 1). The marginal cost-price, the cost-price of each additional cord obtained by lengthening the rotation age 10 years, was calculated by dividing the total increase in cost per acre resulting from lengthening the rotation by 10 years by the additional cords obtained.

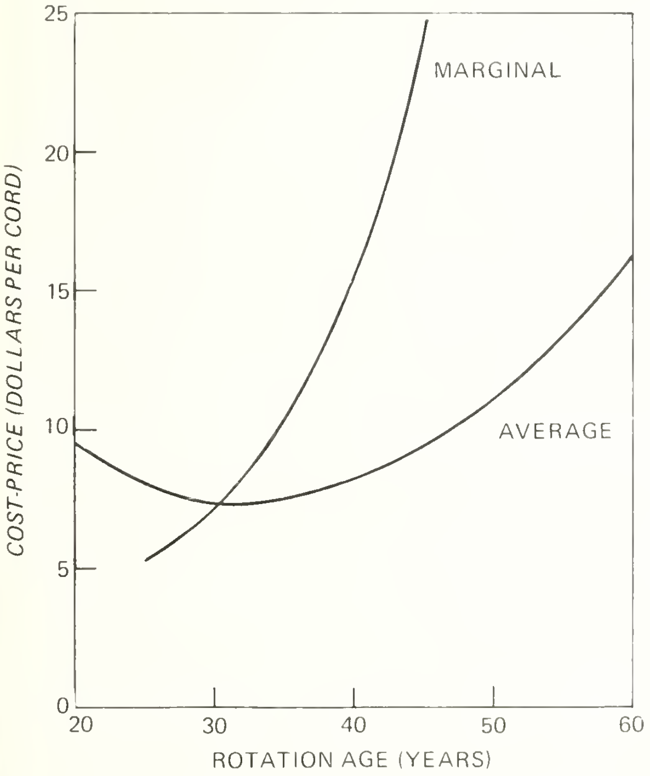

Figure 1.--Illustrative average and marginal cost-prices of growing jack pine pulpwood to different rotation ages on site index 60 land, earning 5 percent return on investment, for specified costs.

Note that the minimum cost-price occurs for a rotation of 30 years, $7.32 per cord. A rotation of 20 years produces less volume per acre, in smaller diameter trees, and at a higher per-unit price. It is clearly less desirable in terms of cost-price than a 30-year rotation. A 40-year rotation increases the cost-price by $0.92 per cord and therefore appears less desirable than the 30-year. However, the analyst or forest manager may decide that the additional volume per acre (an increase of almost 8 cords) and the increase in diameter (1.6 inches) may reduce logging costs or timber sales administration costs per cord, or increase the quality of the product sufficiently to offset this increase in cost-price. The marginal cost-price in going from age 30 to 40 is $10.30 per cord (taken at age 35) for the added 7.9 cords. The large increase in average cost-price of going from a 40-year to a 50-year rotation ($2.83 per cord) may be more difficult to justify. The marginal cost-price of each added cord is $24.24.

Cost-prices also can be used to compare the cost of growing timber on different sites. Again, we will use the jack pine yield table to illustrate this comparison for site indexes from 40 to 70 (table 2). The cost prices have been graphed (fig. 2) to better illustrate their relation to site index. For the rotation ages and costs used in these examples, it is obviously cheaper to grow wood on the better sites than on the poor sites. With such a graph one could establish a maximum cost-price as a cutoff point to determine the lowest acceptable site index on which to grow trees. For example, if $8 per cord were established as the upper limit on cost-price, then sites below SI 55 would not be acceptable because the cost to grow timber would be greater than $8 per cord.

It should be emphasized that these results are illustrative and would vary with the costs and yields assumed.

Several other useful graphs can be constructed from cost-price data. For example, graphs of cost-price over a range of site indexes can be constructed for several cost levels for any specified rate of return. This was done for jack pine using the rotation ages given in table 2 and a 5-percent rate of return, for costs per acre of $10, $20, $30, and $40 (fig. 3). Note that this graph also can be used to determine the maximum costs per acre one can incur on a given site for a specified cost-price of timber. For example, the most one can spend to grow jack pine for no more than $5 per cord, and earn 5 percent on invested capital, would be about $10 on SI 40, $14 on SI 50, $20 on SI 60, and $26 on SI 70.

Another useful graph for this purpose can be constructed for a single interest rate by plotting cost-price over discounted costs for each site index (fig. 4). From this graph one can quickly determine what the cost-price will be for any site and discounted cost combination. To invest $40 per acre to grow jack pine on site index 50, and earn 5 percent, for example, results in a cost-price of $14 per cord. Or, for any specified cost-price, one can quickly estimate the maximum investment per acre on a given site that will still earn a 5-percent rate of return.

These illustrations of how cost-price can be used in comparing alternatives and in providing information about investment alternatives should be enough to suggest other uses of this technique.

Table 2.--Rotation ages,1/ volume yields,2/ discounted costs,3/ and illustrative cost-prices for growing jack pine on a range of sites

Site index	Rotation age	Volume per acre	Discounted costs per acre	Cost-price per cord
	Years	Cords	Dollars	Dollars
40	45	17.2	20	10.40
50	40	20.0	25	8.70
60	35	22.0	30	7.50
70	30	23.1	35	6.70

1/ Rotation age (to the nearest 10 years) that produces trees that average at least 5.6 inches in diameter.
2/ Unpeeled gross volume per acre in standard cords in trees 5.0 inches d.b.h. or more to a 4.0-inch top d.i.b. in well-stocked stands of jack pine in the Lake States. Interpolated from p. 29, Eyre and LeBarron (1944).
3/ Assumed costs to reflect increasing cost of regeneration on better sites. A 5-percent return on investment is assumed.

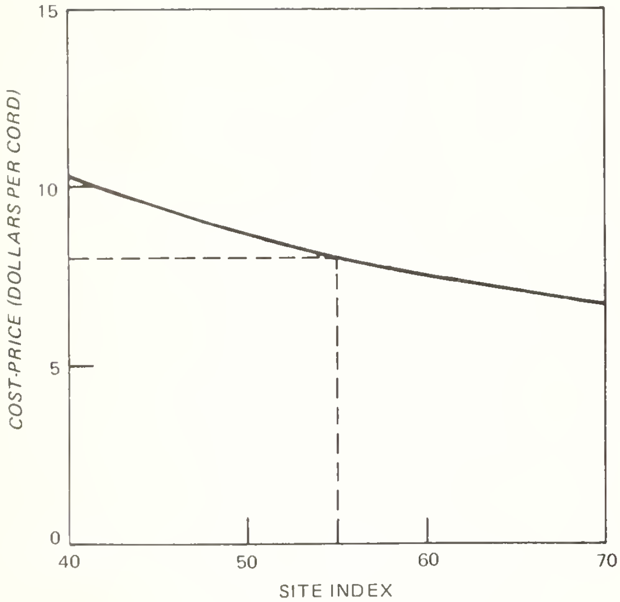

Figure 2.--Illustrative cost-price of growing jack pine pulpwood for a range of sites; costs vary with site, 5 percent return on investment.

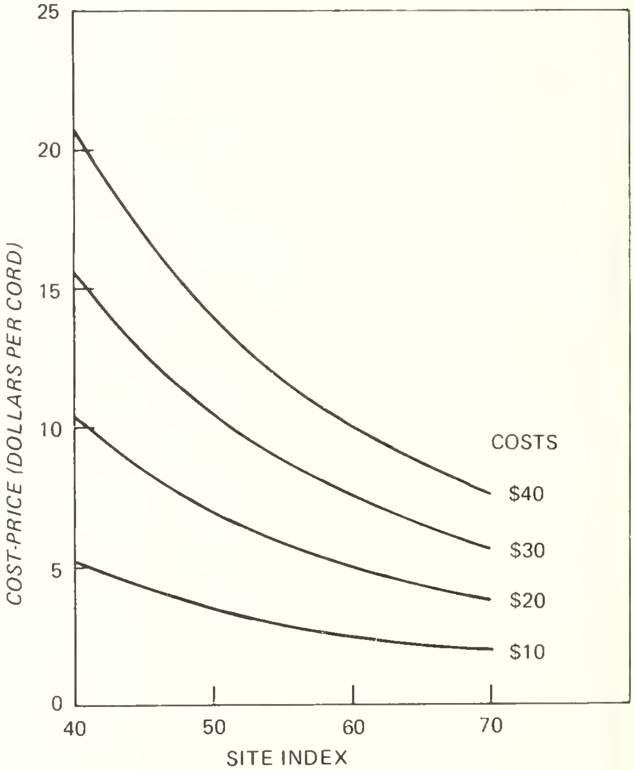

Figure 3.--Illustrative cost-prices for growing jack pine pulpwood for a range of site indexes and specified discounted costs per acre, to earn 5 percent.

One other useful modification of the cost-price concept can be made by rewriting our original cost-price expression in a slightly different form:

$$P_n = C[(1 + r)^n \div V_n].$$

Notice that the only change has been on the right-hand side to separate costs (C) from the remainder of the expression. The part of the expression in brackets can be considered as the cost-price per dollar of discounted costs. It is the reciprocal

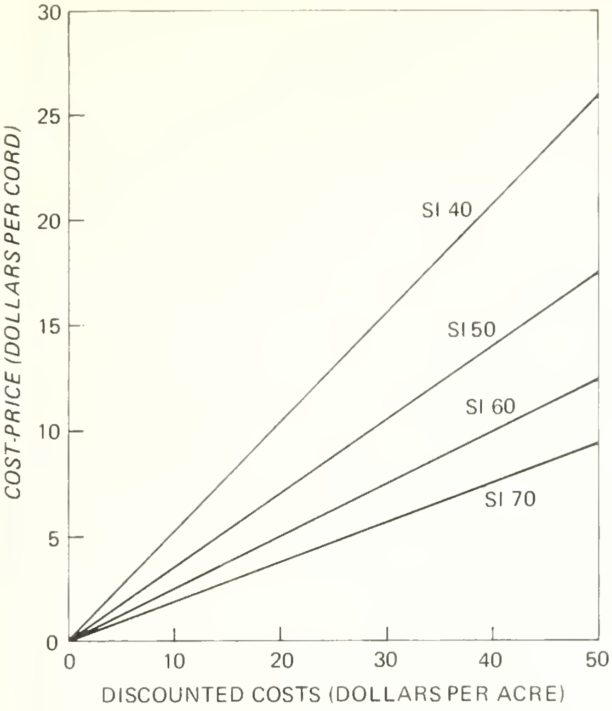

Figure 4.--Illustrative cost-prices for growing jack pine pulpwood for a range of discounted costs per acre and specified site indexes, to earn 5 percent.

of what I elsewhere have called the expectation value index (Lundgren 1966). We shall call this expression the cost-price index. One can easily determine V_n for a specified site index and rotation age n, and then compute the cost-price index for a range of interest rates r. For example, on a site index of 60 a fully stocked stand of jack pine will produce 22 cords of timber at age 35 years. The cordwood cost-price index would be:

r	$(1 + r)^{35} \div 22$
0.03	0.1279
.04	.1793
.05	.2507
.06	.3493
.08	.6720

The cost-price per cord for any specified sum of discounted costs is easily obtained by multiplying this cost-price index by the costs. Thus, for an interest rate of 5 percent and discounted costs of $30 per acre, the cost-price of growing jack pine on SI 60 would be $30(0.2507) = $7.52 per cord.

Tables of such cost-price indexes can be prepared for a given species for specified sites, rotation ages, and interest rates.

SOME GENERAL COST-PRICE CHARTS

It is evident that the formula used to calculate cost-price ($P_n = C(1 + r)^n \div V_n$) is not tied to any particular species, site, or unit of volume In fact, it is a general formula applicable to a wide range of products and production situations. So, it is possible to construct charts to serve as general guides in evaluating production alternatives. Our examples will be confined to timber production, but it should be kept in mind that the output V_n may, with only slight modification, be number of deer, acre-feet of water, number of visitor days, or a number of other types of output

By solving for the cost-price index for a range of specified yields and rotation ages, for a given interest rate, the information necessary to construct a useful type of chart is easily obtained. The cost-price index (in cents per cubic foot per dollar invested) for a given interest rate (say, 5 percent) can be plotted over a range of alternative rotation ages, for a range of specified final yields (fig. 5). From this type of graph, one can quickly determine the cost-price index for a given yield and rotation age. The cost-price index for timber expected to yield 3,000 cubic feet at 30 years would be 0.15 cents or $0.0015 per cubic foot per dollar invested, for this 5-percent graph. If the expected sum of discounted costs were $30 per acre, then the cost-price of this timber at 30 years of age would be ($0.0015/cu ft/dollar invested) ($30) = $0.045/ cu ft.

Alternatively, one can specify the maximum acceptable cost-price index for a given rate of return and then determine the minimum volume output required for each rotation age. For example, suppose we wished to keep the cost-price below $0.05 per cubic foot, and our anticipated discounted costs were $25 per acre. Our cost-price index goal would then be $0.05 ÷ $25 = 0.2 cents per cubic foot per dollar invested. In order to earn 5 percent on our $25/acre invested funds we would have to obtain a final harvest of about 1,300 cu ft per acre at age 20, or 2,200 cu ft per acre at age 30 (fig. 5).

Similar graphs could be made for other interest rates and for other timber product outputs (cords, board feet). A set of general graphs for units of volume output, which can be cunits (100 cu ft), cords, or thousand board feet, for interest rates of 3, 4, 5, 6, 7, and 8 percent, is included in the appendix.

An even more useful general graph can be constructed for a given interest rate and rotation age by plotting cost-prices over discounted investment costs for a range of selected yields expressed either as total yield or as mean annual increment (fig. 6). On such a graph one can read directly the cost-price of growing timber for a

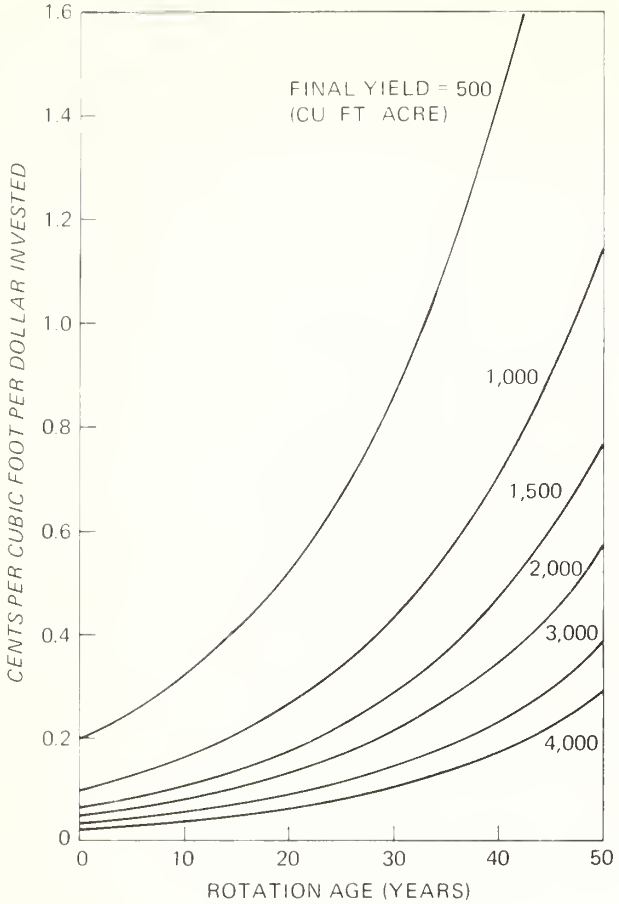

Figure 5.--Cost-price per dollar of invested capital for final yields from 500 to 4,000 cubic feet of timber per acre for rotation ages from 0 to 50 years, to earn 5 percent on invested capital.

specified discounted investment cost and yield for the rotation age and interest rate on which the graph is based. However, a large number of graphs may be required to cover a wide range of alternative interest rates and rotation ages. Such graphs are most practical for a fixed interest rate or for a fixed rotation age.

COST-PRICES FOR MULTIPLE PRODUCTS AND MULTIPLE TIME PERIODS

The cost-price formula given above applies to the simple case where we have only one product produced at one time that is measured in common units, and where each unit is sold for the same price or an average price per unit is applicable. Fortunately, this formula applies to many timber production alternatives where timber is managed in even-aged stands with a single final harvest or regeneration cut.

The above formula can be modified to account for multiple products and multiple harvest cuts over time. To do this, however, requires that some form of relative price index be used to relate different product prices at different time periods to the price for some standard product and time. To illustrate, suppose two products, pulpwood and saw logs, are expected from a single harvest cut at the end of a rotation (n years). Let P_{1n} and P_{2n} be the stumpage price for pulpwood and saw logs, respectively, with V_{1n} the volume in cords and V_{2n} the volume in thousand board feet (MBF). The cost-price equation would be:

$$P_{1n}V_{1n} + P_{2n}V_{2n} = C(1 + r)^n.$$

To calculate a cost-price, we establish a standard price (P), and express each product price as some proportion of that standard price. For our two products that means, $P_{1n} = k_1P$ and $P_{2n} = k_2P$. We can simplify things if we choose one of the product prices as a base price. For example, suppose we choose the pulpwood price (P_{1n}) as the standard, so that $P_{1n} = P$. Thus, $k_1 = 1.0$. We still have $P_{2n} = k_2P$. Here, k_2 expresses the value ratio of MBF/cord, so that k_2 cords are worth 1 MBF, or k_2 cords/MBF.

Substituting into the previous expression we have:

$$PV_{1n} + k_2PV_{2n} = C(1 + r)^n.$$

Then:

$$P(V_{1n} + k_2V_{2n}) = C(1 + r)^n$$

$$P = C(1 + r)^n \div (V_{1n} + k_2V_{2n}).$$

We can now use this formula to calculate the standard cost-price for this timber-growing example. To do this we must know the sum of discounted costs (C), the desired rate of return (r), the investment period (n), the volume of cordwood produced in the n^{th} year (V_{1n}), the volume of saw logs produced in the n^{th} year (V_{2n}), and the relative value of saw log stumpage prices in terms of pulpwood prices (k_2).

Suppose that a yield of 12 MBF of saw logs and 15 cords of pulpwood per acre is expected at 40 years; discounted costs are $60 per acre; we wish to earn 6 percent on our invested capital; and we expect that the sawtimber stumpage price in dollars per thousand board feet will be five times the pulpwood stumpage price in dollars per cord. That is, if the pulpwood stumpage price is $6 per cord, the saw log stumpage price will be $30 per MBF.

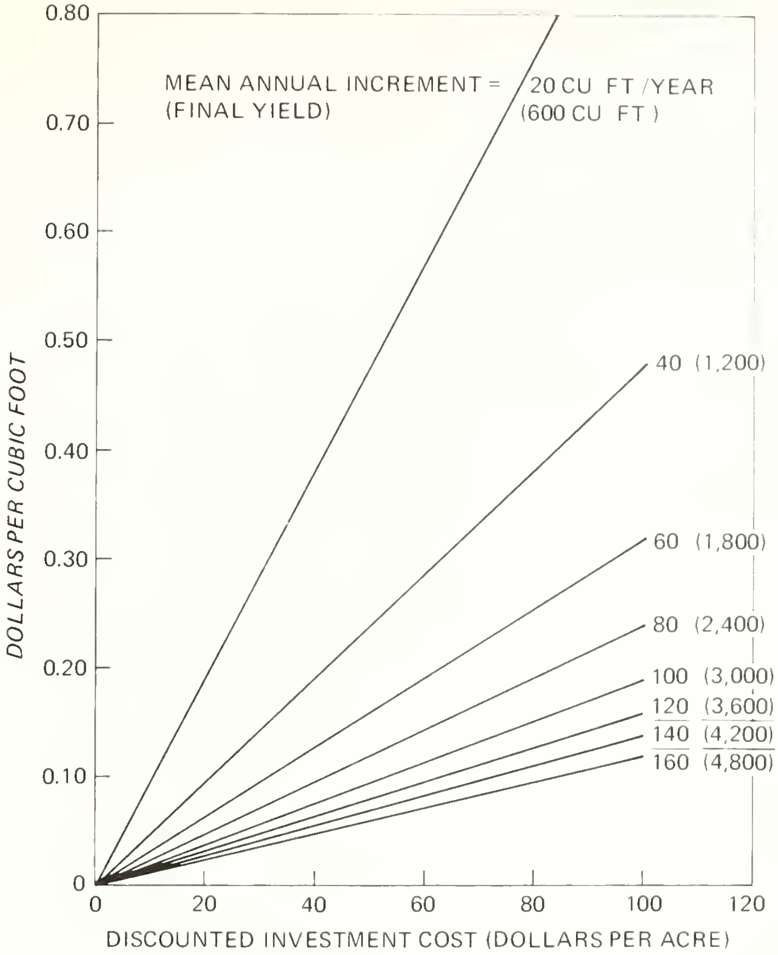

Figure 6.--Cost-price of growing timber to earn 6 percent on a 30-year rotation, for a range of mean annual increments and discounted investment costs per acre.

Thus, k_2 = 5.0 cords/MBF.

The calculated standard cost-price is:

$$P = \$60.00\ (1.06)^{40} \div (15 \text{ cords} + (5.0 \text{ cords/MBF})\ (12 \text{ MBF}))$$

$$P = \$60.00\ (10.286) \div (15 \text{ cords} + 60 \text{ cords})$$

$$P = \$617.16 \div 75 \text{ cords} = \$8.23/\text{cord}.$$

We know that the price of pulpwood $P_{1n} = P =$ \$8.23/cord. We also know that $P_{2n} = k_2P$ = (5.0 cords/MBF) (\$8.23/cord), so that P_{2n} = \$41.15/MBF.

This tells us that if we grow 12 MBF and 15 cords of timber per acre in 40 years, and sell this timber at \$8.23/cord and \$41.15/MBF, then we will just earn 6 percent on an initial investment of \$60 per acre. If we get these yields and prices, our total income of \$617 will be just enough to pay off our compounded initial investment of \$60. These cost-prices are the costs of growing that timber, including a 6 percent return on invested capital.

This concept can be further extended to handle price relatives for different qualities of products (perhaps using, for example, a log quality index such as described by Herrick (1946) and McCauley and Mendel (1969)). It can be used to handle multiple harvest cuts over the rotation and different price levels over time that reflect the impact of tree size on product value or of stand characteristics on logging costs. In general:

$$\sum_{j=1}^{m} \sum_{t=0}^{n} P_{jt} V_{jt} (1 + r)^{n-t} = C(1 + r)^n.$$

Where P_{jt} is the price per unit of the j^{th} product at a time t and V_{jt} is units of the j^{th} product at time t. The left-hand side is thus the sum of discounted incomes for all the m products over the entire rotation to age n.

If each price is expressed in terms of a standard price (P), then $P_{jt} = k_{jt}P$, and we can write

$$P = C(1+r)^n \div \sum_{j=1}^{m} \sum_{t=0}^{n} k_{jt}V_{jt}(1+r)^{n-t}.$$

If desired, this can be simplified to:

$$P = C \div \sum_{j=1}^{m} \sum_{t=0}^{n} k_{jt}V_{jt}(1 + r)^{-t}.$$

AN EXTENSION TO NONTIMBER PRODUCTS

The concept of cost-price is not restricted to timber products. In the general formula given earlier, the term V_{jt} could be any output j at time t. For many nontimber outputs, such as deer harvested or man-days of recreation, an annual output may be expected. If these outputs are constant over time and we wish to calculate a constant cost-price over time we can modify the cost-price formula to simplify calculation. For annual outputs (v) and a constant cost-price (P) over time, the cost-price formula would be:

$$P = \frac{C}{v} \frac{r(1 + r)^n}{(1 + r)^n - 1} .$$

To illustrate, let v be 5,000 man-days of camping experience provided annually for 20 years by a sum of discounted costs (C) equal to $15,000, with a 5-percent rate of return. The cost-price per man-day of recreation would then be:

$$P = \frac{15,000}{5,000} \frac{.05(1.05)^{20}}{(1.05)^{20}-1} = 3(.080) = \$.24/\text{man-day}.$$

Obviously, graphs of the cost-price of annual output can also be constructed.

A WORD OF CAUTION

Any tool is subject to misuse. This seems to be particularly true of new tools. The analytical tool outlined in this paper, although not new to the forestry profession, may be new to a number of readers. Therefore, it is necessary to keep in mind the limitations of cost-price.

Cost-price is one excellent measure of an investment, but it is only one of several. The wise analyst will look at an investment from many viewpoints. He may calculate cost-prices, present net worth, future net worth, internal rate of return, and payback period. Each of these investment criteria provides an additional piece of information about the investment. Each enables the analyst to answer different kinds of questions about an investment than he otherwise could.

The cost-prices derived by the procedure outlined here are subject to all the limitations and uncertainties inherent in the underlying data. If physical outputs are not well known, cost-prices will be uncertain. If costs are known only within a wide range, then cost-prices will likewise be known only within a range of values. This problem is not unique to the cost-price criterion, but is common to other investment criteria as well.

Used with caution and restraint, cost-price provides an additional useful criterion for measuring an investment--the cost of producing a unit of output. Because it is measured in familiar units (for example, stumpage price per unit of output) it may well have a broader appeal to forest managers and resource analysts than other commonly used investment criteria.

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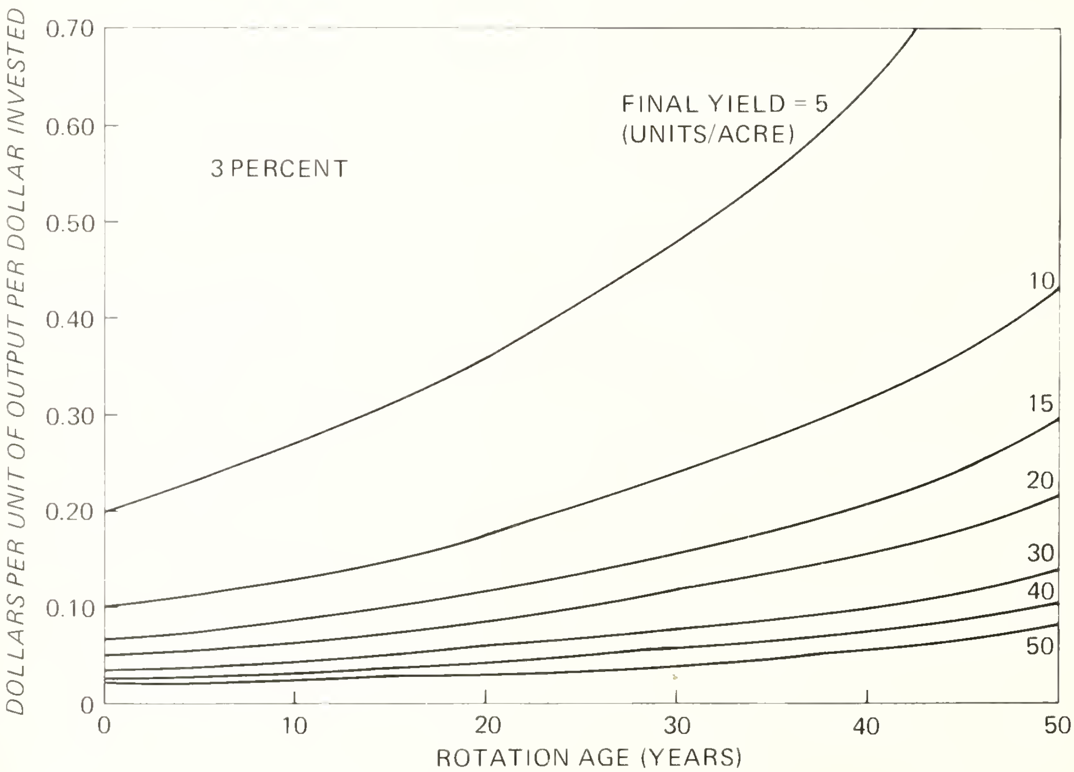
General Graphs of Cost-Price Indexes for Short and Long Rotations

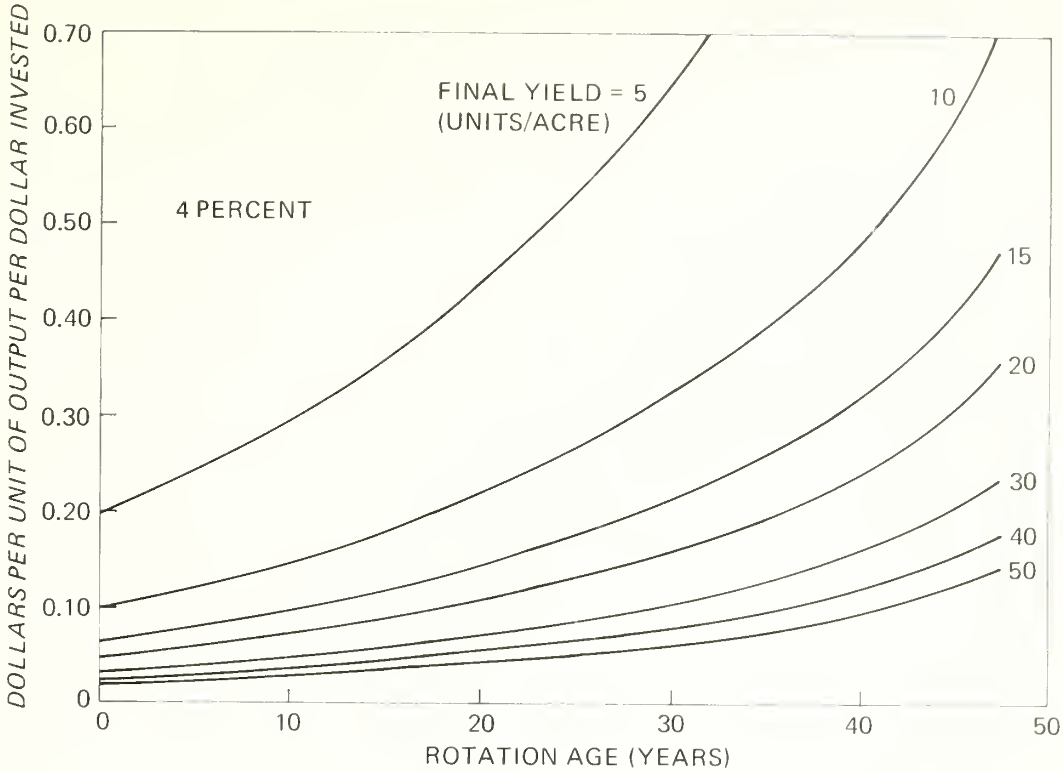
These graphs show cost-price indexes for a given interest rate for specified final yields, expressed as units of output per acre, for a range of rotation ages. These units may be cunits (100 cubic feet), cords, board feet, or other output harvested at the end of the rotation. There are two sets of graphs, one for short rotations (up to 50 years) and one for long rotations (up to 100 years). Each set contains one graph for each of six interest rates from 3 to 8 percent.

To estimate the cost-price of growing timber, obtain the cost-price index from the graph for the interest rate, rotation age, and final yield specified. Multiply this index by the estimated sum of discounted costs of growing this timber (the total dollars invested). This gives the cost-price per unit of product output.

For example, if we wish to earn 6 percent on our invested funds, and can expect to harvest 30 cords of timber per acre at the end of a 30-year rotation on our forest land, then the cost-price index is $0.19 per cord per dollar invested (fig. 10). If our expected total costs (discounted at 6 percent to age zero) were $20 per acre, then the cost-price of growing this 30 cords amounts to ($0.19/cord/dollar) ($20) = $3.80/cord. Similarly, if we had expected a yield of only 20 cords per acre, then the cost-price index would have been $0.28/cord/dollar, so the cost-price of this timber would have been $5.60/cord.

If we were growing sawtimber on a 60-year rotation, expecting 40 thousand board feet at 60 years, and wished to earn 5 percent on our investment, then the cost-price index would be $0.43/thousand fbm/dollar invested (fig. 15). If our investment were $70/acre (sum of all costs discounted at 5 percent), then the cost-price of this sawtimber would be ($0.43/thousand fbm/dollar) ($70) = $30.10/thousand board feet.




DOLLARS PER UNIT OF OUTPUT PER DOLLAR INVESTED
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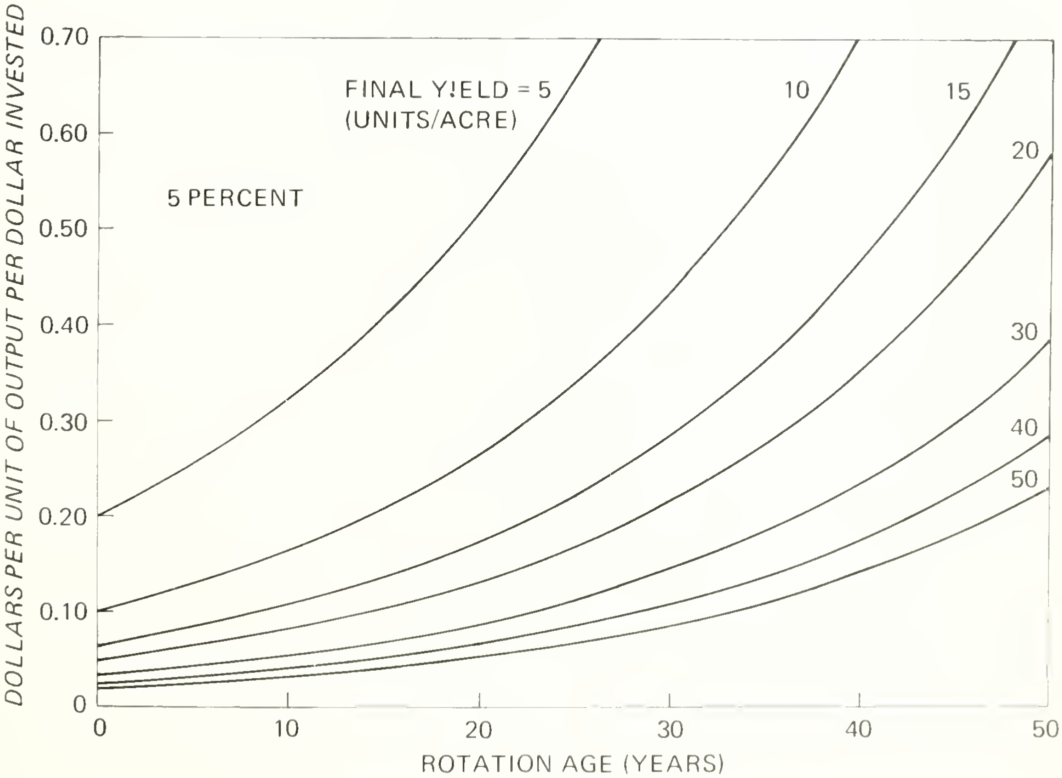
0.60
0.50
0.40
0.30
0.20
0.10
0
FINAL YIELD = 5
(UNITS/ACRE)
10
15
20
30
40
50
4 PERCENT
0
10
20
30
40
50
ROTATION AGE (YEARS)


DOLLARS PER UNIT OF OUTPUT PER DOLLAR INVESTED
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0.60
0.50
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0.30
0.20
0.10
0
FINAL Y!ELD = 5
(UNITS/ACRE)
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15
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40
50
5 PERCENT
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10
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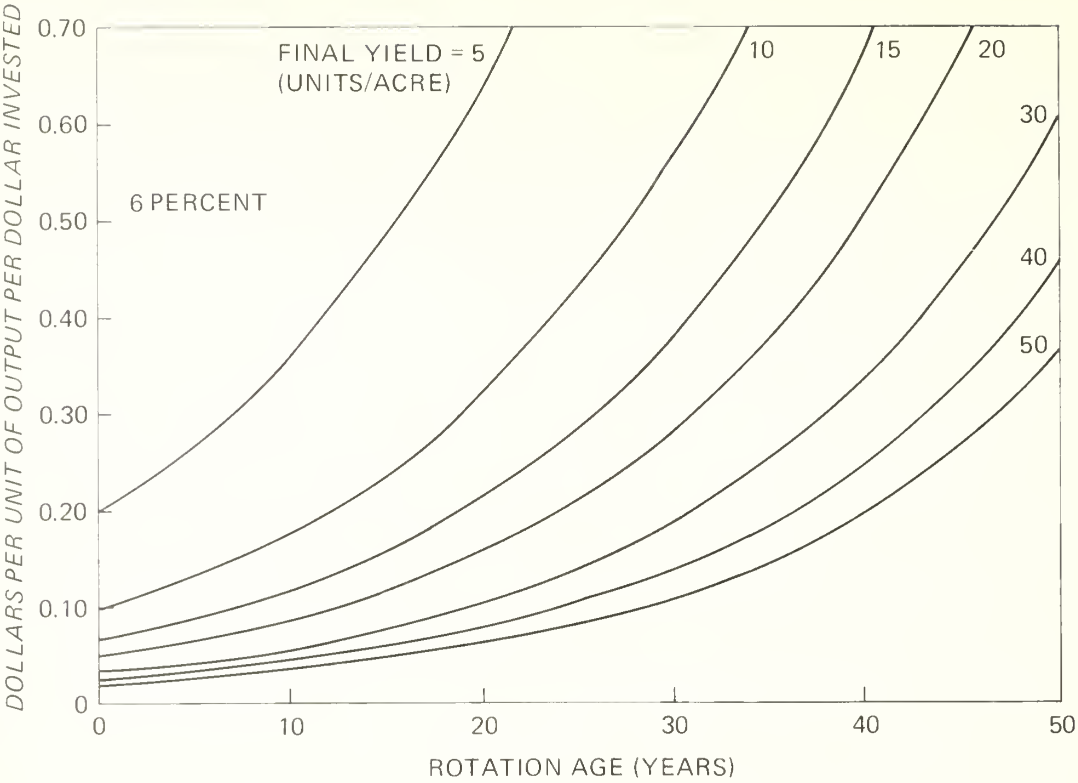
40
50
ROTATION AGE (YEARS)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30
40
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6 PERCENT
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0.30
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0.10
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10
20
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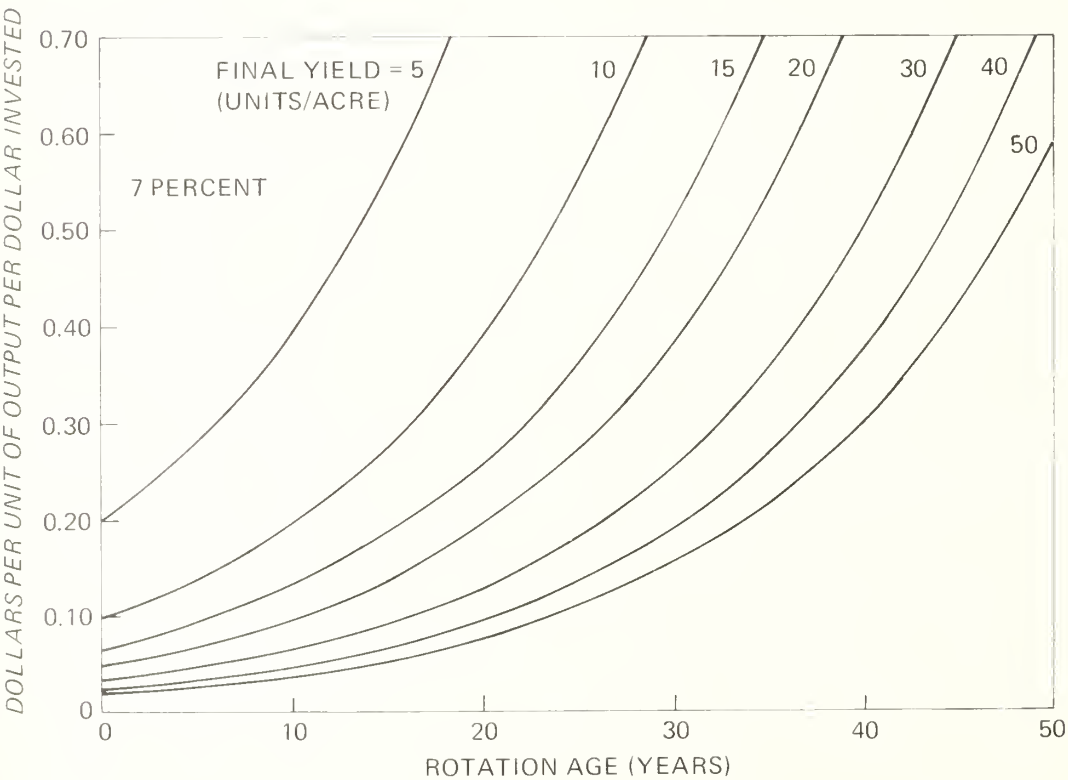
50
ROTATION AGE (YEARS)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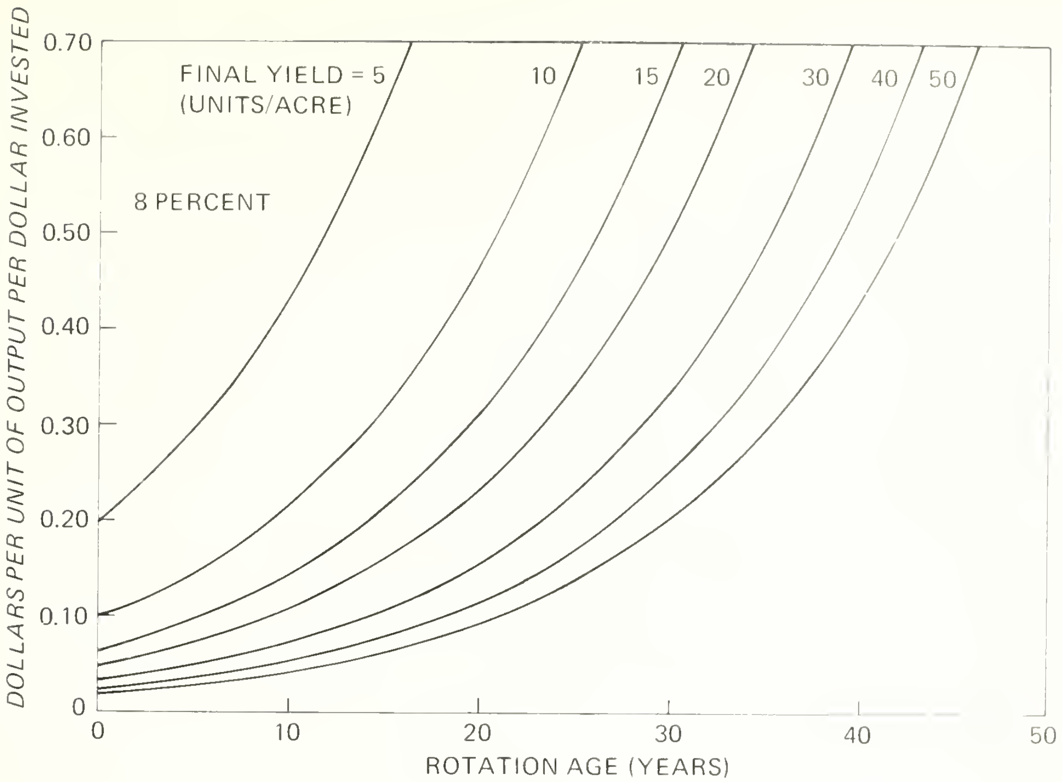
50
ROTATION AGE (YEARS)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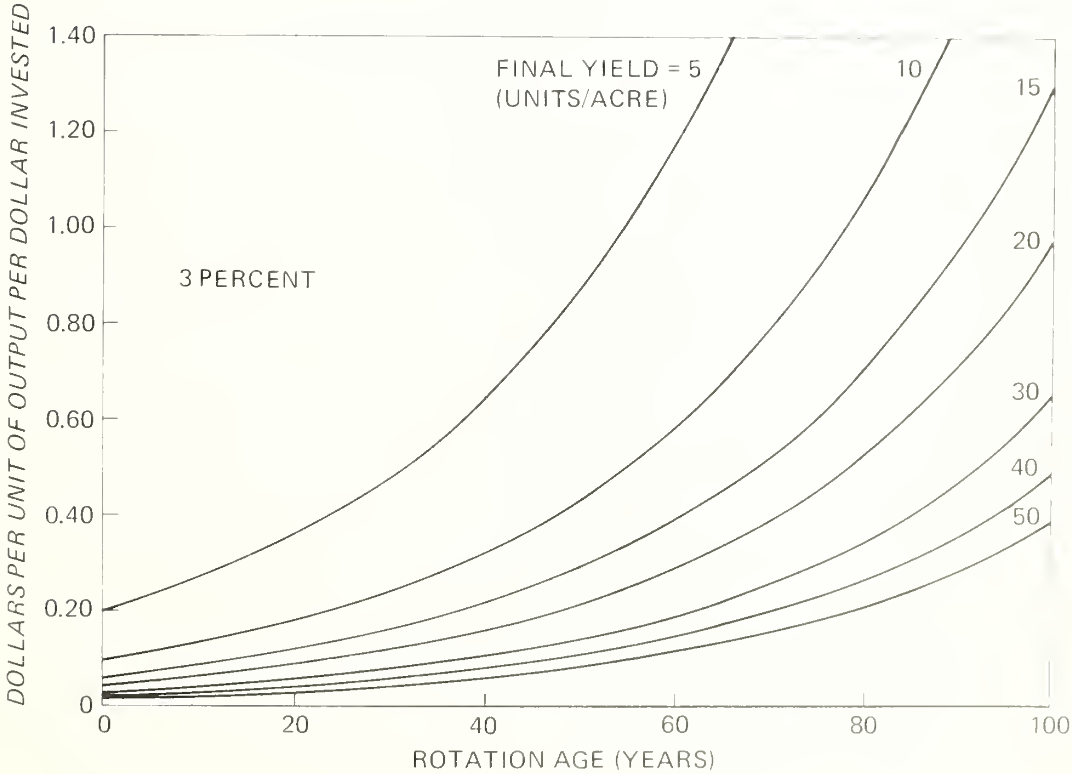
30
40
50
ROTATION AGE (YEARS)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3 PERCENT
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1.00
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0.60
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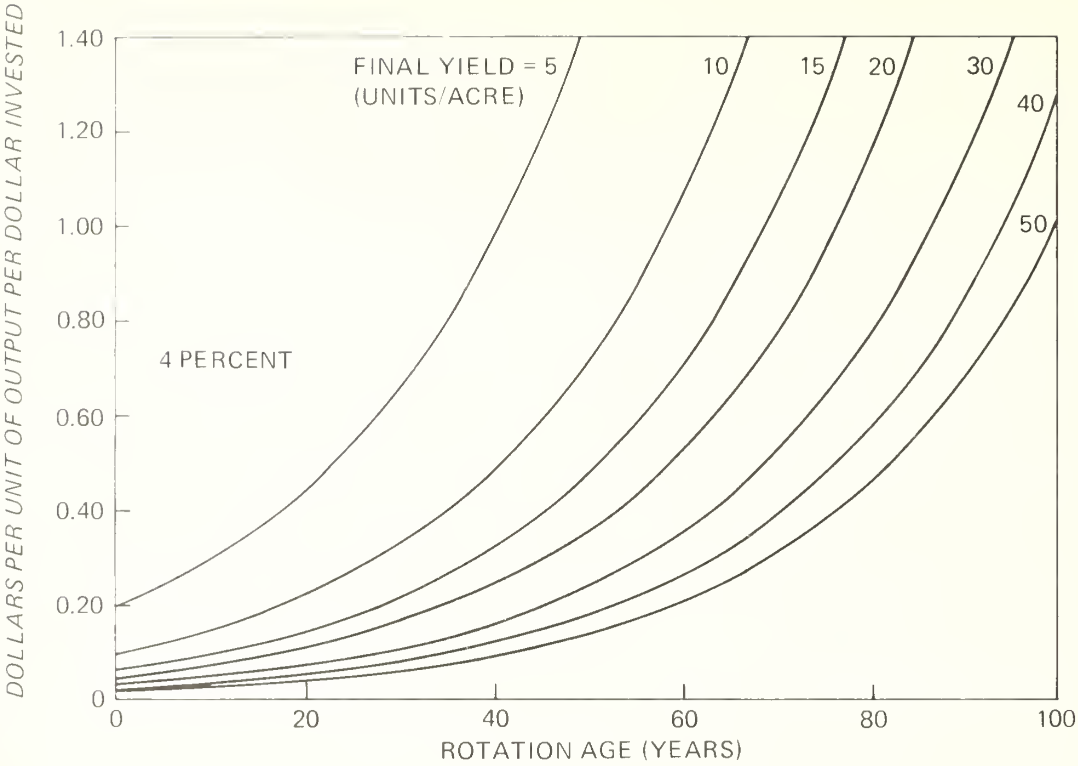
0.20
0
0
20
40
60
80
100
ROTATION AGE (YEARS)


DOLLARS PER UNIT OF OUTPUT PER DOLLAR INVESTED
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FINAL YIELD = 5
(UNITS/ACRE)
10
15
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4 PERCENT
0
20
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60
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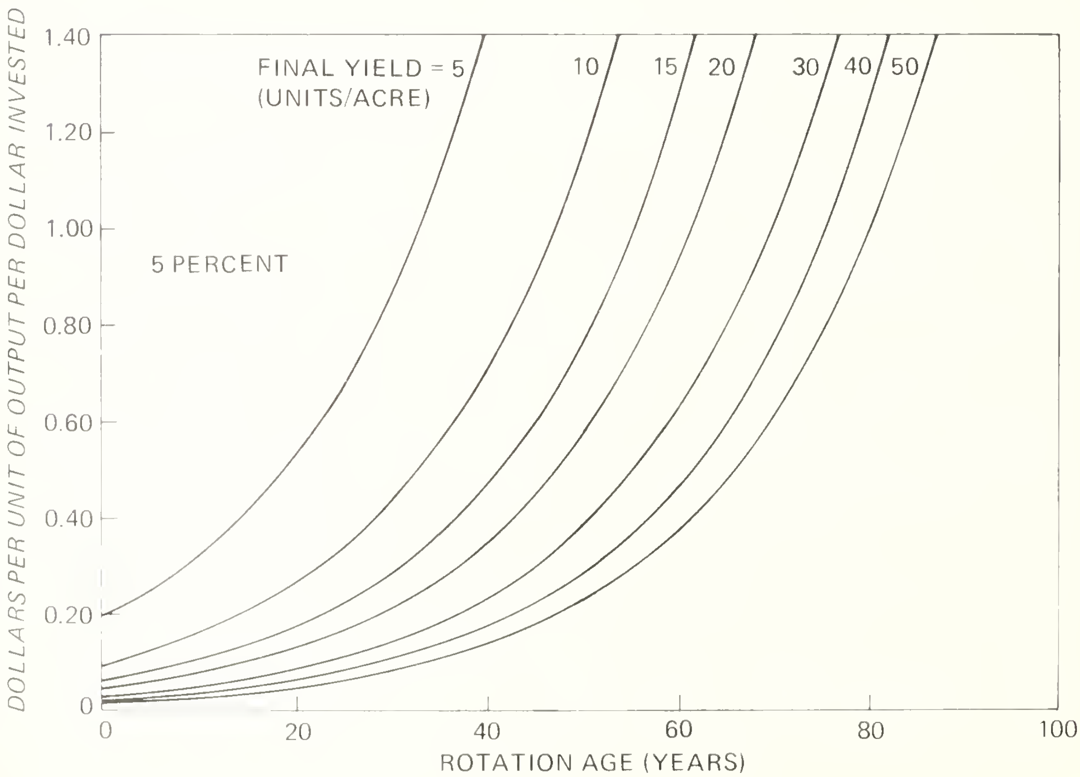
100
ROTATION AGE (YEARS)


DOLLARS PER UNIT OF OUTPUT PER DOLLAR INVESTED
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1.20
1.00
0.80
0.60
0.40
0.20
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FINAL YIELD = 5
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5 PERCENT
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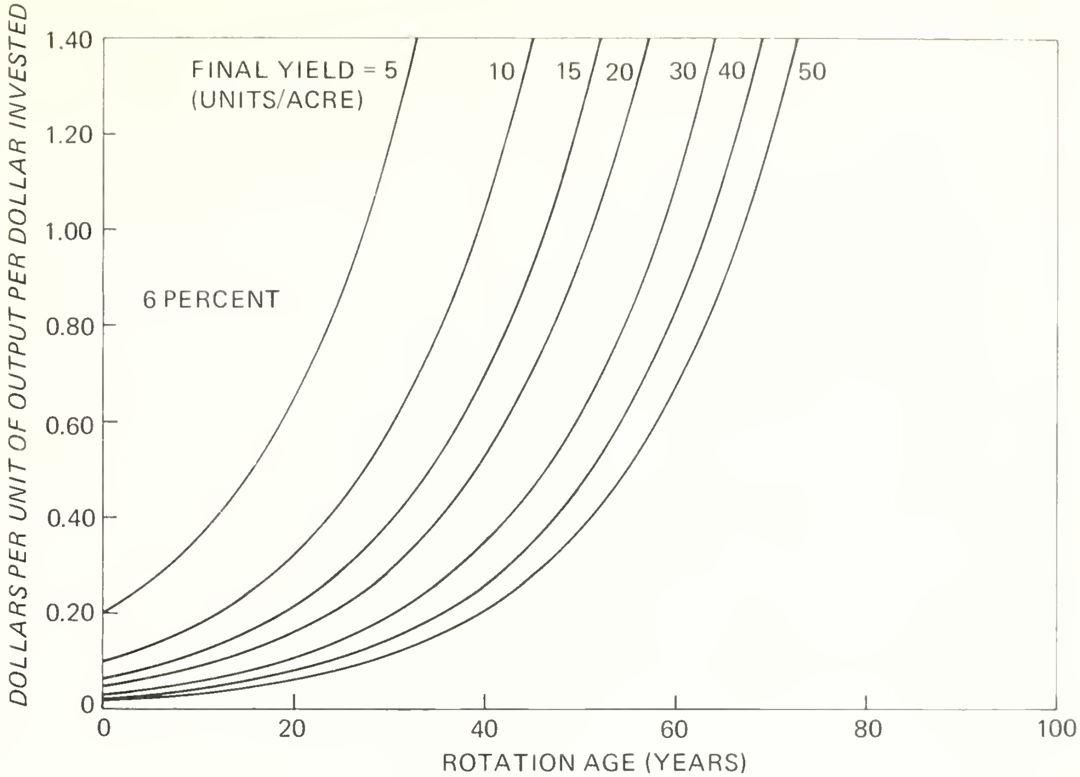
100
ROTATION AGE (YEARS)



FINAL YIELD = 5
(UNITS/ACRE)
10
15
20
30
40
50
6 PERCENT
DOLLARS PER UNIT OF OUTPUT PER DOLLAR INVESTED
1.40
1.20
1.00
0.80
0.60
0.40
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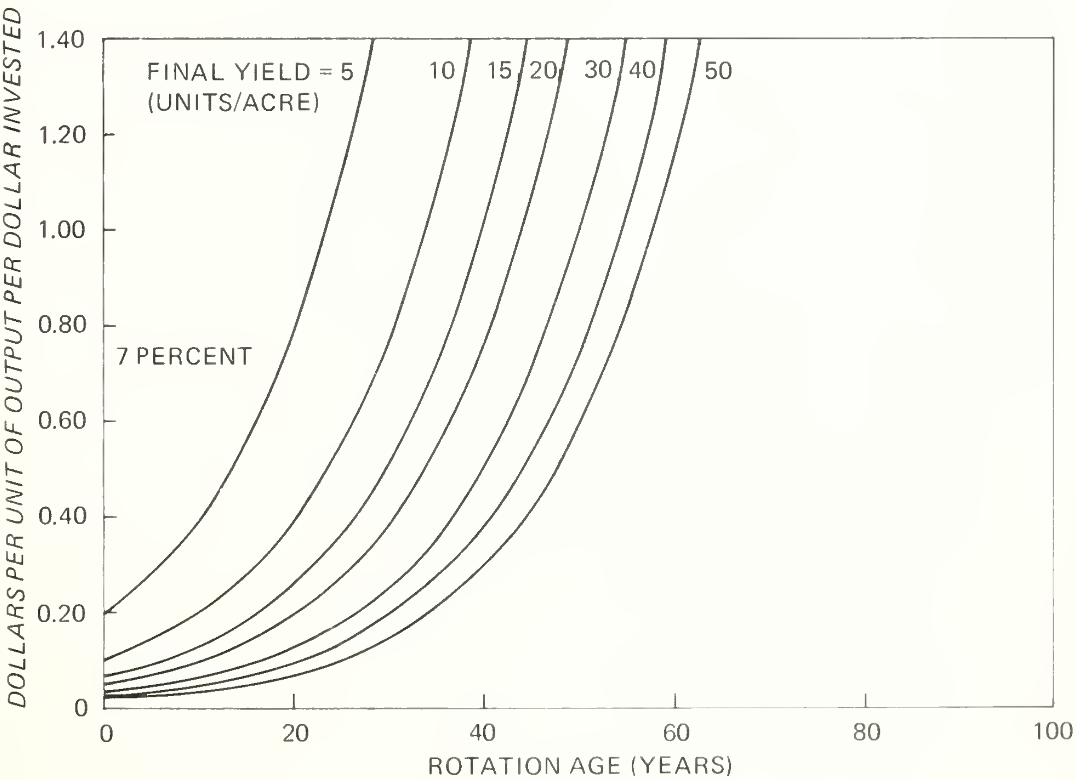
20
40
60
80
100
ROTATION AGE (YEARS)



FINAL YIELD = 5
(UNITS/ACRE)
10
15
20
30
40
50
7 PERCENT
DOLLARS PER UNIT OF OUTPUT PER DOLLAR INVESTED
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
0
20
40
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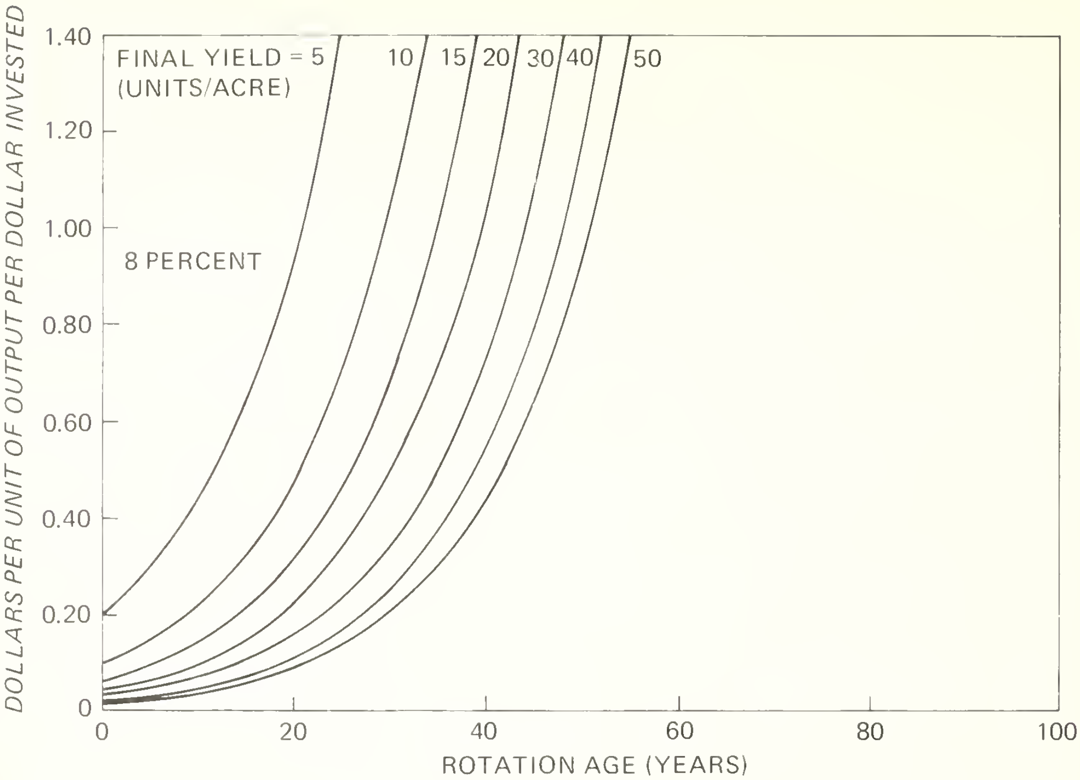
80
100
ROTATION AGE (YEARS)



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NORTH CENTRAL FOREST EXPERIMENT STATION

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Theoretical Methods for Estimating Moments of Inertia of trees and boles

JOHN A. STUROS

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

CONTENTS

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Manuscript approved for publication August 8, 1973

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THEORETICAL METHODS FOR ESTIMATING MOMENTS OF INERTIA OF TREES AND BOLES

John A. Sturos

The increased influx of multifunctional logging equipment into the timber industry has stimulated research in dynamic handling analysis. The designers of such equipment realize that more basic engineering data on trees and tree-length logs are necessary before dynamic conditions can be accurately analyzed. In other words, the tree must be described in engineering terms to predict the dynamic forces and moments required to mechanically handle the trees. Steinhilb and Erickson presented prediction equations for determining the weights and centers of gravity for full trees and boles.[1,2] However, no information is available on the moments of inertia for trees and boles necessary for dynamic handling analysis. This paper compares results from theoretical models for determining mass moments of inertia of trees and boles with a small sample of experimentally determined moments of inertia for red pine and aspen trees and boles.

THEORETICAL MODELS

The theoretical models presented were developed primarily in a study by Snyder and Hutula that was sponsored by the North Central Forest Experiment Station.[3] This model assumed the tree to be composed of a truncated cone of variable density (the bole) and a sphere (the crown). Comparisons between this model and the experimental data showed that better correlation was obtained with the boles than the trees. Therefore, different models of tree crowns were investigated by the author; specifically they were a right-circular cone (fig. 1) and a biconical-shaped crown (fig. 2). Both models were studied for aspen and red pine.

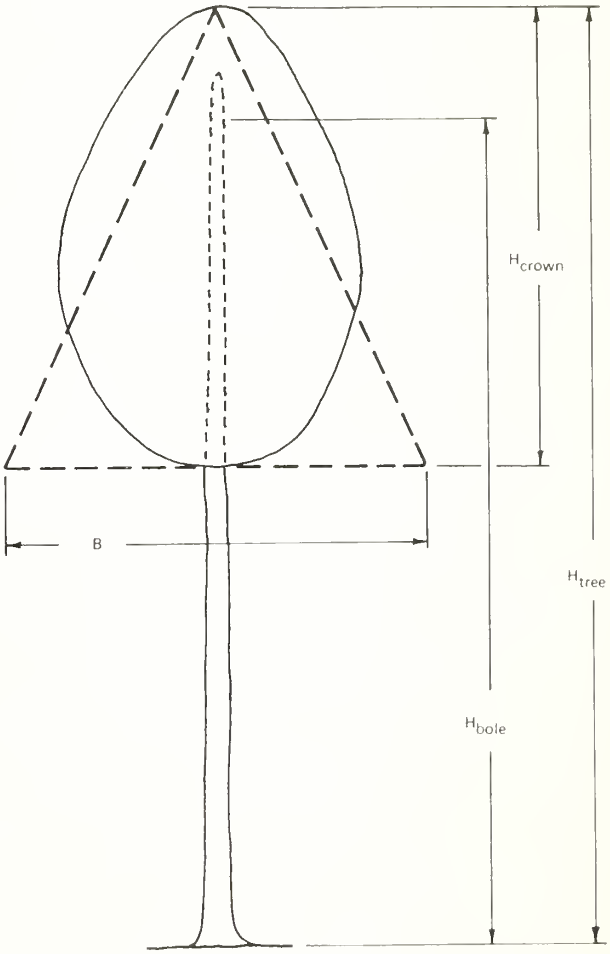

Figure 1.--Mathematical model of a tree with the bole as a truncated cone and the crown as a right circular cone.

The derivation of the theoretical models is included in Appendix B (refer also to Appendix A for the complete list of symbols). The method requires knowing the following tree parameters: d.b.h., D_{top}, H_{tree}, H_{bole}, W_{tree}, W_{bole}, C_{tree}, C_{bole}, and H_{crown}. Estimates of these variables, with the exception of H_{bole} and H_{crown}, have been

[1] *H. M. Steinhilb and John R. Erickson. Weights and centers of gravity for quaking aspen trees and boles. USDA For. Serv. Res. Note NC-91, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn. 1970.*

[2] *H. M. Steinhilb and John R. Erickson. Weights and centers of gravity for red pine, white spruce, and balsam fir. USDA For. Serv. Res. Pap. NC-75, 7 p. North Cent. For. Exp. Stn., St. Paul, Minn. 1972.*

[3] *V. Snyder and D. Hutula. Theoretical analysis of static and dynamic forces incurred in handling full trees and tree-length logs. Mich. Technol. Univ. unpubl. rep., submitted as an in-house report to Forest Eng. Lab., North Cent. For. Exp. Stn., USDA For. Serv., Houghton, Mich. 43 p.*

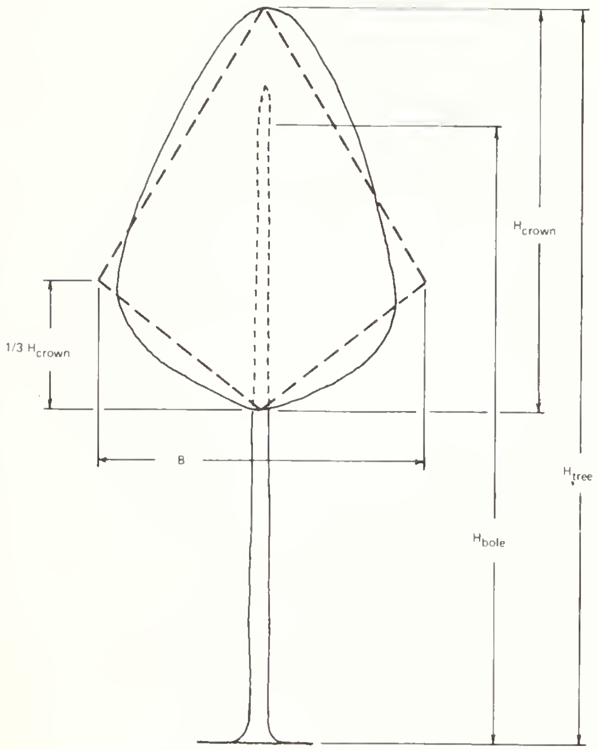

Figure 2.--Mathematical model of a tree with the bole as a truncated cone and the crown as a bicone.

published for various species including aspen and red pine.[1,2] Preliminary prediction equations for H_{bole} and H_{crown} for aspen and red pine are as follows:

Aspen:

$$H_{bole} = 1.51 + 0.8217\,(H_{tree}) + 0.0002\,(H_{tree})^2$$

$$H_{crown} = 29.64 + 0.1437\,(H_{tree}) + 0.0007\,(H_{tree})^2$$

Red pine:

$$H_{bole} = -6.08 + 0.9514\,(H_{tree}) + 0.0009\,(H_{tree})^2$$

$$H_{crown} = 25.96 - 0.0715\,(H_{tree}) + 0.0038\,(H_{tree})^2$$

EXPERIMENTAL PROCEDURE

During the summer of 1970 the sample trees were selected from adjoining pure aspen and red pine stands on a dry upland site near Alberta in Baraga County, Michigan. Data were obtained from 15 red pine and 12 aspen trees. The red pine trees ranged from 7 to 13 inches in d.b.h. and from 69 to 78 feet in height (table 1). The aspen trees ranged from 7 to 12 inches in d.b.h. and from 60 to 72 feet in height. In this paper the tree is defined as including everything above the stump. The bole is defined as the portion of the stem above the stump, delimbed and topped at a 3-inch diameter outside bark.

The mass moments of inertia for the trees and boles were determined experimentally by using the pendulum principle. The field experiments determined: (1) the weight, (2) the center of gravity, and (3) the period of oscillation of the tree or bole as it was suspended horizontally and oscillated through a small angle. Knowing the weight (W) in pounds, the distance from the center of gravity of the tree to the axis of oscillation (h) in feet, and the period of oscillation (T) in seconds, the moment of inertia about a transverse axis through the center of gravity of the tree was calculated by the following equation (refer to Appendix C):

$$\overline{I} = (T^2Wh/4\pi^2) - (Wh^2/g).$$

The d.b.h. of each sample tree was measured to the nearest 0.1 inch. The tree was then felled in the direction causing the least damage and loss of limbs, and skidded to a nearby landing. The maximum skidding distance was 300 feet, but the majority of trees were skidded only about 100 feet. The diameter outside bark of the felled tree was measured at the stump, at 2 and 4 feet from the butt, and at 8-foot intervals thereafter to the top diameter of 3 inches. The length and top diameter of any residual portion of the bole above the last 8-foot section, as well as the total overall length of the tree above the stump, were also measured. All lengths were measured to the nearest 0.1 foot.

The tree was picked up by a high-lift fork lift within 4 hours after felling. The tree weight was determined by placing a load transducer between the fork lift and a chain sling suspending the tree. The sling connections included a swivel and uniball joint to allow the tree to hang freely. A point on the tree vertically below the apex of the sling was marked as the center of gravity (fig. 3).

The period of oscillation of the tree was determined by oscillating the suspended tree through a small angle and measuring the elapsed time between the successive oscillations. The time was measured with an electric circuit and switch, the switch being a metal rod inserted into the tree. The switch opened and closed the circuit as the tree oscillated past a contact that was mounted on a vertical rod hammered into the ground (fig. 4). The closing of the switch caused a small change in voltage that was recorded on an oscillograph recorder. The recorder was used to measure time accurately between each voltage change or oscillation of the tree. The average period of oscillation used in the calculations was obtained over at least 10 oscillations. In order to decrease the amount

Table 1.--*Range of variables for aspen and red pine trees and tree-length boles*

Variable	Aspen	Red Pine
D.b.h. (in.)	7.1 to 12.1	7.0 to 13.5
Tree height (ft.)	60.50 to 72.67	69.58 to 77.75
Bole length (ft.)	45.25 to 60.58	59.00 to 69.75
Tree weight (lbs.)	555 to 1,475	582 to 2,335
Bole weight (lbs.)	485 to 1,320	520 to 1,945
Tree center of gravity (ft. from butt)	22.67 to 28.75	28.00 to 31.33
Bole center of gravity (ft. from butt)	18.25 to 23.75	23.25 to 25.42
Tree moment of inertia (lb.-ft.-sec.^{2})	3,232 to 14,726	6,569 to 24,266
Bole moment of inertia (lb.-ft.-sec.^{2})	1,558 to 8,308	4,376 to 16,102

Figure 3.--Setup showing the procedure used in weighing and locating the center of gravity of full trees

Figure 4.--Setup showing the procedure used in measuring the period of oscillation of the full tree.

of tree bending and thereby prevent the tree from contacting the ground while it oscillated, a manilla rope was tied to the butt of the tree, placed over a pulley attached to the fork lift, and then tied to the top of the tree.

After the data were obtained the tree was limbed and topped to a 3-inch diameter outside bark. The resulting bole was suspended, weighed, its center of gravity marked, and the period of oscillation measured in the same way as detailed above.

ASPEN AND RED PINE RESULTS

Equations for estimating the moments of inertia for aspen and red pine trees and boles were obtained through linear regression analyses. These equations and the associated standard errors of estimate are presented in table 2. D.b.h. was the only independent variable used. The range in height was not enough to provide information on either the value of height as an estimator or on the relationship of moments of inertia to d.b.h. over all height classes.

The 95-percent upper tolerance limits were calculated for each equation. The upper tolerance limit gives reasonable assurance (probability 0.90) that not more than 5 percent of the trees or boles from the population represented (70-foot height class) will exceed this limit. Equations and tolerance limits are shown in figures 5, 6, 7, and 8. These upper tolerance limits are offered as moment of inertia guides in the design of timber harvesting equipment.

Table 2.--*Prediction equations for the moment of inertia of red pine and aspen trees and tree-length boles*

Equation	N	Standard error of estimate	Correlation coefficient
Red pine tree:			
Y = 2,763.9 (d.b.h.) - 13,599	15	1,375	0.9728
Red pine bole:			
Y = 1,712.3 (d.b.h.) - 8,497.9		1,151	.9479
Aspen tree:			
Y = 2,514.0 (d.b.h.) - 15,239	12	1,031	.9672
Aspen bole:			
Y = 1,324.4 (d.b.h.) - 8,059.3		1,051	.8915

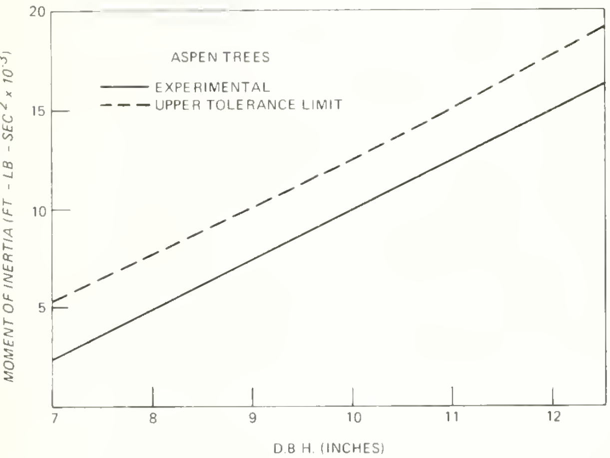

Figure 5.--Moment of inertia prediction equation for aspen trees in the 70-foot height class. The dashed line is the 95-percent upper tolerance limit.

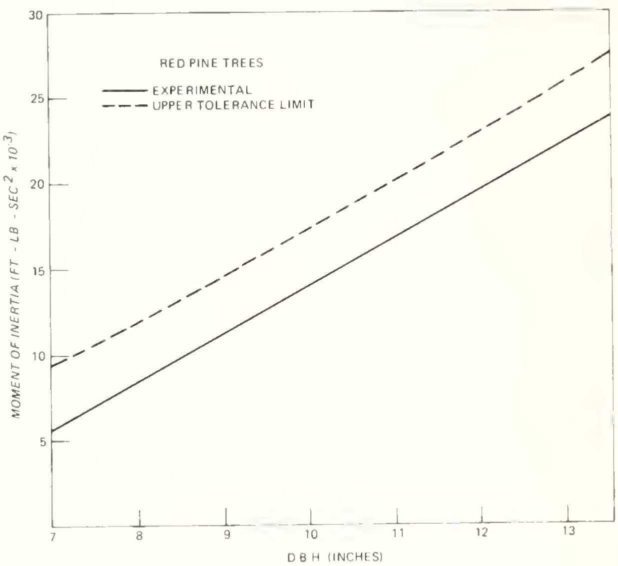

Figure 7.--Moment of inertia prediction equation plus its 95-percent upper tolerance limit for red pine trees in the 70-foot height class.

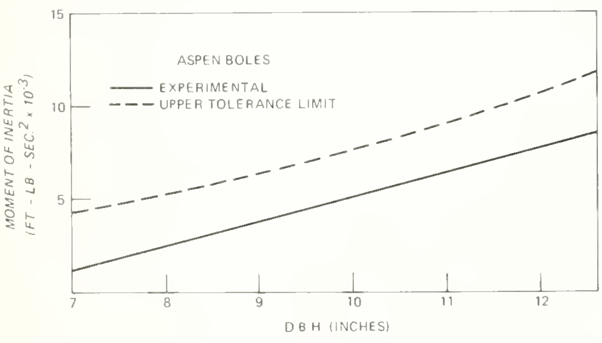

Figure 6.--Moment of inertia prediction equation plus its 95-percent upper tolerance limit for aspen boles obtained from trees in the 70-foot height class.

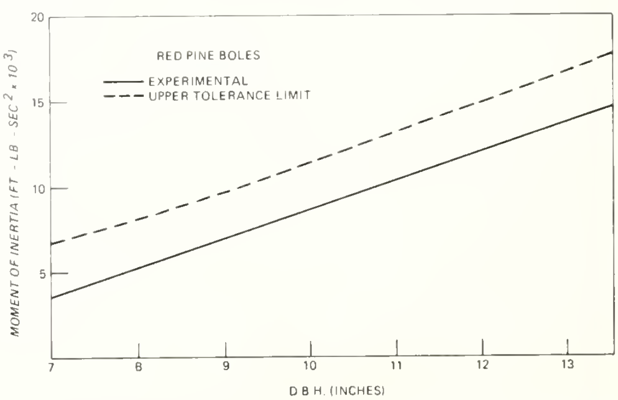

Figure 8.--Moment of inertia prediction equation plus its 95-percent upper tolerance limit for red pine boles obtained from trees in the 70-foot height class.

MODEL EVALUATION

The theoretical moment of inertia was calculated for each aspen and red pine tree and bole. Each of the tree characteristics used in the model was measured directly.

To evaluate each theoretical model the differences between the theoretical and experimental moments of inertia were analyzed statistically. A summary of these analyses is presented in table 3. In general, the theoretical tree models gave values that were not significantly different from the experimental results, but the bole theoretical models gave biased results. In all cases there was a linear relationship between the theoretical and experimental results.

Though close agreement was obtained between the theoretical and experimental results with the aspen concial tree model, the differences observed were correlated with d.b.h. With the aspen biconical tree model the theoretical moments were significantly higher than the experimental moments but approximated the upper tolerance limits of the experimental data. The bias was consistent throughout the data; the differences were not related to tree characteristics.

The conical red pine tree model gave moments of inertia that were not signficantly different from the experimental; there were large differences from tree to tree (range in the differences was from -3,238 to +5,015), yielding a large standard error. The differences between theoretical and experimental results were correlated with tree height.

The theoretical model consistently overestimated the moment of inertia of the aspen and red pine boles but never exceeded the upper tolerance limits of the experimental data. These differences were relatively constant throughout the range of the moments of inertia. For the aspen boles they were correlated with bole length. For the red pine boles the differences were correlated with both d.b.h. and bole length.

These analyses indicate the limitations when using the theoretical models for estimating the moments of inertia for trees in the 70-foot height class. A demonstration of the utility of the model was conducted on a taller tree. The experimental and theoretical moments of inertia for an 88-foot aspen tree with 18.8-inch d.b.h. were calculated and close agreement found as indicated in the tabulation:

	Experimental value (ft.-lb.-sec.^{2})	*Conical-shaped model (ft.-lb.-sec.^{2})*	*Biconical-shaped model (ft.-lb.-sec.^{2})*
Tree	53,783	55,261	63,087
Bole	30,581	34,485	34,485

UTILIZATION FOR OTHER SPECIES

As mentioned in the introduction, basic engineering data on the moments of inertia of trees and boles are needed to enable a dynamic handling analysis for a specific machine design. Equations for estimating the moments of inertia

Table 3.--*Summary of the statistical analyses made in comparing the theoretical and experimental values of moment of inertia*

	Aspen			Red pine	
	Trees			Trees	
	Conical-shaped crown	Biconical-shaped crown	Boles	Conical-shaped crown	Boles
Number of samples	10	10	12	12	13
Mean difference (theoretical - experimental)	-80	1,191	1,147	744	1,314
Standard deviation of the differences	1,030	975	349	2,274	836
Standard error of the mean difference	326	308	101	657	232
Confidence interval about the mean with one standard error	-406 245	883 1,499	1,046 1,248	88 1,401	1,082 1,546
$t_{calculated}$	-0.25	3.86	11.40	1.13	5.67
Correlation coefficient: differences vs. d.b.h.	-.56	.08	.29	.31	.49
Correlation coefficient: differences vs. tree height or bole length	-.25	.23	.52	.66	.73
Linear regression: experimental vs. theoretical					
Slope	1.05	.93	.94	.81	.86
Intercept	404	400	779	2,462	156
Correlation coefficient	.96	.97	.99	.94	.98

for aspen and red pine trees and boles, presented earlier, can be used for trees of those species, within the range of data shown in table 1. For trees outside these ranges and for trees of other species, the theoretical models could be used to obtain estimates. The theoretical approach is necessary because no other information is available. The models should work best with species that are similar to aspen or red pine.

A dynamic analysis method in which the above data can be used has been developed by Sturos and Mattson.[4] This technique utilizes a computer program developed by IBM Corporation called Continuous System Modeling Program (CSMP). Equations relating the tree weight, center of gravity, and moment of inertia to d.b.h. can all be incorporated into the program. The dynamic forces and moments required in handling any specified size of tree through any specified handling mode can be determined.

SUMMARY

Estimating equations for the moments of inertia of trees and boles and their upper tolerance limits have been presented for a limited aspen and red pine tree and bole population. The test of the theoretical models on the aspen and red pine data shows they have some promise but more research is necessary. The theoretical models gave moments of inertia for the aspen and red pine trees that were not significantly different statistically at the 0.05 level from the actual moments of inertia. Overestimation of the moments of inertia of the boles was evident, but the amount was consistent through the range of d.b.h. tested. Correlation of the differences between the experimental and theoretical results to tree characteristics is evident. Some improvements were obtained in the tree model by using the conical crown form rather than the biconical form.

The theoretical methods presented are only a start in obtaining more realistic design data and are presented here for consideration by others. Though certain simplifying assumptions were made, the models give conservative figures on which the designer can specify his first prototype.

[4] *John A. Sturos and James A. Mattson. Dynamic analysis of handling full trees and tree-length logs. Am. Soc. Agric. Eng. Trans. (In press.)*

APPENDIX A

Legend of Symbols

A = Cross-sectional area of the bole (ft.^{2}).

C_{tree} = Distance from butt to center of gravity of full tree (ft.).

C_{bole} = Distance from butt to center of gravity of tree-length bole (ft.).

C_{crown} = Distance from butt to center of gravity of crown (ft.).

d = Bole diameter at arbitrary point (ft.).

d.b.h. = Bole diameter at breast height (in.).

D_{top} = Bole diameter at top (in.).

g = Gravitational acceleration, 32.2 ft./sec.^{2}.

h = Distance from center of gravity of tree or bole to axis of oscillation (ft.).

H_{tree} = Height of full tree with crown (ft.).

H_{bole} = Height of tree-length bole (ft.).

H_{crown} = Height of crown (ft.).

IX_{bole} = Moment of inertia of bole about transverse axis through center of gravity of bole (ft.-lb.-sec.^{2}).

IZ_{bole} = Moment of inertia of bole about longitudinal axis (ft.-lb.-sec.^{2}).

IX_{tree} = Moment of inertia of full tree about transverse axis through center of gravity of full tree (ft.-lb.-sec.^{2}).

IZ_{tree} = Moment of inertia of full tree about longitudinal axis (ft.-lb.-sec.^{2}).

I_{crown} = Moment of inertia of crown about transverse axis throuch center of gravity of crown (ft.-lb.-sec.^{2}).

ρ = Density of bole (lb./ft.^{3}).

T = Period of oscillation of the full tree or tree-length bole (sec.).

W_{tree} = Weight of full tree (lbs.).

W_{bole} = Weight of tree-length bole (lbs.).

W_{crown} = Weight of crown (lbs.).

B = Width of theoretical tree crown.

APPENDIX B

Theoretical Method

If the bole of the tree is assumed to be a truncated cone, the diameter d varies linearly along the bole length and is given by:

$$d = C_1 - C_2 Z$$

where Z is measured from the butt end. The coefficients C_1 and C_2 are determined by using the following conditions:

$$d = \text{d.b.h.}/12 \text{ at } Z = 5 \text{ (breast height)}$$
$$d = D_{top}/12 \text{ at } Z = H_{bole} \text{ (top of bole).}$$

The factors 1/12 in the equations are used because d.b.h. and D_{top} are in inches and d is in feet. Using the above equations, the coefficients C_1 and C_2 are obtained as:

$$C_1 = \frac{\left(H_{bole} \times \text{d.b.h.}\right) - 5\,D_{top}}{12\,(H_{bole} - 5)}$$

$$C_2 = \frac{\text{d.b.h.} - D_{top}}{12(H_{bole} - 5)} .$$

The density ρ of the bole is taken to vary linearly along the bole length in the form:

$$\rho = K_1 - K_2\,Z .$$

The coefficients K_1 and K_2 are determined by using the known bole weight and CG location.

$$W_{bole} = \int_0^{H_{bole}} \rho A dz = \frac{\pi}{4} \int_0^{H_{bole}} (K_1 - K_2 Z)(C_1 - C_2 Z)^2 dz$$

$$= \frac{\pi H_{bole}}{4} \left[C_1^2 - C_1 C_2 H_{bole} + \frac{1}{3} C_2^2 (H_{bole})^2 \right] K_1$$

$$- \frac{\pi (H_{bole})^2}{4} \left[\frac{1}{2} C_1^2 - \frac{2}{3} C_1 C_2 H_{bole} + \frac{1}{4} C_2^2 (H_{bole})^2 \right] K_2$$

$$C_{stem} =$$

$$\frac{1}{W_{bole}} \int_0^{H_{bole}} \rho A z dz = \frac{\Pi}{4 W_{bole}} \int_0^{H_{bole}} (K_1 - K_2 Z)(C_1 - C_2 Z)^2 z dz$$

$$= \frac{\pi (H_{bole})^2}{4 W_{bole}} \left[\frac{1}{2} C_1^2 - \frac{2}{3} C_1 C_2 H_{bole} + \frac{1}{4} C_2^2 (H_{bole})^2 \right] K_1$$

$$- \frac{\pi (H_{bole})^3}{4 W_{bole}} \left[\frac{1}{3} C_1^2 - \frac{1}{2} C_1 C_2 H_{bole} + \frac{1}{5} C_2^2 (H_{bole})^2 \right] K_2 .$$

The above two equations are two linear-algebraic equations which can be solved for K_1 and K_2.

The mass moment of inertia of the bole about a transverse axis can be computed by treating the bole as a long slender rod with a variable density and cross section. Using the integral definition of moment of inertia and the transfer-axis theorem, the moment of inertia of the bole about transverse axis x through the bole CG is determined to be:

$$IX_{bole} =$$

$$\frac{1}{g} \int_0^{H_{bole}} \rho A Z^2 dz - \frac{W_{bole} (C_{bole})^2}{g}$$

$$= \frac{\pi}{4g} \int_0^{H_{bole}} (K_1 - K_2 z)(C_1 - C_2 z)^2 z^2 dz - \frac{W_{bole} (C_{bole})^2}{g}$$

$$= \frac{\pi K_1 (H_{bole})^3}{4g} \left[\frac{1}{3} C_1^2 - \frac{1}{2} C_1 C_2 H_{bole} + \frac{1}{5} C_2^2 (H_{bole})^2 \right]$$

$$- \frac{\pi K_2 (H_{bole})^4}{4g} \left[\frac{1}{4} C_1^2 - \frac{2}{5} C_1 C_2 H_{bole} + \frac{1}{6} C_2^2 (H_{bole})^2 \right]$$

$$- \frac{W_{bole} (C_{bole})^2}{g} .$$

Two types of crowns were investigated, namely a right circular cone and a biconical shape as shown in figures 1 and 2. The moment of inertia of a right circular cone about its own center of gravity is:

$$I_{crown} = \frac{W_{crown}}{g} \left(\frac{3}{80} B^2 + \frac{3}{80} H^2_{crown}\right) .$$

Assume: $B = H_{crown}$,

then: $I_{crown} = \frac{3}{40} \frac{W_{crown}}{g} (H^2_{crown})$

$$C_{crown} = H_{tree} - 3/4\ H_{crown} .$$

The biconical-shaped crown studied was made up of two unequal right-circular cones with a common base, the top cone being twice as high as the bottom one as shown in figure 2. The center of gravity of this bicone with respect to the base of the tree is:

$$C_{crown} = H_{tree} - 7/12\ H_{crown} .$$

The moment of inertia of this bicone about its own center of gravity is:

$$I_{crown} = \frac{W_{crown}}{g} \left(\frac{3}{80} B^2 + \frac{19}{720} H^2_{crown}\right) .$$

Assume: $B = H_{crown}$,

then: $I_{crown} = \frac{23}{360} \frac{W_{crown}}{g} H^2_{crown} .$

The moment of inertia of a full tree about a transverse axis through the CG of the full tree is given by:

$$IX_{tree} = IX_{bole} + \frac{W_{bole}}{g} (C_{tree} - C_{bole})^2 + I_{crown} + \frac{W_{crown}}{g} (C_{tree} - C_{crown})^2 .$$

APPENDIX C

Experimental Method

The moment of inertia of a compound pendulum (I') about its axis of oscillation is given by the following equation:[5]

$$I' = T^2Wh/4\pi^2$$

where: T = period of oscillation (seconds),
W = weight of pendulum (pounds), and
h = distance from the center of gravity of the pendulum to the axis of oscillation (feet).

Therefore, by using the parallel-axis theorem, the moment of inertia of a pendulum (tree or bole) about its center of gravity ($\bar{I}$) is given by the following equation:

$$\bar{I} = I' - Wh^2/g = (T^2Wh/4\pi^2) - (Wh^2/g)$$

where: g = acceleration due to gravity (feet/second^2).

The effect of the amplitude of the oscillations and the damping at the point of suspension are assumed negligible.

[5] *E. Hausman and E. P. Slack. Physics. Ed. 2, p. 159. New York: D. Van Nostrand Co. 1939.*

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NORTH CENTRAL FOREST EXPERIMENT STATION

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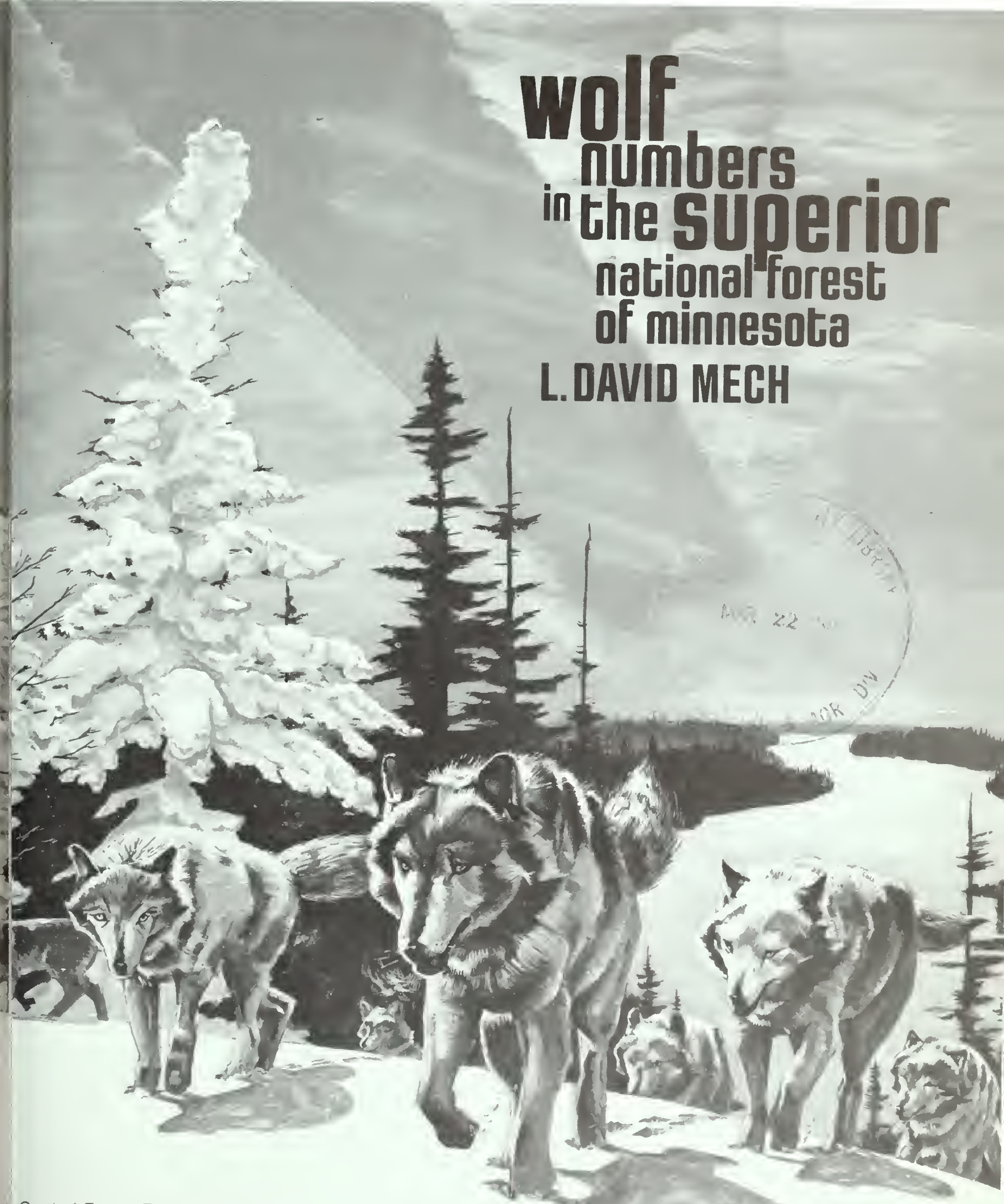
wolf numbers in the superior national forest of minnesota

L. DAVID MECH



r Central Forest Experiment Station
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CONTENTS

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Manuscript approved for publication August 13, 1973

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PREFACE

This publication on wolf numbers is based on an intensive, continuing study of the spatial organization and population-regulating factors of wolves in the Superior National Forest. The details of spacing and population regulation will be the subject of an extensive report, now being prepared.

Meanwhile, it was deemed worthwhile to publish this shorter paper to provide the scientific community, wildlife and forest administrators, and the general public with one of the important fruits of this research, an estimate of the number of wolves in the Superior National Forest.

WOLF NUMBERS IN THE SUPERIOR NATIONAL FOREST OF MINNESOTA

L. David Mech

The purpose of this paper is to present an estimate of the number of eastern timber wolves (*Canis lupus lycaon*) inhabiting the Superior National Forest of northeastern Minnesota. Such an estimate is important because: (1) the main population of this subspecies of wolf in the United States occurs in Minnesota, with probably fewer than 50 other individuals remaining elsewhere in this country (Mech 1970), and therefore, the subspecies has been declared "endangered" by the U.S. Secretary of the Interior;[1/] (2) the ecologically sound management of the wolf depends at least partly on knowledge of wolf numbers, densities, and population trends; (3) the Superior National Forest harbors a significant part of the total wolf population of Minnesota; and (4) the 3,000 square miles of federally owned land contained within the Forest boundaries represents a large part of wolf range under public control.

Accurate estimates of wolf populations are difficult to make because the animals are elusive, they occur in relatively low densities, and they travel over large areas. Therefore, the few estimates of wolf numbers that have been made anywhere have varied greatly in precision and area covered.

Outside of the Superior National Forest, reasonably accurate censuses have been conducted on Isle Royale in Lake Superior, in certain regions of Alaska, and in Algonquin Park, Ontario. All of these censuses used small aircraft during winter and relied on visual tracking and observation of wolves and attempts at identifying individual packs.

On Isle Royale's 210 square miles, researchers estimated wolf populations at between 15 and 28 from 1959 through 1970, based on attempts at complete counts (Mech 1966, Jordan et al. 1967, Wolfe and Allen (in press)). On 20,000 square miles of south-central Alaska, wolf estimates varied from 12 to 450 during the period 1953 through 1967 based on transect sampling, with the variation thought to reflect actual population changes (Rausch 1969). In Algonquin Park, wolf numbers were estimated at about 290 in 2,900 square miles from 1958 to 1962 as projected from an intensive sampling of 500 to 1,000 square miles (Pimlott et al. 1969) In all three cases, hundreds of hours of flying were involved in obtaining the estimates.

The first attempt to estimate wolf numbers on the Superior National Forest was made by Ols in 1938. Based on his extensive travels throug out the Forest and interviews with trappers, ga wardens, and rangers, he subjectively estimated a wolf density of one wolf per 10 square miles for some 2,500 square miles of wilderness on th Forest.

The next estimate was made by Stenlund (1955) for the period 1948 to 1953. Using subj tive observations supplied by warden-pilots, pr vate pilots, and trappers, he judged that the population was between 205 and 273 wolves, with the mean about 240, on 4,100 square miles of th Forest, or one wolf per 17 square miles.

From 1964 through mid-1969, Mech and Frenzel (1971) conducted a series of studies in the Forest that depended primarily upon aerial observations of wolves, tracks, and kills and included the aerial tracking of five radio-tagg wolves. Besides the 319 locations we obtained through studying the five radioed wolves and their associates, we also saw a total of 323 wolves (no doubt many of them duplicate sightings) during 77 separate observations. Some 490 hours of flying were involved in those studies.

Although at that time we were unable to estimate the wolf population on the Forest, we did compare our observations with the 112 observations of 318 wolves summarized by Stenlund (1955 and concluded that the wolf population of the Forest probably had increased between 1953 and 1967, but that it apparently had remained stable between 1967 and early 1969.

While these studies were being expanded, Va Ballenberghe (1972) also conducted a study of th wolves of the Forest from 1969 through early 197 He too used radio-tracking as a primary techniqu During his last 2 years he concentrated on a 1,006-square-mile area of the Forest adjacent to Lake Superior. As will be discussed in detail later, he defined 11 packs containing 79 members occupying an estimated 720 square miles, for an average density of one wolf per 9.1 square miles

1/ *This subspecies of wolf is still common throughout eastern Canada and is not considered endangered there. In addition, several other subspecies of wolves inhabit western and northern Canada and Alaska, where they are not considered threatened.*

THE PRESENT STUDY

The present study is basically a continuation and expansion of the earlier investigations by Mech and Frenzel (1971) and includes data collected through June 30, 1973. The area studied is the entire Superior National Forest (exclusive of the separate Virginia District), with the most intensive work being conducted in the central region of the Forest. (See Stenlund (1955) and Mech and Frenzel (1971) for a description of the area.) The Forest, outside of the Virginia District, encompasses a total of 4,203 square miles, about 3,000 of which are federally owned.

The area studied intensively for the present population estimate is an irregular-shaped, 1,005-square-mile region that extends from Lake Vermilion on the west to Fourmile Lake on the east, with the town of Isabella on the south boundary, and the Canadian border on the north (fig. 1). About half this region is in the Boundary Waters Canoe Area (BWCA), with about 20 percent in the zone where no timber cutting is allowed. Densities of deer (*Odocoileus virginianus*), the wolf's primary prey, on this basic census area, range from the lowest to nearly the highest on the Forest. Moose (*Alces alces*), a secondary food source, occur throughout the area in various densities, including the highest density known for the Forest (Peek 1971).

METHODS

The methods used in this study include (1) live-trapping wolves, extracting blood samples from them, and examining, weighing, radio-tagging them (Kolenosky and Johnston 1967), and radio-tracking them from the air and ground as described by Mech and Frenzel (1971); (2) directly observing radio-tagged individuals and their associates from the air whenever possible; (3) determining the ranges, territories, movements, and interactions of packs and lone wolves; (4) determining the actual density of pack wolves in the intensive census area by direct counting of pack animals; (5) observing tracks and nonradioed wolves on the basic census area and on the rest of the Forest and compiling the observations of wolves and tracks reported systematically by other workers on the

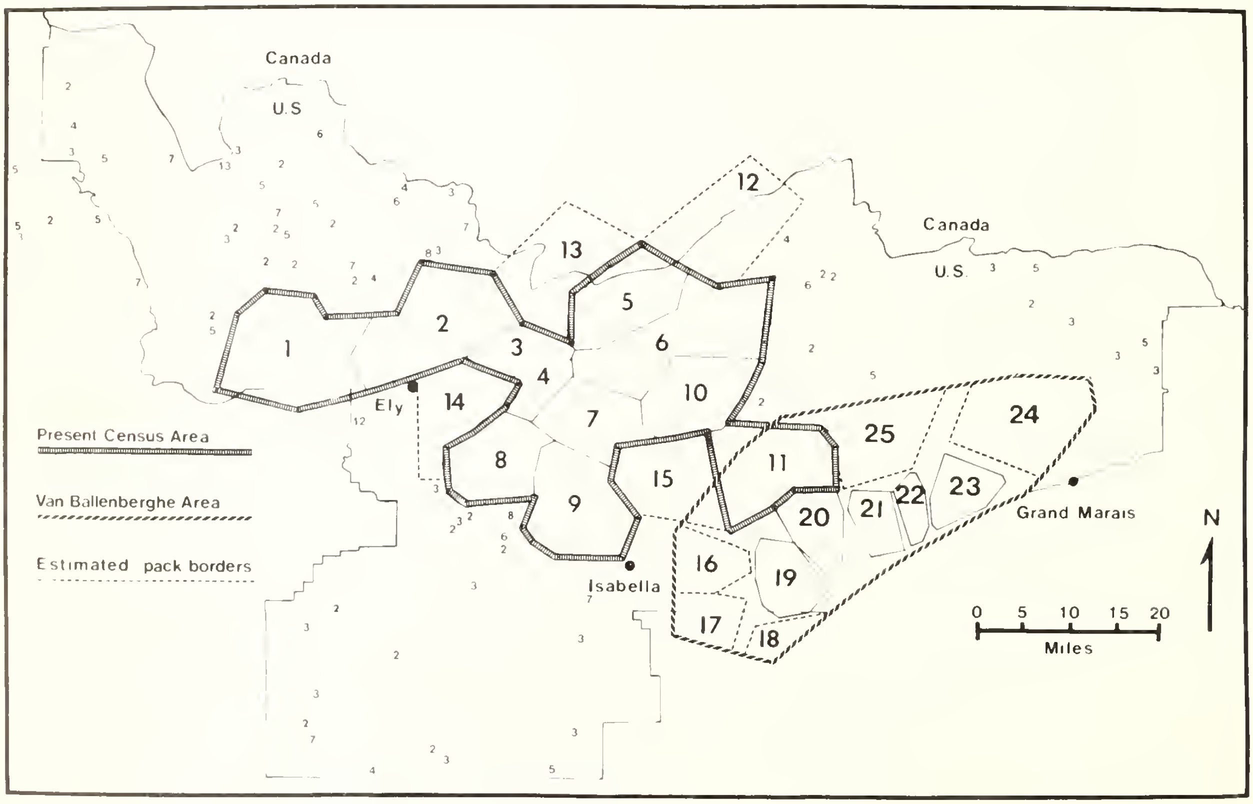

Figure 1.--The Superior National Forest study area. Large numerals identify wolf packs (table 3), and lines around them indicate approximate pack territory borders. Small numerals represent the sizes of packs or their tracks observed outside of the intensive census areas (lone wolves not plotted).

Forest; (6) applying an adjustment factor to account for lone wolves and pairs; (7) projecting the density figures for the basic census area to the entire Forest, with adjustment of the estimate in certain areas to account for unusual circumstances not significant in the basic census area.

RESULTS

Data used in the present investigations include those reported in the pilot study by Mech and Frenzel (1971) plus more substantial data collected since then. The author and his assistants flew for approximately 1,600 hours during the study, and radio-tagged a total of 77 wolves on the Forest, six of them twice. The transmitter-collars (Mech and Frenzel 1971) have functioned as long as 20 months on wolves, including one operating since November 4, 1971 and still going. More than half (43) of the radioed wolves were located over periods of at least 4 months each, and 38 percent (28) for at least 6 months each. Radioed wolves followed for shorter periods were those that dispersed out of range, died, were killed, or on which transmitter-collars failed. I located wolves by radio over 3,000 times and actually observed them on 1,337 occasions, or 41 percent of the time (table 1).

Table 1.--*Seasonal distribution of radio locations and observations of wolves, 1968-1973 (as of June 30, 1973)*

	Wolves	Radio locations	Radioed wolves actually observed	
	Number	Number	Number	Percent
January	44	389	231	59
February	41	641	439	68
March	34	367	236	64
April	31	221	79	36
May	31	262	32	12
June	31	263	13	5
July	22	112	6	5
August	17	68	5	7
September	19	100	11	11
October	49	223	11	5
November	59	274	92	34
December	47	307	182	59
Total		3,227	1,337	41 (Average)

Members of 12 contiguous packs were radio-tagged during this study, and were radio-located intermittently (usually at least once per week) for periods ranging from 3 months to 5 years (table 2). Sufficient data were obtained from 10 of those packs to allow an accurate determination of their ranges and total members. Observational data from one additional pack that was not radio-tagged were also adequate for this purpose because the pack contained the only black wolves in the general region and therefore was identifiable, and because its range was bordered on six sides by ranges of radio-marked packs. Thus the basic census area of 1,005 square miles upon which the population estimate for the Forest is based, is the region inhabited by these 11 packs (fig. 1, packs 1 to 11).

Because we were not always able to radio-tag members of each study pack during each year of the investigation, information on pack sizes during some years had to be determined from strictly observational data of tracks and unmarked packs. Data from packs that were radio-tagged for more than 1 year indicated that pack home ranges were consistent from year to year. Therefore, once a range was delineated by radio-tracking data, all the observations that were made in that range before or after the delineation were considered to apply to the pack occupying that range. A total of 76 such observations was made (table 2).

Nevertheless, for some of the study packs, yearly or seasonal pack size data are incomplete. The period for which the most data are available from the basic census area is winter 1971-72, so those data will be used to project an estimate for the Forest. Estimates of population trends before and after this period will be based on comparisons with those data.

To understand wolf population dynamics, one must be aware of the annual sociological cycle of the wolf pack, a description and documentation of which will be published in more detail elsewhere. Briefly, however, a pair of adults in Minnesota mates in February, and an average-sized litter of five or six pups is produced in late April. Under good conditions, the survivors become adult-sized by autumn and accompany the adults during winter. As early as February of their first year, and possibly before, some of the pups may disperse from the pack, although usually they remain with the adults at least until a second litter of pups is produced. During the next winter, the pack is composed of the adult pair, the surviving new pups, and whichever yearlings have not dispersed or died during summer. As winter progresses, however, some pack members, presumably some of the yearlings and/or some of the pups, disperse and/or perish. Each year, this history is repeated, with new pups being produced, yet the pack usually remains approximately the same size from year to year.

Therefore, it is of particular interest to assess the size of each pack in early winter, when the surviving pups accompany the rest of the pack, and again in the spring, after the winter's loss. Such an assessment is best made on radioed packs because at any given time a pack may temporarily split, or any number of members may wander away from the group for a

Table 2.--Radio-tracking and observational data on which pack size estimates are based (as of June 30, 1973)
(In numbers)

Pack	Radioed wolves	Months of data	Biological years[1/] represented by radio-tracking data	Radio locations	Observations based on radio-tracking	Observations of pack or tracks when not radioed
Glenmore L.	5	11	2	83	55	2
Newton L.	3	17	3	178	74	7
Pagami L.	2	6	2	69	32	9
Greenstone L.	1	5	1	41	29	10
Ensign L.	3	13	2	158	63	8
Thomas L.[2/]	--	--	5	--	--	14
Quadga L.	5	7	2	101	52	3
Harris L.	7	34	5	426	185	4
Jackpine	12	25	4	558	218	4
Maniwaki L.	3	18	3	155	77	14
Timber L.	1	3	[3/] 1	19	9	1
Total	41	--	--	1,479	675	76

1/ A biological year begins in late April when the pups are born.
2/ This pack was not radioed but was identifiable because of its black members.
3/ See also Van Ballenberghe (1972).

day or two, rendering incidental single counts of the pack open to inaccuracies. Only after a number of counts are made over a period of weeks can one be certain of the full complement of a pack. This means that single observations of unmarked groups may tend to be lower than the actual number in the pack and should only be used when radio-tracking data are unavailable.

During late November 1971 through February 1972, referred to hereafter as "winter 1971-72," the maximum sizes of the 11 packs occupying the basic census area (fig. 1, packs 1 to 11) totaled 82 wolves (table 3). The packs in the Superior National Forest are basically territorial, with each occupying a discrete area (Mech 1972). Therefore, the number of wolves in the 11 packs represented the total number of pack wolves in the census area, and this amounts to a pack-wolf density of 1 wolf per 12.3 square miles in early winter.

In addition to the pack wolves, an unknown number of lone wolves and pairs also circulate within the census area, having dispersed from the 11 packs and their neighbors. Their numbers can be estimated, however, from figures given by Mech and Frenzel (1971, table 10):

1. Assume that the proportion of lone wolves, pairs, and packs observed incidentally are reasonably representative of the proportion in the population at large.

2. 34 of 77 observations (or 44 percent) involved loners and pairs, and 56 percent involved packs (Mech and Frenzel 1971, table 10).

3. Let X = the total number of population units (packs, pairs, and loners) in the census area.

4. 0.56X = 11 packs.

5. X = 11/.56 = 19.6 population units.

6. 32 percent of the population units observed were loners (Mech and Frenzel 1971, table 10).

7. 0.32(19.6) = 6.3 loners.

8. 11.0 packs + 6.3 loners = 17.3 packs and loners.

9. 19.6 population units - 17.3 packs and loners = 2.3 pairs.

10. Therefore, there were 11 packs, an estimated 6 loners, and an estimated 2 pairs (4 wolves) on the 1,005-square-mile census area; or 82 pack members, 4 members of pairs, and 6 lone wolves, totaling 92 wolves, an estimated density of 1 wolf per 10.9 square miles in early winter 1971-72.

11. Because there may be less chance of observing lone wolves and pairs than of packs, one might arbitrarily double the number of these individuals. When added to the 82 pack members the new figure would yield an estimate of 102 wolves on the census area, or an estimated density of 1 wolf per 9.9 square miles.

12. Thus, the estimated number of wolves on the census area in winter 1971-72 was 92 to 102, or a density of 1 wolf per 9.9 to 10.9 square miles.

In spring 1972, it was known that the 11 packs totaled not more than 61 animals (table 3), a decrease of at least 26 percent over winter.

Table 3.--*Sizes of known wolf packs on the Superior National Forest (Underlined figures indicate pack was radioed. Packs 16 to 25 from Van Ballenberghe (1972). Winter figures are the maximum pack sizes observed from December through February; spring figure represents maximum pack size observed during March and April.)*

(In numbers)

Pack		1966-67		1967-68		1968-69		1969-70		1970-71		1971-72		1972-73	
No.[1]	Name	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring
1.	Glenmore L.	6	--	--	--	8	--	--	--	--	--	12	8	12	4
2.	Newton L.	6	--	6	--	8	--	11	11	--	7	7	7	[2]6	--
3	Pagami L.	6	--	--	--	--	--	--	--	6	6	5	[3]3		
4.	Greenstone L.	--	--	--	--	4	--	--	--	5	5	4	[3]3	6	3
5.	Ensign L.	[4]7	--	--	--	--	--	--	--	--	11	15	[3]9	10	5
6.	Thomas L.	--	5	5	--	6	--	--	--	--	6	5	5	7	0
7.	Quadga L.	--	--	--	--	--	--	--	--	6	6	5	[3]4	2	--
8.	Harris L.	--	--	--	--	5	5	--	4	9	6	3	2	4	4
9.	Jackpine	--	--	--	--	--	--	6	5	7	6	9	6	7	6
10.	Maniwaki L.	8	8	6	--	10	7	14	--	7	--	9	7	9	3
11.	Timber L.	--	--	--	--	--	--	8	--	--	--	[5]8	[3]7	7	--
12.	Knife L.	--	--	--	--	13	9	--	--	--	--	--	8	--	--
13.	Canadian Pt.	7	6	--	--	[4]6	--	--	9	8	4	4	--	--	--
14.	Birch L.	--	6	--	--	--	--	--	--	--	--	--	--	6	--
15.	Sawbill	--	--	--	--	6	--	--	--	3	2	5	3	[2]4	--
16.	Houghtaling Creek	--	--	--	--	--	--	--	--	--	--	5	--	--	--
17.	Manitou R.	--	--	--	--	--	--	--	--	--	--	6	--	--	--
18.	Dyers L.	--	--	--	--	--	--	--	--	--	--	8	--	--	--
19.	Cross R.	--	--	--	--	--	--	--	--	--	--	9	--	--	--
20.	Temperance R.	--	--	--	--	--	--	--	--	--	--	8	--	--	--
21.	Onion R.	--	--	--	--	--	--	--	--	--	--	8	--	--	--
22.	Lutsen	--	--	--	--	--	--	--	--	--	--	5	--	[6]5	[6]5
23.	Ward L.	--	--	--	--	--	--	--	--	--	--	10	--	--	--
24.	Devils Track	--	--	--	--	--	--	--	--	--	--	7	--	--	--
25.	Clara L.	--	--	--	--	--	--	--	--	--	--	5	--	--	--

1/ See figure 1.
2/ Based on a single observation from the ground.
3/ May be less.
4/ May be more.
5/ Van Ballenberghe (1972).
6/ Lloyd Scherer (personal communication).

No doubt the decline of pack members was caused not only by mortality but also by dispersal of members into the ranks of the lone wolves. However, in the Superior National Forest the lone wolf is an insecure and temporary member of the population, having a much lower survival rate than permanent pack members (Mech 1972).

To convert the population estimates for the basic census area to meaningful figures for the Forest, it would not suffice merely to project the density figures to the total Forest acreage and then compute the standard error. This is because the 11 packs from which data are available were not chosen at random from the total population of packs within the Forest. Therefore, a nonstatistical approach will be used to derive a subjectively modified projection of the data from the census area.

Three types of data are available to aid in this projection. The first type includes data from two packs adjacent to the basic census area that were radio-tagged but from which relatively few location data were obtained (fig. 1, packs 12 and 15). Observational data (sightings and tracks recorded by the author an his assistants, and reports of sightings and tracks by other personnel) were also obtained for both these packs and for two other packs adjacent to the basic study area (table 3; fig. 1, packs 13 and 14). Although such data are not considered sufficient to fully delineate the ranges of these four packs, they do tend to support the data from the basic census area, and bolster confidence that the figures from the census area are generally applicable beyond it.

The second type of data for the Forest outside of the basic census area are those presented by Van Ballenberghe (1972). These data are based on trapping and recapture in 1970 and on radio-tracking during 5 months in summer 1971 and from 1 to 3 months per pack in winter 1971-72. Van Ballenberghe estimated the sizes and ranges of five packs (fig. 1, packs 19 to 23), and the sizes and approximate ranges of six other adjacent packs (fig. 1, packs 11, 16, 17, 18, 24, and 25), one of which was included in the present study.

Van Ballenberghe's 720-square-mile census area can be divided into two general zones. A

213-square-mile "core" region extends from the southeast boundary of the Forest, along the Lake Superior shore and to about 10 miles inland, and northeastward to within about 7 miles south of Grand Marais. This area includes a number of deeryards (Krefting 1938, Erickson et al. 1961), where winter deer densities are the highest in the State, having reached an estimated 166 deer per square mile in 1959 (Krefting and Shiue 1960). Five packs inhabited this area on a year-round basis and contained a total of 40 members during winter 1971-72, a density of one pack wolf per 5.3 square miles (fig. 1, packs 19 to 23; table 3).

The second zone in Van Ballenberghe's census area comprised 507 square miles extending in a 5- to 10-mile-wide semicircle inland and adjacent to the core region. Prey populations in most of this peripheral area were typical of those of the Forest in general. Six packs, including 39 members in total during winter 1971-72, occupied this area, for a density of one pack wolf per 13.0 square miles (fig. 1, packs 11, 16 to 18, 24, and 25; table 3). This compares favorably with the density of pack wolves in the 1,005-square-mile census area of the present study, one wolf per 12.3 square miles. (Van Ballenberghe made no estimate of the number of lone wolves and recently formed pairs in his study, so only pack-wolf densities can be compared.)

Van Ballenberghe's data are of interest here for two reasons. First, those from the peripheral zone confirm the density figures from the present study and demonstrate that they can be applied to a much larger area of the Forest. Secondly, the density data from the core area containing the deeryards indicate that this area is unique in the Forest. Although there are a number of smaller deer concentration areas throughout the Forest (Erickson et al. 1961), none approaches those of the Lake Superior shore in extent or numbers of deer. Furthermore, several of these smaller yards occur within the 1,005-square-mile census area of the present study, and in general do not seem to support unusually high wolf densities, probably because they are too small and dispersed.

The third type of data available for the remainder of the Forest consists of sightings and tracks recorded by project personnel and reports of sightings and tracks from other field workers, primarily Forest Service and Minnesota Department of Natural Resources employees (fig. 1). A total of 73 such observations was recorded, including some of those already reported (Mech and Frenzel 1971).

When a popu[illegible] estimate is based on such data alone, the estimate is subject to a high degree of error and must always be viewed with utmost caution. However, in the present study these data are useful in helping to decide subjectively the degree to which the density figures from the census area are applicable to the rest of the Forest.

In this respect, two judgments have been made from the observations. In general, packs of wolves or their sign have been observed throughout most of the Forest outside both intensive census areas (fig. 1). These observations establish that wolf packs do occur throughout most of the Forest. Because the remainder of the Forest is similar in topography, vegetation, and land use, the assumption is reasonable that the wolf density figures from the census area can be projected to much of the remainder of the Forest.

The second judgment from the observational data is that in areas of high accessibility, i.e., with a high density of roads, most observations other than those of lone wolves are those of pairs or other small groups of wolves or their tracks. I attribute this to the fact that in accessible areas, wolves are killed by humans year-round, so full-sized packs rarely get the chance to develop and persist. There are always enough wolves left to keep the population "smoldering" in accessible areas, because of the dispersing animals from the reservoir of packs in wilderness areas (Mech 1972). Nevertheless, there is a constant cropping of accessible populations, and thus presumably a lower density.

Therefore, I have arbitrarily assumed for a total of 540 square miles of the Forest--13 townships and halves of four other townships containing a high density of roads--the wolf density is approximately half that of the census area, or about one wolf per 19.8 to 21.8 square miles.

However, such an unusually low density in the accessible areas would be nearly compensated for by the abnormally high density of wolves in the deeryard area along the shore of Lake Superior. In that 213-square-mile area, the density of pack wolves was one per 5.3 square miles (Van Ballenberghe 1972), close to 2-1/2 times the density of the intensive census area of the present study.

Thus, it would be reasonable to project the density figures from the 1,005-square-mile census area to the total Forest exclusive of the Virginia District. A density of one wolf per 9.9 to 10.9 square miles applied to these 4,203 square miles amounts to an estimated 386 to 425 wolves or 405 ± 20, on the Superior National Forest in winter 1971-72.

The above estimate applies to the wolf population during the part of the biological year when the maximum number of surviving pups is circulating about with the adult members, and thus can be considered a measure of the maximum free-roving population of wolves on the Forest. As shown earlier, by spring 1972 the study packs had diminished in size by an average of about 26 percent, which, when projected, would yield a population estimate for that period of 286 to 315 wolves, or 300 ± 15.

Although lone wolves may have decreased at an even greater rate over the winter (Mech 1972), some of the decrease in pack members resulted from dispersing members becoming lone wolves, so these two factors would tend to compensate for each other.

From winter 1971-72 to winter 1972-73, a decrease in wolf numbers was observed in seven of the 11 study packs (table 3) in the central region of the Forest, where deer populations are lowest.

There was no evidence that the decrease occurred elsewhere, so it may be unsound to project the census-area density figures to the rest of the Forest for winter 1972-73. The best estimate for that winter is that the Forest wolf population generally remained about the same as that of the winter before in an estimated 80 percent of the Forest, but that in the remaining 20 percent it dropped by about 15 percent (based on packs 1 to 11, table 3), yielding an estimate of 374 to 412 wolves or 388 ± 14, for winter 1972-73.

An overwinter reduction in number of pack wolves seems to be a general phenomenon, probably taking place during most years under normal conditions. If the 26 percent overwinter decline for 1971-72 were applied to the winter 1972-73 figures, an estimate for wolf numbers in spring 1973 could be made. However, on an estimated 20 percent of the Forest where the decline took place from 1971-72 to 1972-73, the 1972-73 overwinter reduction, based on pack numbers 1, 3 to 6, and 8 to 10, was 55 percent, so this estimate would be too high. An estimate of 257 to 285 wolves or 271 ± 14 appears more accurate, based on an assumed 26 percent overwinter decline for 80 percent of the Forest, and a 55 percent overwinter decline for the remaining 20 percent.

DISCUSSION AND CONCLUSIONS

Early estimates of wolf numbers on the Superior National Forest were largely subjective, so there is little to be gained by comparing them with the present estimates. However, it does appear from comparisons of recent data with past observations of pack sizes that from about 1950 to 1967 the wolf population increased (Mech and Frenzel 1971). This increase may be attributable to a prohibition against aerial hunting of wolves in the BWCA in 1951 (Stenlund 1955), the curtailment of wolf control as a program by the Minnesota Conservation Department in 1955, and the repeal of the bounty in 1965.

From 1967 to 1969 it appears that the wolf population on the Forest remained relatively stable (Mech and Frenzel 1971).

From winter 1970-71 to 1972-73 the best indication of population trends can be obtained by comparing the relative sizes of nine packs from which the most radio-tracking data are available. The mean size of these packs for winter 1970-71 was 6.7; for 1971-72, 6.8; and for 1972-73, 5.9 (table 4).

Table 4.--*Average annual winter pack sizes for the nine radioed packs for which there are sufficient data*

(In numbers)

Pack	Winter 1970-71	Winter 1971-72	Winter 1972-73
Harris L.	9	3	4
Jackpine	7	9	7
Quadga L.	6	5	2
Maniwaki L.	7	9	9
Pagami L.	6	5	} 1/6
Greenstone L.	2/5	4	
Newton L.	7	7	6
Glenmore L.	--	12	12
Timber L.	--	3/8	7
Average size	6.7	6.8	5.9

1/ By winter 1972-73, the Pagami L. and Greenstone L. packs, after an attack by one upon the other, apparently merged. To compare the average pack sizes for this year with previous years, this combined pack is treated as two in computing the average size.

2/ Could have been larger.

3/ Van Ballenberghe (1972).

The mean sizes of wolf population units of three or more animals observed during the winters of 1966-67, 1967-68, and 1968-69 (not necessarily all of the same packs studied in 1970-73) was 6.5 wolves per pack (Mech and Frenzel 1971, table 1, excluding 25 observations of lone wolves and nine observations of pairs).

The above mean pack sizes strongly suggest that the wolf population of the Superior National Forest has remained comparatively stable during the six winters from 1966-67 (and possibly earlier) through 1971-72, and that in part of the area it decreased in 1972-73.

The decrease may be linked closely to a general decline in numbers of deer that is ocurring throughout not only northeastern Minnesota (Erickson et al. 1961, Mooty 1971), but also throughout midnorthern and northeastern United States and south-central and southeastern Canada (Anon. 1972, Byelich et al. 1972), apparently caused by maturing forests and an increasing predominance of conifers.

Although a gradual decrease in the deer population of northeastern Minnesota has been underway for two or more decades (Karns 1967), the most drastic decline in recent years took place in the winter of 1968-69, when the area experienced the deepest snowfall on record (Mech and Frenzel 1971). The drop in wolf numbers from 1971-72 to 1972-73 was most apparent in the area of the Forest that was historically the poorest deer range, primarily the eastern half of the BWCA (Olson 1938). This will be discussed and documented in a later paper. Suffice it to say for now that during winter 1971-72, there were virtually no deer present in some 300 to 500 square miles of the east-central portion of the Superior National Forest and in an even larger area in 1972-73. Some deer still inhabit that region during summer and migrate to wintering areas beyond. However, many deer overwintered in that region through 1968-69 (Mech and Frenzel 1971), and thus supported wolf packs there, whereas they do not now.

Two main conclusions should be apparent from the above. First, it appears that even with relatively high deer populations on the Forest, wolves will not increase beyond a certain average density, approximately one wolf per 9.9 to 10.9 square miles in early winter except in local areas with extremely high prey densities (Kuyt 1972, Van Ballenberghe 1972, Parker 1973). This agrees closely with studies of wolves on Isle Royale (Mech 1966) and Algonquin Park, Ontario (Pimlott et al. 1969), as summarized by Pimlott (1967) and by Mech (1970).

Secondly, maintenance of peak wolf numbers on the Forest depends primarily on restoration of higher densities of deer, which in turn depends on the rejuvenation of maturing forest (Erickson et al. 1961, Mooty 1971, Byelich et al. 1972).

A final word of caution is necessary: the results herein apply only to the Superior National Forest, so far as is now known. This area comprises only one-third of the primary wolf range in Minnesota and only about one-sixth of the total wolf range in the State (fig. 2). It is not sound to project wolf densities or population trends from the Forest to the remainder of wolf's range in the State

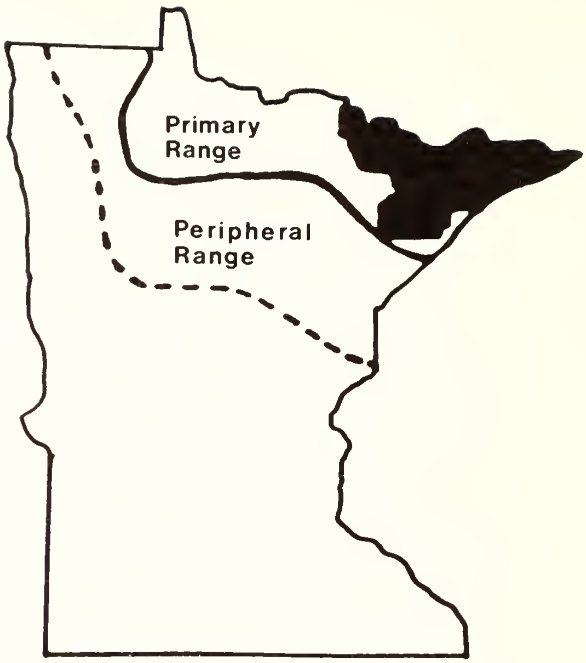

Figure 2.--The primary and peripheral ranges of the wolf in Minnesota. (The Superior National Forest is shown in black.)

unless substantial evidence from several other areas demonstrates that such a projection is warranted.

ACKNOWLEDGMENTS

This study was financed by the U.S. Bureau of Sport Fisheries and Wildlife, the USDA North Central Forest Experiment Station, the USDA Superior National Forest, the Ober Charitable Foundation, the World Wildlife Fund, and the New York Zoological Society.

I am especially grateful to W. W. Cochran of the Illinois Natural History Survey for help and advice concerning the radio-tracking system used in the study. The AVM Instrument Co.,[2/] Champaign, Illinois, supplied the equipment.

The skill, patience, and care of the following pilots were critical to the safety and success of the study: Steve Gheen, Walt Newman, and Chick Beel (USDA Forest Service); Pat Magie, Dick Mahl, Carlo Palumbi, and Gary Mitchell (Wilderness Wings Flying Service, Ely); and John Winship (U.S. Bureau of Sport Fisheries and Wildlife).

2/ Mention of trade names does not constitute endorsement by the USDA Forest Service.

Trapper Robert Himes, Ray, Minnesota, live-trapped approximately half of the wolves that were radioed, and the following students skillfully assisted with various aspects of the fieldwork: Jeff Renneberg, Tim Wallace, Roger Powell, Glenn Bialke, Fred Harrington, Roger Peters, Scott Larson, Dudley Parkinson, and Jim Klitzke.

The administrative support of Travis Roberts, Robert Burwell, Sam Jorgenson, Clarence Faulkner and other Bureau personnel is also hereby acknowledged along with that of James T. Morgan, Robert Brander, and Miron Heinselman of the North Central Forest Experiment Station, and Harold Andersen and Craig Rupp of the Superior National Forest, and their assistants and field personnel.

P. Addison and L. Ringham, Ontario Department of Lands and Forests, granted special permission for us to aerially radio-track wolves venturing into the Quetico Provincial Park. The Minnesota Department of Natural Resources issued special research permits for this study, and conservation officer-pilot Robert Hodge, through Department of Natural Resources personnel Fred Thunhorst and Milt Stenlund, contributed several observations of wolves.

The following biologists reviewed this article and made several helpful suggestions for improving it: Victor Van Ballenberghe, South Dakota State University; Milton H. Stenlund, Minnesota Department of Natural Resources; Lester Magnus and Karl Siderits, Superior National Forest; and Robert Brander, North Central Forest Experiment Station.

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☆U.S. Government Printing Office 1973 – 762-272

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Manuscript approved for publication July 27, 1973

MEAN PRECIPITATION-HOURS FOR THE CONTERMINOUS UNITED STATES

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Of all of the common weather phenomena, precipitation probably exerts the strongest influence on man and his activities. Since it influences man in different ways, there are a number of ways of describing the process. Most questions about precipitation can be reduced to "How much?," for precipitation amount is of prime concern in such activities as drought measurement and snow removal. There are, however, other ways of characterizing precipitation that are equally important. Knowing maximum precipitation amounts per unit time is essential in engineering storm drains. Knowing the frequencies of expected precipitation days is of help to the farmer during haying and other harvesting operations. And there are many other activities where precipitation, or the lack of it, plays a dominant role.

In the battle against forest fire, moisture content of fuels is a vital concern. Fuel moisture content is affected by a wide range of atmospheric phenomena--i.e., humidity, temperature, insolation, wind, fog, dew, and precipitation. Fine fuels (materials less than 1/4 inch in diameter) respond rapidly to changes in most of these weather variables. Larger fuels show more gradual responses and are particularly sensitive to the absorption process during precipitation periods. Because fuels absorb water slowly, the duration of precipitation is more critical than the amount.

Simard (1968) and Fosberg (1972) found that for moisture absorption in round-wood fuel, the maximum *effective* rate of precipitation is on the order of a millimeter per day assuming continuous precipitation. Greater precipitation intensities do not result in increased absorption; the water simply runs off. For this reason the National Fire Danger Rating System (NFDRS) uses a precipitation value of 0.01 inch per hour as input (Deeming *et al.* 1972). This is the smallest amount recorded by most measurement devices. Theoretically, an even lower hourly value could be used in the system.

It would appear important to construct a climatology for this aspect of precipitation. The objective of this paper, therefore, is to present monthly, nationwide patterns of mean precipitation-hours, and as a corollary, the nationwide patterns of average precipitation-hours per precipitation-day (P.H./P.D.). There are a number of potential uses for such information. Obviously it should be of help to fire-weather forecasters, planners of prescribed burns, and others engaged in fire-behavior prediction and control efforts. But it may also be of use to agriculturists studying plant growth, pathologists studying plant and tree diseases where wetness is a critical factor, and entomologists studying environmental factors that are important in the life cycle of insects.

This type of summary does not, of course, tell anything about duration of individual storms. A summary of mean precipitation-hours should be viewed as a basic climatological tool.

DATA SOURCE AND COMPUTATIONAL PROCEDURES

A precipitation-day is defined as a 24-hour period having a precipitation amount of at least 0.01 inch. Maps of the mean monthly and annual number of days with 0.01 inch or more of precipitation have already been published for the United States (U.S. Dep. of Commerce, National Oceanic and Atmospheric Administration (NOAA) 1968). A precipitation-hour is defined as an hour having a precipitation amount of at least 0.01 inch.

A more comprehensive study might involve either computing precipitation probabilities from tabulated frequencies or fitting a mathematical function to tabulations and computing precipitation probabilities from this function. Unfortunately, the amount of basic data needed to accomplish either goal is overwhelming. For instance, if observation information were to be processed by computer, tabulation of 10 years of hourly data at any one station would necessitate an input of 24 hours X 365 days X 10 years, or a total of 87,600 punched cards. Consequently, a different approach was used in this study. If a greater effort is warranted at a future time, perhaps techniques proposed by Gringorten (1966) using a simple Markov chain process would provide a reasonable compromise between massive input volume and required results.

Our approach makes use of published summaries from which the mean number of precipitation-hours per month as well as the mean number of P.H./P.D. can be computed (U.S. Dep. of Commerce, NOAA 1963). A series of NOAA booklets give a 1951 to 1960 tabulation of hourly observations for individual first-order stations. Ninety comprehensive station booklets are available for the continental United States plus information for Honolulu, Hawaii, and San Juan, Puerto Rico. These provide the basic data used in this study.

STATISTICAL ASPECTS

As stated, the volume of hourly data needed to do an in-depth analysis of precipitation probabilities makes that objective untenable. But even though it necessitates a tedious computational procedure, the frequency curve form for hourly sampled precipitation should be examined; consequently, hand tabulations were carried out for 11 stations over selected months for the years 1952 to 1961. These stations are scattered across the country (table 1); the 2- or 3-month computation for each covers the station's major fire-season. Two sets of stations were selected close together in two States (Oregon and Georgia) to determine if there are major differences in curve form between coastal and inland areas (there were none apparent in these data).

The data were grouped by number of cases of P.H./P.D. The number of occurrences of hourly totals per precipitation-day was then calculated as a percentage of the total number of precipitation-days, resulting in various curve forms, real or apparent (fig. 1). The commonest curve type was evident at seven of the 11 stations: Atlanta, Bandon, Flagstaff, Marquette, Minneapolis, Portland, and Savannah. Here the modal group occurred at a 2 clock-hour precipitation-day. Most curves then either declined with increasing P.H./P.D. (fig. 1, Minneapolis) or declined but then maintained a steady percentage value over a number of groups of precipitation-hours before continuing the decline. In climates or seasons where the "brief shower" is not a normal situation, the tabulation is almost forced to show the 2-hour duration mode. It results from our convention of recording clock-hour precipitation totals. As an example, if there is a 60-minute rain it will be logged as a 2-hour event unless it starts promptly at, say, 8:01 and ends at 9:00.

Another situation occurred at Milwaukee, Albany, Oklahoma City, and Missoula. At these stations 1-hour precipitation-days were most frequent. This is probably the result of brief shower activity, that increases the probability that the precipitation event will be included within a single clock-hour. At Milwaukee there was a percentage decrease until the 3-hour precipitation-day group and then an increase over 4- and 5-hour precipitation-day groups before the major curve decline (fig. 1, Milwaukee). At Albany and Oklahoma City there was a relatively steady percentage decline along the curve. This same curve type occurred with the Missoula data, but the decline was much more pronounced (fig. 1, Missoula). At Missoula, 33 percent of the precipitation-days were contained in 1-hour periods, and a relatively uniform decline occurred along the curve after that.

The tail is another important feature of these curves. The longest precipitation period occurred at Marquette--over the entire 24 hours. The 10 other stations had at least 1 day with 16 to 23 hours of precipitation over the examined time period. The time defining a precipitation-day is rigid--midnight to midnight. Consequently, the computational method used here inflates the number of daily precipitation events and thus underestimates tail length. This distortion is not too important in some regions during spring and summer months because thunderstorm activity tends to be a late afternoon and early evening phenomenon ending within the defined hours of the precipitation-day. For longer lasting precipitation events, however, the period carries into the

Table 1.--*Eleven-station comparison of base data, means, percentile levels, and gamma-beta parameter values*

(1) Station	(2) Range of months tabulated (1952 to 1961)	(3) Number of precipitation-days in 10-yr. tabulation period	(4) Mean of P.H./P.D.	(5) Percentile level of values in column (4)	(6) Median or number of P.H./P.D. at 50th-percentile level	(7) Column (4) minus column (6)	(8) Gamma distribution parameter estimates: Gamma	(9) Beta
		Days	*Hours*		*Hours*	*Hours*		
Albany, N.Y.	April-May	280	5.2	63	3.7	1.5	1.36	3.81
Atlanta, Ga.	Feb.-April	307	5.6	65	4.0	1.6	1.67	3.38
Bandon, Ore.	July-Aug.	51	4.1	67	2.8	1.3	1.86	2.22
Flagstaff, Ariz.	April-June	109	4.9	65	3.5	1.4	1.74	2.81
Marquette, Mich.	April-May	241	5.6	64	4.0	1.6	1.27	4.38
Milwaukee, Wis.	April-May	225	4.4	63	3.2	1.2	1.81	2.50
Minneapolis, Minn.	April-May	185	5.2	62	3.8	1.4	1.48	3.57
Missoula, Mont.	July-Sept.	198	3.1	63	2.2	0.9	1.34	2.31
Oklahoma City, Okla.	March-April	160	4.2	63	3.1	1.1	1.80	2.42
Portland, Ore.	July-Aug.	71	4.6	65	3.3	1.3	1.92	2.41
Savannah, Ga.	Feb.-April	255	4.7	62	3.6	1.1	1.72	2.92
Eleven-station average	--	--	4.7	65	3.3	1.3	--	--

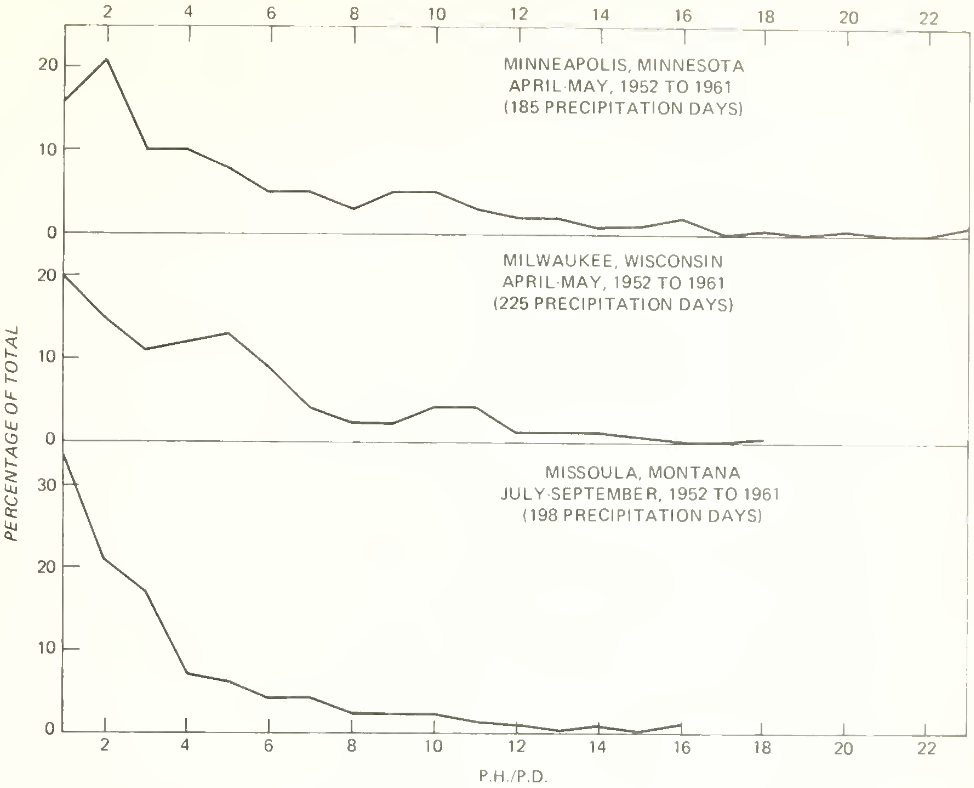

Figure 1.--*Three distributions showing the occurrence of average hours of precipitation per precipitation-day. Distributions are presented as a percentage of the total number of precipitation-days.*

following day. This fact also accounts, in part, for the variation in the skewness factor that shows up in some of the computed distributions (fig. 1).

Changnon and Huff (1967), among others, have attempted to bypass some of the problems inherent in studies of precipitation duration by using a "6-hour definition." They define a storm as a precipitation period separated from preceding and succeeding precipitation by 6 hours or more. Shenton and Skees (1970) have expanded this concept by analyzing for eight "storm definitions"--letting dry periods vary from 1 to 8 hours between precipitation and redefining the concept of a storm dependent upon dry period length. Their work on distribution of storm durations shows that in the Southeast about three-fourths of the storms are over within 3 hours if the criterion is 1 dry hour between storms. Almost nine out of 10 storms are over within 6 hours using the same 1 dry-hour criterion. Their data also indicate there is a fair percentage of precipitation carryover into a following calendar day if a rigid definition of day is used and if one assumes random precipitation with respect to time of day.

Because of the discussed restrictions of t basic data tabulated for this study, alternate methods of defining precipitation duration coul not be used. Also, problems could develop in using alternative tabulation methods because solutions obtained might not apply to operation systems such as the NFDRS. Information must be definable within the restrictions of a given system if it is to be usable, and operational systems usually specify a rigid time period for input data.

Because of the shape of the frequency distributions (fig. 1), few of the classical distr butions appear suitable to describe these preci itation data. Shenton and Skees (1970) feel th this may be due to the J-shaped distribution fe ture. Mode is at either the 1- or 2-hour distr bution group. A study they conducted shows tha this factor rules out a number of possible functions. They did find that a modified-logarithmic distribution often produces a good fit, although this statistical form depends upo one parameter and consequently lacks flexibilit

Results obtained with a fit of the gamma probability function are explored here because is a two-parameter frequency distribution; a fit of this function yields both scale and shape. Reliability tests performed on these data showed that the goodness-of-fit was much better with it than with other tested functions. As shown by Thom (1958), the gamma probability function is given by the equation:

$$f(x) = \frac{1}{\beta^{\gamma}\Gamma(\gamma)} x^{\gamma-1}e^{-x/\beta}, \text{ where } \beta>0 \text{ and } \gamma>0.$$

Here x is the random variable, β is the scale parameter, γ is the shape parameter, and Γ is the usual gamma function. The shape parameter, gamma, is inversely related to the skewness of a frequency distribution. That is, a smaller gamma indicates that a few large values cause positive skewness and that the mean departs further from the median value. A large gamma causes the probability function to approach normality. Beta, the scale parameter, indicates range or dispersion. A larger beta indicates a greater tendency to deviate from either the mean or the median. β and γ are inversely related by the function $\beta = \bar{x}/\gamma$, where $\bar{x}$ is the mean. Therefore $\gamma\beta = \bar{x}$ and $\gamma\beta^2 = \sigma^2$.

Barger *et al.* (1959), Feyerherm *et al.* (1966), Strommen and Horsfield (1969), and others have shown that the gamma probability function presents a practical application for precipitation in a climatological data series. The features can be illustrated by contrasting data at Missoula and Atlanta (table 1, columns 4 and 6). These latter data were computed from frequency tabulations after fitting the gamma function.

At Missoula the 50th-percentile value is 2.2 P.H./P.D. At Atlanta the value is 4.0. This indicates, of course, that usually there are longer precipitation periods at Atlanta. By comparing the differences in the expected hours of precipitation for the high and low probabilities for these two stations, we can assess variability. At Missoula the range between the 20th-percentile precipitation value and the 80th-percentile is about 4.0 hours (table 2). At Atlanta the range between the 20th- and 80th-percentile levels is 6.3 hours. Thus, while longer precipitation periods can be expected at Atlanta relative to Missoula, the periods at the eastern location show much greater variation.

This contrast is shown graphically in figure 2. Missoula data reach high-percentile levels rapidly. Atlanta data reach high-percentile levels much more slowly. Averaging of all station data in table 2 produces a curve more like the Atlanta curve than the Missoula curve (fig. 2). This means that the sample of 11 stations is more representative of longer period precipitation patterns.

The station average for the 50th-percentile is about 3.3 P.H./P.D., as contrasted with the arithmetic average of 4.7 hours (table 1). This reflects the difference between the median and the mean found in skewed distributions. It indicates that the simple averaging used to produce the monthly maps (fig. 3) overestimates the 50th-percentile level by about 1.4 precipitation-hours during major fire-seasons. Simple averaging produces a value at about the 65th-percentile level. Both this situation and the clock-hour recording procedure previously discussed produce a bias. *Therefore, when using these data maps during the fire season, one should subtract about 1-1/2 hours from the map values to arrive at actual values.* During snow seasons the difference value will probably be even higher.

Table 2.--*Cumulative percentage frequencies of precipitation-hours/precipitation-day at 11 stations*
(In P.H./P.D.)

Station	Percentile level							
	20	30	40	50	60	70	80	90
Albany, N.Y.	1.4	2.1	2.8	3.7	4.8	6.2	8.0	10.8
Atlanta, Ga.	1.5	2.3	3.1	4.0	5.0	6.4	7.8	10.7
Bandon, Ore.	1.2	1.7	2.2	2.8	3.6	4.2	4.8	5.5
Flagstaff, Ariz.	1.3	2.0	2.8	3.5	4.5	5.5	7.0	8.2
Marquette, Mich.	1.4	2.1	3.0	4.0	5.0	6.5	8.5	11.2
Milwaukee, Wis.	1.3	1.8	2.5	3.2	4.1	5.1	6.5	8.8
Minneapolis, Minn.	1.5	2.2	2.9	3.8	4.9	6.2	8.0	11.6
Missoula, Mont.	<1.0	1.2	1.7	2.2	2.8	3.7	4.9	6.8
Oklahoma City, Okla.	1.2	1.8	2.4	3.1	4.0	4.9	6.2	10.0
Portland, Ore.	1.3	1.9	2.6	3.3	4.1	5.2	6.3	7.2
Savannah, Ga.	1.4	2.1	2.8	3.6	4.5	5.6	7.2	9.6
Average	1.2	1.9	2.6	3.3	4.3	5.4	6.8	9.1

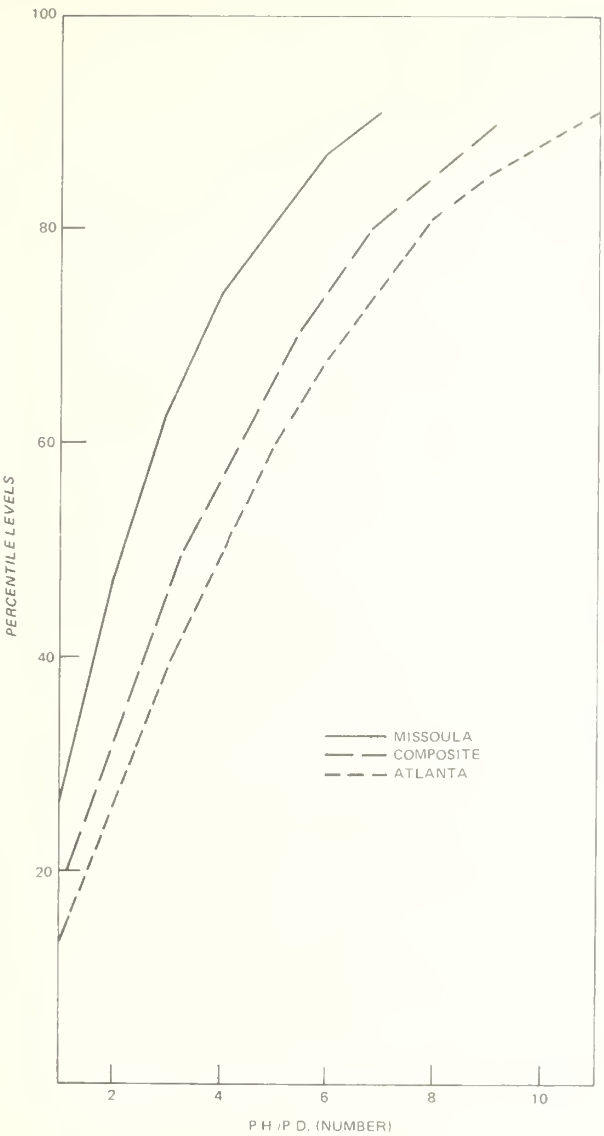

Figure 2.--*Cumulative percentage frequencies of hourly precipitation-day groups at two stations and the 11-station composite.*

PATTERNS OF HOURLY PRECIPITATION

Isolines are drawn for all mapped data east of the Rocky Mountains (figs. 3 and 4). The procedure is questionable west of the 105° W. meridian due to a combination of sparse data and mountainous terrain. Therefore, western-region values were plotted on the maps at the site of precipitation observations with no attempt to draw constant-value lines.

The annual plot of precipitation-hours (fig. 4A) shows similar patterns to those produced by the U.S. Dep. of Commerce, NOAA's (1968) maps of "mean number of days with 0.01 inch or more of precipitation." Highest hourly concentrations are in the New England States and the Pacific Northwest. The lowest are in the Southwest. The winter months (December, January, and February) furnish the major portion of this total in the New England States. The Pacific Northwest includes this same time period as well as late fall and early spring in its major concentration of hourly means. Greatest extremes are experienced in southern California, where an average of about 50 hours of precipitation during January changes to few or no hours from June through September.

The charts of mean P.H./P.D. do not always conform to the same patterns as the previous set of charts. (Discussed values of P.H./P.D. are the plotted-map values, although, as stated, map values are more than 1 hour greater than 50th-percentile values.) Although high-annual figures (fig. 3, annual) predominate in the New England States, much of the trend across the country as seen in the other annual chart (fig. 4, annual) is not well delineated. On an annual basis the vast majority of stations average out between 4 and 5 P.H./P.D. There is, however, considerable variation over the country from month to month.

Highest values are recorded along the Northeastern-Coastal region and isolated portions of the far Northwest. This is mostly a winter and early spring snow-shower phenomenon, with values of over 7 P.H./P.D. at this time. The shortest precipitation intervals occurred throughout California during July--1.0 P.H./P.D. (fig. 3, July). However, these means should be viewed with caution. The previous set of map data showed that less than 5 hours of rain fell in California during the 10 July periods covered. The small data base will not produce a meaningful statistic.

The most obvious application of these data is as climatological input to the NFDRS when "real-time" information is not available. As an example, if one only knows that rain has fallen at Minneapolis on a given day in March but does not know the precipitation-time intervals, they could be estimated with the P.H./P.D. March chart. That map shows the 5.0 P.H./P.D. line passing near Minneapolis. Subtracting 1-1/2 hours to compensate for recording and computational bias gives a value of 3.5 precipitation-hours for the given March precipitation-day at that station.

Figure 3.--*Mean annual and monthly maps of precipitation-hours per precipitation-day (based on period from 1951 to 1960). The highest and lowest mean values are shown within the analyzed area so gradients might be more easily identified.*

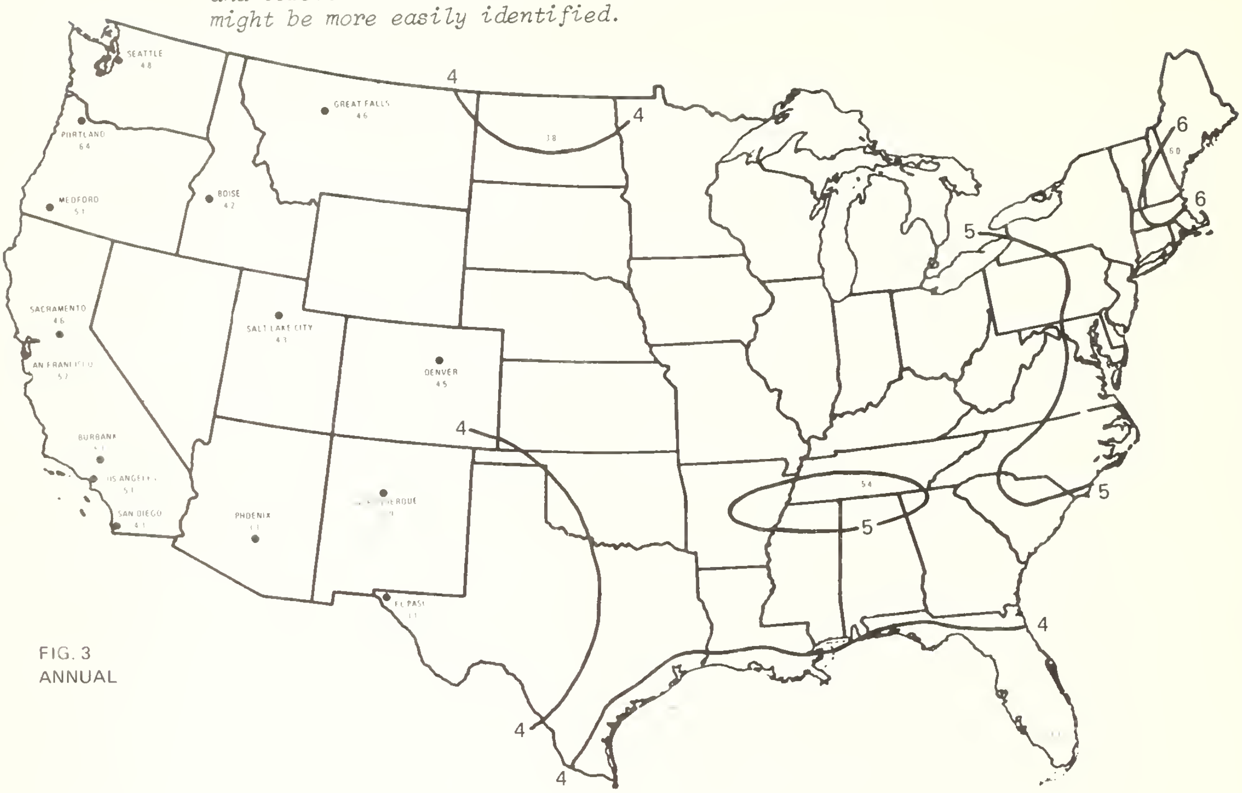

FIG. 3
ANNUAL

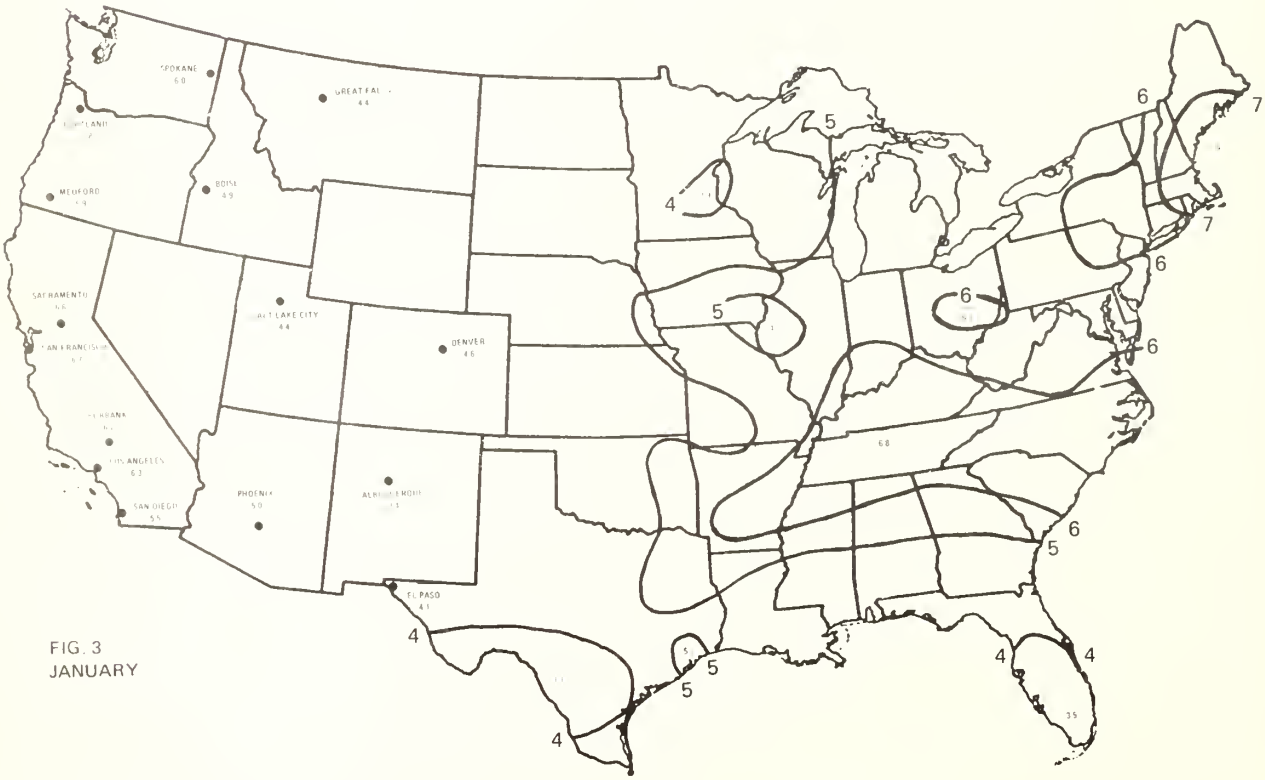

FIG. 3
JANUARY

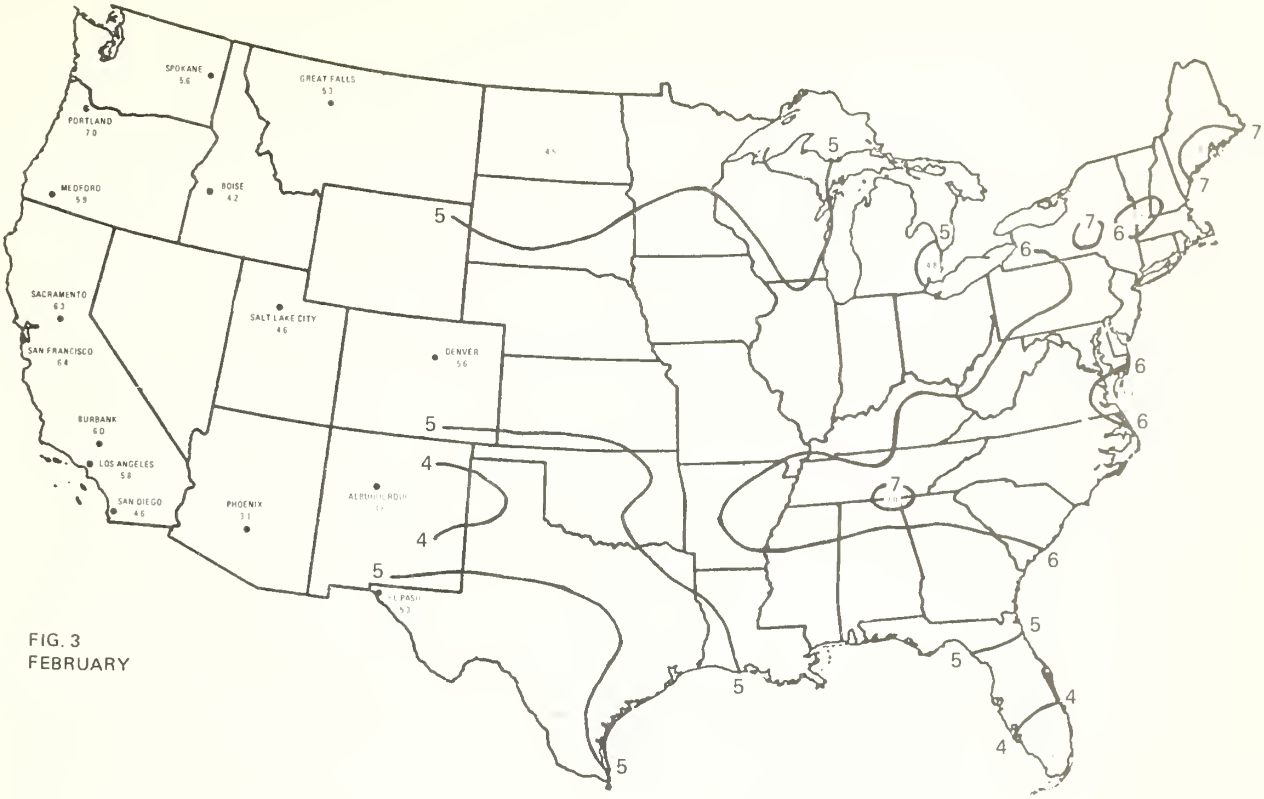

FIG. 3
FEBRUARY

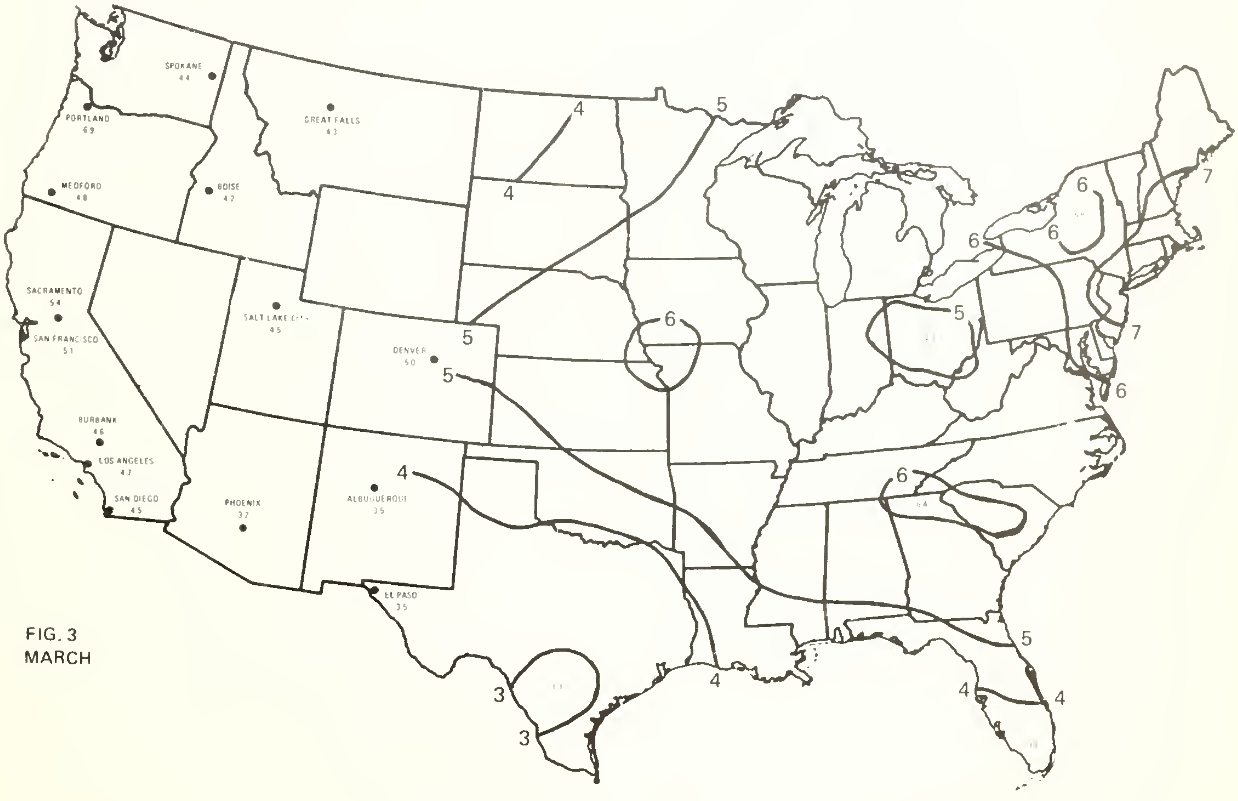

FIG. 3
MARCH

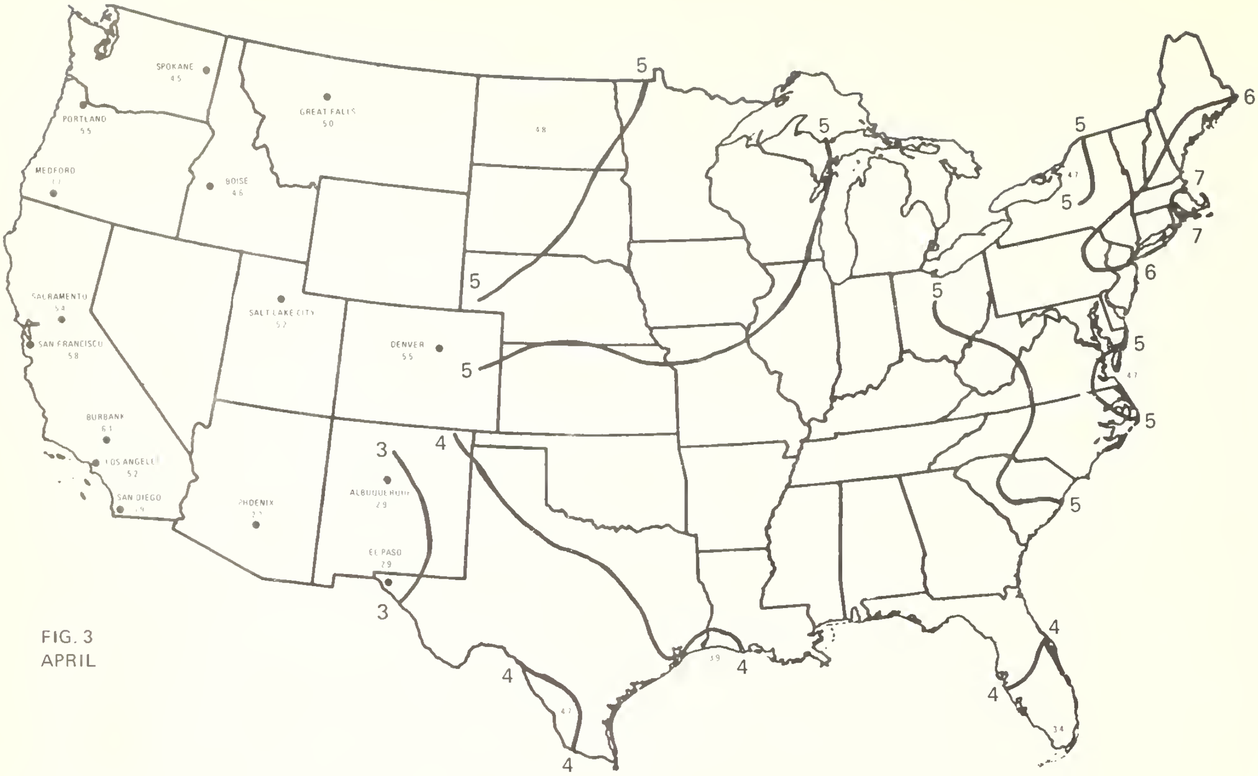

FIG. 3
APRIL

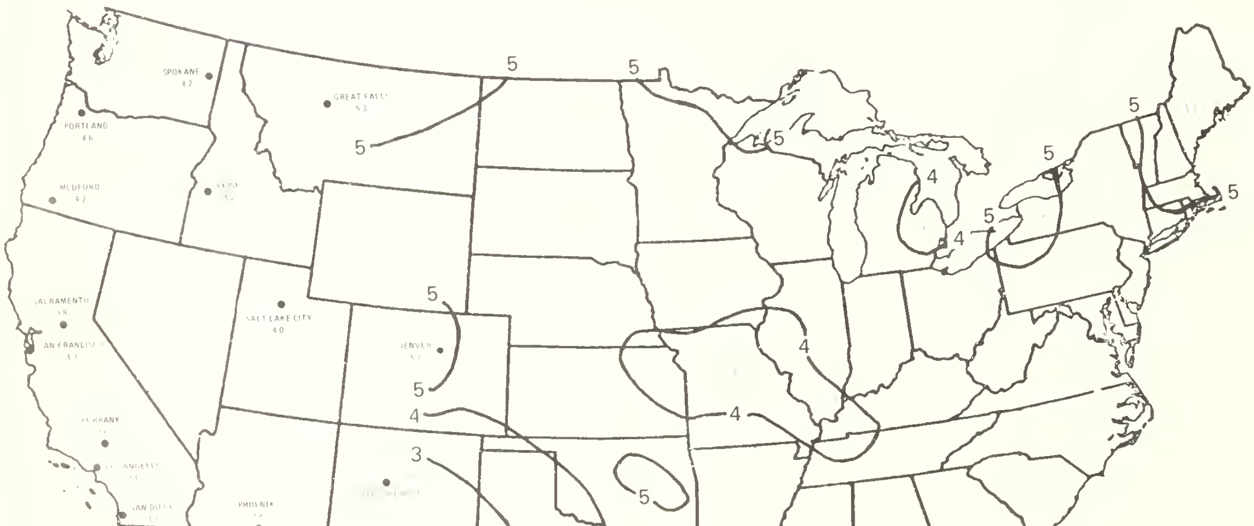

FIG. 3
MAY

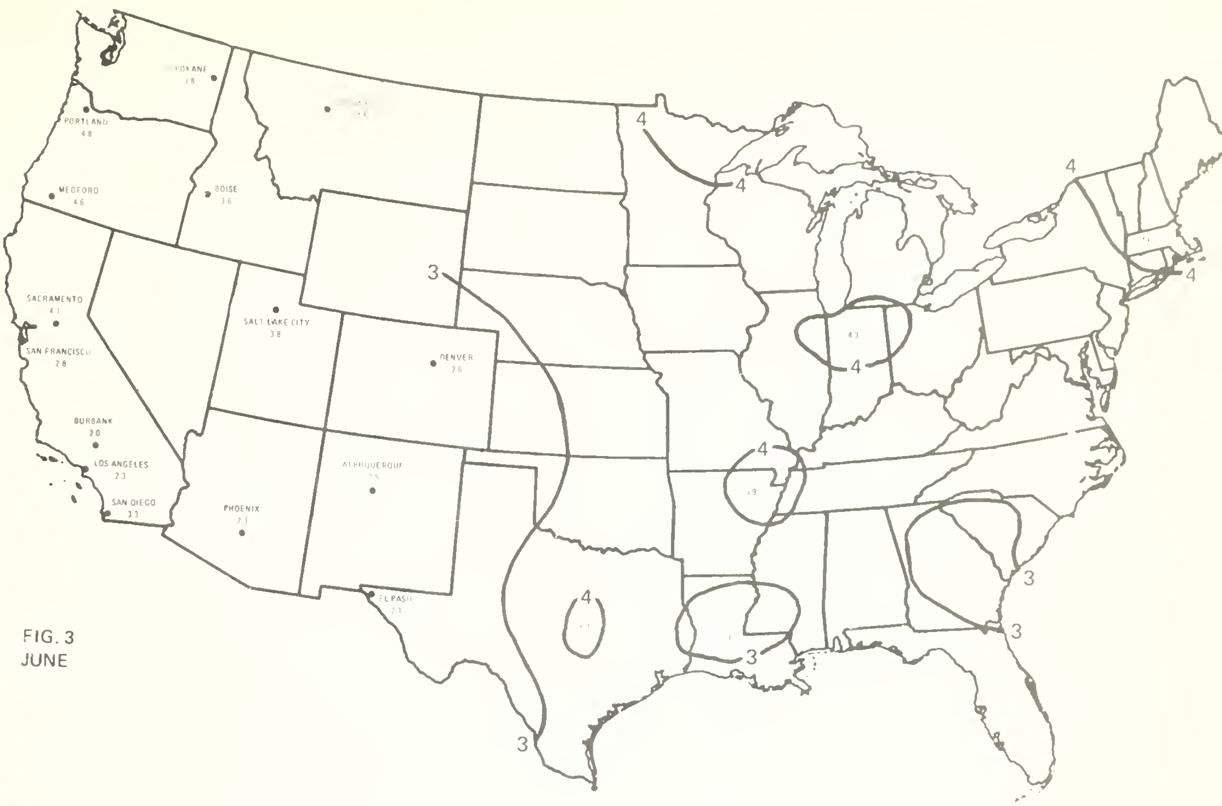

FIG. 3
JUNE

FIG. 3
JULY

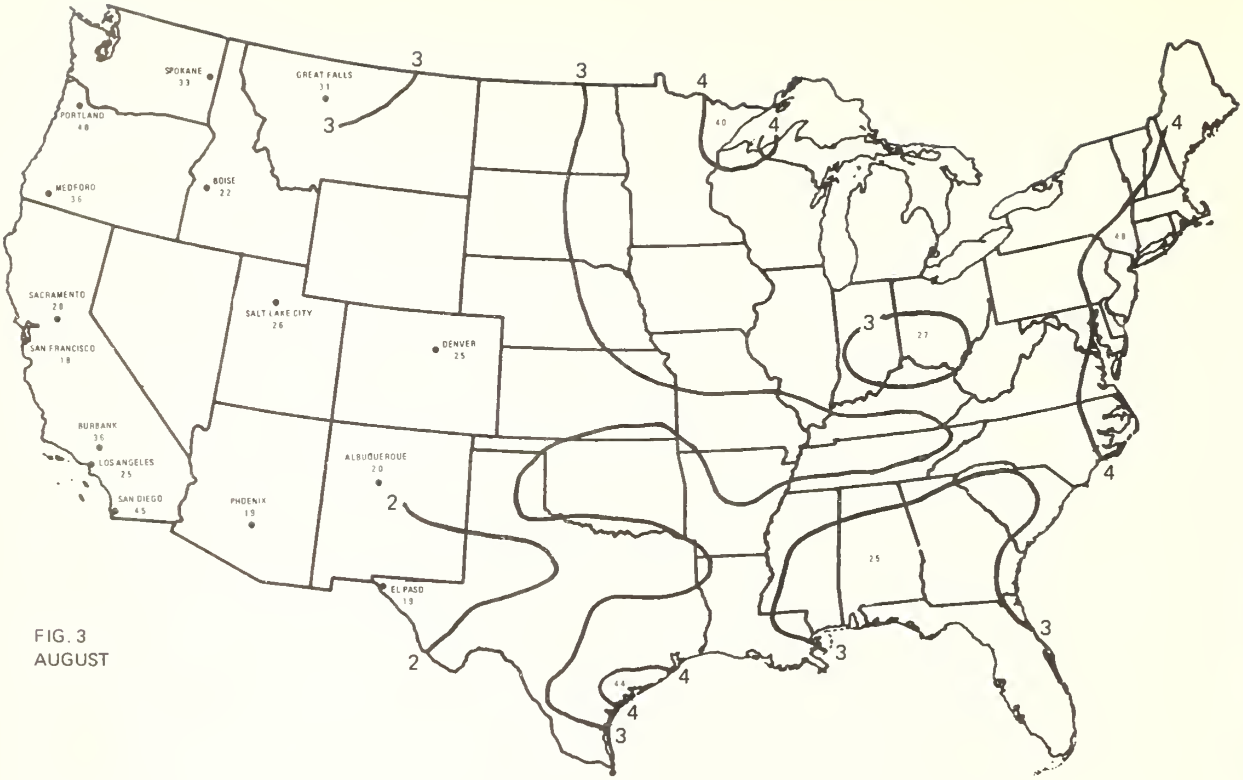

FIG. 3
AUGUST

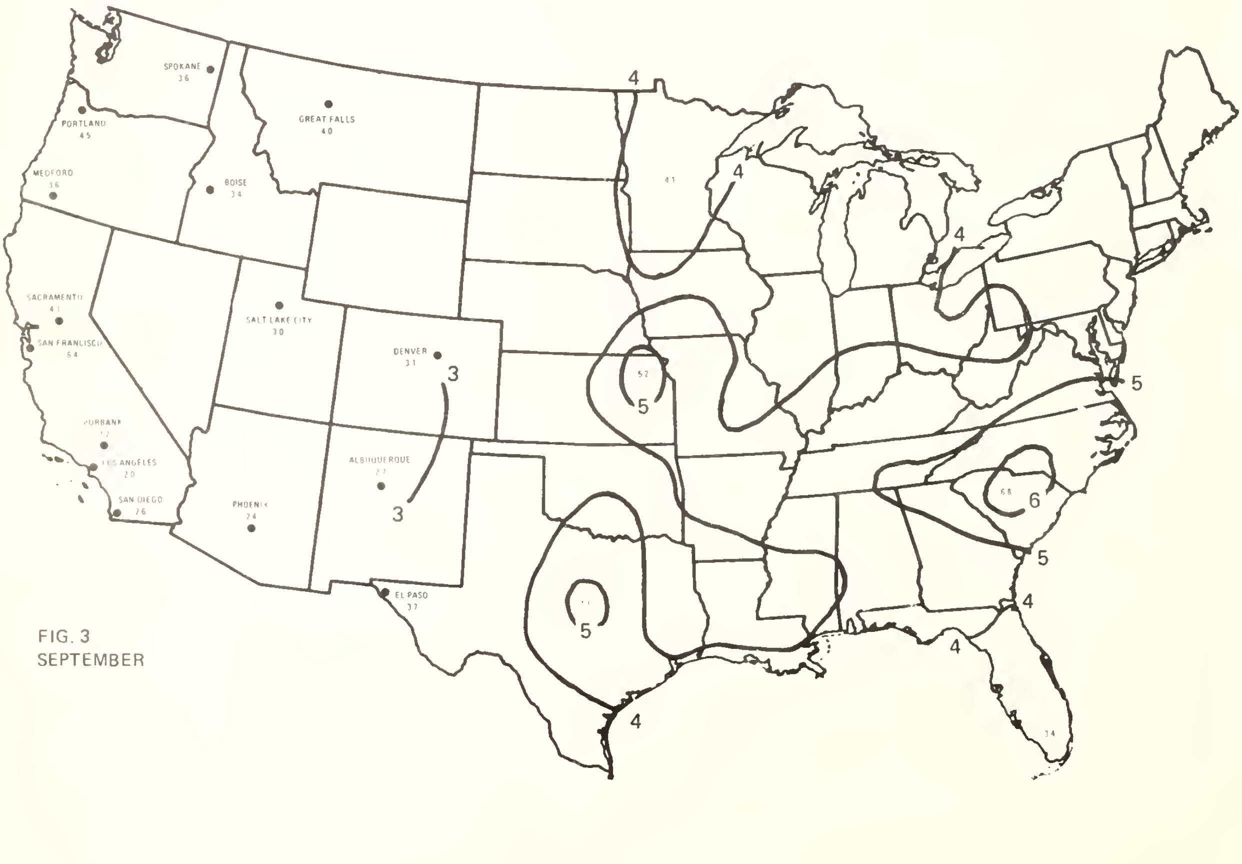

FIG. 3
SEPTEMBER

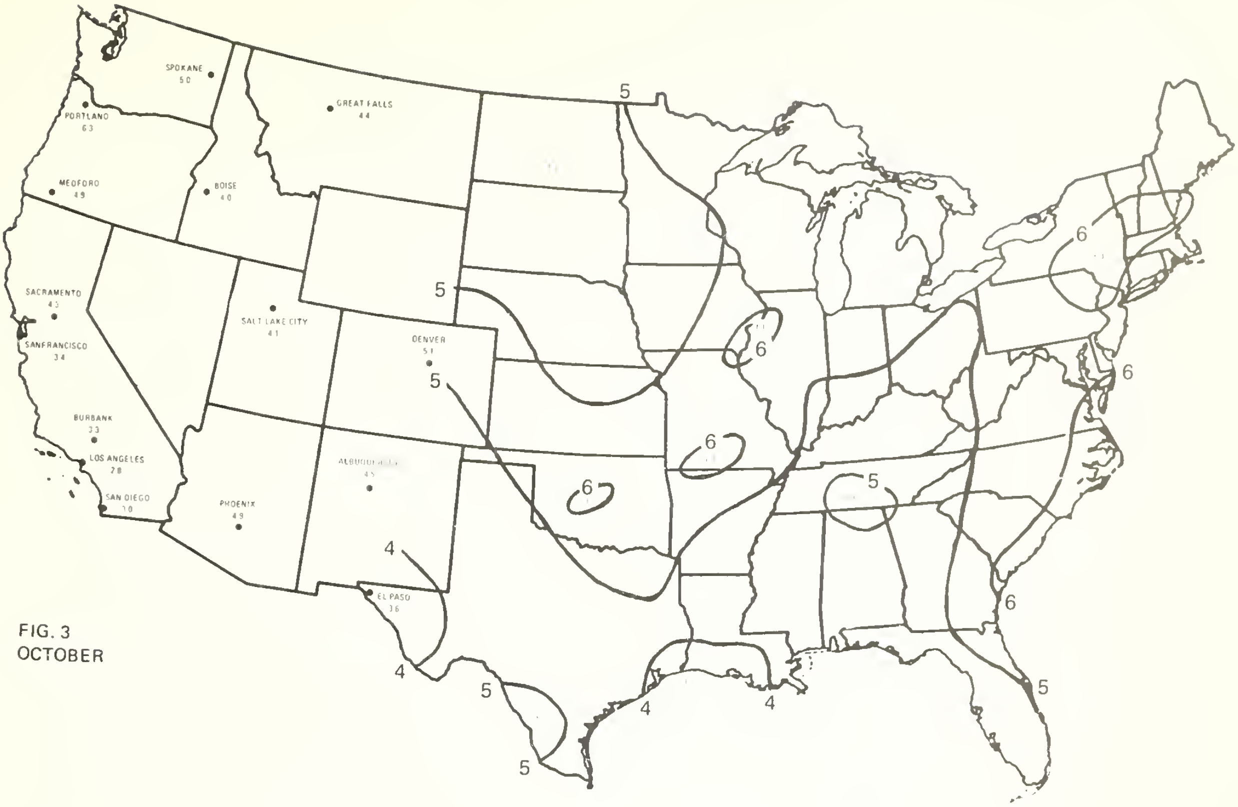

FIG. 3
OCTOBER

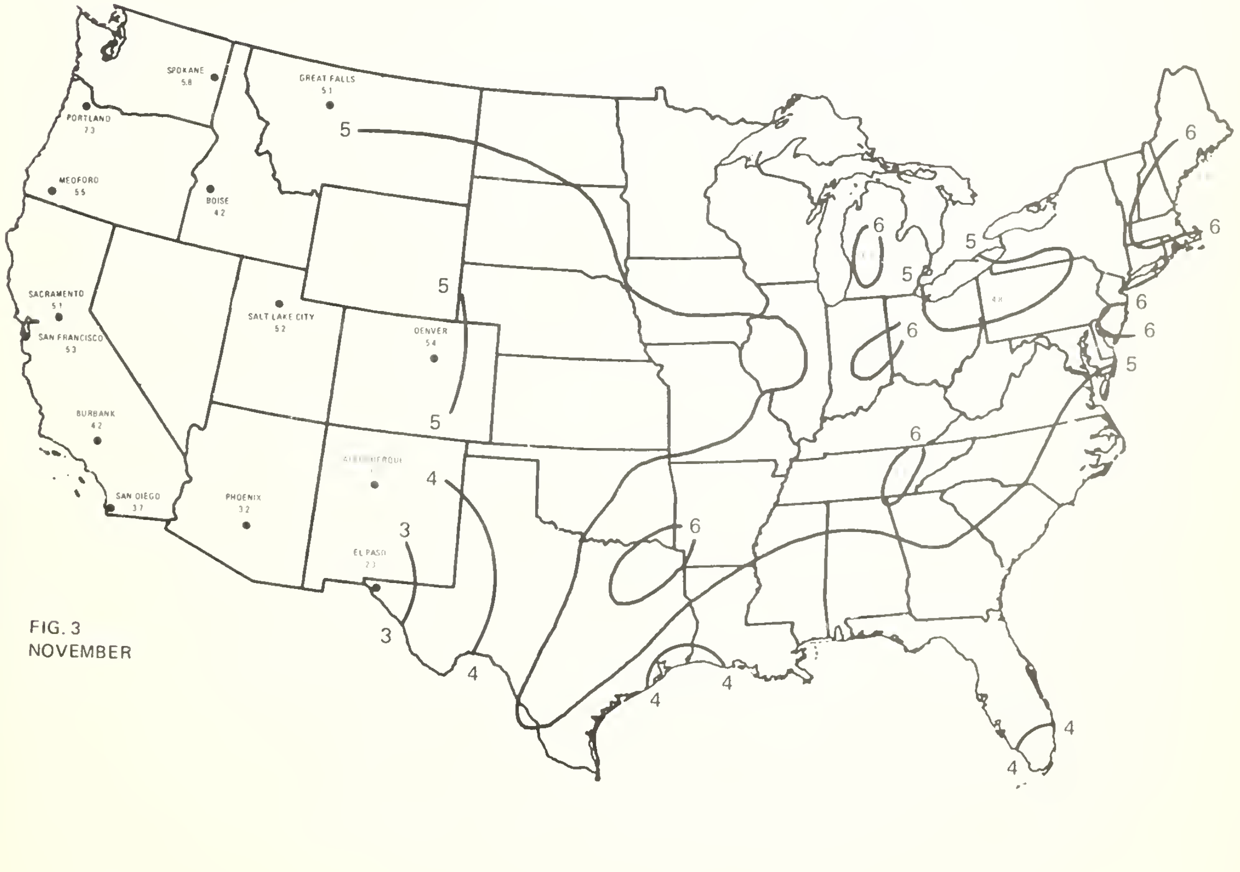

FIG. 3
NOVEMBER

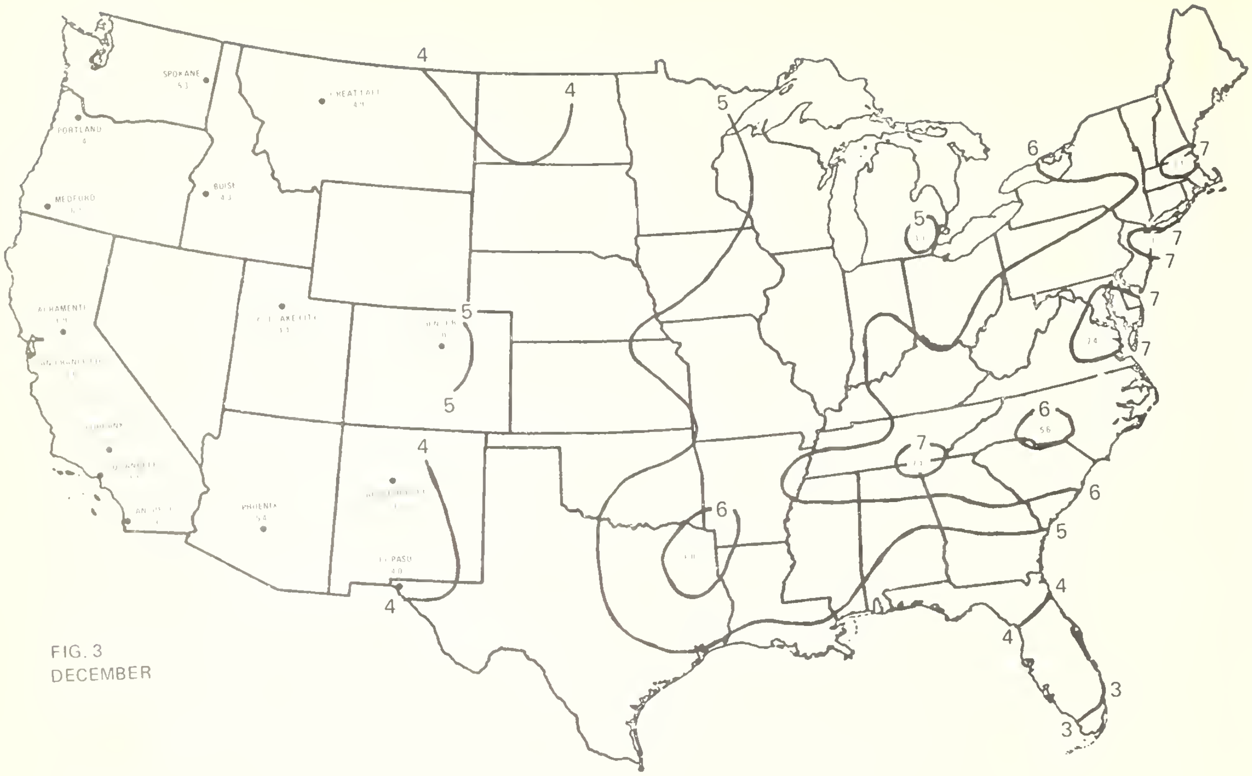

FIG. 3
DECEMBER

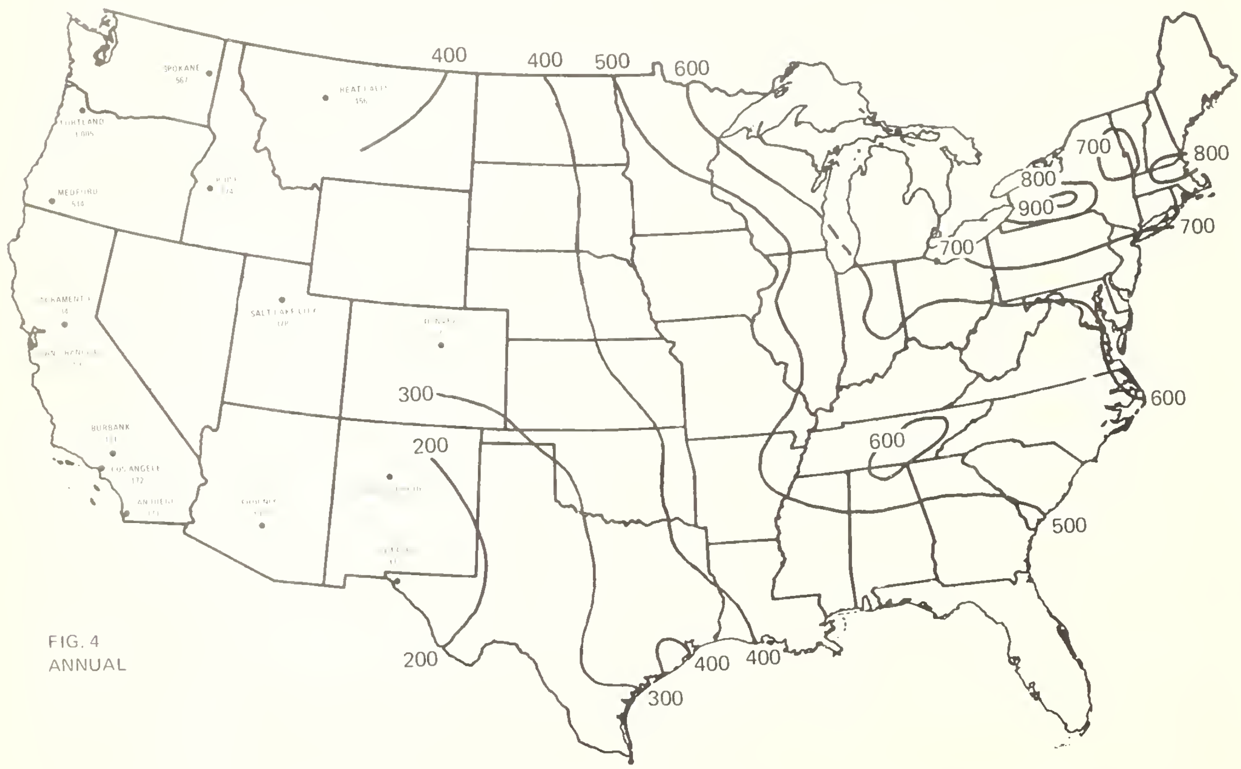

FIG. 4
ANNUAL

Figure 4.--*Mean annual and monthly maps of number of hours with precipitation (based on period from 1951 to 1960).*

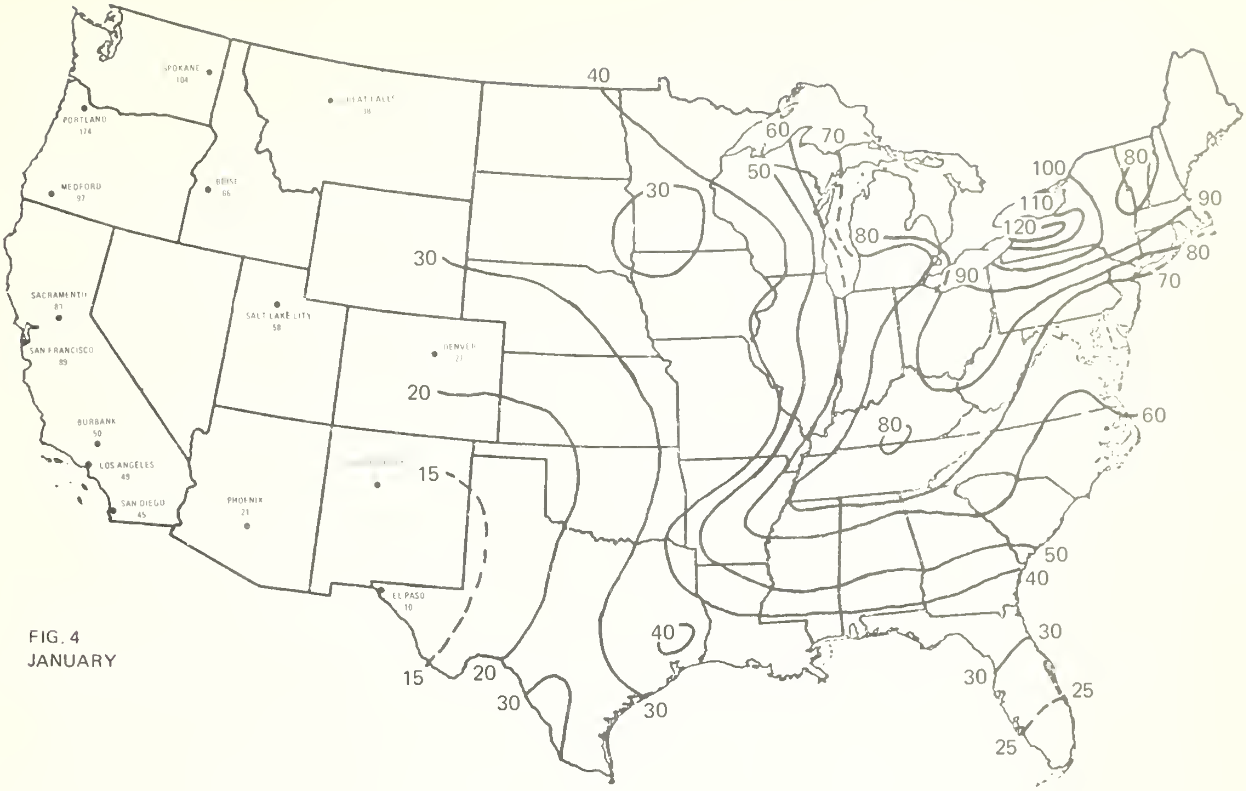

FIG. 4
JANUARY

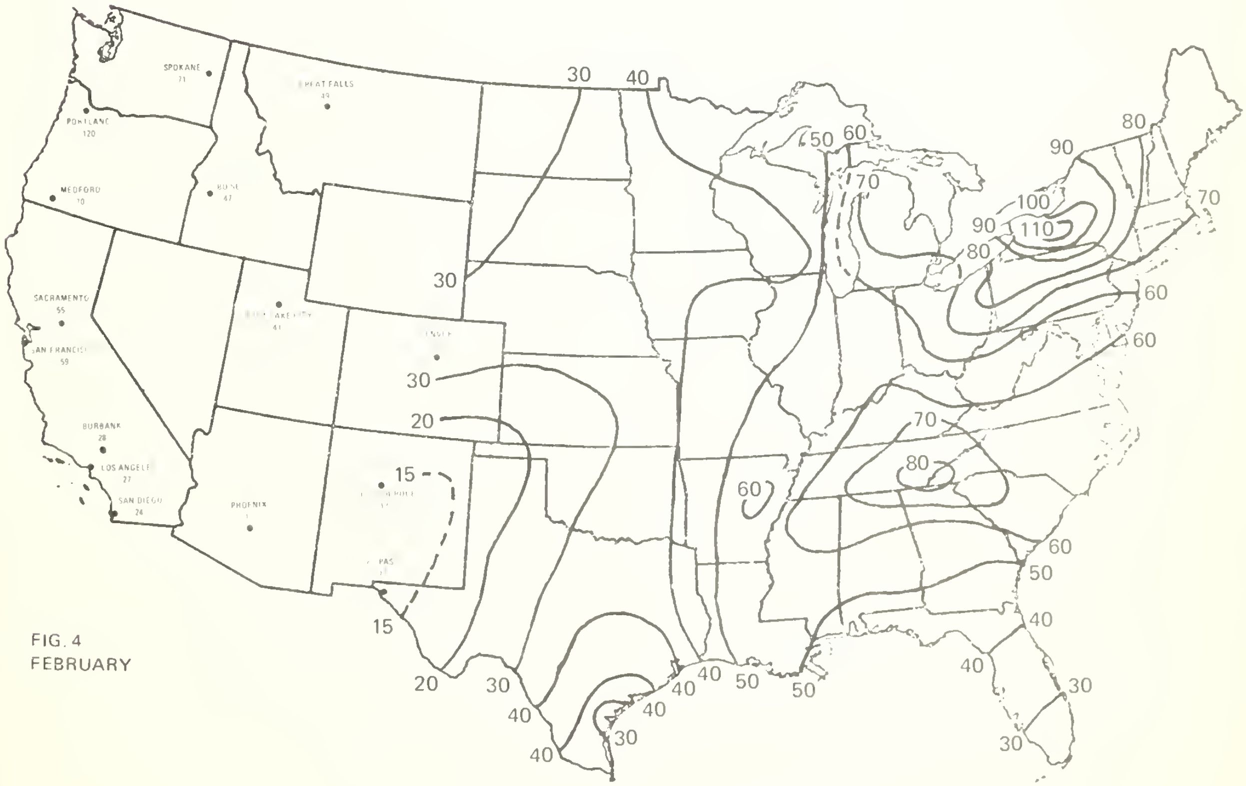

FIG. 4
FEBRUARY

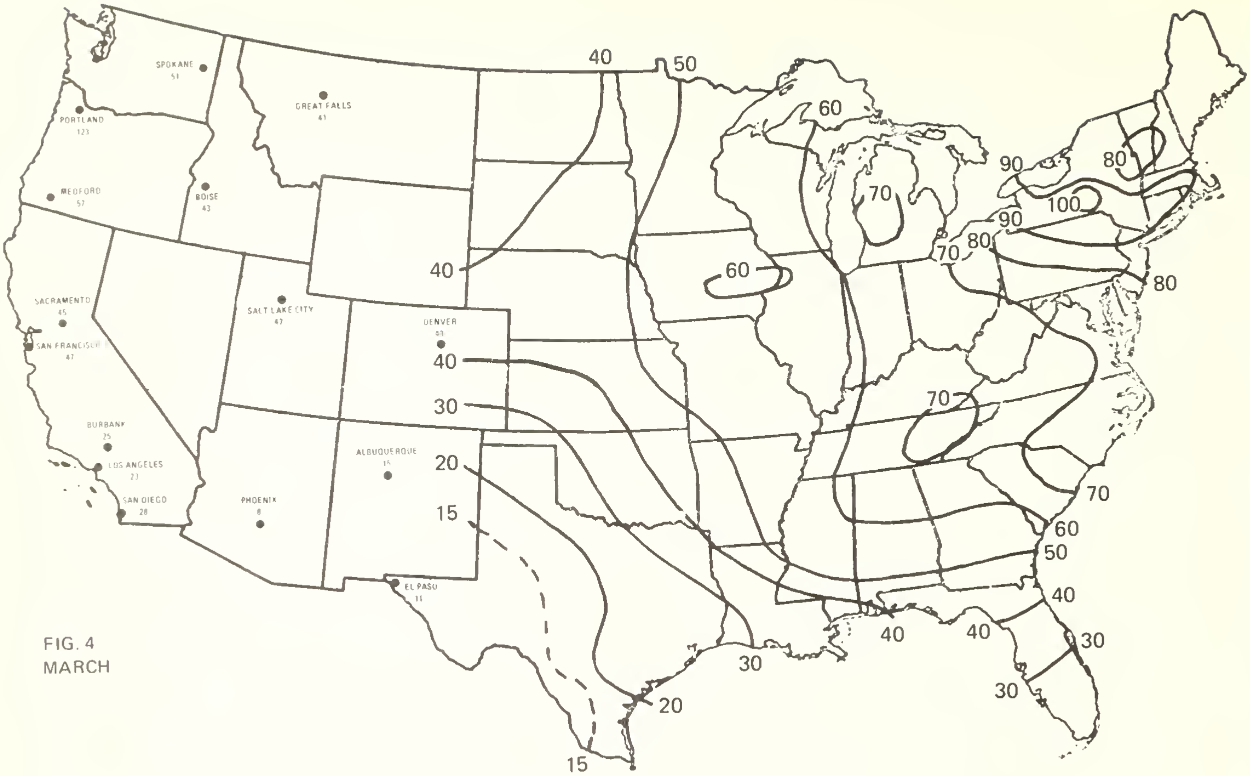

FIG. 4
MARCH

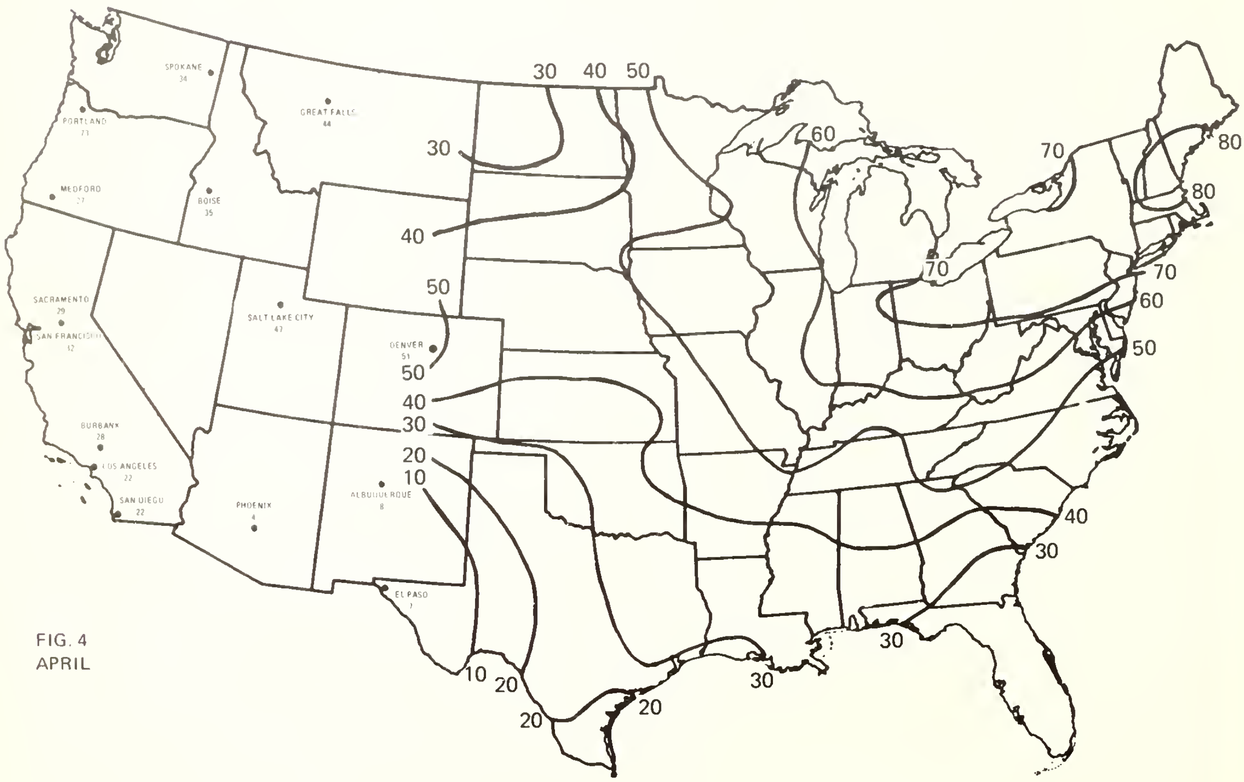

FIG. 4
APRIL

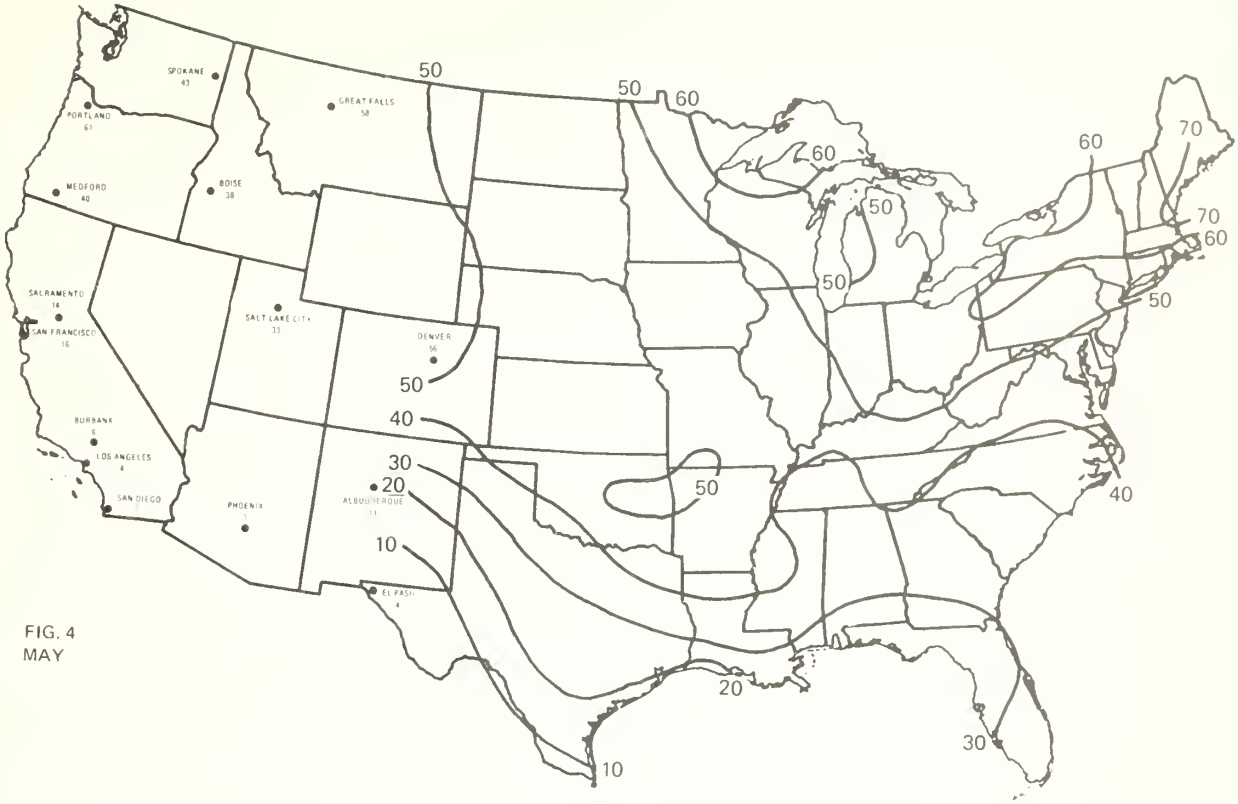

FIG. 4
MAY

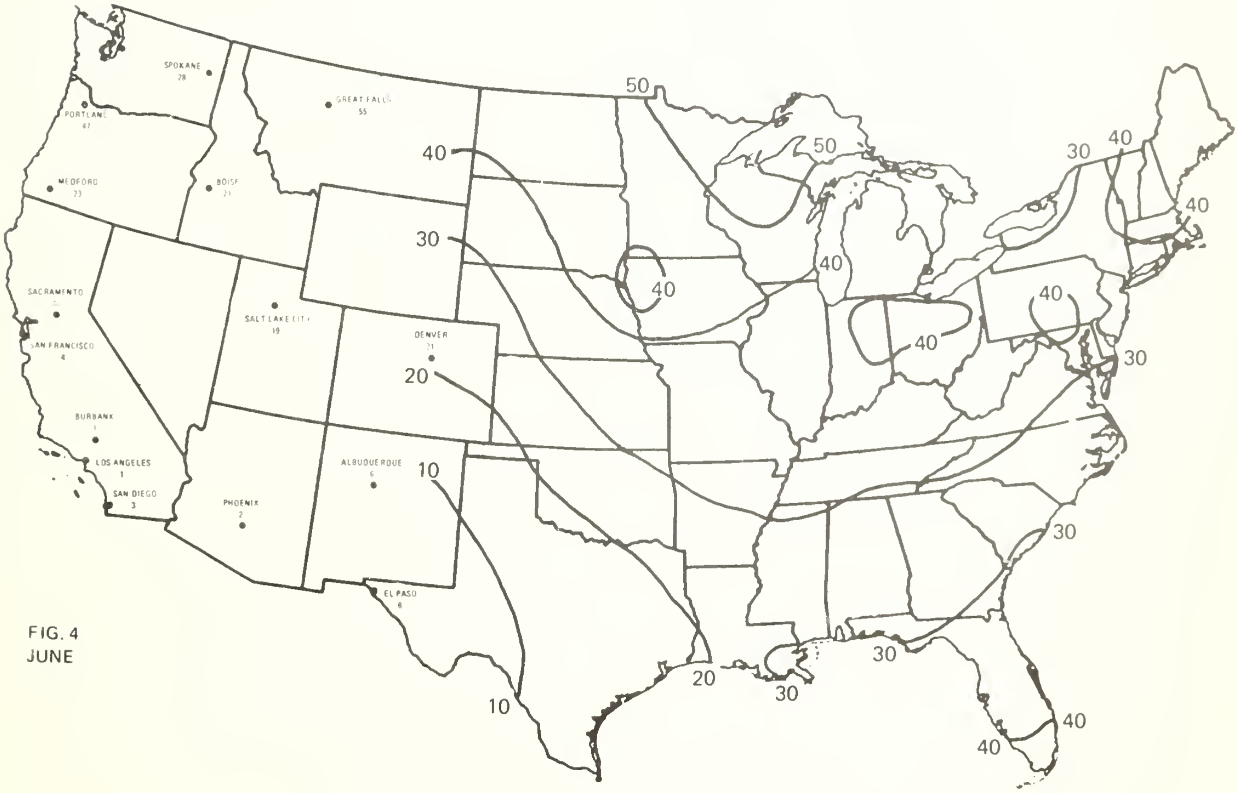

FIG. 4
JUNE

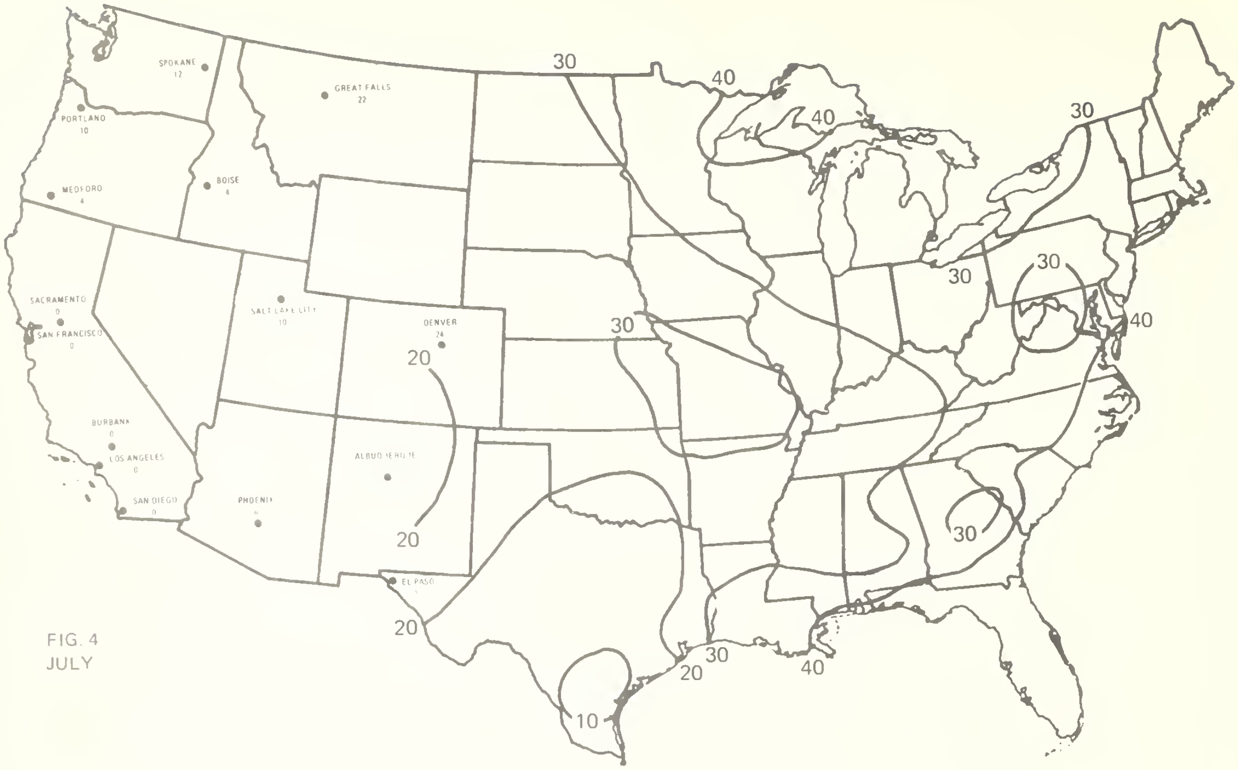

FIG. 4
JULY

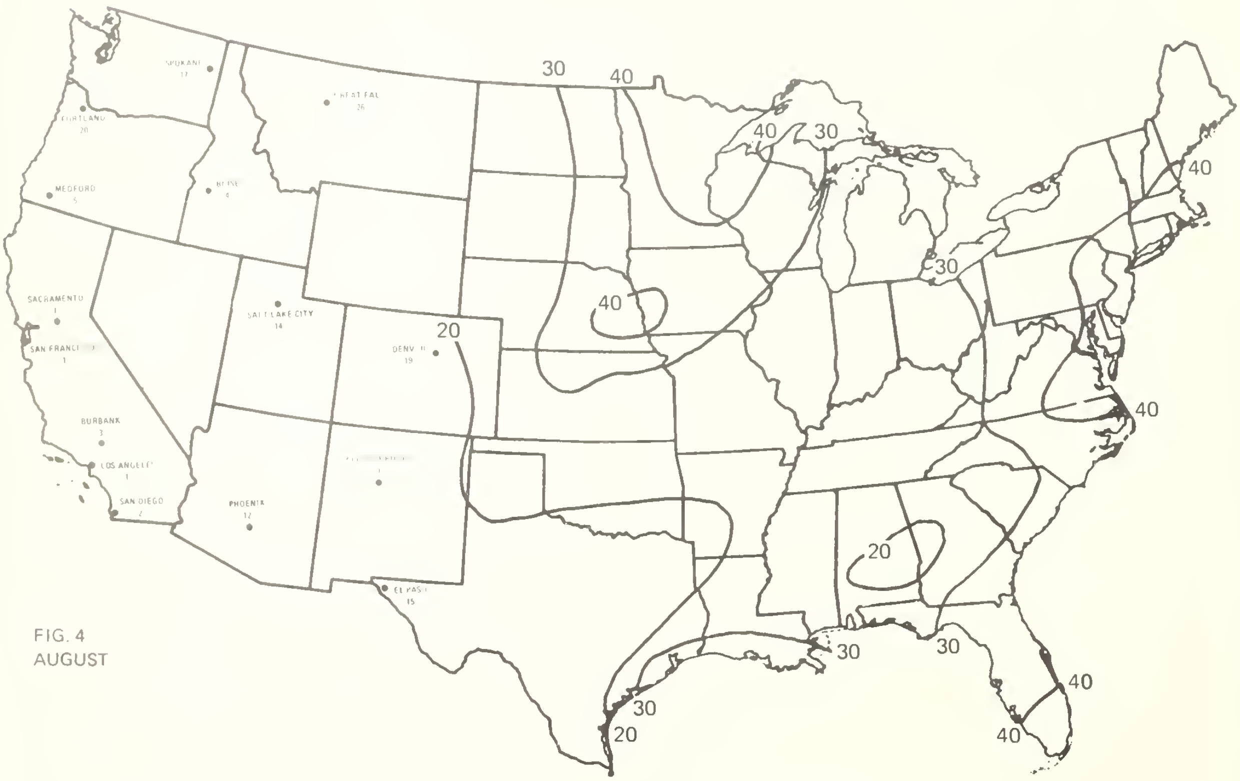

FIG. 4
AUGUST

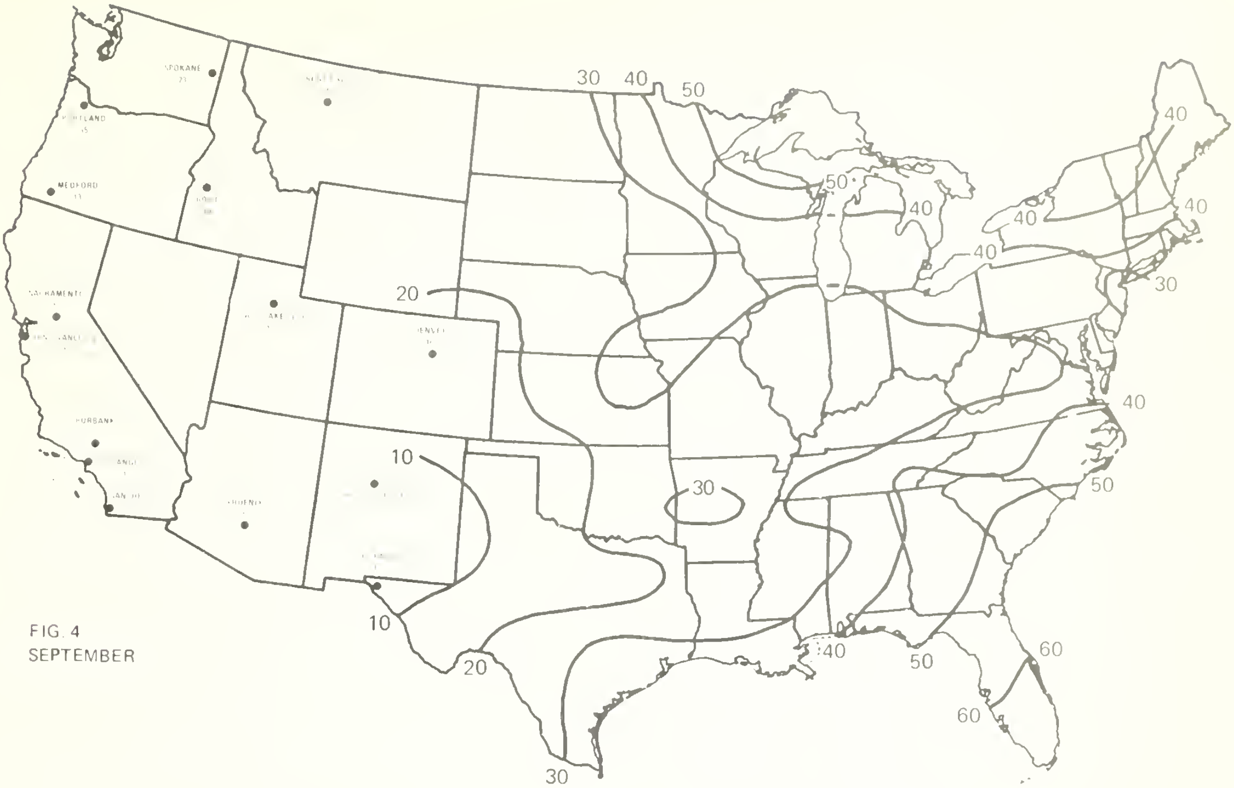

FIG. 4
SEPTEMBER

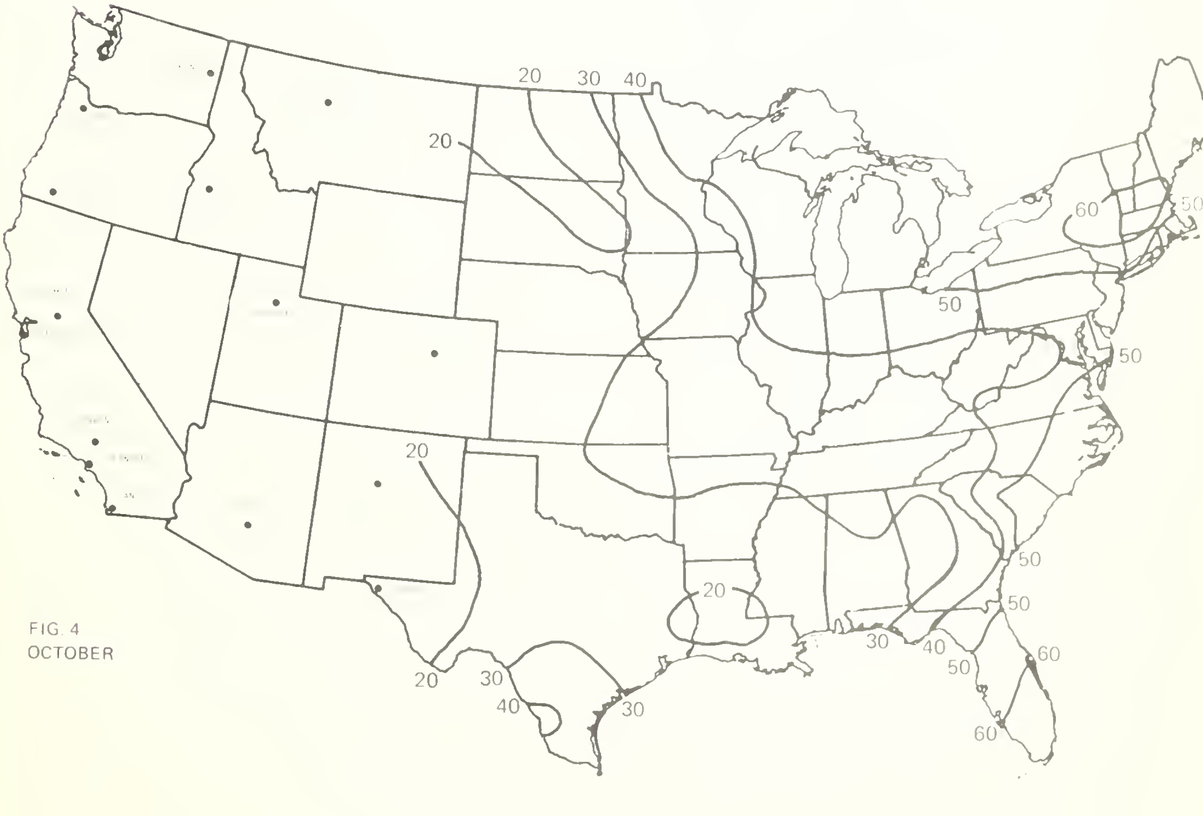

FIG. 4
OCTOBER

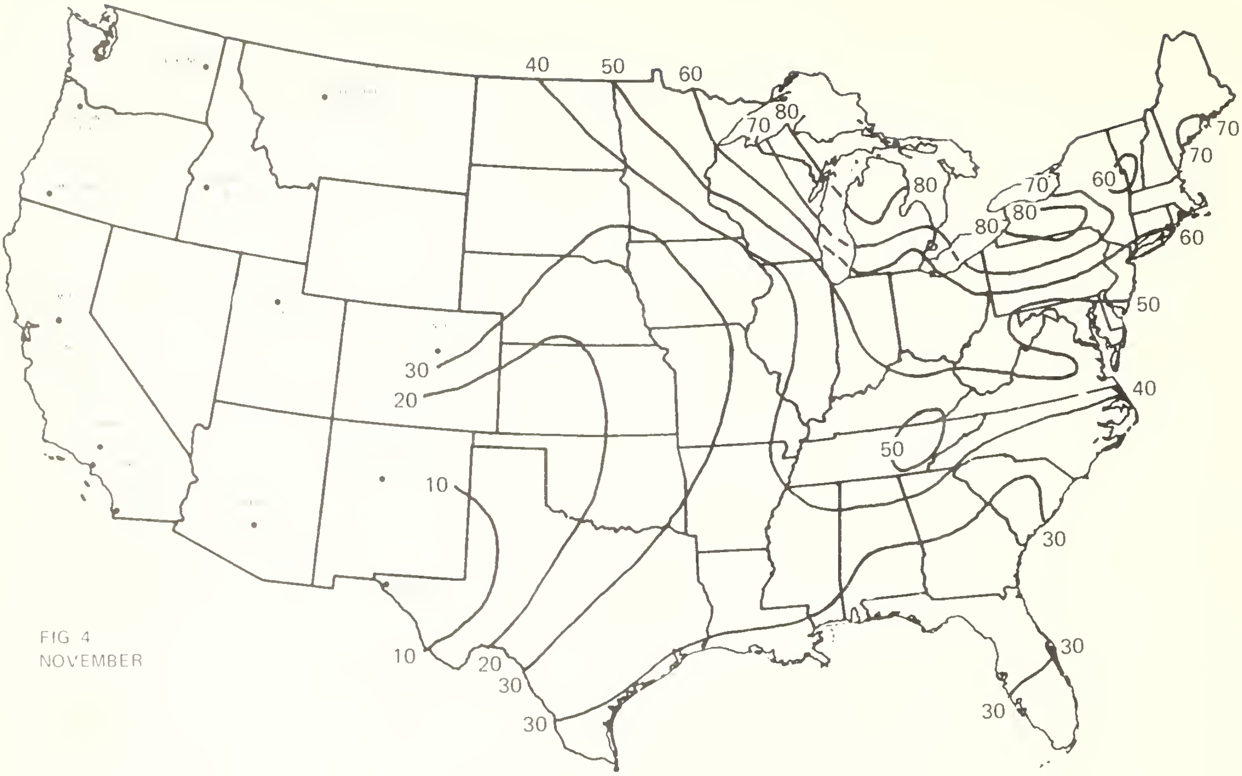

FIG 4
NOVEMBER

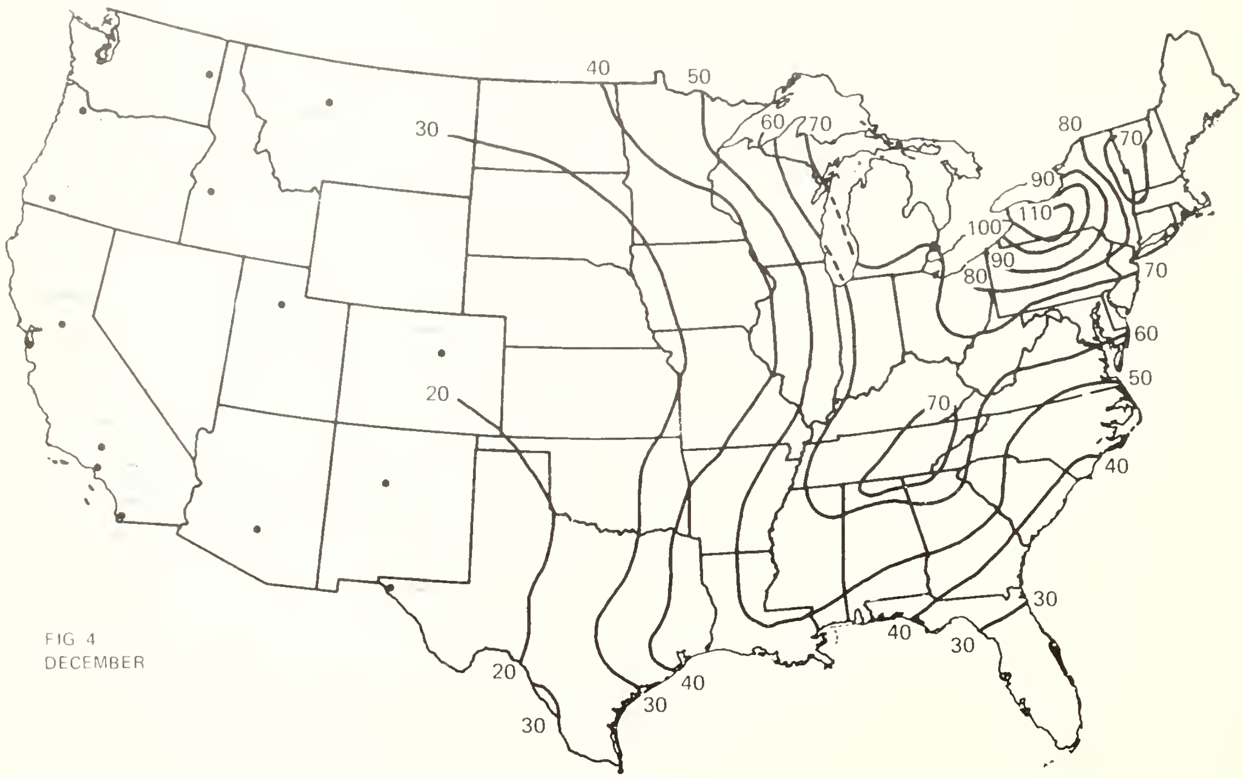

FIG 4
DECEMBER

SUMMARY

With the introduction of new models to describe the complex physical world (such as the new NFDRS), it is necessary to examine physical variables as they fit into the models. Because of the absorption properties of fuels, exposure time to precipitation is critical. An examination of total hours of precipitation per day from 11 stations across the United States shows a J-shape frequency distribution. The mode is located at the 1- or 2-hour group with the curve trailing far to the right. Fitting a gamma-probability function to the data gives average, 50th-percentile readings of about 3.3 precipitation-hours per precipitation-day during major fire-seasons. Simple averaging of the same data produces a value of 4.7 precipitation-hours per precipitation-day.

Mean maps for the United States show the highest spatial averages of P.H./P.D. in the Northeast and the Northwest. Highest monthly averages occur as snow-shower phenomena with greatest occurrence during the winter and early spring. Annually the greatest number of precipitation-hours occur in these same two geographic regions. Nationwide patterns of the "mean number of hours with precipitation" are similar to computations of "mean number of days with 0.01 inch or more of precipitation" (U.S. Dep. of Commerce, NOAA 1968).

A good estimate of P.H./P.D. can be derived from the included charts. During major fire-seasons subtract 1.5 hours from the given map values.

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☆U.S. Government Printing Office: 1973 – 762-330

NORTH CENTRAL FOREST EXPERIMENT STATION

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1923 1973

USDA Forest Service
Research Paper NC-99
1973

ESTABLISHING EVEN-AGE NORTHERN HARDWOOD REGENERATION BY THE SHELTERWOOD METHOD A PRELIMINARY GUIDE

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Manuscript approved for publication August 21, 1973

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ESTABLISHING EVEN-AGE NORTHERN HARDWOOD REGENERATION BY THE SHELTERWOOD METHOD--A PRELIMINARY GUIDE

Richard M. Godman and Carl H. Tubbs

Shelterwood cuttings are proving to be one of the most reliable methods for establishing even-aged stands of northern hardwoods (fig. 1) (Behrend and Patric 1969, Curtis and Rushmore 1958, Leffelman and Hawley 1925, Metzger and Tubbs 1971, Tubbs and Metzger 1969). This system provides a partial canopy that encourages full stocking of desirable species, stimulates early seedling growth to shorten the establishment period, and restricts the intensity of competition from grasses and herbaceous plants. Other methods of establishing even-aged stands in the Lake States, such as heavy diameter-limit cutting and various forms of clearcutting, have generally given less consistent results (Metzger and Tubbs 1971). They have yielded great variation in both stocking and height development and frequently converted areas to grassy openings or patches dominated by partial stocking of pioneer species.

Shelterwood trials in northern hardwood types of the Lake States have all been successf in establishing even-aged reproduction although the length of time it takes has varied. Advantages of the shelterwood method are its adaptability to mechanized harvesting, its desirable esthetic appearance while a new stand is becomi

Figure 1.--*Shelterwood stand 3 years after the initial cut.*

established, and its flexibility for wildlife habitat improvement and recreational use. Results from eight shelterwood cuttings and several other studies were used to develop this guide for shelterwood harvesting in the Lake States. Some of the recommendations are preliminary and will be refined as more results become available.

The first shelterwood trials were established in 1958 on the Argonne Experimental Forest in northeastern Wisconsin and the Upper Peninsula Experimental Forest in the Upper Peninsula of Michigan. The soils in these areas are silt loams and sandy loams, respectively; average site index was 65 for sugar maple (Acer saccharum Marsh.) and yellow birch (Betula alleghaniensis Britton) and 70 to 75 for basswood (Tilia americana L.) and white ash (Fraxinus americana L.) in both areas. Reproduction was present under both Argonne and Upper Peninsula stands at the time of the initial cut although in some treatments the advanced regeneration was removed.

OBJECTIVES OF THE TWO-CUT SHELTERWOOD SYSTEM

The objective of the shelterwood system is to develop dense, uniform, seedling stands during the regeneration period. Stand density influences not only growth and yield but also largely determines stem quality (Godman and Books 1971). Since the role of density is important throughout the stand rotation, the regeneration system must assure adequate stocking with a minimum establishment period. Under Lake States conditions, a two-cut shelterwood system will establish even-aged northern hardwood stands of tolerant species within an acceptable time. With a few modifications it also is suitable for establishing stands of less tolerant species.

The two-cut shelterwood cannot be used to secure natural regeneration in stands younger than 40 years or in stands having trees smaller than about 8 inches d.b.h. This is the age and size when sugar maple, the most abundant tree of the tolerant species, begins to produce seed.

GENERAL GUIDELINES

Making the First Cut

The residual crown cover is the key to successful establishment of even-aged stands by shelterwood cuttings. The amount and uniformity of the residual crown cover affect the intensity and duration of the light reaching the seedlings on the forest floor. Adequate shade must be provided to prevent the shallow-rooted seedlings from drying out until the root systems have developed. A transition period must also be provided for the seedlings to adapt and develop in a more open environment. Partial shade is also necessary to retard herbaceous competition which responds rapidly to increases in light intensities (Stroempl 1971, Metzger and Tubbs 1971).

After the first cut the residual canopy should admit about 40 percent of full sunlight. This compromise amount will permit good seedling establishment while restricting herbaceous competition somewhat. If severe competition is expected, more crown cover should be left. Regeneration is usually best obtained under a high, uniformly distributed canopy of large trees. Marking must therefore be from below, and all residual trees should be considered part of the residual overstory.

Experienced marking crews can estimate the proper amount of residual crown cover by eye. Normally they should try to leave a canopy that covers slightly more than one-half of the ground area.

The percent crown cover of a given area can be obtained more accurately by first summing the crown areas of individual trees, listed according to tree diameter and species (tables 1-3, column 2), and expressing the sum as a percent of the plot area (table 4).

Basal area should be disregarded in marking for crown cover because the basal area-crown area relationship varies sharply with both the diameter and species involved. Although average crown width increases with stem diameter for all species, there are significant differences in crown width among species groups in typical northern hardwood stands (fig. 2). In addition, small diameter trees (except for the hemlock-conifer group) have disproportionately wider crowns per inch of stem diameter than larger trees. Consequently, marking stands to the same basal area without regard to diameter and species will result in considerable variation in the percent of actual crown cover (fig. 3).

The fact that basal area is a poor indicator of crown cover can be further shown by comparing three plots with crown covers ranging from 37 to 57 percent, but all having about the same basal area (table 4).

Residual trees should have a full crown, be vigorous and able to withstand a more open site, and be capable of making good volume growth during the regeneration period. A diameter increase will often raise the grade of the butt log and increase economic returns from the removal cut. Fully crowned, vigorous trees will grow better and are not likely to have epicormic sprouts that could cause degrade. Trees with pronounced forks should not be left, particularly those with large diameter limbs and heavy callous growth at the fork. They are likely to split in open stands, reducing both the crown cover and tree value.

Table 1.--*Crown area of northern hardwood species by diameter classes and theoretical stocking for different levels of crown cover*

D.b.h.	Crown area	Crown cover (percent) 50: Trees	50: Basal area	50: Spacing	60: Trees	60: Basal area	60: Spacing	70: Trees	70: Basal area	70: Spacing
	Sq ft	No.	Sq ft	Ft	No.	Sq ft	Ft	No.	Sq ft	Ft
1	20	1,089	6	6	1,306	7	6	1,525	8	5
2	37	589	13	9	706	15	8	824	18	7
3	56	389	19	11	467	23	10	544	27	9
4	78	279	24	12	335	29	11	391	34	11
5	104	209	29	14	251	34	13	293	40	12
6	133	164	32	16	196	39	15	229	45	14
7	164	133	36	18	159	43	16	186	50	15
8	199	109	38	20	131	46	18	153	54	17
9	238	92	40	22	110	48	20	128	57	18
10	279	78	43	24	94	51	22	109	60	20
11	325	67	44	26	80	53	23	94	62	22
12	373	58	46	27	70	55	25	82	64	23
13	422	52	48	29	62	57	26	72	67	25
14	480	45	48	31	54	58	28	64	68	26
15	536	41	50	33	49	60	30	57	70	28
16	598	36	51	35	44	61	32	51	71	29
17	662	33	52	36	40	62	33	46	73	31
18	728	30	53	38	36	63	35	42	74	32
19	803	27	53	40	32	64	37	38	75	34
20	881	25	54	42	30	65	38	35	76	36
21	952	23	55	44	27	66	40	32	77	37
22	1,035	21	56	46	25	67	42	30	78	38
23	1,120	19	56	47	23	67	43	27	79	40
24	1,207	18	57	49	22	68	45	25	79	42

Table 2.--*Crown area of basswood by diameter classes and theoretical stocking for different levels of crown cover*

D.b.h.	Crown area	Crown cover (percent) 50: Trees	50: Basal area	50: Spacing	60: Trees	60: Basal area	60: Spacing	70: Trees	70: Basal area	70: Spacing
	Sq ft	No.	Sq ft	Ft	No.	Sq ft	Ft	No.	Sq ft	Ft
1	11	1,980	11	5	2,376	13	4	2,772	15	4
2	22	990	22	7	1,188	26	6	1,386	30	6
3	33	660	32	8	792	39	7	924	45	7
4	43	506	44	9	608	53	8	709	62	8
5	54	403	55	10	484	66	10	565	77	9
6	69	316	62	12	379	74	11	442	87	10
7	86	253	68	13	304	81	12	355	95	11
8	103	212	74	14	254	89	13	296	103	12
9	126	173	76	16	207	92	14	242	107	13
10	153	142	78	18	171	93	16	199	109	15
11	181	120	79	19	144	95	17	168	111	16
12	207	105	83	20	126	99	19	147	116	17
13	241	90	83	20	108	100	20	126	117	19
14	274	80	85	23	95	102	21	111	119	20
15	312	70	86	25	84	103	23	98	120	21
16	349	62	87	26	75	105	24	87	122	22
17	388	56	88	28	67	106	25	79	124	24
18	427	51	90	29	61	108	27	71	126	25
19	470	46	91	31	56	110	28	65	128	26
20	518	42	92	32	50	110	29	59	128	27
21	567	38	92	34	46	111	31	54	129	28
22	614	36	94	35	43	112	32	50	131	30
23	665	33	94	36	39	113	33	46	132	31
24	712	31	96	38	37	115	35	43	134	32

Table 3.--*Crown area of hemlock-conifers by diameter classes and theoretical stocking for different levels of crown cover*

D.b.h.	Crown area	Crown cover (percent)								
		50			60			70		
		Trees	Basal area	Spacing	Trees	Basal area	Spacing	Trees	Basal area	Spacing
	Sq ft	No.	Sq ft	Ft	No.	Sq ft	Ft	No.	Sq ft	Ft
1	1	21,780	119	1	26,136	142	1	30,492	166	1
2	4	5,445	119	3	6,534	142	3	7,623	166	2
3	10	2,178	115	4	2,614	138	4	3,049	166	4
4	17	1,281	112	6	1,537	134	5	1,794	156	5
5	27	807	112	7	968	134	7	1,129	156	6
6	38	573	112	9	688	134	8	802	156	7
7	52	419	112	10	503	134	9	586	156	9
8	68	320	112	12	384	134	11	448	156	10
9	87	250	111	13	300	133	12	351	156	11
10	107	204	111	15	244	133	13	285	156	12
11	129	169	111	16	203	133	15	236	156	14
12	154	141	111	18	170	133	16	198	156	15
13	181	120	111	19	144	133	17	168	156	16
14	209	104	111	20	125	133	19	146	156	17
15	241	90	111	22	108	133	20	126	156	19
16	274	80	111	23	95	133	21	111	156	20
17	309	70	111	25	85	133	23	99	156	21
18	346	63	111	26	76	133	24	88	156	22
19	386	56	111	28	68	133	25	79	156	24
20	427	51	111	29	61	133	27	71	156	25
21	471	46	111	31	56	133	28	65	156	26
22	518	42	111	32	50	133	29	59	156	27
23	563	39	111	34	46	133	31	54	156	28
24	612	36	111	35	43	133	32	50	156	30

Sensitive species, such as yellow birch, normally should not be left. Yellow birch is susceptible to severe attack by sapsuckers in the open environment of a shelterwood cut and may be killed outright or subject to top damage and reduced growth.

Unmanaged northern hardwood stands often include small areas that are well stocked with saplings. These may be left at the forester's discretion if they are extensive enough. Scattered saplings should be removed.

Response of Tolerant Seedlings to Varying Amounts of Crown Cover

Stocking and height growth of the regeneration varies with percent crown cover left in the overstory following the initial cut (table 5). In the oldest study 60 percent crown cover resulted in all quadrats being stocked with desirable species at a density in excess of 44,000 seedlings per acre. Little crown cover or removal of the canopy in a single cut (Metzger and Tubbs 1971) can result in inadequate numbers and partial stocking but much cover tends to suppress seedling establishment. Variations in crown cover do not necessarily result in changes in species composition (Tubbs 1968).

Height growth of the seedlings under the 60 percent crown cover was slowing down at the end of the 7-year period. At this stage the crown cover had increased to 76 percent (table 5). Although seedling growth should continue at this amount of crown cover (as suggested by stand 2, table 5) there will obviously be a gradual reduction in future growth rates. This suggests that greater amounts of crown cover might be used to hold the regeneration at browse height for a longer use period in the vicinity of winter deeryards.

Factors Influencing Herbaceous and Shrub Growth

Grass and shrubs commonly invade heavily cut hardwood stands. In some cases these species appear to retard tree reproduction for lengthy periods. Both intensity of cut and season of logging appear related to invasions by grass and shrubs. Site and geographic location are also factors.

Logging while the ground is snow covered has advantages over summer logging for both the initial and removal cuts. Winter cuttings result in lower seedling mortality, less ground competition, and less damage to seedling stems. In one initial cutting trial, the summer-logged area had only one-third as many seedlings as the

Table 4.--*Comparison of three 1/10-acre plots marked to the same basal area but having different percentages of crown cover*

D.b.h.	Number of trees: Northern hardwoods	Basswood	Hemlock	Plot total: Basal area	Crown area1/
				Sq ft	Sq ft
LARGER TREES OF MIXED CROWN WIDTH					
8	2			0.7	398
10					
12					
14			1	1.1	209
16		1		1.4	349
18					
20	1			2.2	881
Total				2/5.4	3/1,837
SMALLER TREES OF A SINGLE CROWN WIDTH					
8	2			0.7	398
10	1			.5	279
12	2			1.6	746
14	1			1.1	480
16	1			1.4	598
Total				4/5.3	5/2,501
SMALLER TREES OF A MIXED CROWN WIDTH					
8		2		0.7	206
10			1	.5	107
12		2		1.6	414
14		1		1.1	274
16	1			1.4	598
Total				6/5.3	7/1,599

1/ Average crown area per tree given in Column 2, tables 1, 2, and 3.
2/ Basal area per acre = 54 sq ft.
3/ Percent crown cover = $\frac{1,837}{4,356}$ = 42.
4/ Basal area per acre = 53 sq ft.
5/ Percent crown cover = $\frac{2,501}{4,356}$ = 57.
6/ Basal area per acre = 53 sq ft.
7/ Percent crown cover = $\frac{1,599}{4,356}$ = 37.

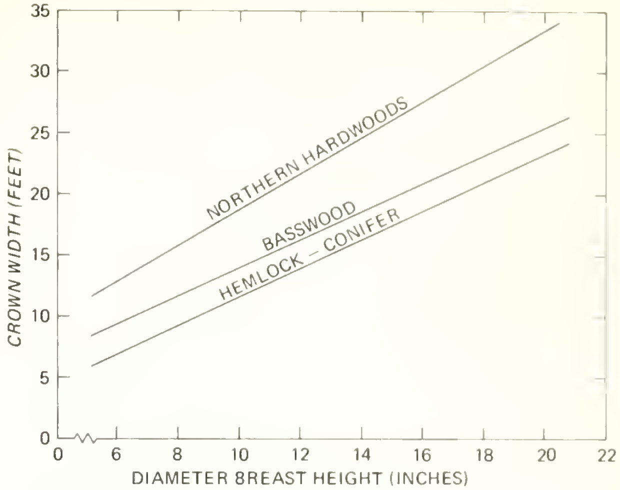

Figure 2.--*Average crown width by stem diameter and species group.*

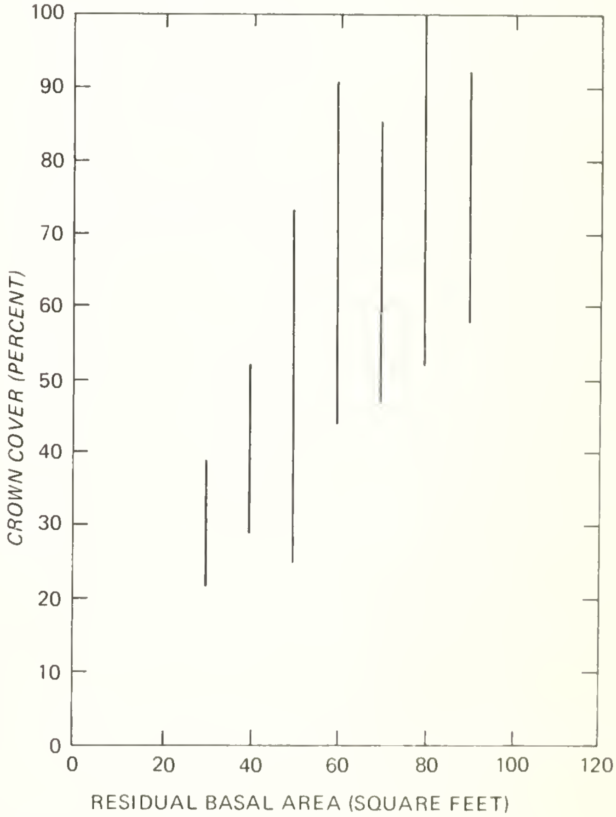

Figure 3.--*Observed variation in percent of crown cover associated with different basal area densities in northern hardwood stands.*

area that was cut in winter, and raspberries were dominant on 75 percent of the quadrats at the end of the third growing season. It appears that the summer-logged area will require a much longer time to establish regeneration because of competition from herbaceous vegetation. The stocking may also remain sparse because of seedling loss from skidding.

Geographical location and site also determine if competition from herbaceous vegetation will be harmful to regeneration. In the Upper Peninsula Experimental Forest raspberry growth fostered by heavy cuttings ultimately had little adverse effect on tree regeneration. Foresters must make use of local experience in deciding whether shrubs and herbaceous vegetation will be a significant factor.

Overstory Removal

The shelterwood overstory should be harvested as soon as the established seedlings

Table 5.--*Influence of different amounts of crown cover on stocking and height growth 7 years after a shelterwood cutting*

Stand number	Crown cover: Initial cut	Crown cover: After 7 years	Quadrats stocked	Seedlings per acre: Total	Seedlings per acre: More than 3.6-feet tall
	Percent	Percent	Percent	Number	Number
1	60	76	100	44,040	9,800
2	76	94	100	33,400	2,500
3	130	158	100	17,100	700

have deep root systems, are capable of responding to full sunlight, and dominate the competing vegetation. Normally these conditions are met when the seedlings are at least 3-feet tall. At this stage they generally retain dominance over herbaceous competition. If advanced regeneration was present before the initial cut, it is usually well enough established within 3 to 8 years to remove the overstory.

Trees that are not financially mature at the second cutting may be left if there are enough to make a cut economic at a later date. However, increasing the number of cuttings will inevitably result in a stand of many size classes.

The overstory should be logged when there is snow cover to minimize seedbed disturbance and damage to seedlings. However, we have found that as much as 50 percent of the reproduction can be damaged without permanent adverse effects. Damaged seedlings grow rapidly and the minor crooks that develop in the early stages disappear as stem size increases (Jacobs 1969). We find that leader growth can exceed 3 feet during the year after stem breakage, which rapidly brings the seedling sprouts back to the level of the more slowly growing, undamaged seedlings.

Lopping slash also damages seedlings. Since hardwood slash deteriorates rapidly in this type and fire danger is normally low (Eyre and Zillgitt 1953), lopping may be less necessary here than in other forest types.

MODIFICATIONS TO INCREASE THE PROPORTION OF YELLOW BIRCH

There are two major requirements for the establishment of large numbers of rapidly growing yellow birch seedlings. First, the seedbed must be cool and moist during the germination period (Tubbs 1969a). Second, competition from tolerant species (especially sugar maple) should be reduced either by choosing sites that are less suitable for those species, or removing advanced reproduction, or both (Tubbs and Metzger 1969, Tubbs 1970).

Site Selection

Hemlock-hardwood sites have proven to be the easiest on which to establish birch. These sites are relatively cool and wet, and advanced reproduction of competing species is often deficient.

Yellow birch makes good growth on moderately to well drained soils but these are also good sugar maple sites. Even after scarification, birch numbers and growth are relatively low because the maple re-invades rapidly and inhibits birch growth (Tubbs and Metzger 1969).

The sandier hardwood soils which tend toward excessive drainage are natural birch sites in the north but birch establishment after scarification is scanty on them because of the dry, infertile nature of the seedbed.[1/] These sites have a low priority because successful birch reproduction will probably be infrequent. However, on sandy soil with a high water table birch sometimes reproduces in fair numbers.

Seedbed Preparation

Scarification to expose the mineral soil gives the best results over the widest range of conditions. Scarification should mix the humus and mineral soil thoroughly and destory as much advance regeneration as possible. The mineral soil provides a cool, moist environment for germination; the humus stimulates growth (Tubbs and Oberg 1966). Simply scraping the humus away on typical podsols exposes the A_2 horizon which is deficient in nutrients and often of moisture.

Ideally, 50 percent or more of the area (Godman and Krefting 1960) should be scarified after leaf fall in a good seed year and before harvesting operations begin. Scarified seedbeds generally remain suitable for 2 or 3 years. Yellow birch has at least moderate seed crops every 3 years (USDA Forest Service 1965) so that the chance of having adequate numbers of seed is good even if scarification cannot be done during a seed year. On poorly drained soils low mounds help birch establishment (Tubbs 1963).

1/ *Unpublished data on file at the Northern Hardwoods Laboratory, Marquette, Michigan.*

Mounds need only be a foot or two in height and rounded or flat on top.

Prescribed fire is an inexpensive way to remove advanced growth and forest litter; in 1969 costs were estimated at less than $1 per acre in Ontario (Burton et al. 1969). To be most effective, burning should be done in the spring during or immediately after the leaf-out period when advanced seedling numbers can be drastically reduced.

Although burning has the virtue of being cheap and easier than scarifying on some sites, it has several shortcomings. The number of days that are conducive to spring burning are few. The resulting seedbed is dark colored and hot; on well-drained sites both germination and survival rates may be low (Tubbs 1969b). A recent trial has shown that fires hot enough to expose the mineral soil (which is more moist and cooler than burned litter) may kill overstory trees. In one study, this opened the canopy enough to encourage herbaceous species which reduced birch survival drastically. Overstory kill can be minimized by burning before harvesting when fuel quantities are low. Light burns cause no significant changes in nutrient status or soil microbial populations (Burton et al. 1969).

Killing advanced seedlings with foliage sprays during the growing season has resulted in increases of birch (Tubbs and Metzger 1969). Because the litter is not removed, however, only about half as much birch will become established as after scarification.

The First Cut

Overstory density is important to yellow birch establishment on most sites because of its influence on seedbed moisture, temperatures, and herbaceous competition. Full sunlight following clearcutting is detrimental to germination and establishment in most situations because yellow birch cannot tolerate the high temperatures and moisture conditions which result (Godman 1959, Tubbs 1969a). Open stand conditions promote raspberry growth and grass invasion which can also contribute to birch failures (Metzger and Tubbs 1971, Tubbs 1969a, Godman and Krefting 1960). After seedlings are well established, however, full sunlight promotes the best growth (Burton et al. 1969). Consequently, the first cut should provide the cool, moist conditions necessary for establishment while the second cut releases the seedlings. A wide range (from 30 to 70 percent) of overstory results in satisfactory establishment of yellow birch. In areas where development of heavy herbaceous competition is expected, heavy shade (up to 70 percent crown cover) will probably be necessary to control competition if birch is to succeed. More shade than this, however, generally results in poor seedling vigor.

Good birch sites are often moist so the most abundant species tend to be shallow rooted and subject to post-logging decadence. Prudence dictates that special attention be paid to leaving vigorous trees in the overstory, especially if a long establishment period is expected. Epicormic sprouts will develop but should not be important for short periods; when sprouts are small, these defects will be slabbed off along with defects from logging wounds (Meyer et al. 1966).

Because yellow birch seedlings compete poorly with sugar maple, some attempt should be made to discriminate against sugar maple in the overstory. Sugar maple normally does not produce moderate seed crops until reaching 10- to 14-inches d.b.h. (USDA Forest Service 1965) and the larger trees will obviously produce the most seed. Thus, where spacing permits, remove the largest sugar maples first.

Leaving many yellow birch in the overstory for seed probably will not increase birch stocking and may lead to losses from decadence and mortality (Jacobs 1960). Seed has been shown to be adequate 5 chains from the source (Benzie 1959). In another study enough seed was produced on a scarified area containing four trees per acre to provide over 1/2 million seedlings per acre (Godman and Krefting 1960). One seed-bearing birch per acre should provide adequate insurance against unfavorable climatic conditions or seed crop failures.

Seeding and Planting

Seeding and planting to augment natural regeneration seldom have been practiced. Earlier experimental evidence (Stoeckeler and Limstrom 1950) indicates that planting in open conditions often will be unsuccessful. However, recent trials have shown that yellow birch seedlings can be successfully planted on moist soils under a shelterwood overstory. Establishment can be improved by removing half the seedling stem before planting (Godman and Mattson 1971).

Direct seeding has been successful on small plots under a shelterwood canopy. Tree percent may be low, however, even on favorable sites (Tubbs 1969a). At least 1/4 pound of seed is needed per acre on scarified sites to get a dense stocking.[2/] In the Upper Peninsula of Michigan seed sown before January germinates well the following spring; seed sown after this date germinates late in the summer (Tubbs 1964).

Overstory Removal

Overstories may be removed when the yellow birch seedlings average 2 to 4 feet in height.

2/ Number of seed varies from 330,000 to 1 million per pound.

The establishment period runs from a minimum of 3 years (Burton et al. 1969) to 7 or 8 years (Tubbs and Metzger 1969) at which time birch should be an acceptable height. In controlled studies, removal of shade from vigorous birch of this size had no effect on growth the following growing season (Tubbs and Metzger 1969). Damage to the reproduction should be light if removal is made during the winter but seedling birch apparently recover from any damage short of uprooting. Winter logging that removed 20 or more square feet of basal area resulted in insignificant mortality of birch reproduction (Tubbs and Metzger 1969). In another study, severely top-damaged young birch seedlings sprouted back to make better height growth than undamaged seedlings (Tubbs 1969a).

SUMMARY OF RECOMMENDATIONS FOR APPLYING TWO-CUT SHELTERWOOD IN NORTHERN HARDWOOD STANDS

General Rules for Tolerant Species

1. Stands selected should be moderately well stocked with advanced regeneration of desirable species. At the minimum, stands should average at least 8 inches d.b.h.

2. Marking must be from below. Leave 60 percent crown cover at regular spacing. All trees left must be considered part of the residual crown cover.

3. Initial logging should be done only when the ground is snow covered to minimize seedling loss.

4. The overstory can be removed when the reproduction attains a height of 3 to 4 feet. Log when the ground is snow covered, removing all stems. Lopping of slash should be minimized and restricted to esthetic or access areas.

Modifications to Favor Yellow Birch

1. Attempts to regenerate yellow birch should focus on cool, moist (hemlock-hardwood) sites.

2. Marking should tend to discriminate against sugar maple in the residual overstory. Leave no more than 70 percent crown cover of the most vigorous trees.

3. Scarify 50 percent or more of the surface area after leaf fall and prior to logging. Scarification should aim at mixing the humus and mineral soil and destroying advance regeneration. Kill advanced regeneration prior to cutting on sites too difficult to scarify.

4. Make the first cutting during moderate or better seed year, or direct seed before midwinter at a rate of at least 1/4 pound per acre on the scarified area. One seed tree per acre may be left for insurance.

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FIFTEEN-YEAR RESULTS FROM SIX CUTTING METHODS IN SECOND-GROWTH NORTHERN HARDWOODS

Gayne G. Erdmann and Robert R. Oberg

NORTH CENTRAL FOREST EXPERIMENT STATION

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The authors wish to acknowledge the contribution of the late Dr. Joseph H. Stoeckeler who planned and established the study. We also want to thank Thomas W. Church, Jr., and Rodney D. Jacobs for conducting and maintaining the study in later years and Gilbert A. Mattson and the late Harold C. Bell for their assistance in stand measurements and logging supervision.

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Manuscript approved for publication August 21, 1973

FIFTEEN-YEAR RESULTS FROM SIX CUTTING METHODS IN SECOND-GROWTH NORTHERN HARDWOODS

Gayne G. Erdmann and Robert R. Oberg

Presently there are over 9 million acres of northern hardwoods in the Lake States. Most of these hardwoods are in second-growth poletimber stands under 70 years of age. These second-growth stands either originated following commercial clearcutting between 1900 and 1930 or developed after years of high-grading. Consequently, they are now primarily even-aged with a scattering of older residuals, or uneven-aged. Today's uneven-aged stands usually have fewer ages and size classes than the original old-growth stands. Most stands contain a mixture of species. Sugar maple (*Acer saccharum* Marsh.) is the most abundant species on well-drained sites. Common associates are basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), yellow birch (*Betula alleghaniensis* Britton), red maple (*Acer rubrum* L.), American elm (*Ulmus americana* L.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.).

How do these stands respond to different methods of cutting and what are some of the management alternatives? During the winter of 1951-1952 a study was begun to answer these questions. This study compares the effects of different cutting methods on tree growth, species composition, and product yield in three second-growth northern hardwood stands in northeastern Wisconsin. Study objectives were: (1) to obtain information on basal-area production and volume yield in terms of cubic feet, board feet, and cords, and (2) to obtain growth and mortality data under different cutting methods. Other specific objectives dealing with tree quality and development of regeneration have been reported elsewhere (Godman and Books 1971, Metzger and Tubbs 1971).

This paper compares 15-year results of single-tree selection cuts to three stocking levels, a crop-tree release cut, and an 8-inch stump diameter limit cut in these stands. Management implications derived from a wide range of beginning basal area stocking levels are also discussed.

STUDY AREA

Three 40-acre stands located on the Argonne Experimental Forest in northeastern Wisconsin were chosen for the study. The stands are on good sites and are typical of those originating from commercial clearcutting.

Site indices at 50 years were similar for the three stands: about 65 for sugar maple and yellow birch, and about 70 for basswood and white ash. The soils are well- to moderately well-drained Iron River loams with a layer of boulders just beneath the surface.

When the study was established, two of the stands were composed primarily of 45-year-old, even-aged, pole-sized trees. The third stand contained a higher proportion of small saw-log-sized trees, but pole-sized trees were also well represented. The trees left from the original cut were mostly low-grade trees (short merchantabl bole lengths or poor quality) as old as 170 years.

Before cutting, the stands averaged 237 trees 4.6 inches d.b.h. and larger per acre, of which 59 percent were sugar maple, 10 percent basswood, 7 percent yellow birch, 6 percent white ash, and 5 percent hemlock. Occasional red maple, American elm, paper birch (*Betula papyrifera* Marsh.), black ash (*Fraxinus nigra* Marsh.), black cherry (*Prunus serotina* Ehrh.), aspen (*Populus* spp.), and ironwood (*Ostrya virginiana*) trees were also present.

Basal area stocking of all trees 4.6 inches d.b.h. and larger averaged 92 square feet per acre before cutting. Sugar maple was the predominant species, accounting for 57 percent of the basal area. Basswood made up 10 percent of the basal area, hemlock 9 percent, yellow birch 8 percent, white ash 6 percent, and other less common species 10 percent.

Before cutting, the stands averaged 2,199 cubic feet of peeled wood per acre.[1] Sugar maple accounted for 56 percent of the cubic-foot volume.

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[1] *Includes stump, stem, tip, and branches to 4.0 inches d.i.b. tops.*

CUTTING METHODS

A brief description of the cutting methods and subsequent treatments is given below:

Cutting method	Treatment and residual basal area[2/]
Control	Uncut stand with 94 sq. ft. basal area per acre.
Light selection	Cut to residual basal area of 90 sq. ft. per acre.
Medium selection	Cut to residual basal area of 75 sq. ft. per acre.
Heavy selection	Cut to residual basal area of 60 sq. ft. per acre.
Crop tree	Crown-released 30 to 50 crop trees per acre and cut all understory trees, except for trainers, within a 10-foot radius of a crop-tree bole. Residual basal area averaged 60 sq. ft. per acre.
Diameter limit	Cut all trees with stump diameters of 8 inches or more. Residual basal area averaged 21 sq. ft. per acre.

In the selection cuttings overmature and defective growing stock were removed first. Valuable yellow birch, sugar maple, basswood, and white ash were favored, while balsam fir (*Abies balsamea* (L.) Mill.) over 6 inches d.b.h., ironwood and any hemlock except those of good form and crown development were removed. The selection cuttings in 1951 left a stand of desirable hardwood trees 4.6 inches d.b.h. and larger at the required densities. After 10 years, the selection cuttings were recut to originally assigned densities. This time fewer saw-log trees were cut in an attempt to start building an all-aged stand structure. The crop-tree and 8-inch diameter limit treatments were not recut in 1961.

MEASUREMENTS AND ANALYSIS

A randomized block design was used with six cutting treatments in each of three blocks. Treatment plots were 5x5 chains square or 2.5 acres in size. A cluster of five permanent 0.1-acre circular plots were installed as the sampling units within each treatment plot.

A 100-percent inventory was made of each 0.1-acre growth plot before and after cutting in the winter of 1951-1952. Estimates of cull- and saw-log grade recovery were made from the volume cut in 1951-1952. End-of-the-growing-season inventories were repeated in 1957, in 1961 before and after cut, and in 1966. All trees 4.6 inches d.b.h. and larger were measured to the nearest 0.1 inch and tallied by species.

In the analyses data from the five 0.1-acre plots within each treatment were combined to make a 1/2-acre measurement unit for each treatment in each block. Growth and yield data were computed for the three measurement periods and then combined for the 15-year record.

General relationships of basal-area growth, cubic-foot growth, cordwood growth, and board-foot growth to basal area stocking were also investigated using the 1/2-acre growth plots. Basal-area densities at the beginning of the measurement period and corresponding periodic annual growth from each of the 54 1/2-acre growth plots (six one-half-acre plots x three blocks x three periods) were used in developing freehand growth curves and a board-foot growth model.

Trees were felled and sectioned in 1952 and 1969 for local volume table construction. Measurements for cubic-foot volumes included diameters inside bark beginning at a 1-foot stump to the nearest 0.1 inch at 8.3 foot intervals to a 4.0-inch, top, and total tree heights to the nearest foot. In addition, measurements on saw-log trees (9.6 inches d.b.h. and larger) included those needed to compute Scribner board-foot volumes to a variable merchantable top diameter that was limited by branches, defect, or other deformity, but not less than an 8.0-inch d.i.b. top. Total cubic-foot volumes inside bark were computed for each tree over 4.6 inches d.b.h. using Smalian's formula for the stump, stem in 8.3 foot lengths to a 4.0-inch d.i.b. top, the tip, and branches to 4.0-inch d.i.b. tops. Then following Spurr's (1954) volume line method, separate local cubic-foot volume tables were constructed for sugar maple, basswood, yellow birch, and white ash. The sugar maple volume-line equations were also used for calculating cubic-foot volumes of other less commonly associated species such as red maple and American elm. Merchantable board-foot and cordwood volumes were derived from the total cubic-volume estimates by use of appropriate converting factors for different mean stand diameters (Spurr 1954). A cord was assumed to contain 79 cubic feet of solid wood in our cordwood computations.

In 1957 and 1961 complete sapling inventories by 1-inch classes were taken on each 0.1-acre growth plot.

2/ Basal area per acre in trees 4.6 inches and larger.

DEFINITION OF TERMS

Terms used in our growth analyses are defined as follows.

Survivor growth.--Growth on trees originally 4.6 inches d.b.h. and larger that were living at both the beginning and end of each of three (4- to 6-year) observation periods.

Ingrowth.--Growth on trees that attained measurable size during each observation period. Ingrowth is used in the following ways: a tree that grew into the 4.6 inch d.b.h. class during an observation period was considered new growing stock; a tree that grew into the 9.6 inch d.b.h. class was considered a new saw-log tree.

Mortality.--The number, initial volume, or basal area of all trees that died during each observation period. Such trees were assumed to have made no growth during the period.

Gross growth.--Volume or basal area for each observation period = survivor growth + ingrowth.

Net growth.--Volume or basal area for each observation period = gross growth - mortality, or survivor growth + ingrowth - mortality.

RESULTS

Basal Area Growth

Net basal area growth of all trees 4.6 inches d.b.h. or larger ranged from 2.32 to 3.22 square feet of basal area per acre per year for the six cutting treatments (table 1). Net basal area growth was least on the uncut control and tended to increase with decreasing basal area, but differences in average net and gross basal area growth among the various cutting treatments were not statistically significant.

Net basal area growth was surprisingly good in the 8-inch diameter limit treatment, which had been cut back to 21 square feet of basal area per acre. The high ingrowth volume more than offset the low survivor growth rate. Although there were enough small trees to fully utilize the site in the diameter limit cut by 1961, stocking was insufficient in trees 8 inches and larger for a second cut.

Basal Area Growth and Stocking

In northern hardwood stands both periodic gross and net annual basal area growth peaked at about 45 square feet of basal area per acre (fig. 1). Net annual basal area growth exceeded 3 square feet per acre between 20 and 70 square feet of beginning basal area stocking. Below 20 square feet per acre, net growth was reduced because the site was not being fully utilized by trees pole-sized or larger. Above 115 square feet, net growth per acre dropped off sharply due to higher mortality.

Average annual basal area growth of trees surviving the measurement period was constant between 45 and 80 square feet per acre but decreased above the 80-square-foot stocking level. Average basal area ingrowth into the 4.6-inch d.b.h. class decreased from about 1 square foot per acre annually at 50 square foot stocking to less than 0.1 square foot annually above 115 square foot stocking.

Fifteen-Year Mortality

Fifteen-year mortality for all species of trees 4.6 inches d.b.h. and larger averaged only

Table 1.--Average annual gross and net basal area growth, survivor growth, ingrowth, and mortality on all trees 4.6 inches d.b.h. and larger by cutting method (15-year basis)1/ (Square feet per acre per year)

Cutting method	Survivor growth	Ingrowth2/	Gross growth	Mortality	Net growth
Control	2.87	0.23	3.10	0.78	2.32
90 sq. ft.	2.81	.27	3.08	.42	2.66
75 sq. ft.	2.82	.27	3.09	.37	2.72
60 sq. ft.	2.83	.54	3.37	.29	3.08
Crop tree	3.23	.55	3.78	.64	3.14
Diameter limit	2.29	1.33	3.62	.40	3.22
$S_{\bar{x}}$	.15	.11	.23	.13	.34

1/ Values in the same column enclosed by a bracket are not significantly different (0.05 level) using Duncan's new multiple range test.
2/ Into 4.6 inch d.b.h. class.

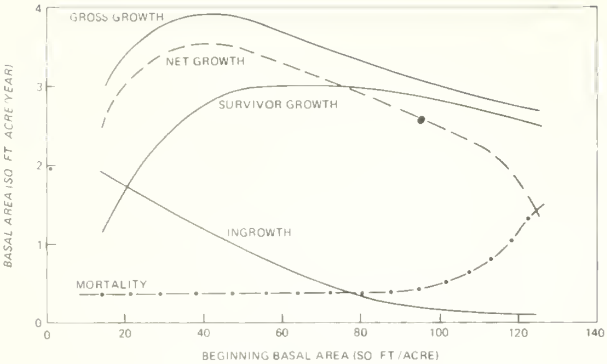

Figure 1.--Relation of periodic annual gross and net basal area growth, survivor growth, ingrowth, and mortality to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

9 percent for all treatments. Losses were low regardless of the cutting method used. Significantly more pole-sized trees (19 per acre) died than did saw-log sized trees (three per acre).

Sugar maple, the most abundant species, accounted for half of the total 15-year mortality; yet, only 7 percent of the sugar maple stems died. Hemlock, white ash, and red maple mortality was also low (5 to 6 percent), while mortality of yellow birch, basswood and other moderately tolerant species[3/] was between 12 and 15 percent. Short-lived and intolerant species dropped out of the stand most rapidly. The number of aspen stems decreased by 75 percent during the study.

There were no significant differences in 15-year mortality by cutting method in terms of number of trees, basal area, cubic-foot volume, cordwood volume, or Scribner board-foot volume. Eventually, however, the uncut stands would suffer considerable volume loss through natural mortality even with a tolerant species like sugar maple.

Fifteen-Year Ingrowth

Sugar maple made up significantly more of the 15-year ingrowth than any other species. It accounted for almost 87 percent of the trees growing into the 4.6 inch d.b.h. class, while basswood, yellow birch, red maple, and ironwood each contributed about 2.5 percent. Ingrowth increased with intensity of cut, especially when cutting removed large trees, as in the diameter limit treatment. This treatment had the highest ingrowth, with 139 trees growing to measurable size during the observation period; the uncut control had the least ingrowth, with only 26 trees coming into the measurable class. In all treatments except the control, gain in numbers of trees and basal area per acre from ingrowth more than offset mortality. Nearly all of the gain in ingrowth over mortality was made by sugar maple, regardless of the cutting treatment used. An average of 50 sugar maples per acre attained measurable size, while only 11 maples per acre died during the 15-year period. Ingrowth for red maple slightly exceeded mortality. For white ash and hemlock, ingrowth just balanced mortality. Mortality exceeded ingrowth for yellow birch, basswood, ironwood, aspen, balsam fir and other hardwood species. None of the cutting methods favored intolerant species.

3/ Includes American elm, white birch, black ash, black cherry, and red oak.

Diameter Growth

Diameter growth at breast height varied by original tree-size class, cutting treatment, beginning stocking level, and species. Sawtimber-sized trees (9.6 inches d.b.h. and larger) grew faster than pole-sized trees (4.6 to 9.5 inches d.b.h.) during the three measurement periods (table 2). The combined 15-year data show that poles averaged only 0.15 inches growth per year in diameter, while saw logs averaged 0.20 inches per year.

Table 2.--Periodic average annual diameter growth per tree for poles and saw logs by cutting method and years after cutting (In inches)

Cutting method	Years after cutting: 1 to 6	7 to 10	11 to 15	15-year average
POLES				
Control	[1/]0.12 a	0.10 a	0.09 a	0.10 a
90 sq. ft.	.12 ab	.10 a	.12 b	.11 a
75 sq. ft.	.14 bc	.12 b	.15 c	.14 bc
60 sq. ft.	.16 c	.14 b	.15 c	.15 bc
Crop tree	.20 d	.18 c	.15 c	.18 c
Diameter limit	.22 d	.23 d	.18 d	.21 d
Average	.16	.14	.14	.15
SAW LOGS				
Control	.17 a	.15 a	.13 a	.15 a
90 sq. ft.	.19 ab	.17 ab	.18 b	.18 ab
75 sq. ft.	.20 ab	.18 abc	.19 b	.19 bc
60 sq. ft.	.22 ab	.24 c	.22 bc	.22 cd
Crop tree	.24 b	.21 abc	.19 b	.21 bcd
Diameter	no trees	.22 abc	.25 c	[2/].23 cd
Average	.20	.20	.19	.20

1/ Treatment values within a column followed by the same letter are not significantly different at the 0.05 level.
2/ Except a 9-year period for the diameter limit treatment.

Cutting treatments leaving the lowest basal area densities (60 square feet or less) had the highest annual growth rates per tree. Pole trees in the diameter limit treatment grew about twice as fast as those in the control while saw-log trees in this same treatment grew about 1.5 times as fast as those in the control. However, because of the low residual stocking (21 square feet) in the diameter limit treatment, total growth per acre was reduced and the site was not fully utilized by growing stock for at least 6 years after the 1951 cut.

Cutting treatments that reduced basal area to 75 square feet or lower improved growth response on poles throughout the 15-year study period. Diameter growth response of poles in light selection cuts (90 square feet) was not improved.

During the first 6 years after cutting, annual diameter growth rates for saw-log trees were similar for all cutting treatments, ranging from 0.17 inches per year for control trees to 0.24 inches per year for trees in the crop tree treatment. During the last 5-year period, the average annual saw-log-tree growth rate of only 0.13 inches in the control was significantly lower than in all other treatments. During this same period the highest growth rate was 0.25 inches per year for saw-log trees in the diameter limit treatment.

Diameter growth also varied by species. Basswood and white ash grew faster than sugar maple but yellow birch was the slowest growing hardwood species in these stands. In managed stands growth rates of 2.0 to 2.5 inches per decade can probably be maintained on saw-log trees after low-vigor trees are harvested. Without cutting, growth rates of 1.0 to 1.5 inches per decade can be expected.

Average diameter growth of trees increased as stand density decreased (fig. 2). Diameter growth of sawtimber-sized trees averaged 0.2 inch or more per year at stand densities below 75 square feet of basal area per acre. At 125

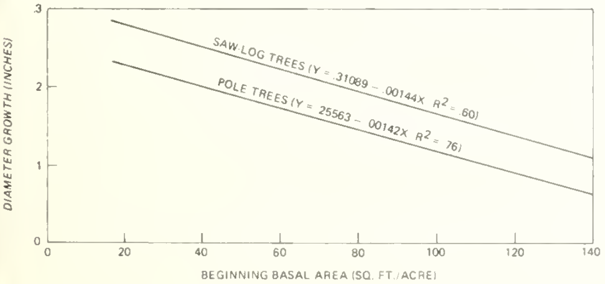

Figure 2.--Relation of mean annual d.b.h. growth of pole- and saw-log-sized trees to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

square feet, the highest density studied, sawtimber grew 0.13 inch per year. At the same time, pole-sized trees averaged 0.2 inch or more per year at stocking levels below 40 square feet of basal area compared with only 0.1 inch per year at stocking levels above 110 square feet. These are stand averages, however, and diameter growth of individual trees varied considerably depending on species, growing space, initial tree vigor, age, crown class, and crown vigor.

Cubic-Foot Volume Growth

For all cutting treatments, average gross and net cubic-foot volume growth were similar over the 15-year period. Gross total cubic-foot volume growth averaged from 111 to 136 cubic feet per acre per year for the six cutting treatments (table 3). Net cubic-foot volume growth ranged from 102 to 123 cubic feet per acre per year. During the first 6-year period after cutting, net growth was significantly lower on the 8-inch diameter limit cut than on any other cutting treatment, averaging only 82 cubic feet per acre per year. But over the 15-year period significantly higher ingrowth on the diameter limit treatment offset differences in survivor growth rates between treatments so that average total cubic-foot production was similar regardless of the cutting treatment used.

Periodic gross and net annual cubic-foot volume growth varied with beginning basal area stocking in hardwood stands (fig. 3). Gross cubic-foot volume growth increased rapidly up to a stocking level of 45 square feet, continued increasing at a reduced rate until peaking at 95 square feet, then declined slightly at higher stocking levels. Net cubic-foot volume followed a similar pattern up to 95 square feet, but dropped sharply above 115 square feet due to increasing mortality.

Cordwood Volume Growth

Average annual gross and net cordwood growth, like total cubic-foot growth, were about the same for all six cutting treatments. Net cordwood growth averaged about 1-1/4 cords per acre annually over the 15-year study period.

Gross and net cordwood growth on pole-sized trees were significantly higher in the 8-inch diameter limit cut than in any of the other cutting treatments. In this treatment, net cordwood growth in pole-sized trees averaged 0.70 cords per acre per year, as compared with a range of 0.05 to 0.33 cords per acre per year for the other cutting treatments.

In general, average annual net cordwood volume growth in all trees over 4.6 inches d.b.h. peaked at 1-1/3 cords per acre per year at 95 square feet

Table 3.--Average annual gross and net total cubic foot volume growth, survivor growth, ingrowth, and mortality on all trees 4.6 inches d.b.h. and larger by cutting method (15-year basis)[1]

(In cubic feet per acre per year)

Cutting method	Survivor growth	Ingrowth[2]	Gross growth	Mortality	Net growth
Control	127	5	132	20	112
90 sq. ft.	121	5	126	11	116
75 sq. ft.	118	5	123	9	113
60 sq. ft.	112	11	123	7	116
Crop tree	125	11	136	13	123
Diameter limit	84	27	111	9	102
$S_{\bar{x}}$	6.0	2.2	7.0	4.8	9.7

1/ Values in the same column enclosed by a bracket are not significantly different (0.01 level) using Duncan's new multiple range test.

2/ Into 4.6 inch d.b.h. class.

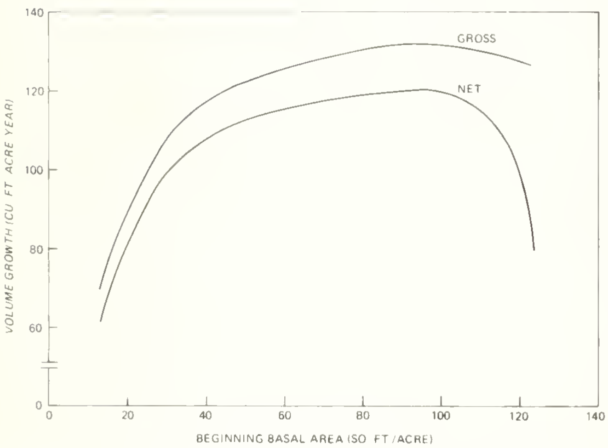

Figure 3.--Relation of periodic annual gross and net cubic-feet volume growth to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

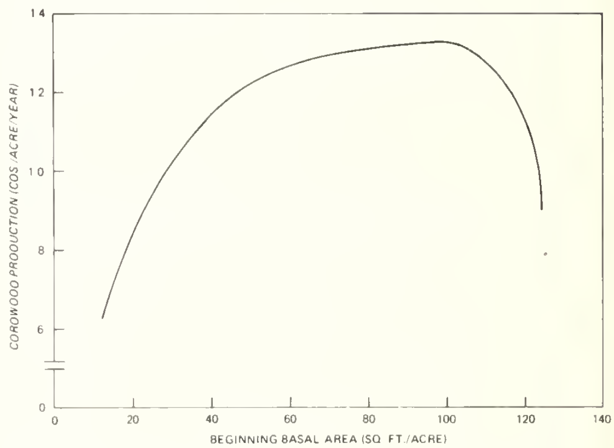

Figure 4.--Relation of annual net cordwood production in pulpwood and saw-log-sized trees to beginning basal area per acre (all trees 4.6 inches d.b.h. and larger, site index 65 at age 50 for sugar maple).

of basal area (fig. 4). When beginning stocking levels were below 50 square feet or above 110 square feet, net cordwood production dropped off sharply.

Cordwood growth in pole-sized trees in a given stand is strongly related to the beginning basal area stocking in saw-log (9.6 inches d.b.h. and larger) trees. For example, cordwood growth in pole-sized trees ranged from about 1 cord per acre annually with no saw-log-sized trees present to almost no cordwood growth with 75 square feet or more of saw-log-tree stocking.

Board-Foot Volume Growth[4]

Average annual gross and net Scribner board-foot volume growth, survivor growth, ingrowth, and mortality of saw-log-sized trees are shown for each cutting treatment in table 4. In fifteen years, gross and net board-foot growth were significantly higher on the more lightly cut treatments than on either the 60 square-foot selection cut or the diameter limit cut. Average annual board-foot

4/ Cull volume has not been deducted.

Table 4.--Average annual gross and net Scribner board-foot volume growth, survivor growth, ingrowth, and mortality on saw log-size trees (9.6 inches d.b.h.+) by cutting method (In board feet per acre per year)

Cutting method	Survivor growth	Ingrowth[1]	Gross growth	Mortality	Net growth
Control	[2] 279a	73a	352a	18a	334a
90 sq. ft.	288a	72a	360a	13a	347a
75 sq. ft.	275a	74a	349a	11a	338a
60 sq. ft.	183b	73a	256b	7a	249b
Crop tree	219ab	93a	312a	24a	288ab
Diameter limit	21c	54a	75c	4a	71c
$S_{\bar{x}}$	30	12	24	10	25

1/ Into 9.6 inch d.b.h. class.

2/ Values followed by the same letter in a column are not significantly different (0.01 level) using Duncan's new multiple range test.

survivor growth was best on the 90 square-foot per acre selection cut, but differences in survivor growth rates between the 90 square-foot selection cut, the 75 square-foot selection cut, the crop-tree release cut, and the control treatment were not statistically significant. Ingrowth into the saw-log size class (9.6 inches d.b.h. and larger) was similar for all cutting methods, averaging 73 board feet per year.

Yields

Calculated yields by treatment in the two harvest cuttings are given in table 5. Yields for various products are given to aid managers with different product objectives. Products actually harvested included saw logs, pulpwood from poles, and a limited amount of pulpwood from the tops of saw-log trees. In terms of cubic-foot volumes cut per acre, the diameter limit cut had the heaviest cut in 1951 with 1,600 cubic feet harvested per acre. The crop-tree treatment had the next highest cut with 694 cubic feet per acre, followed closely by heavy, medium, and light selection cuts. The selection cuts in 1961 yielded another 705 to 824 cubic feet per acre.

Board-foot yield in 1951 was greatest in the heavy diameter limit cut--3,617 board feet per acre. Yields from the other treatments ranged from about 800 to 1,600 board feet per acre. About 1,500 board feet per acre were

Table 5.--Total volume cut per acre by cutting treatment and product in 1951 and 1961

Cutting treatment	Cubic-foot[1] 1951	Cubic-foot[1] 1961	Scribner board-foot[2] 1951	Scribner board-foot[2] 1961	Cull[3]	Cordwood volume[4]: Poles 1951	Poles 1961	Tops of saw logs 1951	Tops of saw logs 1961	Poles and saw logs 1951 and 1961
	Per acre	Per acre	Per acre	Per acre	Percent	Per acre	Per acre	Per acre	Per acre	Per acre
Check	0	0	0	0	--	0.00	0.00	0.00	0.00	0.00
90 sq. ft.	430	705	835	1486	19.4	1.44	2.06	.35	.76	11.99
75 sq. ft.	542	824	1264	1800	9.9	1.17	2.19	.50	.82	14.59
60 sq. ft.	647	789	1626	1491	10.1	1.12	2.98	.57	.78	15.26
Crop tree[5]	694	14	1455	24	15.8	2.19	.15	.44	.04	7.56
Diameter limit[5]	1600	0	3617	0	9.2	4.21	.00	1.05	.00	17.25

1/ Includes the peeled volume of stump, stem, tip, and branches to a 4.0 inch d.i.b. top of all trees 4.6 inches d.b.h. and larger.

2/ Includes all trees 9.6 inches d.b.h. and larger to a variable top but not less than 8.0 inches d.i.b. Board-foot volumes listed are net volumes without deductions for cull.

3/ Average 1951 woods and millrun cull percent of saw-log volume.

4/ Peeled 8.3 foot lengths to a 4-inch d.i.b. top for poles (4.6 to 10.5 inches d.b.h.) and saw logs (9.6 inches and larger) and stem and limbs above the last log to a 4-inch d.i.b. top for tops and saw logs. Saw logs were not actually harvested as cordwood but are presented as such for total cordwood values.

5/ Material was essentially all cut in 1951.

rvested from each of the three selection eatments in 1961. Cull percent in 1951 was nerally low, averaging 11.5 percent of the oss volume cut.

Cull percents in the selection treatments d the crop-tree treatment were higher than the diameter limit treatment. This is cause all saw-log-sized trees of quality re cut in the diameter limit treatment, ile poor-quality trees were favored for itting in the other treatments.

Saw logs produced in the 1951 cut averaged 4 percent Grade 1; 21.4 percent Grade 2; and .2 percent Grade 3. Future cull percentages ould be lower and percentages of better grade gs are expected to be higher from the improve-nt cuts in the selection and crop-tree treat-nts. The smaller size and poorer quality of e growing stock in the diameter limit cut make less attractive for future log and veneer oduction, but more attractive for pulpwood oduction.

Stumpage returns from the first cut ranged om $55 per acre for the diameter limit treatment a low of $13 for the light selection cut (table . In the other treatments, stumpage returns r acre averaged $15 for medium selection, $17 r heavy selection, and $15 for the crop-tree eatment. The second cut in the winter of 61-1962 was limited to the three selection eatments. Stumpage returns from this cut were ill low, averaging $21 per acre. Future returns ould be higher with grade improvement from lection cutting and because sugar maple stumpage lues have increased from $14 to $15 per thousand 1951 to $32 to $40 per thousand in 1972.

Residual Volumes

Early dollar returns have been low from our lection treatments in second-growth stands cause we have been concentrating on building the residual volumes and basal area stocking of sirable trees in the larger diameter classes. addition, we have not been cutting growth.

In old-growth northern hardwoods on a similar te Eyre and Zillgitt (1953) reported a maximum t growth rate of 295 board feet[5/] per acre per ar over a 15-year period, with a residual lume of 6,300 board feet per acre. Their net owth with cull deducted increased with three ccessive 5-year periods to 281 board feet per re per year. In our selectively cut second-owth stands, net growth averaged 311 board et[4/] per acre annually over a 15-year period, th beginning residual volumes of 1,650 to 100 board feet per acre. During the last year period our maximum annual net growth

5/ Gross growth minus mortality without duction for cull.

Table 6.--Stumpage returns in dollars per acre by cutting treatments in 1951 and 1961

Cutting treatment	Stumpage return: 1951[1/]	1961[2/]	Total
Check	0	0	0
Light selection	12.85	22.96	35.81
Medium selection	15.05	29.42	44.47
Heavy selection	17.14	15.35	32.49
Crop tree	14.64	0.12	14.76
Diameter limit	55.40	0	55.40

1/ Actual stumpage returns from scaled and graded material on plots in 1951.

2/ Estimated from volume cut on plots using 1951 cull percentages and stumpage values by species in 1961. No estimate of cull percent or grade recovery was made in 1961.

averaged 356 board feet[4/] per acre on the light selection treatment. Ingrowth only accounted for 55 board feet of this net growth figure.

In 1961, the beginning of this maximum growth period, the light selection treatment had the highest basal area stocking in saw-log-sized trees (57 square feet per acre) and the largest residual volume (4,955 board feet per acre) of the three selection treatments. Thus, we feel that an annual net growth rate of 300 board feet per acre can be maintained by selection cutting to basal area densities of 60 to 90 square feet per acre, once a suitable size-class distribution is obtained on sites that average 65 feet at age 50 years for sugar maple.

The 1966 residual volumes in the selection cuttings ranged between 3,900 and 6,800 board feet per acre (table 7), indicating continued high board-foot production. The 1972 estimated value of these stands is also shown in the table. So far, we have not been cutting growth. After the next (third) cut we expect to be able to harvest growth in the form of large-diameter, high-value trees on a sustained yield basis. Residual stand volume on the crop tree treatment reached 5,800 board feet per acre in 1966. This volume was concentrated in better quality trees, which indicates potentially high board-foot production and high-quality yields in the future. The 1966 residual volume for stands in the diameter limit treatment averaged only about 1,100 board feet per acre. Current annual production is low and there will be a long time interval before quality saw-log material can be harvested.

Stand Structure

During the 15-year study, stand structure has changed considerably due to ingrowth, natural mortality, and recutting in the selection stands.

Table 7.--Residual volumes per acre 15 years after the initial cut in terms of various products and 1972 saw-log values[1]

Cutting treatment	Cubic-foot volume[2]	Scribner board-foot volume[3]	1972 saw log values[4]	Poles	Tops of saw logs	Poles and saw logs
			Dollars per acre	Cords	Cords	Cords
Check	3,920	8,318	266	11.73	3.69	41.75
90 sq. ft.	3,120	6,835	219	8.74	3.28	33.34
75 sq. ft.	2,707	5,936	190	6.88	3.16	28.91
60 sq. ft.	2,301	3,901	125	9.02	2.61	24.15
Crop tree	3,192	5,788	185	11.48	3.87	33.69
Diameter limit	1,972	1,083	35	14.07	1.98	19.96

1/ No deduction was made for cull.

2/ Peeled, stump, stem, and tip.

3/ To a variable top but not less than 8.0-inch d.i.b.

4/ Using $32 per M for woodsrun hardwood saw logs with no deduction for cull, managed stands should be worth considerably more.

5/ Peeled 8.3-foot lengths to a 4-inch d.i.b. top for poles (4.6 to 9.5 inches d.b.h.) and saw logs (9.6 inches d.b.h. and larger) and the stem and limbs above the last log to a 4-inch d.i.b. top for tops of saw logs.

The number and basal area of stems in the sawtimber-size class increased, while the number and basal area of stems in the pole-size class decreased (tables 8, 9). Increases in number of trees and basal area of stems in the largest d.b.h. class were most rapid following heavy selection cutting and crop-tree release, because diameter growth was faster at lower densities. The structure and stocking in sapling-size trees (2-4 inch d.b.h. class) in 1961 was also better in the heavy selection treatment than in the light and medium selection treatments. Although we still have too many pole-size trees (5 to 9 inches) and too few large saw-log trees (20 to 24 inches d.b.h.), the stand structure has greatly improved on all selection treatments and is approaching a distribution that should result in sustained yield. The size-class distribution recommended by Eyre and Zillgitt (1953) can be obtained with the third cut, except in the 20-24 inch class. The frequency distribution of trees by diameter classes in the crop-tree treatment in 1966 was similar to the distribution recommended for selection stands. Of course, the 1951 diameter-limit cut left an essentially even-aged residual stand.

Board-Foot Growth and Stocking

Beginning stand basal area in either saw-log- or pole-sized trees is a good indicator of future annual net board-foot growth. This is true for both all-aged and even-aged management. A model was developed from 54 combinations of beginning basal area stocking and corresponding board-foot yields from our cutting study (fig. 5). The main stands of trees used in constructing the model were young and rapidly increasing in merchantable height.[6] Therefore, we do not expect the high growth rates shown in the model to be sustained continuously. However, peaks on the model for different combinations of stocking are meaningful for maximum board-foot growth.

Yields averaging 300 board feet annually should be possible once a balanced structure is obtained under all-aged management. At this time there is no reason to believe that mean annual increment would be any higher or lower under even-aged management.

At extremely high densities (above 130 square feet of saw logs and poles), net board-foot growth rates fall off sharply because of mortality. We had only four combinations of gross saw-log- and pole-sized basal area densities that exceeded 120 square feet per acre, with the highest combined density being 133 square feet. More data at high densities are required to better define the levels where mortality is important in reducing yields.

6/ Individual small saw-log trees increased as much as 16 feet in merchantable height (to a variable top diameter but not less than 8 inches d.i.b.) in 15 years, but height improvement averaged only about 4 feet for a given saw-log d.b.h. class. Merchantable heights in the larger saw-log size classes were probably "set" by large limbs that were present before cutting in 1951. Any improvement that has occurred in the larger size classes was due to cutting, gradually eliminating residual trees with short merchantable boles.

Table 8.--Average number of trees per acre after cutting in 1951, before and after cutting in 1961 and 1966, and 15-year net changes by d.b.h. class and cutting treatment

Cutting treatment	D.b.h. class					
	2 to 4[1/]	5 to 9	10 to 14	15 to 19	20 to 24	Total 10+
Recommended structure for selection cutting[2/]	202	65	28	17	8	53
Beginning structure all treatments combined	--	184	44	9	<1	54
90 square feet basal area						
1951	155	169	46	7	0	53
1961	135	140	65	17	1	83
1961 cut	--	-23	-14	-4	0	-18
1966	--	115	55	18	1	74
15-year change[3/]	--	-54	9	11	1	21
75 square feet basal area						
1951	111	144	42	5	0	47
1961	95	123	63	15	0	78
1961 cut	--	-26	-16	-5	0	-21
1966	--	87	56	15	0	71
15-year change[3/]	--	-57	14	10	0	24
60 square feet basal area						
1951	203	163	25	3	0	28
1961	172	173	43	10	1	54
1961 cut	--	-38	-14	-5	0	-19
1966	--	126	43	7	2	52
15-year change[3/]	--	-37	18	4	2	24
Crop tree						
1951	225	159	25	3	0	28
1961	225	161	55	7	1	63
1966	--	150	67	9	1	77
15-year change	--	-9	42	6	1	49
Diameter limit						
1951	255	112	0	0	0	0
1961	221	192	9	0	0	9
1966	--	196	29	0	0	29
15-year change[3/]	--	84	29	0	0	29
Check						
1951	183	203	41	9	0	50
1961	165	173	63	16	2	81
1966	--	151	67	20	4	91
15-year change[3/]	--	-52	26	11	4	41

1/ Sapling counts were made in 1957 (1951 column) and 1961.
2/ Eyre and Zillgitt (1953).
3/ Includes 1961 cut.

CONCLUSIONS AND RECOMMENDATIONS

Individual tree diameter growth rates were t at lower densities. However, sites were not ly occupied until stand density reached about square feet of basal area per acre. Further- e, live limbs were much more abundant following ting to the lowest density (21 square feet of al area per acre), especially in the second (Godman and Books 1971).

Periodic basal area growth and cubic-foot ume growth were similar over a wide range of nd densities. Net annual cubic-foot production relatively constant in stands containing ween 50 and 115 square feet of basal area per e. Annual gross and net basal area growth ked at 45 square feet of residual basal area acre, but annual basal area survivor growth was relatively constant between 45 and 100 square feet of basal area per acre.

The best management practices for second-growth hardwood stands depend primarily upon the owner's objectives and then upon stand conditions and species composition on the land in question. Owners interested only in producing pulpwood or other bulk products can manage their stands over a wide range of residual stand densities without losing cubic-foot or cordwood volume growth. Owners interested in producing continuous yields of white ash, basswood, yellow birch or more intolerant species should manage under some even-aged system. If advanced sugar maple reproduction is present at stand regeneration time, sugar maple understory control would be required to obtain a high proportion of valuable intolerant species (Tubbs and Metzger 1969).

Table 9.--Basal area stocking per acre after cutting in 1951, before and after cutting in 1961 and 1966, and 15-year net changes by d.b.h. class and cutting treatment

Cutting treatment	D.b.h. class					
	2 to 4[1]	5 to 9	10 to 14	15 to 19	20 to 24	Total 10+
Recommended structure for selection cutting[2]	8	16	22	26	20	68
Beginning structure all treatments combined	--	45	33	13	<1	47
90 square feet basal area						
1951	8	44	34	9	0	43
1961	7	39	48	24	2	74
1961 cut	--	-8	-10	-6	0	-16
1966	--	32	42	26	3	71
15-year change[3]	--	-12	8	17	3	28
75 square feet basal area						
1951	6	38	31	7	0	38
1961	5	35	47	22	0	69
1961 cut	--	-8	-13	-8	0	-21
1966	--	25	41	22	0	63
15-year change[3]	--	-13	10	15	0	25
60 square feet basal area						
1951	10	36	18	5	0	23
1961	9	45	31	14	2	47
1961 cut	--	-11	-11	-6	0	-17
1966	--	33	30	10	4	44
15-year change[3]	--	-3	12	5	4	21
Crop tree						
1951	12	38	18	4	0	22
1961	10	43	39	10	2	51
1966	--	42	48	14	3	65
15-year change	--	4	30	10	3	43
Diameter limit						
1951	13	21	0	0	0	0
1961	10	47	6	0	0	6
1966	--	52	18	0	0	18
15-year change[3]	--	31	18	0	0	18
Check						
1951	9	50	30	14	0	44
1961	8	47	46	24	5	75
1966	--	42	48	29	10	87
15-year change[3]	--	-8	18	15	10	43

1/ Sapling counts were made in 1957 (1951 column) and 1961.
2/ Eyre and Zillgitt (1953).
3/ Includes 1961 cut.

Early release treatments might also be required to maintain favorable growth of moderately tolerant and intolerant species.

The selection system is well suited to owners whose objectives are to produce high-quality sugar maple saw logs and sustain the "big tree look." Earlier workers in the Lake States and the Northeast recommended leaving a residual stand containing between 70 and 85 square feet per acre (in trees 5 inches d.b.h. and over) for best growth and quality development (Eyre and Zillgitt 1953, Arbogast 1957, Jacobs 1969, Leak et al. 1969). Our data generally parallel these findings, but we feel that the first cut in overstocked pole-sized stands can be heavier than previously recommended in the Lake States. Based on a 3-square-foot annual net growth rate, a stand thinned to 50 square feet of saw logs and poles would reach Eyre and Zillgitt's (1953) recommended 85-square-foot level in about 12 years. Cutting down to a minimum residual stocking level of 65 square feet per acre (in trees 4.6 inches d.b.h. and over) as suggested by Trimble (1970) would probably be safer from the standpoint of logging damage and unexpected mortality. In these same stands Godman and Books (1971) also found that tree quality improved with increasing residual basal area densities.

Our data from 45- to 60-year-old stands show that at least 50 square feet of saw-log trees with not more than 60 square feet of pole trees are required to produce 300 board feet (net Scribner) per acre annually. Diameter growth rate on saw-log-sized trees averaged 2 inches or more per decade at stand densities below 75 square feet of basal area per acre. Diameter growth is stimulate at lower densities (Eyre and Zillgitt 1953, Arbogast 1957) and the recommended balanced

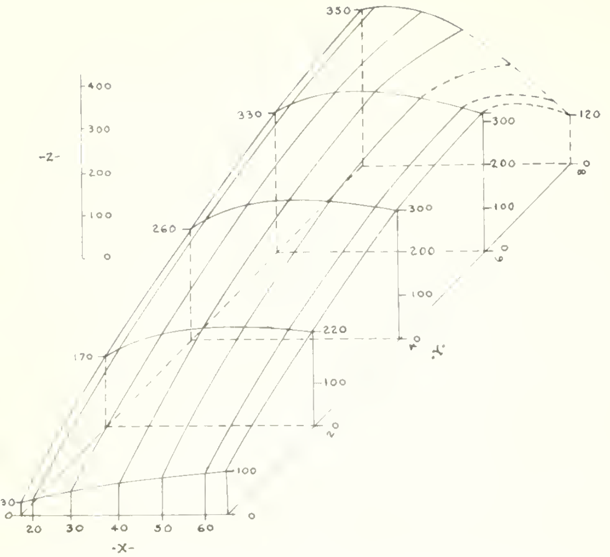

Figure 5.--Relation of periodic annual Scribner net board-foot growth (Z) to beginning basal area of all trees 4.6 to 9.5 inches d.b.h. (X) and beginning basal area of all trees 9.6 inches d.b.h. and larger (Y).

size-class distribution is attained faster. If the first cut creates stands meeting the minimum structure or diameter distribution requirements, sufficient numbers of trees will be available for cutting at 10-year intervals (table 10).

Second-growth northern hardwood stands on good sites (65 feet at 50 years) in the Lake States at this stage of development can be expected to produce sustained growth of 3,000 board feet every 10 years.

However, all annual growth should not be cut until the recommended size-class distribution is attained. Many variations in stocking, structure, composition, and quality occur in unmanaged second-growth hardwood stands depending upon past stand history and site conditions. In many cases, stands are overstocked with pole trees and understocked with saw-log trees. The tendency in marking for the first cut is to "sweeten" the cut by marking too heavily in the larger saw-log classes and to leave large numbers of pole-sized trees. The first cut in an overstocked pole stand should be primarily from below. Only those large-diameter cull and defective trees that will not live to the next cut should be removed to attain the required density (not lower than 65 square feet of basal area per acre on a 10-year cutting cycle). By concentrating the thinning in the pole-sized class the forester improves growing conditions (spacing) around better trees, improves individual growth rates by freeing more trees from competition, and attains the desired structure quicker.

The first cut in second-growth northern hardwood stands thus should be a general improvement cut that removes cull, high-risk, and poor

Table 10.--Minimum stand structure

D.b.h. class (inches)	Minimum: Trees per acre		Minimum: Basal area per acre	
	(Number)		(Sq. ft.)	
2-4	202		8	
5-9	43		12	
10-14	19		17	
15-19	13	36	20	53
20+	4		16	
Total	281		73	

quality growing stock throughout all diameter classes. Whether the manager is thinking in terms of uneven-aged or even-aged management at this time is unimportant as long as the average diameter of the main stand of dominants and codominants is below saw-log size. In the early stages of managing second-growth stands we can remain flexible; intermediate silvicultural treatments can be varied to meet the owner's future objectives.

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☆UNITED STATES GOVERNMENT PRINTING OFFICE: 1973 — 762-332

NORTH CENTRAL FOREST EXPERIMENT STATION

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USDA Forest Service
Research Paper NC-101
1974

IMPROVING ESTIMATES OF WILDERNESS USE FROM MANDATORY TRAVEL PERMITS

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University of Minnesota)

Manuscript approved for publication September 11, 1973

IMPROVING ESTIMATES OF WILDERNESS USE FROM MANDATORY TRAVEL PERMITS

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The recreational use of Forest Service Wilderness and Primitive Areas and other roadless and dispersed recreation areas is rapidly growing. The problems caused by this growth are well known to public land managers and visitors to these areas. In parts of some roadless areas, visitors are encountering each other too often and enjoying their experiences less. Campsites are harder to find, and many are showing evidence of overuse. Consequently, managers and visitors increasingly support the establishment of controls over use.

Information on the recreational use of wildland areas is important for management of these areas. Data are required on both the amount and nature of use. Estimates of wilderness use are among the least valid and reliable of all forest recreation use figures (Lucas, Schreuder, and James 1971). Self-registration data have helped managers make better estimates, but the fact that many visitors do not register has led to recommendations for mandatory permits in all wildernesses to provide better data on use (Hendee and Lucas 1973).

By the end of 1973, permits were mandatory on 43 of the 89 Forest Service Wilderness and Primitive Areas. They were first required in the Boundary Waters Canoe Area (BWCA) in 1966. They are also required in some National Parks; the first was Rocky Mountain in 1968.

Even where permits are mandatory, some groups still fail to obtain them and thus the Wilderness Area gets more use than the permit data show. We found that a study of these groups can help managers improve estimates of use and increase compliance in permit areas.

The objectives of our study were: (1) to determine the number of visitors who did not have permits, (2) to find out how groups that did not obtain permits differed from those that did, (3) to determine a method to improve estimates of wilderness use by adjusting permit data, and (4) to make recommendations for obtaining better permit compliance.

We collected data on permit compliance in the BWCA during a larger 1971 study of carrying capacity.[1/] Personal interviews were held with 1,352 groups of BWCA visitors between May 14 and September 6, 1971. Groups were interviewed at access points outside the BWCA before they began their trip and then given a "BWCA Trip Diary" to keep a daily log of their experience.

PERMIT COMPLIANCE

Overall, 88 percent of the groups had a permit at the time they were interviewed (table 1). This is higher than in earlier studies of visitor compliance with wilderness self-registration systems in which between 67 and 75 percent of the parties registered (Wenger 1964; Wenger and Gregersen 1964; Lucas, Schreuder, and James 1971). Groups without a permit were issued one by the interviewer.

Four reasons may account for this high degree of compliance in comparison with self-registration systems. First, the permit is mandatory whereas self-registration is optional. Citations are issued by the Forest Service for failure to have the mandatory permit, and fines have reached twenty-five dollars. A crackdown on groups not having a permit has been instituted since 1970. Prosecutions have been publicized by the mass media. The "word is out" to make sure you have a permit.

Second, permits have been required since 1966. Enough time has passed so nearly all local merchants and most visitors know about the permit and the consequences of not having one.

Third, the Forest Service has nine offices and a visitor information center to facilitate groups in obtaining a permit. Over the past three

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1/ Study objectives, sampling procedures, and other study details are on file at the North Central Forest Experiment Station, St. Paul, Minn.

Table 1.--Percentage of BWCA groups in compliance with mandatory travel permit regulation, 1971, according to selected group characteristics

Group characteristics	Groups in sample	Groups with travel permit
	Number	Percent
Composition**		
Family	712	86
Organizational	140	98
Friends, acquaintances	352	89
Size*		
1 to 2 people	451	87
3 to 4	451	86
5 or more	419	91
Primary mode of travel**		
Paddle canoe	763	92
Motor canoe	195	95
Motorboat	370	76
Length of stay[1/]**		
Daytime only[2/]	295	73
1 to 2 nights	318	92
3 to 6 nights	520	93
7 or more nights	198	92
Daytime visitors' overnight accommodations**		
Home or home of acquaintance	103	89
Resort	40	78
Public or private auto-access campground	113	58
Use of an outfitter[3/]*		
Groups outfitted	480	92
Groups not outfitted	845	86
Primary purpose of visit*		
Fishing	338	84
Other	940	90
Age of leader**		
Under 20 years	112	94
20 to 34 years	618	91
35 to 54 years	469	85
55 or more	87	79
Occupation of leader**		
Professional, technical	559	89
Managers, proprietors	82	85
Clerical, sales workers	91	82
Craftsmen, foremen	178	81
Other labor, service workers	107	84
Student	237	95
Returning BWCA Trip Diary		
Groups that returned Diary	1,093	88
Groups that did not return Diary	238	87
Total	1,352	88

1/ Includes total nights in the BWCA and Canada.

2/ No nights in BWCA, but visit could be for several days.

3/ Outfitted means they rented at least a canoe, boat or motor from an outfitter, resorter or other merchant.

* Chi-square test indicates the difference between groups with a travel permit and those without a permit (not shown) is significant beyond the 0.05 level.

** Differences significant beyond the 0.001 level.

or four years signs telling about the permits have been posted on most major travel arteries. Small signs are posted at each of the seventy access points as well.

Fourth, about a hundred local merchants cooperate with the Forest Service by issuing permits. Most businessmen make sure their clientele know about the permits.

Group Characteristics Related to Permit Compliance

The 12 percent of groups without a permit were different in certain characteristics from groups with a permit. In what characteristics did these two groups differ?

Characteristics Considered Singly

Composition of group.--Youth groups visiting the BWCA under the leadership of an organization had a high compliance rate (table 1). Family parties had the lowest compliance, whereas groups of friends and acquaintances were about equal to the average overall compliance of 88 percent.

Size of group.--Small- and medium-sized parties (1-2 and 3-4 individuals, respectively) had a slightly lower compliance rate than larger groups (table 1). The slightly above-average compliance by larger parties is partly because they are usually organizational groups with an exceptionally high rate of registration (Lime 1972).

Primary mode of travel.--Parties traveling by motorboat were much less likely to have a permit than either paddle canoe or motor canoe parties (table 1).

Length of stay.--Daytime visitors had a permit less often than overnight camping groups (table 1). This was also often noted in studies of self-registration in the West (Wenger 1964; Wenger and Gregersen 1964; Lucas, Schreuder, and James 1971). For visitors who stayed overnight in the BWCA, the number of nights camped made virtually no difference in rate of compliance. Daytime visitors spending their nights in public or private auto-campgrounds (94 percent were in Forest Service camping areas) were less likely to have a permit than were groups staying in either resort-motel accommodations or in their own home or home of a friend (table 1). Presumably, daytime visitors were unaware of BWCA regulations, or if they were aware, felt the probability of being caught was too low to worry about it.

Use of an outfitter or rented equipment.--More groups who rented at least some watercraft equipment had a permit than did groups who did not (table 1). Most local businessmen apparently made sure their clientele knew about the permit.

Purpose of trip.--Groups were asked to select important motives for visiting the BWCA, rather than some other area, from a list of 14 reasons. Parties stating fishing as the most important purpose were less likely to have a permit than were those with other reasons (table 1). This was also a significant characteristic related to self-registration in the western wilderness studies (Wenger 1964; Wenger and Gregersen 1964; Lucas, Schreuder, and James 1971).

Age and occupation of group leader.--Groups in which the party leader was under age 35 more often had a permit than did those with older leaders (table 1). Parties with a teenage group leader had the highest compliance rate. (This is opposite of the findings of the self-registration research.) Groups having a student leader typically had a permit (table 1). Aside from group leaders whose occupation was classified student or professional-technical, all other categories had below-average compliance rates.

Returning the BWCA trip diary.--Just over 80 percent of the diaries distributed were returned. The same return rate was obtained both from groups with a permit and those without (table 1). This suggests groups without permits were not necessarily willfully violating Forest Service rules and regulations. Rather, many--if not most--were simply unaware or unsure of the requirement to have a permit. Interviewers were convinced that the majority of the groups without a permit were not willfully violating the rule. In fact most groups, after we told them they needed a permit, were rather apologetic and very appreciative of being issued one. This appreciation could have assisted us in getting at least some of the diaries back that we otherwise would not have received, but the effect probably was not very great.

Access point.--Groups were studied to learn if those entering certain access points had a lower permit compliance rate than others. Data were collected from 23 of the BWCA's 70 access points and compliance ranged from 70 to 98 percent among places. Access points were classified as to whether they were remote or not remote (based on their distances from main roads, towns, resorts, outfitters). The remote places had a slightly lower compliance (83 percent) compared to the others (89 percent). Access points were also stratified on the basis of the number of groups entering in 1971--heavy, medium, and light use. Virtually no difference was detected among categories.

At only two access points were there significant differences between the "spring fishing season" (ending in mid-June) and remainder of the summer. All locations were combined for each season and then compared. There was no important difference between seasons (87 percent spring and 89 percent summer).

Other visitor characteristics.--Four other characteristics showed no significant differences (at the 0.05 level): (1) travel to Canada during the visit, (2) month of the visit, (3) place of residence of the group leader (local, regional, national), and (4) number of previous visits to the BWCA by the party leader.

Characteristics Considered in Combination

Several of the group characteristics that influenced rate of compliance appeared interrelated. User classes representing the six major visitor characteristics (significant at the 0.001 level, table 1) were cross classified with one another to learn more clearly which factors or combination of factors most influenced compliance.

The cross classification comparisons were made in contingency tables and showed the percentage of visitor groups with permits for each user class. In cases where rates of compliance for individual classes were statistically similar (not implying behavioral similarity), classes were combined. For instance, since both paddle and motor canoe groups had similar compliance rates (92 and 95 percent, respectively), they were combined and compared with motorboat use.

Inspection of the cross classifications indicated that certain characteristics when considered together had more influence on rates of compliance than others. For example, percent of the groups without a travel permit classified by primary mode of travel, and age of group leader, were compared (table 2). Large statistical differences existed between travel modes but not between age classes for each mode of travel. We concluded that mode of travel was more closely related to noncompliance than was age of the party leader.

Organizational groups, which had an exceptionally high rate of compliance (98 percent) were studied in relation to other group characteristics. These groups were typically large (eight or more members) with young leaders, principally students (Lime 1972). These facts may account for the higher rates of compliance of larger groups, young group leaders, and students (table 1).

Some cross classifications showed that characteristics in combination had an important relation to compliance (table 3). Here, differences were large between travel modes, both for overnight and day visitors. Further analysis of day visitors by mode of travel indicated substantial differences in rates of compliance among groups staying overnight at their home (or home of an acquaintance) and those staying at a campground or resort.

Inspection of cross classifications yielded seven distinct user groups based on one or more of four user characteristics. The four user characteristics were: (1) compositon of the group (organizational and nonorganizational), (2) length of stay (overnight and daytime use), (3) primary mode of travel (canoe and motor-

Table 2.--Number and percentage of BWCA groups with mandatory travel permit by mode of travel and age of group leader, 1971

Age of group leader (years)	Mode of travel								
	Canoeists (paddle and motor)			Motorboaters			All combined		
	Total groups in sample	Groups with permit		Total groups in sample	Groups with permit		Total groups in sample	Groups with permit	
	Number	Number	Percent ±2SE	Number	Number	Percent ±2SE	Number	Number	Percent ±2SE
34 and under	592	551	93 ± 2	109	90	83 ± 7	701	641	91 ± 2
35 and older	334	306	92 ± 3	248	183	74 ± 6	582	489	84 ± 3
Total	926	857	93 ± 2	357	273	76 ± 4	1,283	1,130	88 ± 2

Table 3.--Number and percentage of BWCA groups with mandatory travel permit by mode of travel and length of stay, 1971

Length of stay	Mode of travel								
	Canoeists (paddle and motor)			Motorboaters			All combined		
	Total groups in sample	Groups with permit		Total groups in sample	Groups with permit		Total groups in sample	Groups with permit	
	Number	Number	Percent ±2SE	Number	Number	Percent ±2SE	Number	Number	Percent ±2SE
Overnight	857	810	95 ± 2	179	147	82 ± 6	1,036	957	92 ± 2
Daytime 1/	101	78	77 ± 8	191	135	71 ± 7	292	213	73 ± 5
Total	958	888	93 ± 2	370	282	76 ± 4	1,328	1,170	88 ± 2

1/ No nights spent in BWCA, but visit could be for several days.

boat), and (4) daytime visitors' overnight accommodations (home and campground or resort). The seven user groups were:

1. Organizational groups.[2/]

2. Overnight canoeists (paddle and motor).

3. Overnight motorboaters.

4. Daytime canoeists staying at home.

5. Daytime canoeists staying at a campground or resort.

6. Daytime motorboaters staying at home.

7. Daytime motorboaters staying at a campground or resort.

Rates of permit compliance for each group were computed (table 4). The results clearly confirmed that certain groups of visitors were more likely to have a permit than were others. Groups classified as organizational, overnight canoeists, or daytime canoeists staying at home had relatively high rates of compliance (94 to 98 percent). Conversely, daytime canoeists and motorboaters staying at a campground or resort had much lower rates of compliance (60 to 68 percent).

Table 4.--Number and percentage of groups with mandatory travel permit in seven BWCA user groups, 1971

User group	Total groups in sample	Groups with travel permit	
	Number	Number	Percent ± 2SE
Organizational	140	137	98 ± 2[1/]
Overnight canoeists	711	668	94 ± 2
Overnight motorboaters	172	141	82 ± 6
Daytime canoeists staying at home	26	25	96 ± 8[1/]
Daytime canoeists staying at a campground or resort	73	50	68 ± 11
Daytime motorboaters staying at home	75	65	87 ± 8
Daytime motorboaters staying at a campground or resort	107	64	60 ± 9

1/ Confidence limits (95 percent) should be obtained from binomial tables (e.g., Mainland et al. 1956) otherwise two standard errors gives a good approximation.

A METHOD OF ESTIMATING WILDERNESS USE BY ADJUSTING FOR NONCOMPLIANCE

Wilderness use can be more accurately estimated by multiplying the number of groups obtaining permits by an appropriate expansion factor. Individual expansion factors (EF) are derived from the formula

$$EF = \frac{1}{1 - p}$$

where p is the percentage of visitor groups without permits in that use class. Estimates of actual total use for each use class (N) would then be determined from the formula

$$N = n \cdot EF$$

where n is the total number of visitor groups with permits in the use class computed for completed permits.

Individual expansion factors are more valuable for estimating various types of use in an area than for total use. If an estimate of total use is all that is desired by an administrator, he can obtain it by expanding the raw permit data by the percentage of all groups without a permit (in our study, a straight expansion of 12 percent). More likely, however, managers will be interested not only in total use but the *nature of use* as well. Individual expansion factors, then, should be used and individual use estimates summed for total use.[3/] A general expansion factor, such as 12 percent, should not be applied to individual types of use.

Expansion factors both for total use and for various user groups would probably change with time. Wilderness managers would want to keep abreast of shifts in the proportion of use by different user groups as well as changes in the rate of permit compliance.

Estimates of use for each of the seven BWCA user groups in table 4 would be determined by multiplying permit totals by the following expansion factors:

User group	Expansion factor EF ± 2SE
Organizational	1.02 ± .03
Overnight canoeists	1.06 ± .02
Overnight motorboaters	1.22 ± .09
Daytime canoeists staying at home	1.04 ± .08
Daytime canoeists staying at a campground or resort	1.46 ± .23
Daytime motorboaters staying at home	1.15 ± .10
Daytime motorboaters staying at a campground or resort	1.67 ± .03

For example, let us assume there were 650 groups registered as overnight motorboaters. Expanding by the appropriate factor (1.22) gives an estimated 793 actual groups. Two standard errors (±.09) means that actual use, based on a 95 percent confidence interval, would be no less

2/ Includes all organizational groups. The remaining six user groups are composed of nonorganizational groups (families, friends, or acquaintances).

3/ The standard error would be calculated separately for total use.

than 736 or more than 850 groups.[4/] Total use can be estimated by multiplying the appropriate expansion factor and the raw totals for each of the other user groups and then summing them.

Applying the Method to the Present BWCA Permit System

Some of the group characteristics related to compliance are not printed on the BWCA permit. Consequently, not all expansion factors derived from our subsample survey could be used to expand raw BWCA permit data. Four user groups can be identified from the permit, however (fig. 1). These are: primary mode of travel (canoe and motorboat), and length of stay (overnight and daytime use). The four combinations of user groups differed significantly in rates of compliance. Expansion factors were calculated for each group (table 5).

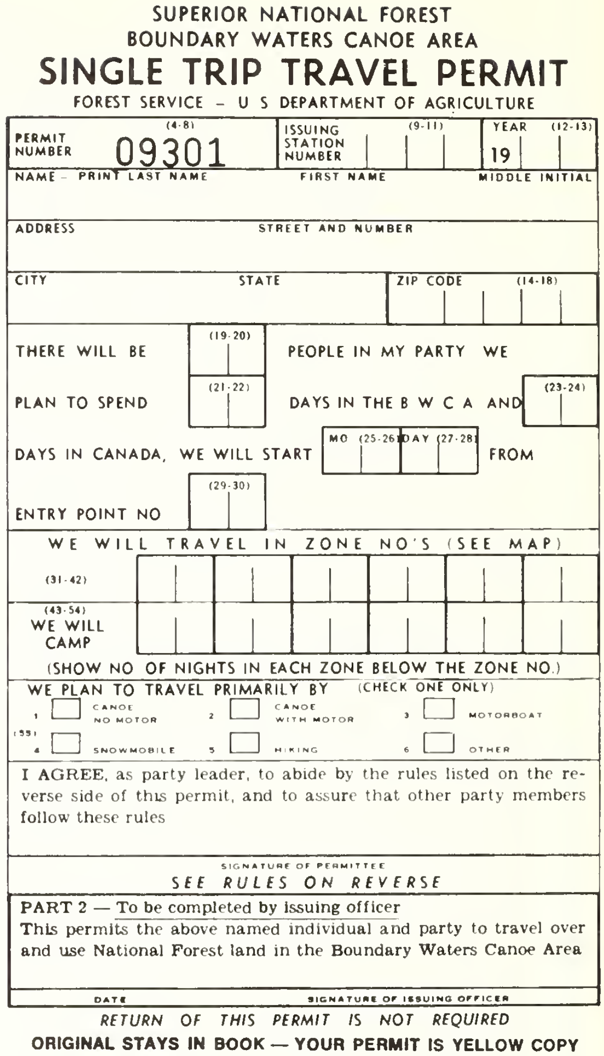
IMPROVING PERMIT COMPLIANCE AND ESTIMATES OF WILDERNESS USE

For the portion of the year we studied BWCA use, compliance with the permit system was indeed good. We feel reasonably sure the fundamental reason many groups did not have a permit was because they were unaware or uncertain of the regulation rather than being hostile to Forest Service rules.

Efforts to improve compliance should be directed to better informing visitors and both local and regional merchants about the permit requirement. It should also be explained *why* permits are necessary for better wilderness management. Visitors and merchants will more readily accept and support management requirements once they understand how permits benefit both the wilderness and themselves.

Daytime visitors staying in resorts and Forest Service campgrounds peripheral to the BWCA are particularly negligent. Although nearly all resort operators are aware of the permit requirement, some are apparently neglecting to inform their guests. As surveillance increases in association with the anticipated use of control measures, particularly in parts of the BWCA where surveillance is now light, the word will undoubtedly get out and compliance will improve. It would be desirable in the meantime, however, to increase the flow of information among concerned parties and avoid at least some of the ill feelings and misunderstanding associated with formal citations.

4/ *The confidence limits are based on a normal approximation and not suitable for small samples. A more refined method involves getting confidence limits for p from tables (Mainland* et al. *1956, page X, Tables V and VI), and then obtaining the corresponding limits for the expansion factor by* $CF = \frac{1}{1-p}$.


SUPERIOR NATIONAL FOREST
BOUNDARY WATERS CANOE AREA
SINGLE TRIP TRAVEL PERMIT
FOREST SERVICE – U S DEPARTMENT OF AGRICULTURE

PERMIT NUMBER (4-8) 09301 | ISSUING STATION NUMBER (9-11) | YEAR (12-13) 19
NAME – PRINT LAST NAME | FIRST NAME | MIDDLE INITIAL
ADDRESS | STREET AND NUMBER
CITY | STATE | ZIP CODE (14-18)
THERE WILL BE (19-20) PEOPLE IN MY PARTY WE
PLAN TO SPEND (21-22) DAYS IN THE B W C A AND (23-24)
DAYS IN CANADA, WE WILL START MO (25-26) DAY (27-28) FROM
ENTRY POINT NO (29-30)
WE WILL TRAVEL IN ZONE NO'S (SEE MAP)
(31-42)
(43-54) WE WILL CAMP
(SHOW NO OF NIGHTS IN EACH ZONE BELOW THE ZONE NO.)
WE PLAN TO TRAVEL PRIMARILY BY (CHECK ONE ONLY)
(55) 1 CANOE NO MOTOR 2 CANOE WITH MOTOR 3 MOTORBOAT
4 SNOWMOBILE 5 HIKING 6 OTHER
I AGREE, as party leader, to abide by the rules listed on the reverse side of this permit, and to assure that other party members follow these rules
SIGNATURE OF PERMITTEE
SEE RULES ON REVERSE
PART 2 — To be completed by issuing officer
This permits the above named individual and party to travel over and use National Forest land in the Boundary Waters Canoe Area
DATE | SIGNATURE OF ISSUING OFFICER
RETURN OF THIS PERMIT IS NOT REQUIRED
ORIGINAL STAYS IN BOOK — YOUR PERMIT IS YELLOW COPY

Figure 1.--Mandatory travel permits have been required in the BWCA since 1966. They are issued by the Forest Service and regional and local merchants.

Table 5.--Number and percentage of groups with mandatory travel permits and expansion factors for four BWCA user groups, 1971

User group	Total groups in sample	Groups with travel permit		Expansion factor
	Number	Number	Percent	EF ± 2SE
Overnight canoeists	865	818	95 ± 1	1.06 ± .02
Overnight motorboaters	138	106	82 ± 7	1.21 ± .08
Daytime canoeists	106	82	77 ± 8	1.30 ± .14
Daytime motorboaters	198	142	72 ± 6	1.39 ± .12

Almost all of the groups without permits who stayed in campgrounds were in Forest Service campgrounds. Although signs explaining travel permit requirements are posted in each camping area (usually at the boat launching site), the placement of the signs is not always the best nor are the messages always clear. Some groups, for example, probably do not read this information because they never visit the launch area during their stay, or because they keep their watercraft on shore adjacent to their campsite. Some are probably not sure where the BWCA boundary is when they are on the water. Detailed explanatory maps placed in a central location in the campground could help here. Additional signs placed on the main road leading into the campground and on bulletin boards throughout the camping area should also help.

Forest Service personnel working in peripheral campgrounds, at access points, and on arterial roads could be trained and instructed to increase personal contacts with the public in addition to their regular duties. Personal communication with the public can do much to strengthen support once the public clearly understands *why* certain "people management" actions are necessary.

Even if compliance were increased, some correction of permit data probably would still be required. Expansion factors based on the nature of use not represented in the raw data can be determined from studying a sample of visitors. To sustain accurate estimates of use, subsequent studies would be required when either the nature of use or rate of permit compliance was thought to have changed.

Some group characteristics used to derive expansion factors, such as belonging to an organizational group or overnight accommodations of daytime visitors, cannot be determined from the questions on the BWCA permit. They could, of course, be added to the permit if useful expansion factors could not be derived from the information already available. In other wilderness areas questions could be added if additional characteristics were thought to be important.

CONCLUSIONS

BWCA groups without travel permits are different from parties with permits in certain characteristics. The characteristics most related to compliance are mode of travel, length of stay, where daytime visitors spend their nights outside the BWCA, and whether or not the group is affiliated with an organization. Reasons for noncompliance are not totally clear, but most of the parties probably are either unaware of the need to have a permit or do not entirely understand BWCA use regulations. Efforts to make daytime visitors more aware of the mandatory permit might substantially increase rates of compliance--especially for those spending their nights in peripheral Forest Service camping areas and private resorts.

The method used in the BWCA to improve estimates of visitor use can be used by any wilderness managers. The percent of groups that did not obtain permits is first determined and appropriate expansion factors are applied to those that did get permits. These expansion factors change with time so that periodic studies of noncomplying groups are necessary.

Because permit compliance in the BWCA is so high and permits provide such a good tally of recreation use, we believe the standard Forest Service "Wilderness Permit" recently approved by the Office of Management and Budget (OMB) will be desirable and well accepted by the majority of the visiting public. The several thousand visitors contacted by field interviewers had virtually no complaints about the required travel permit or the information requested.

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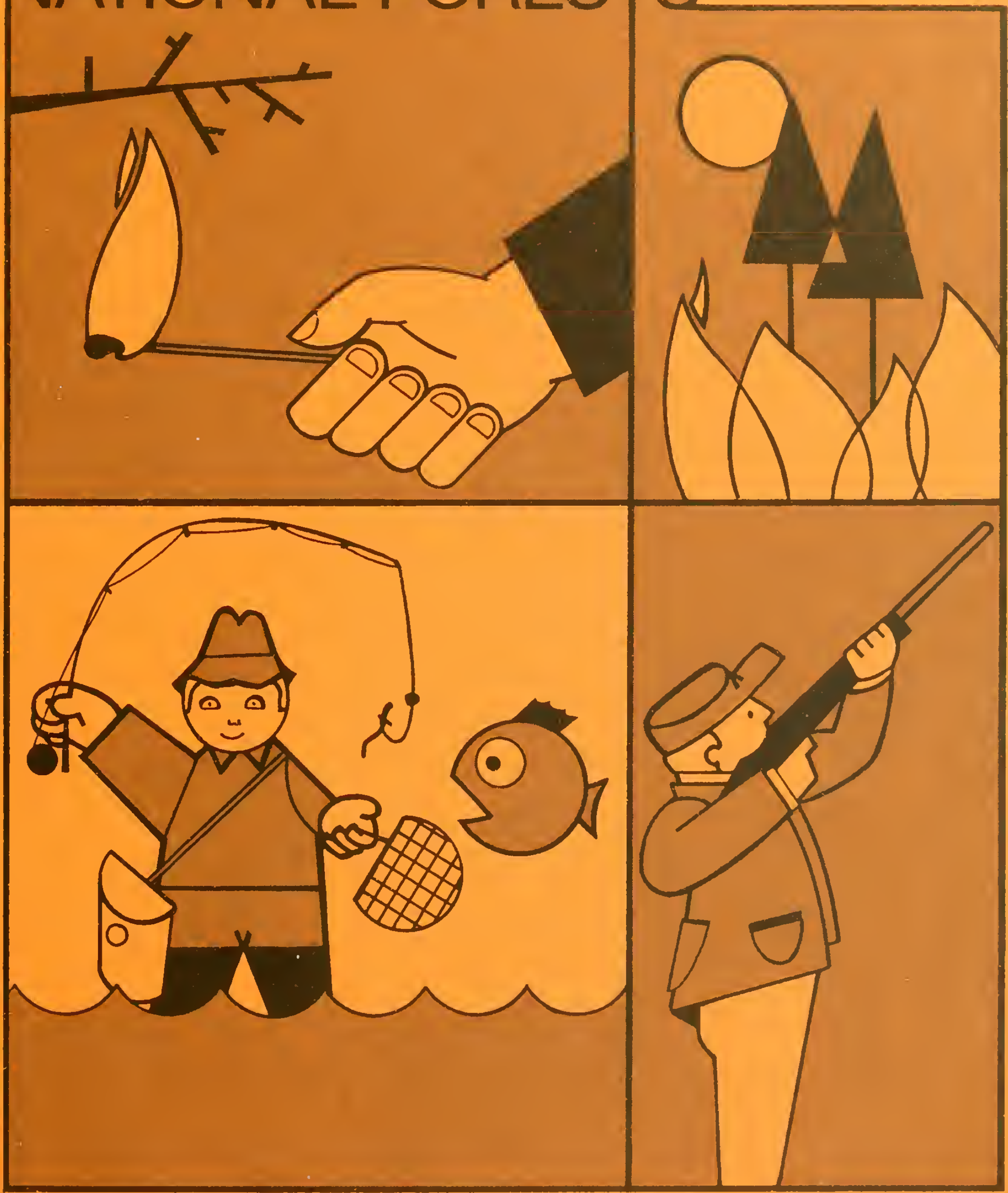
Soil is for plants...not for tire tracks.

USDA FOREST SERVICE
RESEARCH PAPER NC-102
1974

THE CAUSES OF FIRES ON NORTHEASTERN NATIONAL FORESTS



WILLIAM A. MAIN AND DONALD A. HAINES

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE

CONTENTS

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Manuscript approved for publication October 10, 1973

THE CAUSES OF FIRES ON NORTHEASTERN NATIONAL FORESTS

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In the interest of contributing more basic information for fire prevention, the USDA Forest Service issued new fire reporting instructions in 1960. Personnel were to record four revised factors on the fire report form (USDA Forest Service 1960):

1. The person who started the fire was categorized into one of eight groups.
2. The activity[1] in which the person was engaged was categorized into one of eight groups.
3. The land-use cause of the fire was categorized into one of 40 items.
4. The specific cause of the fire was categorized into one of 41 items.

All categories within the above groups were not mutually exclusive. The first group in particular was a problem. Some of the entries could be placed in two or more of the categories because the categories are not rigidly delineated.

The purpose of the present study was to cross-tabulate the above categories of people, activities, land-use causes, and specific causes to find the combination of these categories most responsible for forest fires in the northeastern national forests (fig. 1). Prevention efforts could then be directed toward these groups.

THE DATA BASE

Before cross-tabulating, we examined the sets of people, their activities, and the 2 sets of fire causes for entry and coding errors and then tabulated the 1960-69 data for the 15 national forest protection areas in the northeastern United States. Although the original data were for individual protection areas, we will usually look at the region as a whole in order to determine what groups are causing fires. We must consider forest users not only as individuals, but *en masse* as well, if we are to be successful in influencing the behavior of groups (Herrman 1964).

From 1960 through 1969, the national forests in the northeast recorded 8,486 wildfires and 77,040 burned acres. The following tabulation of the eight activity categories shows the percent of wildfires in each.

Activity[2]	*Percent of total fires*
Incendiarism	23
Land use[3]	22
Tobacco smoking	19
Recreation[4]	18
Equipment usage	7
Lightning[5]	4
Forest usage	1
Miscellaneous[6]	6
Total	100

The top four activities, incendiarism, land use, tobacco smoking, and recreation, are nearly equal in importance as far as number of fires are concerned. The other four activities are lesser problems.

Almost half of the fires, 4,101, were started by local permanent residents who live inside or adjacent to the forest protection boundaries. This agrees with other studies of major fire starters (Banks and Holt 1966, Christiansen and Folkman 1971). Classes of fire starters are shown below by order of importance.

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[1] *Lightning was considered an activity.*

[2] *This category is labeled "statistical cause" in the USDA Forest Service (1960) handbook.*

[3] *Includes fires resulting from refuse burning, land clearing, railroad right-of-way burning, spontaneous combustion, etc.*

[4] *Includes all fires resulting from recreation activity except smoking.*

[5] *Lightning is the only major fire-cause activity not initiated by people. In many western areas of the United States it is the primary cause of wildfire.*

[6] *Includes fires resulting from insect control, smoking bees, glass not set by an incendiarist, destruction of stills by law officers, etc.*

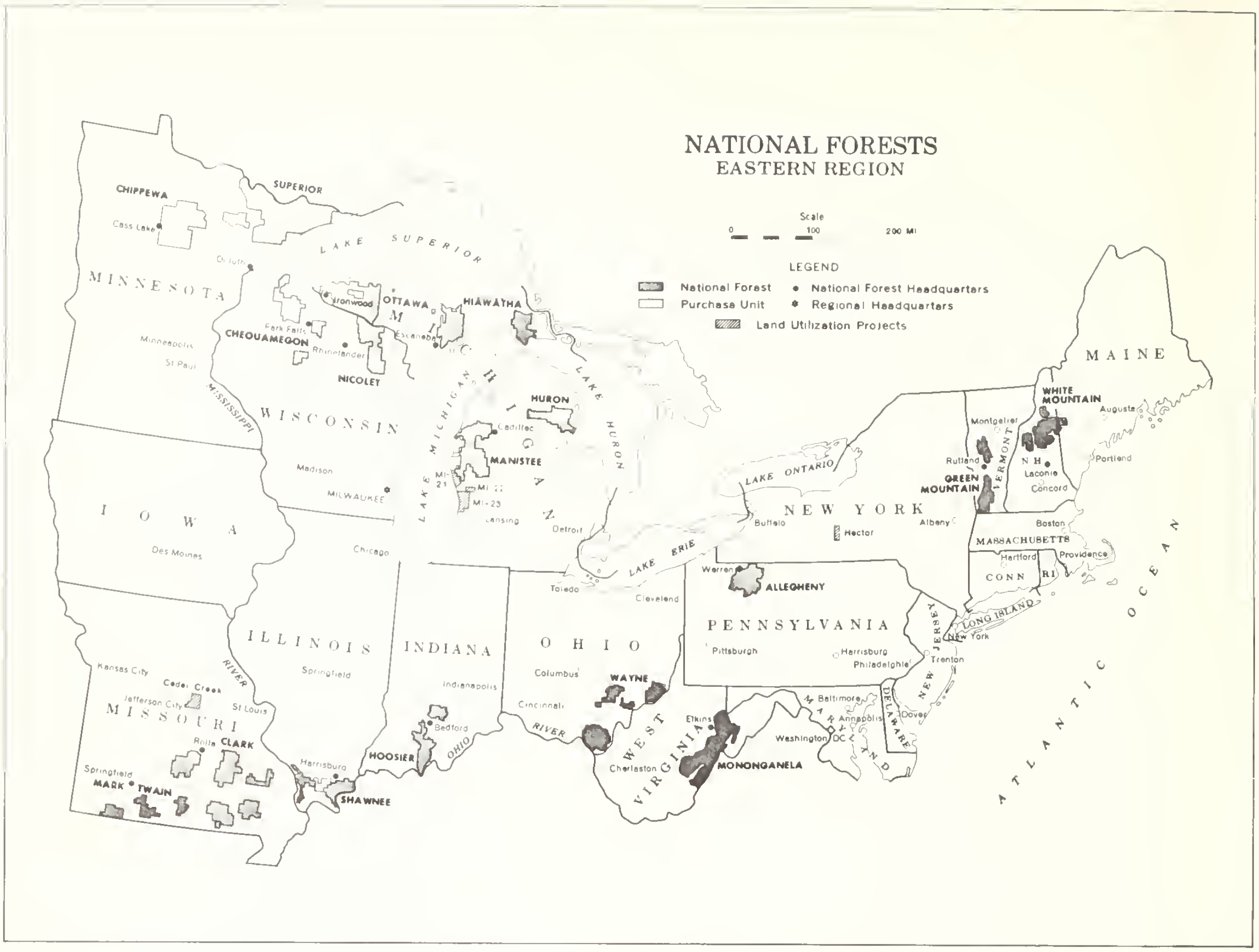

Figure 1.--*National forests in northeastern United States. The Wayne-Hoosier and the Huron-Manistee are combined protection units.*

Class of people	*Percent of total fires*
Local permanent residents	48
Transients, tourists, or other through-travelers	12
Private landowners and businessmen	11
Seasonal workers or visitors	5
Permittees	2
Contractors	1
Public employees	1
Other	20
Total	100

HOW RELIABLE ARE THE DATA?

Even though the individual fire reports of the Forest Service are supposed to be completed uniformly throughout the country, flaws in the reporting form and certain tendencies of those filing the report introduce inaccuracies.

The fire report forms do not have an "unknown" category in the activity block so that the fire investigator is sometimes forced to guess the activity that resulted in the wildfire. Also, the form provides no space for the investigator to state his confidence in the entries.

In other studies the accuracy of entries assigning fires to smokers was found to be less than entries assigning fires to incendiarists. Both were considerably less accurate than entries of lightning fires, campfires, debris-burning fires, and railroad fires. The poor entry record for smoker-caused fires results from a tendency to report unknown fires as smoker-caused (Chandler 1960, Banks and Holt 1966). Inaccuracies also occur in the percent of fires started by locals because investigators tend to report fire starters of unknown residency as nonlocals (Chandler 1960).

Thus, in the following discussion we should keep in mind that the percent of fires assigned to smoking and incendiarism may be somewhat high. Fire start percents assigned to locals are probably low.

CROSS-TABULATING THE DATA

The category percents listed under activity and class of people are already commonly used in operational planning. The problem, however, is that these categories present unclear pictures. For example, the first tabulation shows that 18 percent of the fires are caused by recreational activity. But do locals, transients, or seasonals cause the greatest number of fires while recreating? We attempted to answer this type of question by making cross-tabulations of the various categories of people, activity, land-use causes, and specific causes, producing a list of combinations.

A computer program cross-tabulated the 4 categories, based on number of fires, and generated more than 200 different combinations with 3 or more fires in each. Thirty-five combinations had data with 50 or more fires; 31 meaningful combinations were ranked by the number of fires they represented regionwide (table 1). The leading combinations on the individual protection units of the national forests were listed in table 2.

Local residents involved in incendiarism, specifically pyromania, were by far the leading combination with 907, or 11 percent, of the region's fires (table 1). Pyromania, however, is an unfortunate classification term as it implies that the investigator has made a medical judgment. Incendiarism by local residents for reasons other than pyromania was the third ranked combination. Incendiarism for whatever reason is especially high in the forests of southern Missouri and Indiana. There, as in many southeastern States, fire activity most often results from social, not psychological, causes. This activity is strongly affected by the attitudes and habits of the people; some residents accept woods burning as a normal practice. The high incidence of local incendiarism is largely from four of the region's national forests: the Clark, Mark Twain, Wayne-Hoosier, and the Chippewa (table 2). These forests also account for 59 percent of all the fires in the region.

Interestingly, local hunters and fishermen cause more fires, not by letting cooking fires escape or smoking tobacco products, but rather by hunters attempting to smoke-out game. This is the second leading combination in the region (table 1). The overwhelming number of these fires occur on the two Missouri forests, the Clark and Mark Twain, an area where many residents observe this practice. This situation

Table 1.--*Leading combinations on the national forests in the northeastern region (1960-69) ranked by number of fires*

Class of people	Activity	General land-use cause	Specific cause	Number of fires	Rank
Local	Incendiarism	Incendiary	Pyromania	907	1
Local	Recreation	Hunting and fishing	Smoking game	453	2
Local	Incendiarism	Incendiary	Other things	427	3
Local	Land use	Resident	Refuse burning	413	4
Other	Lightning	Lightning	Lightning	329	5
Owner	Equipment usage	Railroad	Exhaust	255	6
Local	Incendiarism	Incendiary	Grudge fire	251	7
Local	Smoking	Hunting and fishing	Smoking	251	8
Owner	Land use	Resident	Refuse burning	212	9
Transient	Smoking	Hunting and fishing	Smoking	148	10
Transient	Smoking	Highway	Smoking	140	11
Local	Smoking	Smoking	Smoking	125	12
Other	Smoking	Hunting and fishing	Smoking	108	13
Transient	Recreation	Recreation	Cooking fire	103	14
Transient	Smoking	Recreation	Smoking	96	15
Transient	Recreation	Hunting and fishing	Cooking fire	89	16
Transient	Recreation	Hunting and fishing	Smoking game	86	17
Local	Land use	Agriculture	Land clearing	83	18
Seasonal	Smoking	Hunting and fishing	Smoking	82	19
Local	Miscellaneous	Resident	Matches	81	20
Local	Smoking	Recreation	Smoking	78	21
Local	Recreation	Hunting and fishing	Warming fire	75	22
Other	Recreation	Hunting and fishing	Smoking game	67	23
Local	Land use	Resident	Other things	64	24
Local	Smoking	Highway	Smoking	61	25
Local	Land use	Other occupancy	Refuse burning	60	26
Transient	Smoking	Other smoking	Smoking	58	27
Local	Land use	Agriculture	Meadow burning	55	28
Local	Land use	Resident	Land clearing	51	29
Owner	Land use	Agriculture	Land clearing	51	30
Local	Miscellaneous	Miscellaneous	Matches	51	31

Table 2.--*Leading combinations on individual protection units of the national forests (1960-69) ranked by number of fires*

National forest	Class of people	Activity	General land-use cause	Specific cause	Number of fires
Allegheny					
103 total fires	Owner	Equipment use	Railroad	Exhaust emission	7
645 burned acres	Transient	Smoking	Hunt and fish	Smoking	6
489,400 acres protected[1]	Transient	Smoking	Recreation	Smoking	5
Chequamegon					
105 total fires	Other	Lightning	Lightning	Lightning	7
450 burned acres	Seasonal	Smoking	Hunt and fish	Smoking	7
863,600 acres	Transient	Smoking	Hunt and fish	Smoking	4
protected	Other	Smoking	Highway	Smoking	4
Chippewa					
387 total fires	Local	Incendiarism	Incendiary	Other things	31
4,042 burned acres	Local	Land use	Resident	Refuse burning	23
1,246,500 acres	Transient	Smoking	Hunt and fish	Smoking	18
protected	Local	Smoking	Hunt and fish	Smoking	16
Clark					
2,127 total fires	Local	Incendiarism	Incendiary	Pyromania	398
26,767 burned acres	Local	Recreation	Hunt and fish	Smoking game	324
1,537,100 acres	Local	Incendiarism	Incendiary	Other things	143
protected	Local	Land occupancy	Resident	Refuse burning	141
	Local	Incendiarism	Incendiary	Grudge fire	125
	Local	Smoking	Hunt and fish	Smoking	100
	Owner	Land occupancy	Resident	Refuse burning	67
	Other	Lightning	Lightning	Lightning	52
Green Mountain					
65 total fires	Other	Lightning	Lightning	Lightning	8
141 burned acres	Other	Land occupancy	Other occupation	Refuse burning	3
379,000 acres protected					
Hiawatha					
292 total fires	Owner	Equipment use	Railroad	Exhaust emission	53
1,235 burned acres	Other	Lightning	Lightning	Lightning	24
1,189,100 acres protected	Local	Misc. activity	Resident	Matches	10
Huron-Manistee					
1,202 total fires	Owner	Land occupancy	Resident	Refuse burning	87
6,519 burned acres	Local	Land occupancy	Resident	Refuse burning	47
1,750,600 acres	Transient	Smoking	Recreation	Smoking	38
protected	Seasonal	Land occupancy	Resident	Refuse burning	34
Mark Twain					
1,397 total fires	Local	Incendiarism	Incendiary	Pyromania	314
15,573 burned acres	Local	Incendiarism	Incendiary	Other things	118
1,005,700 acres	Local	Recreation	Hunt and fish	Smoking game	88
protected	Local	Land occupancy	Agriculture	Land clearing	57
	Local	Incendiarism	Incendiary	Grudge fire	51

[1]1969 total protected acreage.

Continued on next page

points up the difficulty of trying to overcome local customs in the name of fire prevention.

The refuse-burning fire by local residents is a major problem on northeastern national forests just as it is in the southern region of the country, and was ranked fourth among combinations (table 1).

Even though lightning fires stand apart from these combinations of people-caused fires, they were ranked along with the others for comparison. As the fifth highest combination cause, lightning is not solely a problem of western forests (table 1). It is the main combination cause on five forests; the Chequamegon, Green Mountain, Monongahela, White Mountain, and Superior (table 2). On the Hiawatha it is second only to locomotive exhaust fires. Lightning is of special concern on the Superior because it started 106 fires, almost one third of the regional lightning-fire total.

The combinations ranked sixth, seventh, and eighth were each responsible for about 250 fires (table 1). Railroad exhaust equipment was the primary or secondary cause of fires on five national forests (table 2). A significant number of fires, 48, were caused by fuel sparks from railroad engines. Other unlisted railroad fires were the result of miscellaneous railroad

Table 2 continued

National forest	Class of people	Activity	General land-use cause	Specific cause	Number of fires
Monongahela					
224 total fires	Other	Lightning	Lightning	Lightning	22
1,792 burned acres	Owner	Equipment use	Railroad	Exhaust emission	19
1,191,400 acres	Seasonal	Smoking	Hunt and fish	Smoking	12
protected	Local	Incendiarism	Incendiary	Grudge fire	11
Nicolet					
233 total fires	Transient	Smoking	Hunt and fish	Smoking	15
1,475 burned acres	Transient	Smoking	Other smoking	Smoking	8
941,700 acres	Local	Smoking	Other smoking	Smoking	8
protected					
Ottawa					
164 total fires	Owner	Equipment use	Railroad	Exhaust emission	42
631 burned acres	Other	Lightning	Lightning	Lightning	15
1,223,400 acres	Local	Smoking	Hunt and fish	Smoking	7
protected					
Shawnee					
406 total fires	Owner	Equipment use	Railroad	Exhaust emission	28
5,237 burned acres	Local	Land occupancy	Resident	Refuse burning	21
490,600 acres	Other	Smoking	Hunt and fish	Smoking	15
protected	Transient	Smoking	Highway	Smoking	15
Superior					
604 total fires	Others	Lightning	Lightning	Lightning	106
2,999 burned acres	Transient	Recreation	Recreation	Cook fire	81
2,722,000 acres	Transient	Recreation	Hunt and fish	Cook fire	72
protected	Transient	Smoking	Hunt and fish	Smoking	22
Wayne-Hoosier					
1,108 total fires	Local	Incendiarism	Incendiary	Pyromania	170
9,278 burned acres	Local	Land occupancy	Resident	Refuse burning	109
532,400 acres	Local	Incendiarism	Incendiary	Other things	96
protected	Local	Smoking	Hunt and fish	Smoking	49
White Mountain					
69 total fires	Other	Lightning	Lightning	Lightning	21
131 burned acres	Transient	Recreation	Recreation	Cook fire	6
788,100 acres	Transient	Smoking	Recreation	Smoking	5
protected	Other	Smoking	Recreation	Smoking	4

equipment (23), brakeshoes (12), and improper use of fusees (8). Grudge fires by local incendiarists ranked seventh while fires from local hunters and fishermen smoking tobacco were next (table 1).

An examination of the 4 categories that make up the leading 35 combinations showed that in the class of people category local residents were involved in 17 of the 35 combinations. Also, local residents or owners caused the fires in 9 of the first 10 combinations (table 1). Hunters and fishermen (from the general land use cause category), whether local, transient, or seasonal, are a leading cause of fires, primarily because of smoking-out game and smoking tobacco. Although fire percents from tobacco smoking may be somewhat high as cautioned earlier, hunters and fishermen were the starters in 4 of the leading combinations involving smoking and these caused a total of 589 fires. Other types of recreationists do not appear to be nearly as much of a fire risk as the hunter-fisherman. Campers, picnickers, and other similar recreationists were responsible for well under 300 fires of all kinds. Hunters and fishermen, on the other hand, were responsible for 9 of the leading combinations for a total of well over 1,300 fires (table 1).

Permittees, contractors, and public employees were not found to be major fire starters in the region; none of them appear within the first 60 combinations.

Some of the important cause combinations on the individual forests (table 2) are not significant regionally, and vice-versa. Varying land ownership and use patterns on individual forests have a tremendous influence on the cause of fire.

TABULATION BASED ON COST-PLUS-LOSS EVALUATION

A justifiable argument is often made that an examination of numbers of fires alone does not present the complete wildfire story. Forest fires have varying suppression costs, burned acreage, and most important, value losses. We attempted to integrate these factors using the cost-plus-loss formula currently used by the national forests in their fire planning procedures.

Cost-plus-loss (CL) evaluation is as follows: for fires 1/4 acre or less, CL = 1 unit; for fires more than 1/4 acre to 1/2 acre, CL = 5 units; for fires 1/2 acre to 9 acres, CL = 5 units + (V x A) where:

V = Land value loss. Land was divided into seven classes depending on the type of vegetation and use of the area. Land value losses range from 30 units per acre for class 1 down to 2.5 units per acre for class 7.

A = Burned acreage.

For fires 10 acres or larger, CL = (S x A) + (V x A) where:

V = as above,

A = as above, and

S = suppression cost estimated as 1 unit per acre.

For example, a 50-acre fire on class 3 land (a value loss (V) of 10 units per acre) results in: CL = (S x A) + (V x A), so CL = (1 x 50) + (10 x 50) = 550 units; i.e., 50 units of suppression cost plus 500 units of land value loss result in 550 units of CL.

After machine computation, the leading 30 cost-loss combinations were ranked (table 3). Generally, the ranking of the combinations in tables 1 and 3 is very similar, although there are some important differences.

With the exception of lightning fires, the leading 10 combinations of table 1 are still within the top 10 in table 3, although their order is changed. Refuse-burning fires have increased in significance and are, consequently, of special interest. The two combinations of these fires advanced from fourth and ninth places in table 1 to second and seventh. The importance of this type of fire apparently cannot be judged solely by numbers.

The class of people category is still highly dominated by locals, but two permittee combinations are now among the leaders. Timbering and electrical power transmission were far down the list of general land-use causes when ranking was based on number of fires.

CONCLUSIONS

An analysis of 10 years of data on 15 northeastern national forest protection units shows that fire cause is a diversified problem across the region. Nevertheless, local people most often start fires, no matter what the activity. The local incendiarist is still the most pressing prevention riddle, even though fire-start figures listed under this activity may be somewhat high. Incendiarism is not only the largest northeastern problem in fire prevention, but also the most difficult to solve aside

Table 3.--*Leading combinations on the national forests in the northeastern region (1960-69) ranked by cost-loss units*

Class of people	Activity	General land-use cause	Specific cause	Cost-loss units[1]	Rank
Local	Incendiarism	Incendiary	Pyromania	1,048	1
Local	Land use	Resident	Refuse burning	881	2
Local	Incendiarism	Incendiary	Other things	836	3
Local	Smoking	Hunting and fishing	Smoking	723	4
Local	Incendiarism	Incendiary	Grudge fire	717	5
Owner	Equipment usage	Railroad	Exhaust	453	6
Owner	Land use	Resident	Refuse burning	407	7
Local	Recreation	Hunting and fishing	Smoking game	320	8
Owner	Land use	Agriculture	Land clearing	308	9
Transient	Smoking	Hunting and fishing	Smoking	272	10
Other	Incendiarism	Incendiary	Grudge fire	234	11
Local	Smoking	Smoking	Smoking	216	12
Other	Lightning	Lightning	Lightning	181	13
Other	Land use	Industry	Mill waste	134	14
Other	Smoking	Hunting and fishing	Smoking	131	15
Local	Land use	Agriculture	Land clearing	131	16
Permittee	Land use	Electric power	Powerline	129	17
Local	Recreation	Hunting and fishing	Warming fire	123	18
Local	Smoking	Timbering	Smoking	98	19
Local	Land use	Agriculture	Meadow burn	92	20
Local	Equipment usage	Timbering	Exhaust	91	21
Permittee	Smoking	Timbering	Smoking	87	22
Transient	Incendiarism	Incendiary	Grudge fire	82	23
Local	Land use	Agriculture	Range burn	81	24
Local	Incendiarism	Incendiary	Job fire	79	25
Owner	Equipment usage	Railroad	Fuel sparks	79	26
Local	Smoking	Recreation	Smoking	79	27
Local	Miscellaneous	Resident	Matches	66	28
Seasonal	Recreation	Hunting and fishing	Smoking game	65	29
Transient	Smoking	Highway	Smoking	61	30

[1]In ten thousands of units (10^4).

from the lightning fire. True incendiary fires are not the result of lack of knowledge or even of carelessness, but are, of course, deliberately started, and the individuals responsible have low group identification.

One source of confusion in dealing with this problem results from mixed application of the term incendiarist. Not all people so labeled are psychopaths. Many incendiarists act from traditional, social attitudes. Dramatic successes in fire prevention have resulted by reaching this latter group through community action programs.

Success in preventing fires might be expected by reaching visible groups such as debris burners or equipment operators. Unlike true incendiarists, these people do not attempt to keep their operations secret. Unfortunately, they are not a cohesive group because they have little in common except that most use such things as refuse burners. A group approach, although not as formidable as with true incendiarists, is still difficult.

Railroaders, hunters, and fishermen are all highly visible, relatively cohesive groups that can be more easily reached using traditional prevention techniques. Strong, partly successful efforts in fire prevention are already being used with railroaders in areas of the northeast. In some cases results are achieved after dealing directly with engineers and brakemen. At other times contact with higher level management personnel is necessary.

Because hunters and fishermen become a "reachable" group through licensing, and are more of a fire problem than all other recreationists combined, stronger prevention efforts could be directed toward them. California has done an exhaustive study on hunter attitudes toward--and knowledge of--wildfire and its prevention (Herrman 1962, Davis and Chandler 1962, Folkman 1963). Some of these findings may also apply to the northeast.

A number of prevention approaches could be used with the hunter-fisherman group. Many are proud of being called sportsman; consequently, an appeal to that pride may be effective. Some belong to local rod and gun clubs; these are obvious platforms for fire prevention appeals. Conversely, much of the hunting and fishing, especially that done on northeastern forests with high fire incidence, is the traditional, way-of-life variety rather than in a modern image of *Outdoor Life* or *Field and Stream*. We suspect that there may be a tremendous overlap of those hunters who smoke-out game and leave smoldering warming fires with those incendiarists who set fires to increase grazing land or "green up" the woods. As already pointed out, those incendiarists sometimes may be reached through community action programs.

Most importantly, hunters and fishermen are licensed; information on fire prevention can be passed out during licensing formalities. Finally, infraction of fire laws by this group might be met with the same punishments as game violations. In many States this involves not only fines but also loss of license, fishing tackle, and firearms. With an identifiable group many approaches are possible. Hunters and fishermen account for nine of the primary combinations in fire starts; therefore, concentration on them should be productive.

Forest fire prevention programs must continue to reach the general public with all methods, in all forms. But regional emphasis could be placed upon identifiable classes of people who we can easily contact and with whom there is some leverage. This study indicates that hunters and fishermen are the most obvious group.

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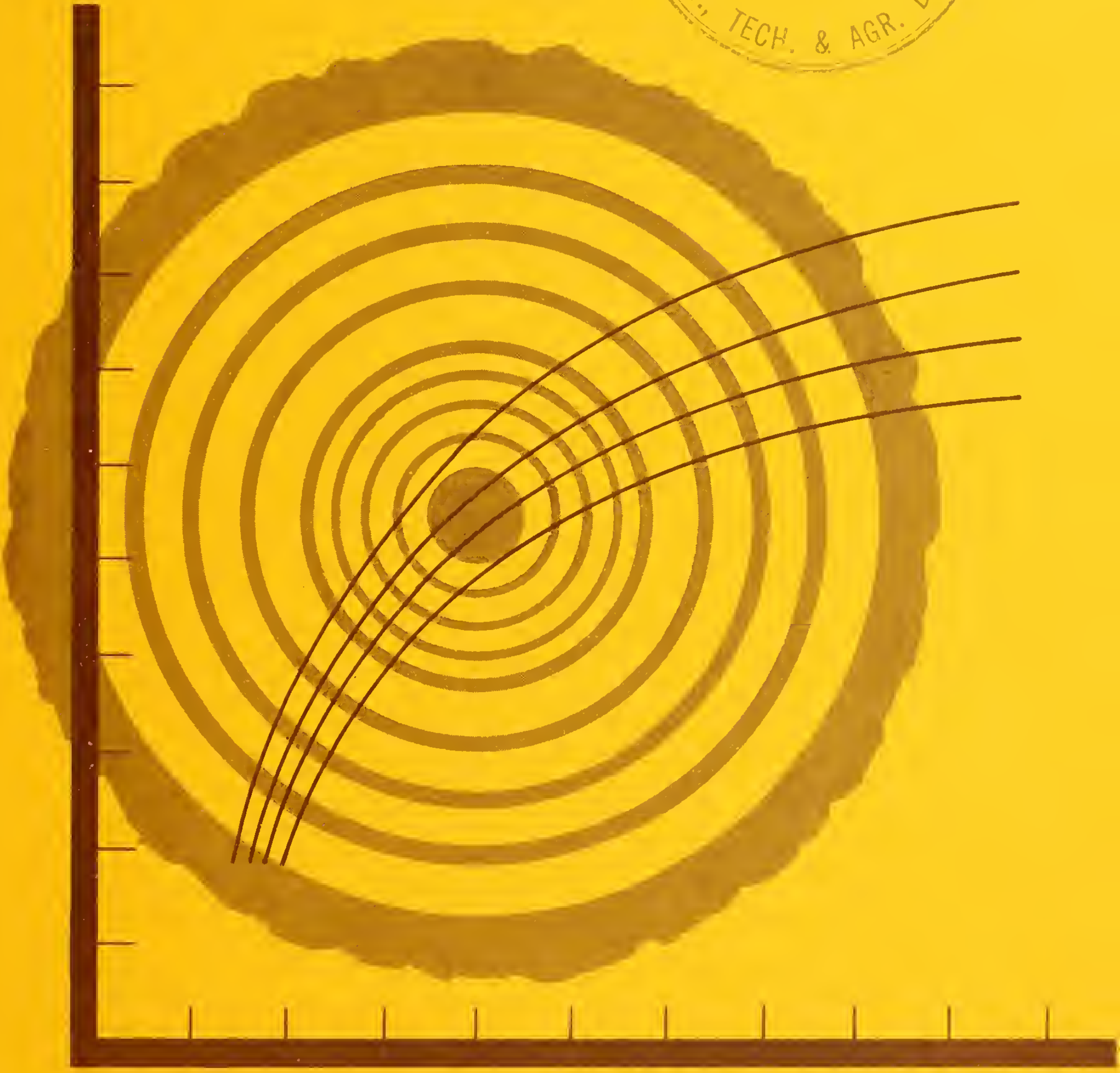
hardwood log quality in relation to site quality



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NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

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Manuscript approved for publication November 5, 1973

HARDWOOD LOG QUALITY IN RELATION TO SITE QUALITY

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Excellent hardwood sites can quickly produce large yields of high-value veneer and saw logs. Field foresters are usually aware of the general relations between site quality and yield quality, and these relations have been confirmed by a few formal studies (Campbell 1959a, Campbell 1959b, Crow 1962). However, quantitative information is limited, and the reasons for site quality-log quality relations have not yet been well defined.

Site index curves and soil-site methods are available for estimating site quality for many of our eastern hardwoods (Carmean 1970, 1972). Normal yield tables also have been developed for the more common hardwood species, and research now underway will produce yield tables for managed hardwood stands. Thus, both quality of site and the quantity of yield from hardwood forest lands can be estimated. However, we still have no dependable means for estimating the quality of yield produced from different hardwood sites. Knowing only the total yield of fiber may be adequate for pulpwood management, but for valuable hardwood species we must also be able to estimate quantity and quality of veneer and high-grade saw logs that can be produced on different sites.

Hardwood log grades rate logs on the basis of defects, on the diameter and length of the clear log, and on the size and shape of the interior knotty core (Lockard et al. 1963, USDA Forest Service 1965, Vaughan et al. 1966). Relationships between these log features and lumber yield are well established. Less well known is how these same log features are related to hardwood site quality. Damage from insects, disease, and other agents certainly affects log grade, and the grade and amount of clear lumber recovered from logs and trees. Assuming that the occurrence of injury is similar on all sites, the amount of clear lumber is largely dependent upon the length and diameter of the clear bole of standing trees, and on the size and shape of the interior knotty core. These are determined by tree age and by growth patterns for tree height, crown length, and bole diameter.

Tree height and bole diameter growth are in turn closely related to site quality, and crown length and bole diameter growth are closely related to stand density. Accordingly, for a given age the amount of clear lumber in a log is a function of site quality and stand density.

Stand density obviously influences tree diameter growth--this well-known fact is the basis for stocking guides and thinning recommendations. Also well known is that stand density influences crown length--dominant trees in dense stands have shorter crowns, and trees in open stands have longer crowns. The influence of stand density on crown length and tree diameter growth has been illustrated for yellow-poplar trees growing on similar sites over a wide range of stand densities (Holsoe 1950). Stem analyses illustrated how stand density was related to live crown length, clear bole length, tree diameter growth, and size and shape of the knotty core.

Holsoe's yellow-poplar study used trees growing on areas of similar site quality so as to better study relations between stand density and bole development. Thus the relation between site quality and bole development has yet to be illustrated. Accordingly, for similar stand densities (fully stocked stands) we will illustrate how site quality determines total height growth which, in turn, determines length of live crown, clear bole length, and size and shape of the knotty core.

The site quality-log quality model we use is based upon research, experience, and some logical assumptions. We hope this model will be a useful hypothesis for future studies concerned with those portions of the model where knowledge is now deficient.

SITE QUALITY AND LENGTH OF THE CLEAR BOLE

Site index curves for four species of upland oaks in the Central States describe the variable height-growth patterns for dominant and codominant trees growing on different sites (Carmean 1972). These new site curves, based on stem analyses, reveal that black oaks on good sites have height-growth patterns different from those on poor sites (fig. 1). On good sites (better than site index 70) early height growth for black oak is very rapid; this early height growth surge continues for 20 to 30 years. In contrast, trees on poor sites (less than site index 60) have much slower early height growth. These different patterns of early height growth are crucial because ultimate log quality is largely determined by the height and diameter growth achieved during these formative years.

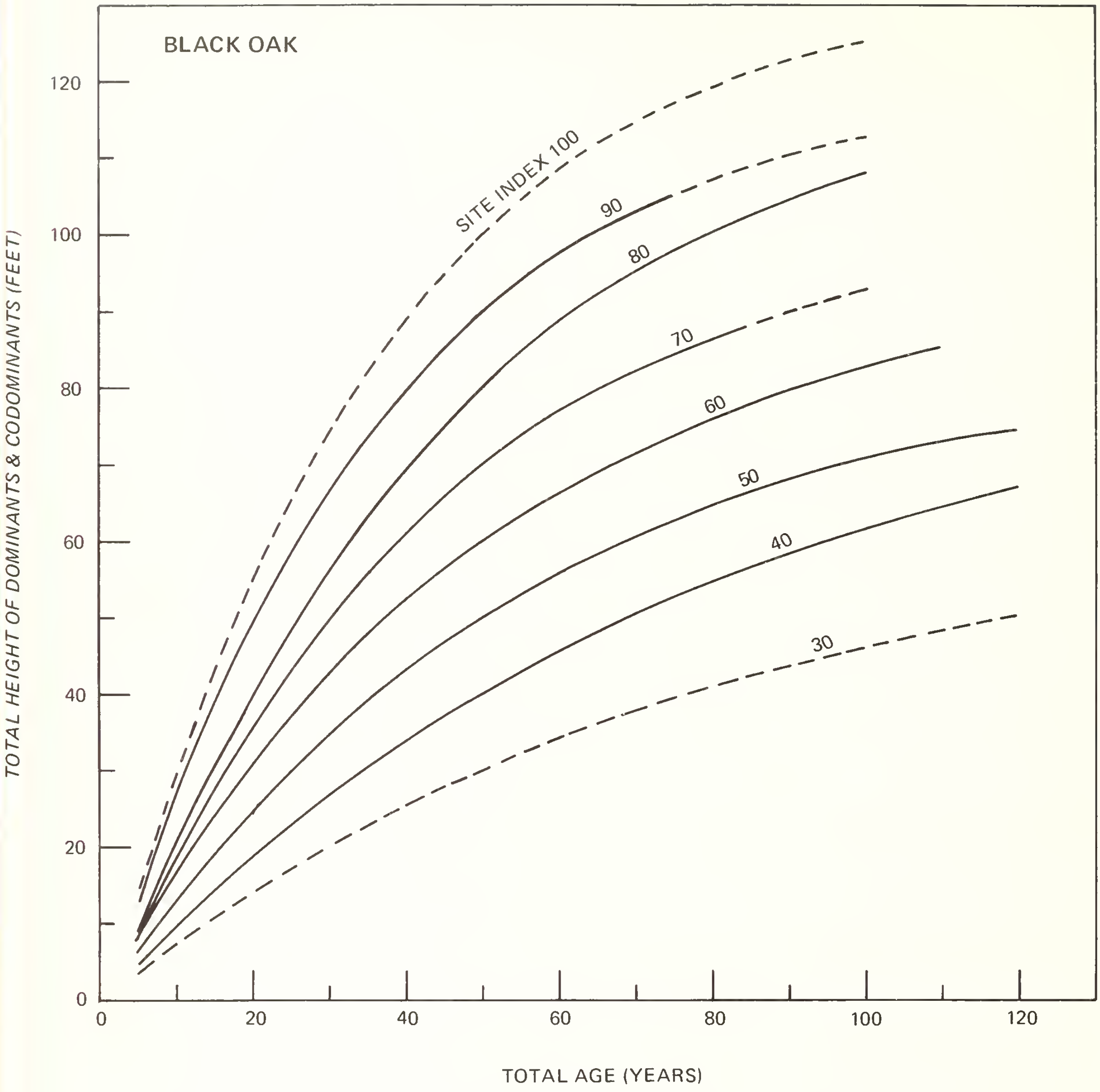

Figure 1.--*Site index curves for black oak in the Central States. These site curves are based on stem analysis data from 300 dominant and codominant black oaks growing in the unglaciated portions of Ohio, Kentucky, Indiana, Illinois, and Missouri (Carmean 1972).*

Dominant and codominant trees in even-aged, well-stocked upland oak forests are assumed to have clear bole lengths constituting about one-third of the total tree height. The upper two-thirds of the stem includes live crown, dead limb stubs, and limb scars not yet healed. In well-stocked stands the length of the live crown and persistence of dead stubs may vary depending upon tree age, species, crown class, site quality, and stand history; however, a clear bole length of about one-third total tree height characterizes red oak trees growing in well-stocked, even-aged stands in Massachusetts and Pennsylvania (Holsoe 1947, Patton 1922, Ward 1964). Yellow-poplar in well-stocked stands also have clear bole lengths varying between one-third and two-fifths of total tree height (Holsoe 1950).

Curves showing when clear boles emerge on different sites (fig. 2) for dominant and codominant black oaks in well-stocked, even-aged stands were calculated merely by reducing the new black oak site index curves by two-thirds. Development of clear boles on contrasting sites can be illustrated as follows: for site index 90 a dominant black oak in an even-aged, well-stocked stand will be about 58-feet tall at 25 years (fig. 1). Assuming the clear bole length is one-third of total tree height, the lower 19 feet of this tree should be free of live limbs and dead branch stubs (fig. 2). At 70 years this tree will be about 103-feet tall and probably will have a clear bole of 34 feet. Thus, at 25 years, this superior-site tree already has produced a 19-foot clear bole; at 70 years it has a 34-foot clear bole--more than two log lengths. In contrast, a site index 50 black oak will only be about 30-feet tall at 25 years of age, and only the lower 10 feet will be free of live limbs and branch stubs; at 70 years it will be only about 60-feet tall, and will have produced only a 20-foot clear bole (figs. 1 and 2).

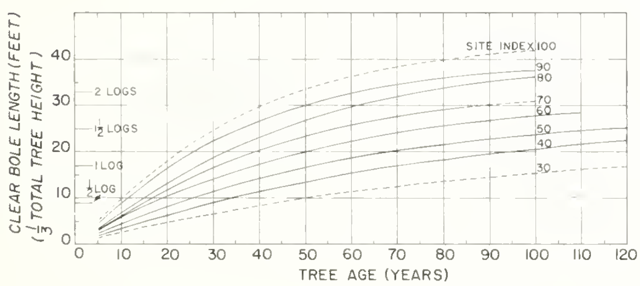

Figure 2.--*Curves showing the development of clear boles for dominant and codominant black oaks growing in even-aged, well-stocked stands differing in site quality. Clear bole lengths are assumed to be one-third of total tree height.*

The curves in figure 3, adapted from figure 2, show the years required for clear boles of 9, 13, 17, 25, and 33 feet to naturally emerge from the crowns of dominant and codominant black oaks growing on different sites. The 17-foot clear bole (one clear log) first appears at about 19 years on extremely good sites (site index 100). This same clear log length appears at about 21, 27, 31, 39, 52, and 71 years for site indices 90, 80, 70, 60, 50, and 40 feet, respectively. Only the best sites can naturally produce trees having a 33-foot clear bole (two clear logs). A 33-foot clear bole first appears at about 49 years on site index 100 lands; this same clear log length

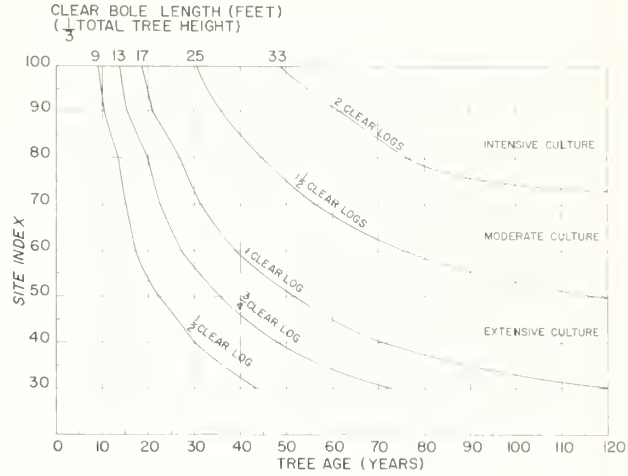

Figure 3.--*Estimated time required for clear boles (one-third total height) of 9, 13, 17, 25, and 33 feet to naturally emerge from the crowns of dominant and codominant black oaks growing in even-aged, well-stocked stands on different sites.*

appears at 62 and 76 years for sites indices 90 and 80, respectively. Black oak site indices 70 and poorer will seldom naturally produce clear two-log boles.

Figures 2 and 3 are for dominant and codominant black oaks growing in fully stocked stands. When accurate site index curves are available, similar curves could be constructed for other species, or for shorter clear bole lengths that may naturally occur in stands less dense than the fully stocked stands used in our model. Furthermore, pruning to perhaps half total tree height might be recommended for certain intensively managed stands (Skilling 1958, Clark and Seidel 1961). For these stands curves showing when dominant and codominant trees could be pruned could be constructed merely by reducing site index curves by half. For example, black oaks could be pruned to 17 feet at 12, 23, and 41 years in stands having site indices of 90, 60, and 40, respectively (fig. 1).

The clear bole relationships portrayed in figures 2 and 3 also can be summarized to show when clear boles naturally appear in well-stocked stands, or when they might be produced by pruning on different forest sites (table 1). This summary lists years required to produce 17-foot and 33-foot clear boles on five different site classes. Similar tables also could be calculated for other site classes, log lengths, or other ratios of clear bole to total height.

Table 1.--*Estimated age at which clear boles of different lengths appear naturally or can be produced by pruning dominant and codominant black oaks growing on different sites*

(In years)

Site quality for black oak (site index)	Clear bole length natural1/: 17 feet	Clear bole length natural1/: 33 feet	Clear bole length pruning2/: 17 feet	Clear bole length pruning2/: 33 feet
Superior sites (>80)	<27	<76	<17	<38
Good sites (71 to 80)	27-31	(3/)	17-19	38-47
Medium sites (61 to 70)	31-39	(3/)	19-21	47-61
Poor sites (51 to 60)	39-52	(3/)	21-28	61-86
Very poor sites (<51)	>52	(3/)	>28	(3/)

1/ Clear bole length assumed to be 1/3 total tree height in well-stocked, even-aged stands.

2/ Pruning to one-half total tree height.

3/ Clear boles can seldom be achieved on these sites.

SITE QUALITY AND THE KNOTTY CORE

Maximum yields of high-grade lumber and veneer are obtained from logs having large amounts of clear wood outside a small, knotty core. Log grades specify that the knotty core of a Grade 1 saw log should have a radius no larger than one-fifth the inside diameter of the small end of the log (Lockard et al. 1963, Vaughan et al. 1966). For example, a Grade 1 saw log 16-inches d.b.h. and 13-inches d.i.b. at 17 feet should have a knotty core no larger than 5.2 inches at 17 feet. Of course, as the diameter of the log increases, the allowable size of the knotty core also increases. Thus a Grade 1 saw log 23-inches d.b.h. and 20-inches d.i.b. at 17 feet should have a knotty core no larger than 8.0 inches in diameter at 17 feet.

These examples show that relatively small logs can qualify as veneer and first-grade logs as long as the knotty core is small. On good sites clear boles rapidly emerge, thus boles have small knotty cores, and high-quality logs can be produced at early ages even though logs may be relatively small in diameter. Furthermore, early thinning and pruning on good sites will produce both larger diameters and smaller knotty cores; as a result, high-quality logs can be produced using short rotations. In contrast, trees on poor sites have short boles, large knotty cores, and slow diameter growth. On these sites logs must be large in diameter before they can qualify as veneer or first grade. Producing large logs on poor sites requires long rotations and thus added interest on management investments.

The knotty core begins at the base of the tree and increases in diameter with increased distance from the ground (fig. 4). In effect, the knotty core in the butt log has the shape of an inverted cone with its apex at the base of the tree (Boyce 1966, Holsoe 1947, 1950). In the lower part of the bole the knotty core slowly increases in diameter with increased height because both tree height growth and the upward movement of the base of the live crown proceed at a rapid and almost linear rate. In the upper part of the bole the knotty core expands more rapidly because of slowed height growth and slowed upward movement of the live crown. Eventually the knotty core emerges at the bole surface where dead limb stubs still persist.

The early formation of the cone-shaped knotty core and the clear wood is illustrated for each of the first 7 years of tree growth (fig. 5). This tree grows 3 feet in height per year, thus the length of clear bole moves upward 1 foot per year,

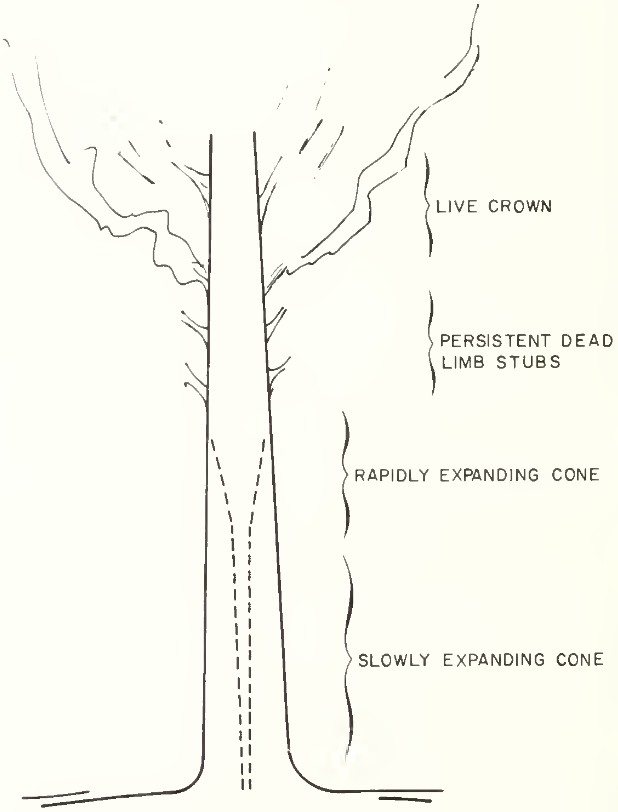

Figure 4.--*The knotty core is shaped like a slowly expanding inverted cone in early years when tree height growth is rapid. In later years height growth slows, the base of the live crown moves upward more slowly, and the knotty core is shaped like a rapidly expanding inverted cone. Eventually the knotty core emerges at the base of the crown where persistent dead limb stubs occur.*

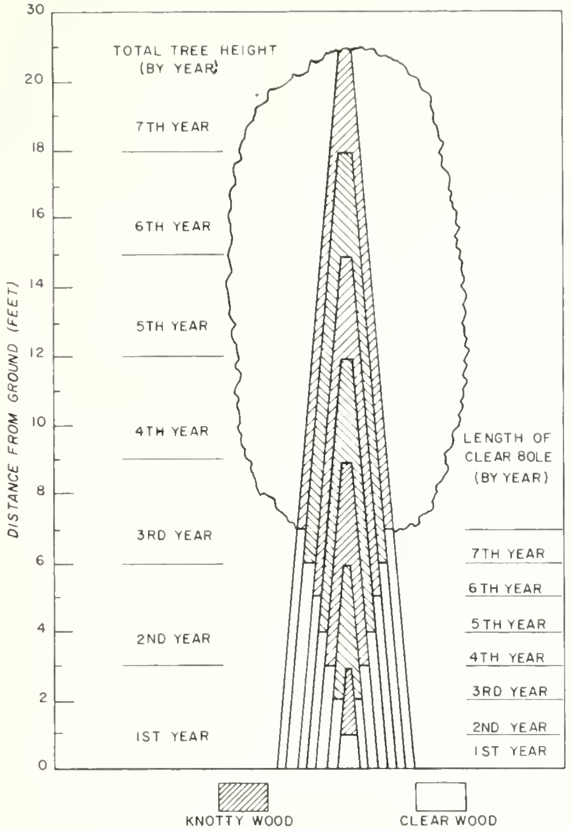

Figure 5.--*Schematic diagram showing the first 7 years of tree-height growth, the clear wood formed on the lower one-third of the bole after healing of the dead limb stubs, and the knotty core formed while live limbs and dead limb stubs are on the upper two-thirds of the bole.*

assuming that each year the clear stem is one-third of total tree height.

Dimensions of the knotty core, as well as the bole itself, can be estimated if we know tree age, annual height growth, annual diameter growth, and number of knotty rings. Annual height growth can be estimated from site index curves (fig. 1), and tree age and annual diameter growth can be estimated from increment cores. The number of knotty rings at any point on the bole can be estimated as follows:

$$\text{Knotty rings at a given point on the bole} = \left(\text{Years for clear bole to emerge at the given point}\right) - \left(\text{Years for tip of tree to reach the given point}\right)$$

For example, we can estimate the number of knotty rings at 7 feet from the ground for the schematic tree (fig. 5). For this tree the clear bole annually moves 1 foot upward, hence 7 years is required for the clear bole to emerge at 7 feet; the tree annually grows 3 feet in total height, hence 3 years is required for the tip of the tree to reach 7 feet. Accordingly, four knotty rings occur at 7 feet.

The black oak site index curves (fig. 1) can be used with the above formula to estimate the dimensions of butt logs and knotty cores when 17-foot clear logs first emerge on good and poor sites (table 2). If clear bole length is one-third total tree height, dominant trees on both site index 80 and site index 40 lands will be about 51-feet tall when a 17-foot clear bole emerges. But the rapidly growing site index 80 tree will reach 51 feet and produce a clear 17-foot bole in only 27 years, while an estimated 72 years will be needed for the site index 40 tree to reach 51 feet (fig. 1). The tip of the site index 80 tree reaches 17 feet in only 9 years; 18 years are needed for the slower growing site index 40 tree to reach 17 feet (fig. 1). Using the formula, at 17 feet the site index 80 tree is estimated to have 18 knotty rings, and the site index 40 tree 54 knotty rings.

Table 2.--*Estimated dimensions of butt logs and knotty cores when 17-foot clear logs first emerge on good and poor black oak sites. These estimates are for dominant and codominant black oaks growing in even-aged, well-stocked stands*

Item	Site index 80	Site index 40
Tree height when 17-foot clear bole appears (feet)[1]	51	51
Years for clear bole to emerge at 17 feet	27	72
Years for tip of tree to reach 17 feet	9	18
Number of knotty rings at 17 feet	18	54
Assumed average annual diameter growth (inches per year)	0.5	0.25
Estimated knotty core diameter at 17 feet (inches)	9.0	13.5
Estimated log diameter at 1 foot (inches)	13.5	18.0

[1]Assuming a clear bole length that is one-third total tree height.

Dimensions of the knotty core and of the butt log itself can now be estimated if the annual diameter growth rate is known. Assuming that the site index 80 tree has an even annual diameter growth rate of 0.5 inches in all portions of the butt log, then the 18 knotty rings at 17 feet have produced an upper log diameter of 9.0 inches (18 x 0.5). This knotty core emerges at the surface at the upper end of the log, but at the 1-foot stump height the knotty core tapers into the pith, and the log diameter is estimated to be 13.5 inches (27 x 0.5) for this 27-year-old tree. Assuming that the site index 40 tree only grows 0.25 inches in diameter per year, we then estimate that the 54 knotty rings at 17 feet have produced an upper log diameter of 13.5 inches (54 x 0.25); at 1 foot this knotty core tapers into the pith, and the diameter is estimated to be 18.0 inches (72 x 0.25) for this 72-year-old tree.

The final step is to calculate the additional time required for the butt log of the site index 80 tree to reach the same size as the site index 40 butt log. If we assume that diameter growth on the good site continues at 0.5 inches per year, then only about 9 additional years will be needed for the 13.5-inch site index 80 tree to reach the same 18.0-inch diameter as the site index 40 tree [(18.0 - 13.5)/0.5]. At 17 feet this tree probably would grow an additional 4.5 inches in 9 years, and thus have the same 13.5-inch diameter as that of the site index 40 tree.

These calculations illustrate that the good site produced an 18-inch log in only 36 years (27 + 9), while the poor site required 72 years to produce the same size log. Furthermore, the good-site log is better because at 17-feet the small knotty core is surrounded by a 2-1/4-inch thick sheaf of clear wood; for the poor site log the 13.5-inch knotty core emerges at the surface of the upper end of the 17-foot log.

This model illustrates that the patterns of both height and diameter growth in the early formative years largely determine clear bole length, log diameter, and the size and shape of the knotty core. This model also shows how tree height and diameter growth data can be used to estimate the dimensions of the knotty core and of the log itself. Tree height-growth values used in this model were taken from detailed stem analyses of black oak (fig. 1). However, for illustrative purposes, clear bole length was assumed as one-third of total tree height, and an even diameter growth was assumed for all portions of the log. The precision of this model could be improved by studies that better define diameter growth and clear bole length for different sites, stand densities, tree ages, crown classes, and tree species.

SILVICULTURAL IMPLICATIONS

This model is based upon dominant and codominant trees that achieve maximum, uninterrupted height growth (fig. 1). Such rapid-growing trees are most commonly found in even-aged stands. In addition, even-aged stands on good sites have greater numbers of valued intolerant species, such as yellow-poplar, white ash, black cherry, and black walnut. Accordingly, even-aged silviculture has been recommended as the best means to grow high-quality upland hardwoods(Roach and Gingrich 1968).

Hardwood forest management of the future will require more precise identification of site quality. On the best sites very intensive silviculture might be applied, including planting of superior genotypes and cultural practices approaching those used in agriculture and management of orchards. To produce the greatest volume of high-grade veneer and saw logs in the shortest time, we should concentrate our efforts on selected crop trees on the better sites. And then we should concentrate on the butt log, because this is the portion of the tree where the best grades of lumber and veneer can be produced; also, reducing the number of defects in the butt log will result in the greatest gains in log quality and log value (Boyce 1966, Boyce and Schroeder 1963, Allen 1964). For high-grade dominant and codominant trees the goal should be early formation of clear butt logs having small knotty cores surrounded by thick sheafs of rapidly growing clear wood.

High-quality upper logs can occasionally be produced on superior sites (site index 80+) because of very rapid early height growth (figs. 2 and 3). However, developing second logs into Grade 1 saw logs will mean longer rotations, because more years are required for the second logs to reach minimum scaling diameter. During the development of the Forest Service Standard Hardwood Saw Log Grades, it was found that butt logs had much more high-grade lumber than upper logs because diameters were larger, knotty cores smaller, knots fewer, and the proportion of clear wood to knotty wood larger (Vaughan et al. 1966).

Pruning selected crop trees on good sites (site index 70+) should be considered (Allen 1964, Boyce 1966, Clark and Seidel 1961, Crow 1962, Skilling 1958, Stern 1971). Species such as black walnut, cherry, white ash, and yellow-poplar should be given first consideration. Selected Grade 1 crop trees (Boyce and Carpenter 1968) of white, red, and black oak also might be profitably pruned on the better sites. Crop trees should be pruned to perhaps one-half total tree height when they are young (less than 25 years) so that knotty cores will be small and long, clear boles will be formed early. On superior sites (site index 80+) pruning selected black oaks to one-half total height can produce 17-foot clear boles in 17 years or less, and 33-foot clear boles in 38 years or less.

As soon as the clear butt log has been formed, stand density should be reduced to produce maximum diameter growth. Stand densities at or somewhat below the lower limit of full site utilization are recommended--this corresponds to the "B level" of stocking recommended by Roach and Gingrich (1968). Frequent thinning is recommended on superior sites (site index 80+) so that maximum diameter growth can be maintained on the selected crop trees. Occasional thinning is recommended for good (site index 70 to 80) and medium sites (site index 60 to 70). Thinning and other silvicultural treatments are not recommended for poor sites (site index 60-) because it is unlikely that trees on such sites will repay cultural investments for growing quality saw logs. However, initial rapid growth does produce limited amounts of pulp and fiber on poor sites, so possibly short rotations for these less valuable products is the best management goal.

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☆U.S. Government Printing Office: 1974--762-575

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USDA FOREST SERVICE
RESEARCH PAPER NC-104
1974

PREDICTING THE LOSSES IN SAWTIMBER VOLUME AND QUALITY FROM FIRES IN OAK-HICKORY FORESTS

1. lumber value losses in dollars
2. volume losses in board feet
3. length of defect in feet
4. cross sectional area of defect in square inches

robert m. loomis

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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Manuscript approved for publication December 4, 1973

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THIS IS ANOTHER OF OUR "NEW LOOK" RESEARCH PAPERS, designed (hopefully) to serve the special needs of each of our two major clients: the practitioner and the scientist.

Realizing that the needs and interests of our two major "clients"--the scientists and the practitioner--are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better. You are about to sample the first fruit of this effort.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

The Documentation section describes the details of the research process. It is for the reader interested in laboratory and field procedures, tabulations, statistical analysis, and philosophical discussion. This section, too, is self-contained.

Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. *We would like to have your opinion.*

PREDICTING THE LOSSES IN SAWTIMBER VOLUME AND QUALITY FROM FIRES IN OAK-HICKORY FORESTS

Robert M. Loomis

APPLICATION

Whether trees are killed or only damaged in a forest fire, there are losses to the forest owner. Losses are soon apparent if the trees are killed, but losses due to injury may not be obvious for many years, perhaps not until harvest. Basal fire wounds provide a threshold for insects and decay which may eventually kill the tree or reduce the quantity and quality of usable wood at harvest time (fig. 1).

Figure 1.--*Basal fire wound on oak tree.*

We have found a way to predict sawtimber losses due to fire wounding by taking a few simple measurements and substituting them in some damage estimate equations we have developed. The equations apply to northern red, black, scarlet, white, and chestnut oaks for all sites in the oak-hickory type. The equations apply to oaks that have basal fire wounds from a single fire and that are expected to survive until harvestable. Any tree having a fire wound extending more than two-thirds (one-half for scarlet oak) of the circumference at 1 foot above the ground is unlikely to survive until harvest time. The equations do not apply to trees that already have butt rot. The prediction equations are most applicable for State and regional timber surveys of fire damage. They may also be used for individual fires and stands but the estimates will be less accurate.

The equations predict: (1) lumber value losses, (2) volume losses, (3) length of scalable defect above stump height, and (4) cross sectional area of the scalable defect at stump height.

To use the equations, the following data are needed: (1) d.b.h. outside bark in inches at time the tree was wounded, (2) wound length in feet above a 1-foot stump, (3) wound width in inches measured as an arc 1 foot above ground, (4) the logarithm (base 10) of the estimated number of years before the tree will be cut, and (5) current or predicted future selling price per board foot of No. 1 common 4/4 lumber of same species.

Wound measurements are most easily made a year or two after a fire when wounds are more evident. If appraisals are made immediately after a fire, the procedure given in an earlier manuscript (Loomis 1973) should be used.

Suppose a black oak is damaged by fire and its measurements are:

DBH outside bark at time tree was wounded=10 inches.
Wound length (WL) above a 1-foot stump=4.5 feet.
Wound width (WW) at 1 foot above ground=15 inches.
Logarithm (base 10) (L) of estimated number of years before tree will be cut =logarithm of 30=1.477.
Current selling price (SP) of No. 1 common 4/4 lumber of same species=$150 per 1,000 fbm or $0.15 per board foot.

To predict the losses, simply "plug in" the data called for in the following four equations.

Lumber Value Loss

To predict lumber value loss in this tree 30 years in the future use the equation:

$$\text{lumber value loss}=SP[-82.45+3.08(WL)+38.94(L)+2.18(DBH)+0.71(WW)],$$

$$=0.15[-82.45+3.08(4.5)+38.94(1.477)+2.18(10)+0.71(15)],$$

$$=\$3.20.$$

Volume Loss

To predict volume loss (International 1/4-inch scale) for this tree 30 years in the future use the equation:

$$\text{volume loss}=-79.14+3.82(WL)+41.14(L)+1.54(DBH)+0.59(WW),$$

$$=-79.14+3.82(4.5)+41.14(1.477)+1.54(10)+0.59(15),$$

$$=23 \text{ fbm}.$$

Length of Scalable Defect

To predict the length of scalable defect above stump height for this tree 30 years in the future use the equation:

$$\text{length of scalable defect}=-2.88+0.98(WL)+2.37(L)+0.07(WW),$$

$$=-2.88+0.98(4.5)+2.37(1.477)+0.07(15),$$

$$=6 \text{ feet}.$$

Cross Sectional Scalable Defect

To predict the cross sectional area of scalable defect at stump height for this tree 30 years in the future use the equation:

$$\text{cross sectional scalable defect}=-185.09+4.67(WL)+111.10(L)+5.13(DBH)+1.32(WW),$$

$$=-185.09+4.67(4.5)+111.10(1.477)+5.13(10)+1.32(15),$$

$$=71 \text{ square inches}.$$

DOCUMENTATION

The 253 oak study trees used to develop the foregoing equations were found in Missouri, Pennsylvania, Kentucky, Ohio, Illinois, and Indiana. They were dominants or codominants of sawtimber size growing on medium or better sites (50 to 90 site index) for black oak (Schnur 1937). Any fire-caused volume loss or log grade change on the lower bole was used in the analysis. Sometimes a damaged bole was as long as 32 feet. Basal fire wounds ranged in age from 6 to 87 years. The trees were felled and the boles scaled and graded by logs in two ways: (1) ignoring fire wounds and associated losses in volume and grade but deducting other normal defect, and (2) deducting losses in volume and grade due to fire as well as other normal defects. The boles were scaled using the International 1/4-inch Rule (USDA Forest Service 1964); logs were graded according to a USDA Forest Service guide (1965).

The board foot volume figures for logs were multiplied by "quality index" (Q.I.)[1] and the sum of the products per tree for "fire" were subtracted from the products for "no fire" to give a "lumber value loss factor."

The four prediction equations in the application section were produced by stepwise regression (Dixon 1968). The coefficient of determination and standard error of the estimate were as follows:

Equations	R^2	Syx
Lumber value loss=SP[-82.45 +3.08(WL)+38.94(L)+2.18(DBH) +0.71(WW)]	0.45	17.03
Volume loss=-79.14+3.82(WL) +41.14(L)+1.54(DBH) +0.59(WW)	.54	15.02
Length scalable defect=-2.88 +0.98(WL)+2.37(L)+0.07(WW)	.73	1.92
Cross sectional area scalable defect=-185.09+4.67(WL) +111.10(L)+5.13(DBH)+1.32(WW)	.48	32.81

The analysis included four dependent variables (lumber value loss factor, volume loss, length of defect, and cross sectional area of defect) and four independent variables (wound length above a 1-foot stump, wound width at 1 foot (stump height), wound age, and d.b.h. outside bark at time of fire).

Regression analysis showed all four independent variables to be significant for prediction of lumber value loss factor, volume loss, and cross sectional area of defect for all oak species combined. The variable, d.b.h. outside bark at time of fire, did not contribute significantly in predicting length of scalable defect for all oak species combined.

Wound length was found to be the best single predictor of the four dependent variables. This variable was followed by wound age (time from wounding to harvest), tree d.b.h. outside bark, and by wound width as regression variables in the selection process.

The decision to combine oak species was based on covariance analysis, consideration of number of trees, variable range, and examination of residuals by species over independent variables. For the oaks as a group, 70 percent of lumber value loss was due to volume loss and 30 percent to quality loss.

[1]Quality index (Q.I.) was developed by Herrick (1946) and used by McCauley and Mendel (1969) and Mendel and Smith (1970). Indexes for the factory grade logs of northern red, black, scarlet, and white oaks were from Mendel and Smith (1970); chestnut oak from McCauley and Mendel (1969); subfactory grade logs from lumber yield tables (Hanks 1973). All indexes for Appalachian hardwoods were based on 1964-68 prices, f.o.b. mills, Johnson City, Tennessee (Lemsky 1964-68); chestnut oak based on 1962-66 prices.

The equations in the application section are usable over a range of sites in commercial oak-hickory forests because the predictions are independent of merchantable height. However, site (including local microclimate) does affect volume and quality loss indirectly by influencing variables such as probability of decay entry, potential butt log quality, growth, and healing rates.

Wound Length

Wound length was the best predictor of the two wound dimensions considered. Hepting (1941) recognized that wound height affected amount of cull, but since wound height was unavailable he used wound width and wound age for predicting cull following fire in Appalachian oaks. Toole (1959) predicted the length of heart rot that extended from the wound top upward in southern bottomland hardwoods by using wound width, stump diameter, and wound age.

Wound Age

The longer a tree has been injured, the greater the chance that the injury will be attacked by wood destroying pathogens. Once decay starts, however, the rate of decay depends on other factors besides wound age: the resistance of the species to decay, the size of the wound, and the rate that the tree forms callus tissue to close the wound. Jensen (1969) presents evidence that supports the hypothesis that a wound must be open to maintain an active decay column. Also, the larger the wound, the longer it takes callus to close it and thus the more extensive the decay that may develop.

Tree Size

Decay following injury does not usually extend into the new growth of the tree (fig. 2). The larger the tree at time of injury, the greater the probability of volume and quality loss. Saplings, even though they develop rot after wounding, usually heal rapidly thus confining the defect to a small area within the tree center where it is least important. Because pole-sized and small saw-timber trees are nearing harvestable size, much volume and quality can be lost to decay if wounds do not heal promptly (fig. 3).

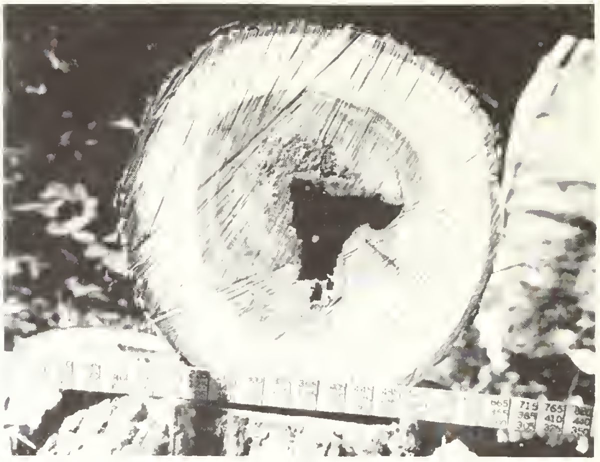

Figure 2.--*This hickory (now 14.8 inches d.b.h.) was only 7.5 inches d.b.h. when wounded. Decay did not spread to new growth.*

Figure 3.--*Where decay causes hollowing of tree bole, the callus growth may curl inward thus permitting an opening that may exist for many years. After 22 years the wound on this section of 50-year-old scarlet oak still had not closed.*

Trees nearing the size for cutting suffer little if cutting is not delayed too long because most of the defect may be removed with the slab in sawing.

Wound Width

In general, oak trees having wounds less than 6-inches wide will probably not lose any quality and no more than about 3 board feet in volume. Trees less than pole size are unlikely to lose any quality. Typically, the width of a single basal wound will be about 50 percent of tree circumference at stump height. This is caused by the "chimney effect" on the leeward side of the tree during a fire. Where wounds exceed 50 percent of circumference, mortality is much more likely because heat has killed the cambium on the windward as well as the leeward side.

As wounds exceed 50 percent the possibility of breakage is greater and tree vigor may be reduced due to loss of conducting tissue (fig. 4). The larger the wound or potential wound as indicated by bark blackening (Loomis 1973), the greater the probability of either immediate or delayed mortality. The probability of crown damage and loss in volume and grade of potential lumber is also greater.

Figure 4.--*Basal fire wounds frequently cause mechanical weakness due to decay and insect activity. This 19-inch black oak was 17 inches d.b.h. when wounded 14 years earlier; wound width at 1 foot was 41 inches--84 percent of circumference.*

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☆U.S. Government Printing Office: 1974 — 762-715

Shhhh...noise pollutes too!

USDA FOREST SERVICE
RESEARCH PAPER NC-105
1974

DESIGN of thin shear blades for crosscut shearing of wood

Rodger A. Arola, Thomas R. Grimm

NORTH CENTRAL FOREST EXPERIMENT STATION
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CONTENTS

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Manuscript approved for publication November 23, 1973

DESIGN OF THIN SHEAR BLADES

FOR CROSSCUT SHEARING OF WOOD

Rodger A. Arola and Thomas R. Grimm

BACKGROUND

During the early 1960's one major obstacle that designers of wood harvesting equipment had to overcome was the lack of information on force and power requirements for crosscut shearing of wood. Over the last 10 years reliable information has been published. However, throughout this 10-year period we have not witnessed widespread acceptability of shear-felled sawtimber as we have with shear-felled pulpwood. Why? The major deterrent has been the splitting of the butt saw log which causes severe monetary losses in the production of lumber.

McIntosh and Kerbes (1968) found that shearing trees reduced felling costs of conventional methods by 37.9 percent in a clearcut lodgepole pine stand and by 48.5 percent in Douglas fir. However, the butt log split an average of 10 inches in the lodgepole pine causing an estimated trim loss of 3 fbm per tree. A thinner shear blade reportedly used on the Douglas-fir limited splitting damage to 4 to 5 inches and crushing damage 1 to 2 inches from the sheared face. All material was unfrozen. Schmidt and Melton (1968) concluded that the type of tree shear they investigated was "not the ultimate machine for use in felling saw log trees."

Research has shown that splitting damage as well as force and power requirements can be decreased by using thinner shear blades (Arola 1971, 1972). But, how thin can we make functional shear blades? Thin shear blades are extremely prone to lateral buckling due to the presence of compressive stresses within the plane of the blade (in addition to unbalanced lateral pressures)(fig. 1).

The problem is further complicated by the fact that conventional "thick or deep beam" analysis does not apply to thin plates subjected to beam-type loadings. One standard assumption in the analysis of deep beams is that plane sections before stressing remain plane after stressing within the elastic range. This assumption, however, is an oversimplification for shear blades having the dimensions of a thin plate rather than a beam. Elasticity theory must be used to determine the stress distributions resulting from beam-type loadings, and complicated plate theory used to determine the critical buckling load or stress which causes failure.

Figure 1.--*Buckled thin shear blade after crosscut shearing a 6-inch diameter oak bolt. Blade thickness is 1/8-inch $B/A \approx 1.0$.*

The literature revealed limited information about methods to predict the elastic stability of thin plates subjected to in-plane loadings. Prestressing can be used to increase the stability of thin plates, but information is also limited on prestressed plates or shear blades.

Despite the lack of theoretical information about the design of thin shear blades there are reports of experimental tests using thin prestressed shear blades. Wiklund (1967) demonstrated the beneficial effect of prestressing shear blades and tested a 10 mm (0.4 in.) thick blade to shear wood 20 to 25 cm (8 to 10 in.) in diameter. In his analysis he treated the thin blade stress distribution similar to that in deep beams subjected to the same loadings. He used a mechanical test arrangement to prestress the shear blade while the stress level was monitored with strain gages. Wiklund also cited field tests conducted in Russia with two opposing prestressed, 5 mm- (0.2 in.) thick blades to shear frozen trees up to 70 cm (≈28 in.) in diameter. Cuts were very smooth with little splitting damage. So, there is an advantage in using thin shear blades to reduce splitting damage and the force needed, and being able to predict increases in blade stability by prestressing.

The Forest Engineering Laboratory therefore initiated an analytical study which led to the development of a versatile computer program for thin plate analysis. (Appendix A). The program was used to solve instability problems of edge-loaded thin plates having several possible shear blade configurations and three different prestress methods, as well as numerous other thin rectangular plate instability problems to which some solutions were previously nonexistent.

PURPOSE

The purpose of this paper is: (1) to present a measure of stability for establishing critical buckling loads for thin rectangular plates which have different depth/width (B/A) or aspect ratios and clamping (boundary) conditions and are subjected to different in-plane compressive loads (see Appendix B for explanation of symbols); (2) to indicate the possible increase in plate stability by applying alternative in-plane prestress loadings; and (3) to exemplify how a designer could use this information to determine whether the critical buckling load will be reached with the expected shear loads, and how prestressing can increase blade stability.

PLATE CONFIGURATIONS ANALYZED

Numerous basic configurations of thin rectangular plates were analyzed. Those which are approximations to thin shear blades are discussed in the body of this paper. The general plate solutions, some of which were previously unsolved, are included in Appendix C.

The primary plate dimensions and coordinate system, the assumed crosscut shear loads, and the prestress configurations were all treated in this analysis (fig. 2). The main crosscut shear load assumed was a cosine-shaped, in-plane distributed load. However, a uniformly distributed load was also analyzed and a relationship developed between the two. These compressive loads which cause instability are considered to be applied to the top edge of the plates with no lateral pressure or perturbation. The in-plane prestress distributions include a uniform tension, a linearly increasing tension, and a bending moment-type stress distribution applied to the vertical edges of the plates.

The plate boundary conditions include clamped and free edges. Additionally, some of the solutions presented in Appendix C include plates with simply supported edges, and/or combinations of simply supported, clamped, and free edges.

The clamped boundary condition indicates that the edge is restrained with respect to deflection and rotation out of the plane of the plate. The simply supported boundary condition indicates that the edge is restrained with respect to deflection out of the plane of the plate but not with respect to rotation.

Some of the plates considered are also assumed to be supported at the bottom edge by a rigid, clamped support. It is assumed that this type of support results in a compressive stress distribution applied to the bottom edge of the plate indentical to the shear load applied to the top edge (fig. 2c).

GENERAL DISCUSSION

The theory used in this work is accurate only for thin rectangular plates made of a linearly elastic, homogeneous, isotropic material. The theory can be applied to thicker plates, but with less accuracy. As a rule of thumb a plate is classified as thin if the ratio L/t is greater than 20, where L is the smaller of the two primary dimensions (A and B) and t is the plate's thickness.

The stability of a thin plate is measured in terms of a critical buckling

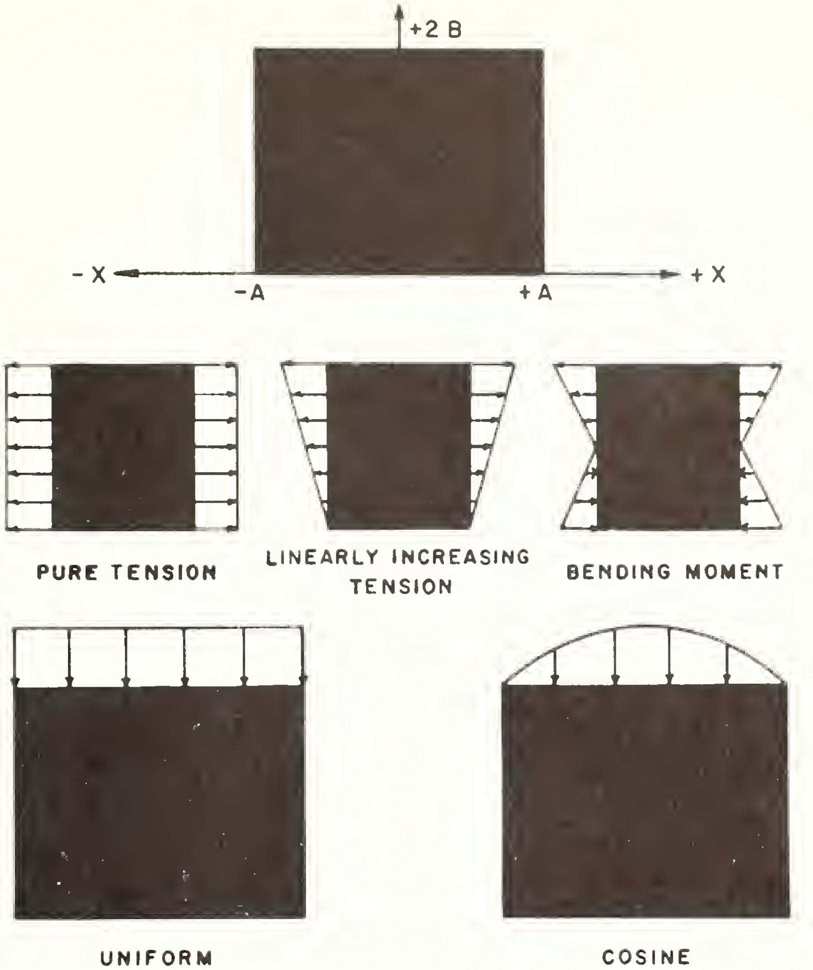


Figure 2.--*Cases treated in thin plate (shear blade) analysis: (A) plate dimensions and coordinate system; (B) prestress configurations analyzed; and (C) assumed shear load configurations analyzed.*

stress which is defined as the lowest value of the midplane stress or stresses for which the initially flat plate has two equilibrium configurations. The two equilibrium configurations are the initial flat configuration and an adjacent infinitesimally deflected configuration. The critical buckling stress establishes where the plate is at a neutrally stable configuration. It is theoretically possible for a plate to remain in its initially flat configuration despite the fact that the in-plane compressive stress exceeds the critical buckling stress. However, the flat configuration is unstable once this stress is reached. Any slight perturbation would cause the plate to buckle.

The critical buckling stress for a given plate configuration is formulated by

$$\sigma_{cr} = \frac{(CKA)\pi^2 D}{t(2A)^2} \text{ or } \frac{(CKB)\pi^2 D}{t(2B)^2}$$

where D is the flexural rigidity of the plate, t is the thickness of the plate, A is one half the plate width in the X direction, CKA is the buckling constant for the A dimension, B is one half the plate depth in the Y direction, and CKB is the buckling constant for the B dimension.

Either of the above expressions make it possible to determine the critical buckling stress for thin plates which have different dimensions and material constants but which are loaded and supported in the same manner and have the same aspect ratio B/A. The buckling constant is independent of material constants for plates having all edges supported. The material properties are accounted for in the flexural rigidity term (D) which is given as

$$D=\frac{Et^3}{12(1-\mu^2)}$$

in which E is the modulus of elasticity, t is the plate thickness, and μ is Poisson's ratio. However, if the plates considered have a free edge or edges, the buckling constant is dependent on Poisson's ratio. For cases with free edges it is therefore necessary to specify the Poisson ratio, along with the buckling constant for a given problem. A value of 0.3 (for steel) has been assumed throughout this analysis.

The prestress distribution analytically applied to the thin plates were expressed in a form similar to that of the buckling constant described above. The peak value of the prestress (PPS) was expressed in terms of a prestress factor (PK), multiplied by the plate stress constant (σ_e). Thus,

$$PPS=(PK)\sigma_e \text{ where,}$$

$$\sigma_e=\frac{\Pi^2 D}{t(2A)^2}.$$

The peak prestress was expressed in the above form so that the numerical results obtained from the instability analysis of the prestressed plates can be applied to other plates with the same aspect ratio but different dimensions and material constants. The effectiveness of the prestress was measured in terms of the increase in the magnitude of the critical buckling stress.

RESULTS

Comparison Between Uniform and Cosine Load Distributions

Most results presented are for plates analyzed with a cosine-type load distribution which, as an oversimplification, was assumed to approximate the blade load due to crosscut shearing of logs. However, the critical buckling stress for several of the same basic plate configurations, but with a uniformly distributed load, was also analyzed. It was found that the total force which will cause buckling for the assumed cosine distributed load (P_c) was less than the total force which will cause buckling for a uniformly distributed load (P_u). This, we believe, is because the cosine-shaped distributed load in effect "wastes" less force near the restrained edges of the plate. The relationship between the total loads for the two assumed load distributions for plates having both clamped and simply supported vertical edges is shown in figure 3.

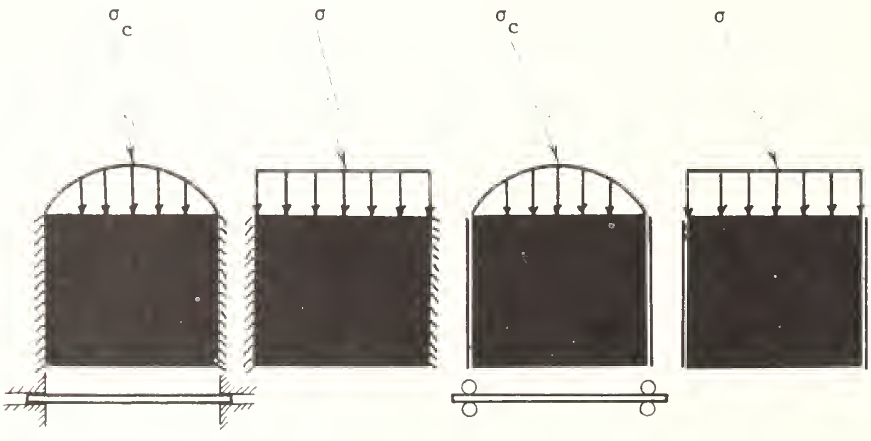


Figure 3.--*Relationship between uniform and cosine distributed buckling loads for clamped thin plates (left) ($P_c \simeq 0.70\ P_u$) and simply supported thin plates (right) ($P_c \simeq 0.75\ P_u$). Where $P_c = {}_0\int^A \sigma_c\, dA = \frac{2}{\pi}(2A)\, t\sigma_c$; and $P_u = {}_0\int^A \sigma\, dA = (2A)\ t\ \sigma$.*

Knowing the total cutting force for a given species and diameter of tree, the results of the instability analysis presented here can relate this cutting force to the peak value of stress. For example, the total force for a cosine distributed load (fig. 3) is

$$P_c = \frac{2}{\pi}(2A)t(\sigma_c).$$

The peak stress is therefore given by

$$\sigma_c = \frac{\pi}{2}\left(\frac{P_c}{(2A)t}\right) \text{ or,}$$

$$\sigma_c = \frac{\pi}{2}\sigma_{avg}, \text{ where}$$

$$\sigma_{avg} = \frac{P_c}{(2A)t}.$$

Thus, the peak stress for the cosine distributed load (σ_c) is found by multiplying the average stress by a factor $\pi/2$ or 1.5708.

If the cutting force were initally assumed to be uniformly distributed on the blade edge and caused buckling, it can be related to the critical buckling stress for cosine-shaped loads. For example, in the case of *two clamped vertical edges* (fig. 3), the total buckling force for the cosine load is equal to ≃ 0.7 times the total force for a uniform load[1]. Also, since

$$2At = \frac{\pi}{2}\frac{P_c}{\sigma_c} \text{ and}$$

$$2At = \frac{P_u}{\sigma_u},$$

these two expressions can be set equal to each other, i.e.

$$\frac{\pi}{2}\frac{P_c}{\sigma_c} = \frac{P_u}{\sigma_u}.$$

Substituting 0.7 P_u for P_c and solving for σ_u results in the following expression:

$$\sigma_u = 0.9094\ \sigma_c.$$

Thus, the critical buckling stress for a thin plate having two clamped vertical edges and a uniformly distributed load can be approximated by multiplying the critical stress for the plate with a cosine load by a factor of 0.9094. A relationship can also be derived for the simply supported boundary condition.

Plates Without Prestressing

Two cases of plate instability illustrate the type of problems that can be solved (fig. 4). Case 1 is a thin plate with a cosine-shaped in-plane load distributed along an otherwise free top (cutting) edge. The vertical edges of the plate are rigidly clamped with respect to rotations and deflections out of the plane of the plate, and are supported by shear forces. The instability in this case is caused by a combination of the compressive stress applied to the top edge and the bending-type stresses in the plane of the plate near the top edge. As the aspect ratio B/A increases, the magnitude of the buckling constant increases until B/A=2.0 (fig. 5, case 1). This plot reveals that for a shear blade loaded and supported as shown for case 1 (fig. 5), it would be wise from a stability standpoint to use a blade with an aspect ratio of at least one. Any further increase in aspect ratio does not yield large increases in the buckling constant.

Case 2 in figure 4 is that of a plate with a rigidly clamped bottom edge as well as clamped vertical edges. Again, the plate is loaded with a cosine-shaped distributed load applied to the top edge but in this case the load is resisted by the bottom edge. The instability is caused by the in-plane compressive stresses in the vertical direction, without any effect of horizontal stresses caused by bending as in case 1. Because there are no bending stresses, the buckling constant is highest for a plate with a small aspect ratio. As the aspect ratio increases, the buckling constant decreases until B/A=1.5 (fig. 4; also fig. 5, case 2). A comparison reveals that case 2 has a consistently higher buckling constant than case 1 and is thus more stable.

---

[1] *T. R. Grimm. Analysis of the instability of thin rectangular plates using the extended Kantorovich method. (Unpublished Ph.D. dissertation on file at Mich. Technol. Univ., Houghton, Mich.) 1972.*

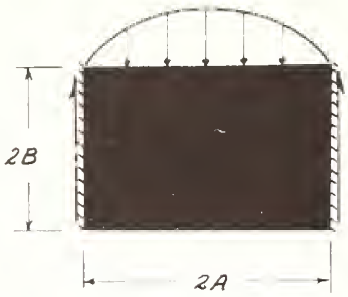
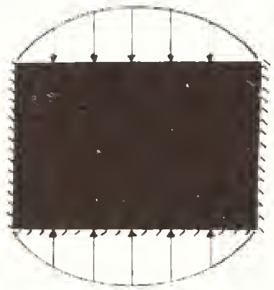
CASE NO.	PLATE CONFIGURATION	ASPECT RATIO B/A	CRITICAL BUCKLING CONSTANT CKA
1	COSINE DISTRIBUTED LOAD 	0.25	1.57461
		0.33	2.00768
		0.50	2.81051
		0.67	3.33195
		1.00	3.82011
		1.50	3.92528
		2.00	3.94223
		3.00	3.94124
2		0.25	6.87814
		0.50	4.84455
		0.75	4.68299
		1.00	4.46835
		1.50	4.42998
		2.00	4.45487

Figure 4.--*Buckling constants for two thin rectangular plates approximating shear blade configurations*[1]

Plates With Prestressing

Plates having the same boundary conditions as those in figure 4, with B/A=1.0, were also analyzed to evaluate three different types of superimposed prestress distributions to increase the blade stability (fig. 6). The in-plane prestress distributions studied include a pure tension, a linearly increasing tension, and a bending moment distribution. A comparison of the magnitudes of the buckling constants with varying prestress factors reveal the effect of these three different prestress distributions on plate stability. The buckling constants were plotted against the prestress factors for the different prestress distributions (fig. 7). In both blade configurations the uniform tension prestress is the most effective for raising the critical buckling stress, the amount of stress that must be reached before buckling will occur. The triangular-shaped prestress is the second most effective, followed by the bending moment distribution.

HOW CAN A DESIGNER USE THIS INFORMATION?

In the following examples of how to use the design information, ideal plate loading and clamping conditions are assumed. The major assumption is that there is no lateral perturbation pressure which would decrease the in-plane load capacity of the blade. In actuality, when thin plates are used as shear blades, conditions are far from ideal. At the start of the actual cut it is unlikely that blade penetration is exactly perpendicular to the fibers--particularly if the cut is made close to the root collar or to a limb juncture. This failure to achieve pure orthogonal cutting conditions causes a lateral pressure on the blade which would increase

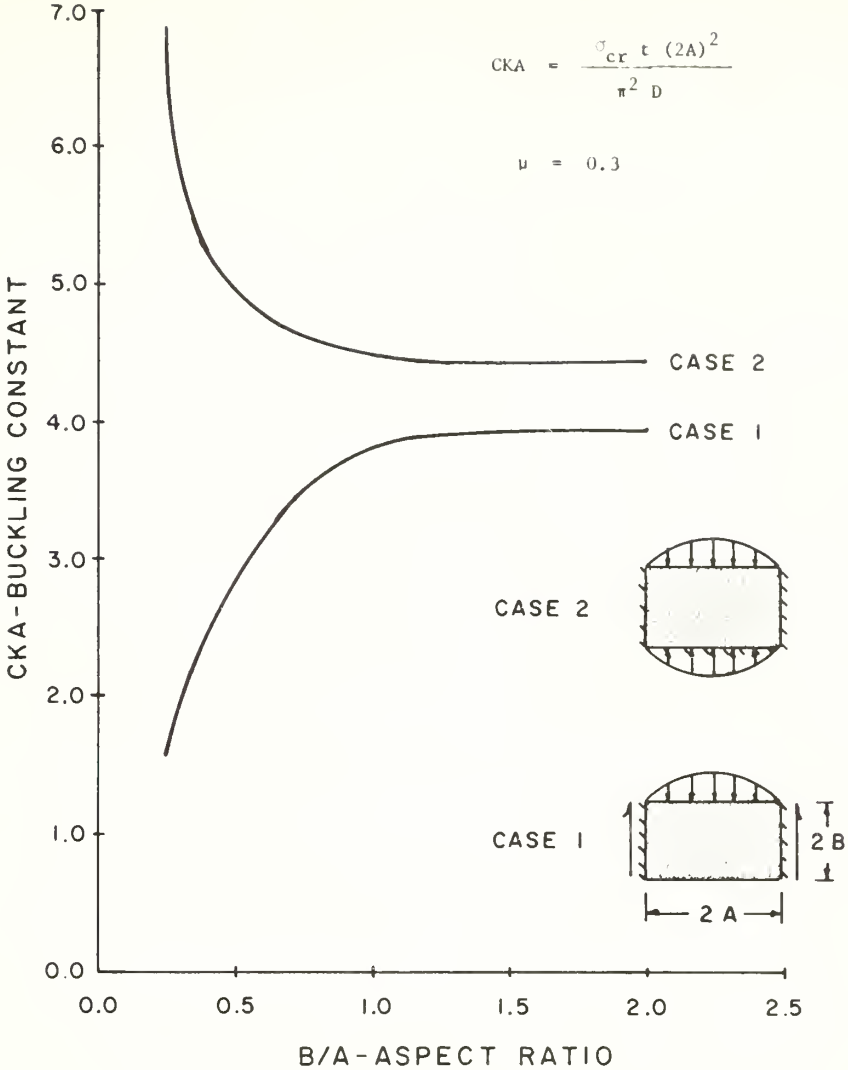


Figure 5.--*Plot of buckling constant vs. aspect ratio for two shear blade configurations*[1]

with penetration as the cutting edge tries to follow the path of least resistance along the fiber lines. Other factors affecting blade performance are misalignment of the blade or plate-containing mechanism, repeated loading, low operating temperatures, and the effect of blade imperfections. If the plate is not flat at the start, the critical buckling stress will be lower.

Because of these factors, the examples below may give theoretical in-plane buckling loads higher than those that actually cause plate or shear blade failure in the field. Nevertheless, we feel the analysis is still useful for preliminary design stages.

Example 1

It will first be assumed that the design engineer has established that his trial shear blade configuration is most closely approximated by sketch A and the plate simplification by sketch B (fig. 8). The L/t ratio is slightly greater than 20 which classifies the plate as "thin."

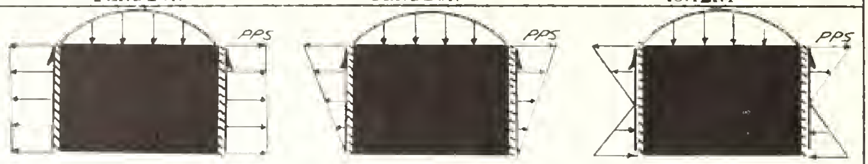
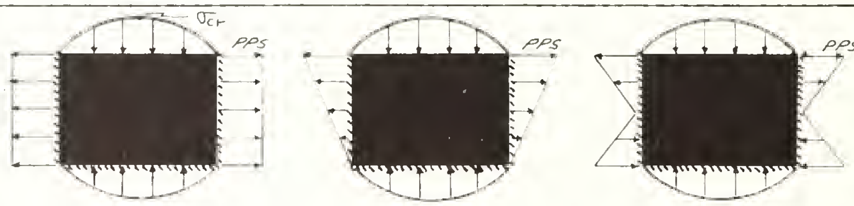
PRE-STRESS FACTOR	TYPE OF PRESTRESS: PURE TENSION	LINEARLY INCREASING TENSION	BENDING MOMENT
CASE 1			
PK	CKA	CKA	CKA
0.0	3.82011	3.82011	3.82011
1.0	4.16841	4.13967	4.10945
2.0	4.46377	4.41270	4.35567
3.0	4.72814	4.65817	4.57458
4.0	4.96946	4.88252	4.76775
CASE 2			
0.0	4.46835	4.46835	4.46835
1.0	4.73063	4.69595	4.65917
2.0	4.97107	4.90410	4.82733
3.0	5.19612	5.09831	4.96290
4.0	5.40748	5.30128	5.20825

Figure 6.--*Buckling constants for prestressed shear blades*[1] *(B/A = 1.0).*

We will assume the design engineer is interested in a blade without prestressing if possible, but is ready to consider adding a uniform prestress to increase the buckling constant for the assumed configuration. The following steps illustrate his checkout procedure.

The flexural rigidity (D) is first calculated for the blade.

$$D=\frac{Et^3}{12(1-\mu^2)}$$

$$=\frac{(30 \times 10^6)(0.375)^3}{12(1-0.3^2)}$$

$$D=144{,}875 \text{ in.-lb.}$$

The critical buckling stress (σ_{cr}) is then computed (for cosine distributed load):

$$\sigma_{cr}=\frac{(CKA)\pi^2 D}{t(2A)^2}$$

$$=\frac{(2.81051)(3.1416)^2\ (1.44875\times 10^5)}{(0.375)(18)^2}$$

$$\sigma_{cr}=33{,}075 \text{ psi .}$$

The expected crosscut shearing stress under actual cutting conditions must now be determined. A nomograph (fig. 9) can be used to estimate force requirements for

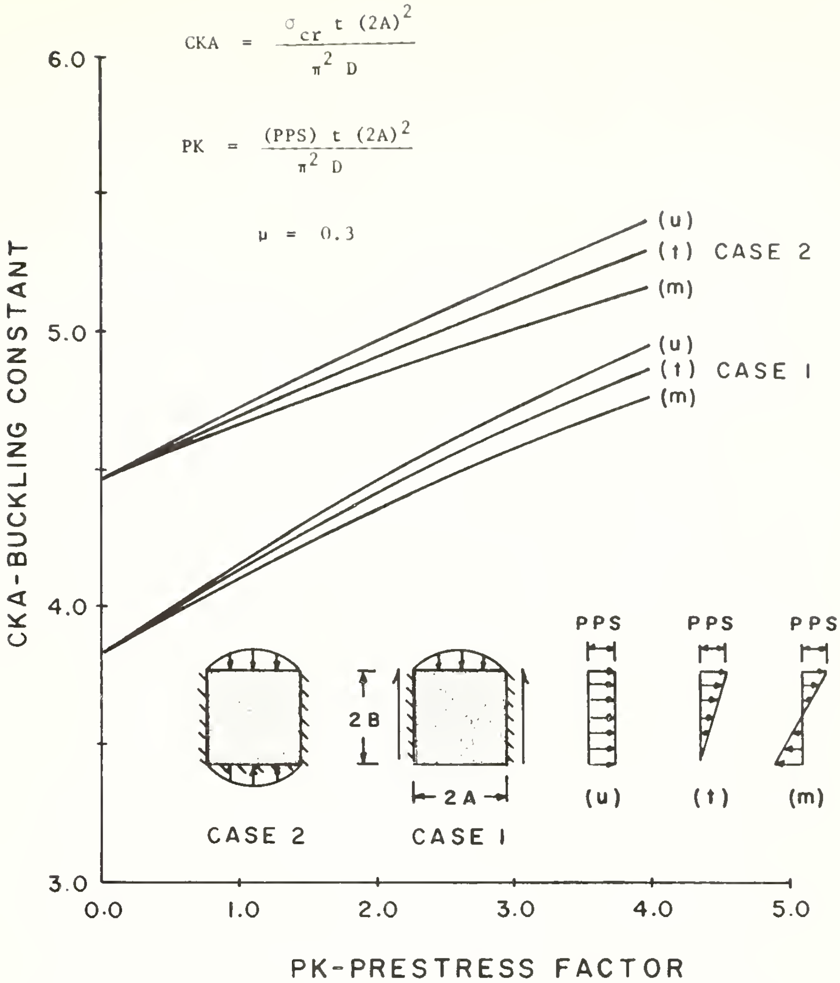


Figure 7.--*Plot of buckling constant vs. prestress factor*[1] *Prestress distributions are uniform (u), triangular (t), and bending moment (m). (B/A = 1.0).*

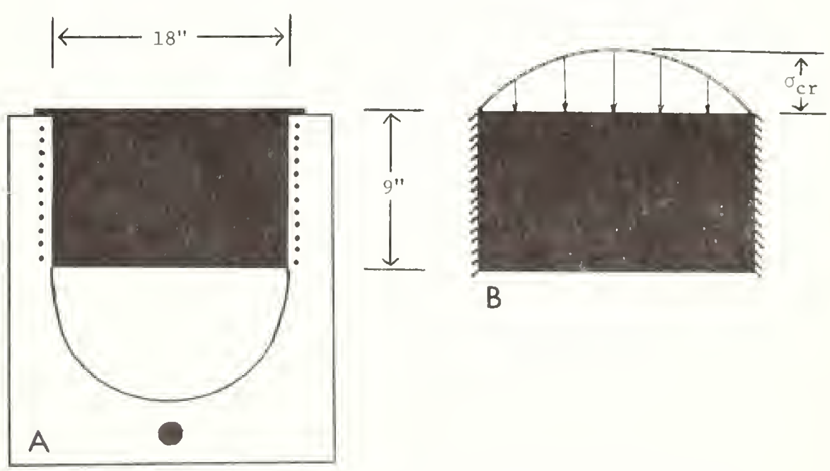


Figure 8.--*Assumed shear blade configuration and simplified rectangular plate which most closely approximates this configuration. (For case A: t = 3/8 inch, E = 30 x 10*^{6} *psi, and* $\mu = 0.3$*; for case B: B/A = 0.5, and CKA = 2.81051 (from fig. 4 case 1)).*

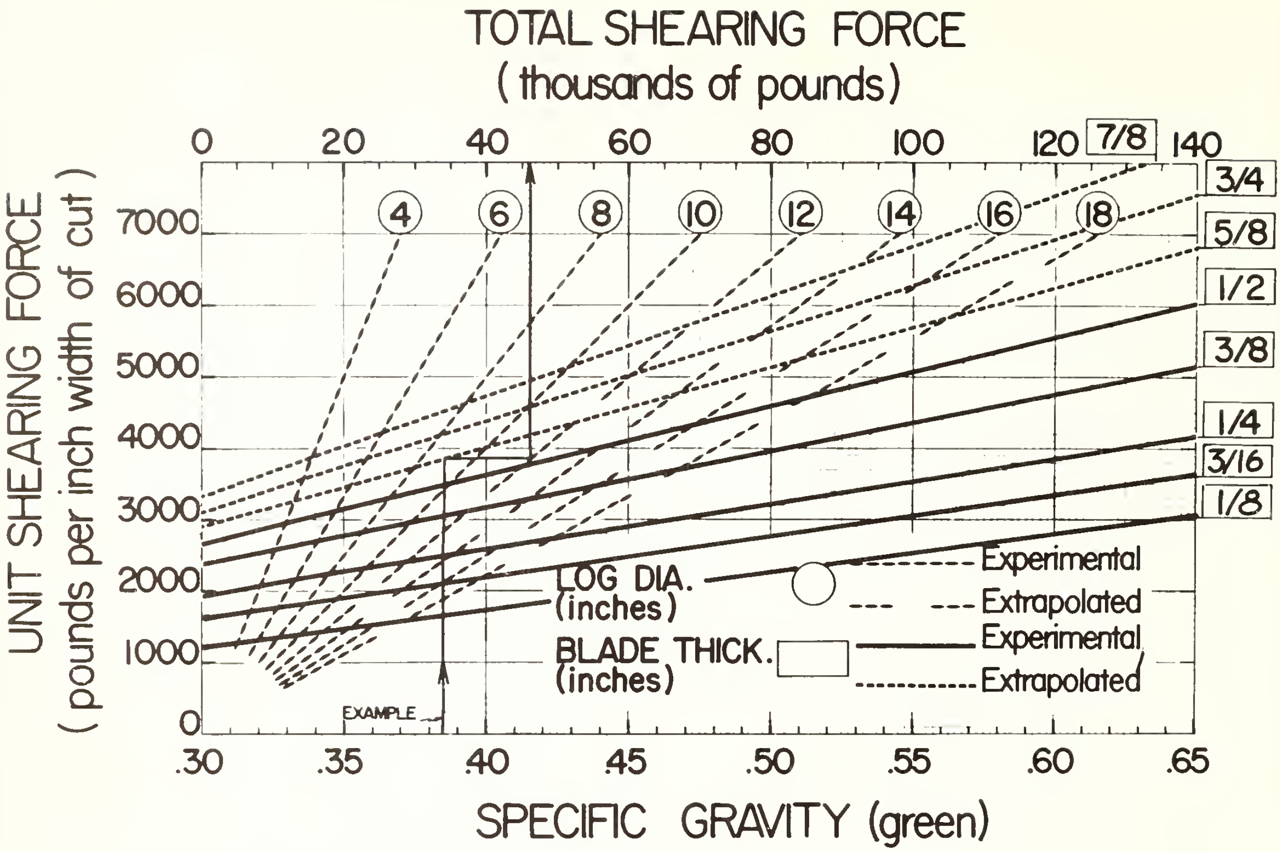


Figure 9.--*Nomograph to estimate shearing force for different blade thicknesses.*

shearing unfrozen species ranging in specific gravity (green) from 0.30 to 0.65, for log diameters up to 18 inches, and blade thickness from 1/8 inch to 7/8 inch (Arola 1972). In this example it will be assumed that the specific gravity of the material to be sheared is 0.50. From the nomograph, the total shearing force is estimated to be 72,000 pounds. To determine the average crosscut shearing stress (σ_{avg}), it is assumed that the total shearing load is distributed uniformly over the thickness and width of the blade (this is contrary to the assumed cosine distribution of figure 3; however, a correction will be made):

$$\sigma_{avg} = \frac{\text{total shearing force}}{t(2A)}, \text{ or}$$

$$\frac{\text{unit shearing force}}{t},$$

$$= \frac{72{,}000}{(0.375)(18)}, \text{ so}$$

$$\sigma_{avg} = 10{,}667 \text{ psi.}$$

This average shearing stress must now be adjusted to correspond to a peak shearing stress value (σ_c) for a cosine distributed load. Thus, from the previous discussion,

$$\sigma_c = 1.5708(\sigma_{avg})$$

$$= (1.5708)(10{,}667)$$

$$\sigma_c = 16{,}755 \text{ psi.}$$

Elastic buckling occurs if $\sigma_c > \sigma_{cr}$.

From these calculations the blade is elastically stable, thus prestressing is not necessary.

Example 2

This example will illustrate a blade configuration that is not elastically stable and how the stability can be increased by changing the support conditions and by adding a uniform prestress of varying magnitudes.

It is first assumed that an 18 by 18 inch (B/A=1.0), 1/4-inch thick blade will be used (to reduce log splitting damage). The L/t ratio for this plate is much greater than 20 and definitely is classed as a thin plate. Further, it is assumed that hard maple up to 18 inches in diameter will be sheared (green specific gravity = 0.65).

The flexural rigidity of the blade is first calculated:

$$D=\frac{Et^3}{12(1-\mu^2)}$$

$$=\frac{(30x10^6)(0.25)^3}{12(1-0.3^2)}$$

$$D=42,926 \text{ in.-lbs} .$$

In the calculations to follow for prestressed shear blades, the uniform prestress magnitudes are incremental values of the plate stress constant. Thus,

$$PPS=PK(\sigma_e) ,$$

where PK takes on values of 0.0, 1.0, 2.0, 3.0, and 4.0. The plate stress constant is calculated as

$$\sigma_e=\frac{\pi^2 D}{t(2A)^2}$$

$$=\frac{(3.1416)^2 (42,926)}{(0.25)(18)^2}$$

$$\sigma_e=5,230 \text{ psi} .$$

Three different blade configurations are used in this example (fig. 10). Case A is a simply supported plate with two edges loosely contained in a slotted assembly (contained edges are free to rotate) and the bottom edge has no restraint. In case B, the blade is rigidly contained along the two vertical edges and the bottom edge is free. This case also considers the addition of an alternative uniform prestress of varying magnitudes. For case C, a rigid support along the bottom edge is added. The critical buckling constants are tabulated for each alternative plate configuration and prestress factor (fig. 6).

From the nomograph (fig. 9), the total shearing force for a 1/4-inch blade is estimated to be 75,000 pounds for an 18-inch-diameter hard maple tree (sp. gr. = 65). The estimated average crosscut shearing stress is calculated as

$$\sigma_{avg}=\frac{75,000}{(0.25)(18)}$$

$$\sigma_{avg}=16,667 \text{ psi} .$$

This average stress is adjusted to a peak shearing stress for a cosine distributed load. Thus,

$$\sigma_c=1.5708(\sigma_{avg})$$

$$=1.5708(16,667)$$

$$\sigma_c=26,180 \text{ psi} .$$

For each alternative combination in fig. 10 the critical buckling stress is calculated from

$$\sigma_{cr}=\frac{(CKA)\pi^2 D}{t(2A)^2} .$$

A comparison between the critical buckling stress and expected crosscut shearing stress reveals whether the blade will buckle elastically. Thus, if

$$\sigma_c>\sigma_{cr} ,$$

elastic buckling is expected.

Based on this comparison of the calculated peak stress value (σ_c=26,180 psi) with the critical buckling stresses it is apparent that both cases A and B are unsatisfactory and buckling would occur under the stated conditions. For case C, the plate is determined to be elastically stable with a prestress factor slightly greater than 2.0.

Several factors were previously discussed which would affect blade performance. Additionally, this design selection does not consider the effect of repeated loading close to the critical buckling stress. It would be desirable to have a "critical buckling fatigue limit" based on repeated

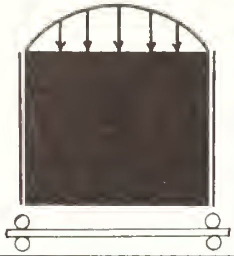
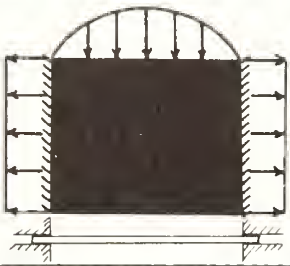
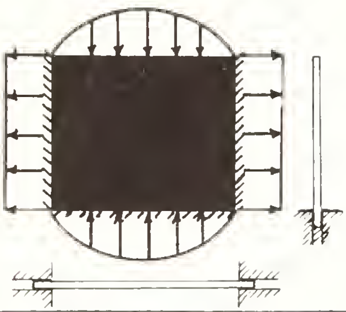
CASE	Prestress Factor PK	Critical Buckling Constant CKA	Critical Buckling Stress σ_{cr} (psi)
A 	0.0	2.10034	10,985
B 	0.0	3.82011	19,980
	1.0	4.16841	21,800
	2.0	4.46377	23,345
	3.0	4.72814	24,730
	4.0	4.96946	25,990
C 	0.0	4.46835	23,370
	1.0	4.73063	24,740
	2.0	4.97107	26,000
	3.0	5.19612	27,175
	4.0	5.40748	28,280

Figure 10.--*Critical buckling stresses for alternative shear blade configurations and uniform prestressing (Example 2). For the calculation of critical buckling stresses the following assumptions were made: 18-inch by 18-inch shear blade (B/A = 1.0), t = 1/4 inch,* $E = 30 \times 10^6$ *psi,* $\mu = 0.3$*, and* $\sigma_e = 5{,}230$ *psi.*

loadings. However, such a figure is nonexistent to our knowledge. Therefore, design judgment must be used to pick a safety factor that would be considered satisfactory.

Thus, to finalize the example we will assume that a prestress factor of 4.0 has been chosen. The uniform prestress magnitude is then calculated from

$$PPS = PK(\sigma_e)$$

$$= (4.0)(5230)$$

$$PPS = 20{,}920 \text{ psi} .$$

SUMMARY AND CONCLUSIONS

Shear blades have generally not been widely accepted as a tool for felling sawtimber due to excessive splitting damage in the butt log adjacent to the sheared face. Research has shown that splitting damage and force requirements can be reduced by decreasing blade thickness. However, a major problem exists with thin shear blades--they have limited structural stability. Even though the yield point of the blade material has not been reached the plate can buckle laterally and ultimately fail.

Methods to analyze thin rectangular plates for load carrying capacity are highly theoretical and extremely difficult and time consuming to calculate. A versatile computer program has been written[1] to analyze the elastic stability of thin rectangular plates subjected to in-plane compressive loadings with varying boundary conditions. The computer program is also capable of determining the effectiveness of various prestress configurations for increasing plate stability.

Several rectangular plate configurations, prestress conditions, and boundary conditions are discussed in this paper to show that thin plate solutions can be used to approximate thin shear blade configurations. Critical buckling constants have been presented for numerous plate problems as a measure, or indicator, of plate stability. We have shown how the elastic stability of thin rectangular plates can be increased by several prestressing alternatives.

By way of formulas and examples, we have demonstrated how the design engineer can use the results of this analysis to mathematically analyze thin shear blades and to estimate expected critical buckling loads. Further, we have shown how the blade stability can be increased by changing boundary or clamping conditions and by prestressing the blade.

Plate problems of more general applicability, some of which had no previous solutions, are included in Appendix C.

An otherwise very complicated problem has been reduced to a very simple checkout and design procedure that a design engineer can follow to estimate the stability of thin shear blades and methods to increase elastic stability. The foregoing analysis is recommended as a starting point in thin shear blade design.

APPENDIX A

Analysis of the Instability of Thin Rectangular Plates Using the Extended Kantorovich Method[1]

The extended Kantorovich method is used to obtain solutions to a large number of previously unsolved elastic buckling problems of thin rectangular plates. In the present work this method is specially adapted to a numerical method of solution. Earlier workers have applied the Kantorovich method to a small number of plate buckling problems but have not used numerical methods of solution.

The classical Kantorovich method involves reducing the problem of minimization of a double integral, the plate potential, to the problem of minimizing a single integral. This is accomplished by using the Galerkin method and expressing the plate equilibrium equation in terms of its Galerkin equation. The deflection surface of the plate is then assumed to be expressible in terms of two separable deflection functions. One of these functions is then assumed *a priori* such that it satisfies boundary conditions, and the remaining unknown function is sought such that the plate potential is a minimum. This results in a fourth order ordinary differential equation which must be satisfied by the unknown deflection function. Solution of the resulting ordinary differential equation gives an eigenfunction for which the corresponding eigenvalue, the critical or buckling stress, can be found by using the plate boundary conditions.

The extended Kantorovich method used in this work is an iterative version of the classical Kantorovich method. Instead of quitting after finding the first approximation to the critical stress based on an *a priori* assumed deflection function, the extended Kantorovich method uses the newly determined deflection function as a trial function in the same manner that the *a priori* chosen function was used. As a result of this, a new approximate critical stress value can be found. This process can be repeated until the approximate critical stress value converges to some value near the exact solution.

In this work the extended Kantorovich method is used to solve buckling problems of plates having a variety of different varying in-plane stress distributions. To make this possible, numerical methods of solution are employed. A Simpson's rule technique is used to determine the integral constants of the fourth order ordinary differential equation mentioned above. The resulting ordinary differential equation, which in general has nonconstant coefficients, is solved by using a numerical technique for solving boundary value problems. This technique reduces the fourth order ordinary differential equation to a system of first order ordinary differential equations. The equations are then solved using a special version of Hamming's modification of Milne's predictor-corrector method.

The solution method is verified by solving a large number of plate buckling problems with known classical solutions. For problems with known exact solutions the numerical program developed is shown to give the exact solutions. Excellent correlation is also found by comparing solutions with known approximate solutions.

Included among the new problems solved are plates with mixed boundary conditions, plates on elastic foundations, and plates with a variable in-plane compressive load applied to only one edge, together with several different in-plane prestress configurations to increase the magnitude of the critical stress. Information from the results for the prestressed plates is of direct interest to equipment designers for use in the design of thin shear blades for cutting logs. Solutions are also found for plates with beam type stress distributions. Based on these new solutions an evaluation is made of the limitations of previous solutions found using deep beam theory.

APPENDIX B

Legend of Symbols

A = one-half the plate length (in.).

B = one-half the plate height (in.).

B/A = plate aspect ratio (dimensionless).

CKA = buckling constant for A dimension, $CKA=\frac{\sigma_{cr}\, t\, (2A)^2}{\pi^2 D}$ (dimensionless).

CKB = buckling constant for B dimension, $CKB=\frac{\sigma_{cr}\, t\, (2B)^2}{\pi^2 D}$ (dimensionless).

σ_{cr} = critical buckling stress which is the lowest peak applied stress for which the plate has two equilibrium configurations--the initial flat configuration and an infinitesimally deflected configuration--(psi).

t = plate thickness (in.).

D = flexural rigidity of the plate, $D=\frac{Et^3}{12(1-\mu^2)}$ (in.-lbs).

E = modulus of elasticity (psi).

μ = Poisson's ratio (dimensionless).

σ_e = plate stress constant (psi), $\sigma_e=\frac{\pi^2 D}{t(2A)^2}$.

PK = prestress factor, $PK=(PPS)/\sigma_e$.

PPS = peak prestress magnitude (psi).

P_c = total (in-plane) force on a plate which is assumed to have a cosine plate stress distribution (lbs), $P_c=\frac{2}{\pi}(2A)t\sigma_c$.

σ_c = peak stress for a cosine distributed load (psi).

P_u = total (in-plane) force on a plate which is assumed to have a uniform plate stress distribution (lbs), $P_u=(2A)t\sigma_u$.

σ_u = uniform stress (psi).

σ_{avg} = estimated average plate stress (psi), $\sigma_{avg}=\frac{\text{total plate force}}{t(2A)}$.

L = smaller value of the two primary plate dimensions (in.).

K = elastic foundation stiffness (psi per inch).

FK = elastic foundation modulus factor.

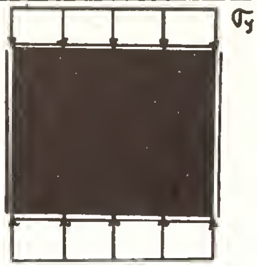
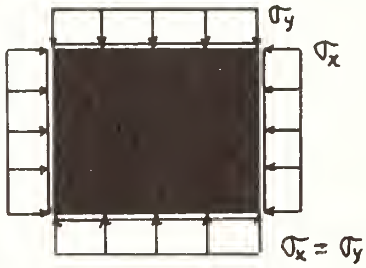
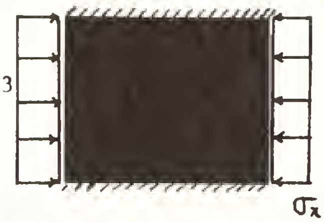
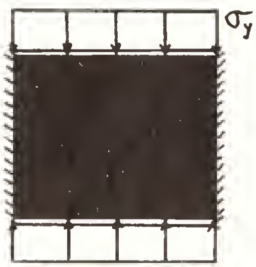
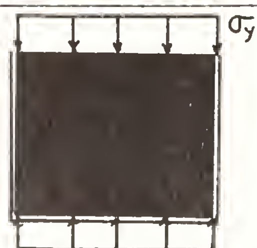
n = number of half waves in v direction.

APPENDIX C

Buckling Constants for Alternative Rectangular Plate Configurations

The buckling constants in this appendix are included for general reference and to demonstrate the capability of the computer program developed for solving buckling problems of plates having an assortment of boundary conditions and loading distributions. Some of the cases given were previously unsolved.

Figures 11 and 12 show plate configurations which have known exact and approximate classical solutions respectively. These cases were solved as a verification of the solution method used[1] These two figures include drawings of the plate configurations, the Kantorovich solutions found, and the known classical solutions

Case No.	Plate Configuration	B/A	Kantorovich Sol'n CKA	Exact Sol'ns CKA
1		1.0	3.99995	4.0
		1.414	4.49017	4.50
		2.0	3.99999	4.0
2		1.0	1.99999	2.0
3		1.0	7.69128	7.692
				7.690
4		1.0	7.69094	7.692
				7.690
5	 μ = 0.3	0.658	2.31005	2.31

(Figure 11 continued on next page)

Figure 11.--*Verification with known classical exact solutions. Cases 1, 2, 5, and 6 refer to Timoshenko and Gere (1961), cases 3 and 4 to Flugge (1962) and Masao (1969), and cases 7, 8, 9, and 10 to Flugge (1962).*

along with literature citations from which the classical solutions were found. Again a comparison of the Kantorovich results and the classical solutions serves as a verification of the accuracy and dependability of the method used here.

(Figure 11 continued)

Case No.	Plate Configuration	B/A	Kantorovich Sol'n CKA	Exact Sol'n CKA
6	 $\mu = 0.3$	0.5	1.58205	1.60
		1.0	2.04294	2.06
		1.316	2.31071	2.31
		2.0	2.26069	2.20
7	 $\mu = 0.3$	0.33	1.29120	1.289
		0.4	1.38522	1.385
		0.67	1.29120	1.289
		1.0	1.65251	1.658
8		1.0	5.74021	5.74
9	 $\mu = 0.3$	1.0	1.4016	1.402
10	 $\mu = 0.3$	1.0	0.95231	0.952

The solutions given in figure 13 are presented to show how the results found in this work compare with "deep beam" solutions for four different plate configurations. All of the cases in figure 13 have beam-like dimensions with respect to length-height ratios, but qualify as thin plates if the thickness is small enough in comparison with

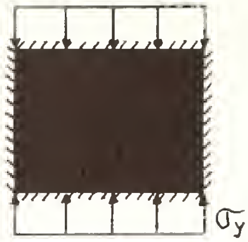
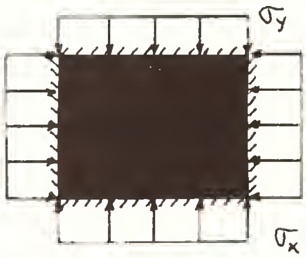
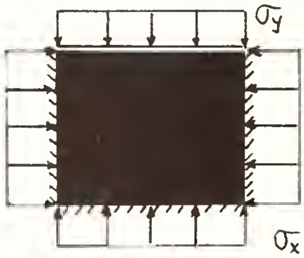
Case No.	Plate Configuration	B/A	Kantorovich CKA	Classical Approx. CKA
1		1.0	10.09468	10.07
2		1.0	5.31427	lower boundary 5.30 upper boundary 5.33
3		1.0	4.31658	4.3144
4		1.0	6.74246	6.74
5	 $\mu = 0.3$	1.0	3.94340	3.928

Figure 12.--*Verifications with known approximate classical solutions. Cases 1, 4, and 5 refer to Flugge (1962), case 2 refers to Timoshenko and Gere (1961), and case 3 refers to Masao* et al. *(1969). (All results from the Kantorovich CKA are from the fourth iteration).*

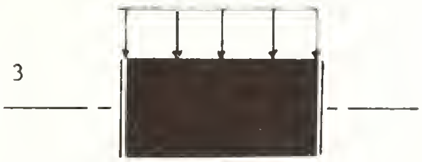
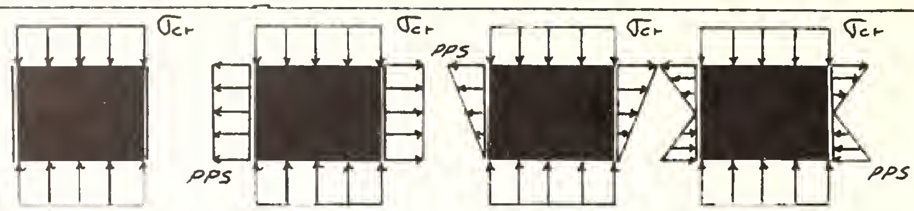
Case No.	Plate Configuration	B/A	Kantoro-vich CKA	Deep Beam Sol'n CKA
1	 $\mu = 0.3$	0.25	8.75170	8.57953
2	 $\mu = 0.3$	0.25	19.37212	17.15906
3	 $\mu = 0.3$	0.25	0.65953	0.80506 D.B. Sol'n for load at center line
4	 $\mu = 0.3$	0.25	1.24944	1.23177 D.B. Sol'n for load at center line

Figure 13.--*Verification with deep beam solutions. All cases refer to Flugge (1962).*

the other dimensions. The Kantorovich solutions for these cases were higher than the deep beam solutions for all cases except case 3. It is expected, however, that the Kantorovich solutions based on thin plate theory are more accurate than the "deep-beam" solutions based on the more simple beam theory.

Figure 14 shows plate configurations which include three different prestress distributions applied to the vertical edges. These cases with prestressing are all new solutions. A comparison of the results shows the relative effectiveness of the three different prestress distributions for the given plate configurations.

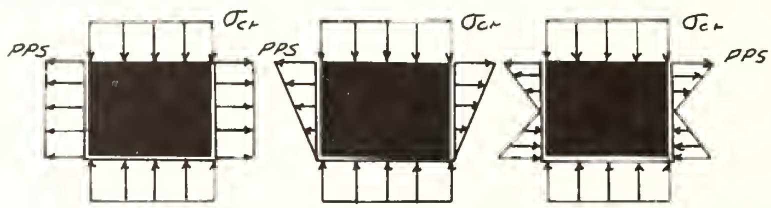
A



B/A	CKA	CKA	CKA	CKA
0.5	1.60	1.78025	1.60582	1.60510
1.0	2.10	2.66409	2.28612	1.69322
2.0	2.16	2.73375	2.44965	2.67556

PPS = σ_e $\mu = 0.3$

B



B/A	PK	CKA	CKA	CKA
0.658	0.0	2.31005	2.31005	2.31005
	1.0	2.93043	2.57187	2.76633
	2.0	3.30538	2.79518	3.12952
	3.0	3.56658	2.98371	3.39728

$\mu = 0.3,\ \sigma_e = \dfrac{\pi^2 D}{t\ (2A)^2}$, $\quad CKA = \dfrac{\sigma_{cr}\ t\ (2A)^2}{\pi^2\ D}$, $\quad PPS = PK\ \sigma_e$

Figure 14.--*Prestressed plates with (A) two free edges and (B) one free edge.*

The two plate buckling problems given in figure 15 are for plates resting on linearly elastic foundations, i.e., the deflection of the plate at any point is resisted by a pressure proportional to the deflection. The buckling constant CKA is given for both plates for a range of elastic foundation stiffness values. The first case, with all four edges simply supported, has a known analytical solution. Excellent agreement was obtained between the buckling constants found using the computer program developed in this work and the buckling constants calculated using the known analytical solution. A previously known solution could not be found for the second case in figure 15--a plate with all four edges clamped.

Figure 16 includes four different plate configurations, all of which are loaded by a cosine-shaped in-plane load applied

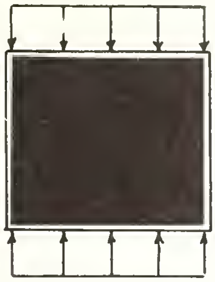
Plate Configuration	B/A	FK $\left(K=\frac{FK \times \sigma_e}{B}\right)$	n	CKA	Known Analytical Solution
	1.0	-0.2	1	-0.03576	-0.03573
		-0.1	1	1.98214	1.98214
		0.0	1	3.99995	4.00000
		0.05	1	5.00876	5.00893
		0.10	1	6.01754	6.01786
A = B = 1.0" , t = 0.02"		0.20	2	7.25855	7.25894
μ = 0.3 , E = 30x10^{6}psi		0.30	2	7.76330	7.76340
		0.40	2	8.26774	8.26787
	1.0	-0.6	1	0.97994	
		-0.5	1	2.61002	
		-0.4	1	4.20788	
		-0.3	1	5.76603	
		-0.2	1	7.27511	
		-0.1	1	8.72306	
		0.0	1	10.09468	
A = B = 1.0" , t = 0.02"		0.1	1	11.36555	
μ = 0.3 , E = 30x10^{6}psi		0.2	2	12.52188	
		0.3	2	12.77076	
		0.4	2	13.21331	
		0.5	2	13.62440	

Figure 15.--*Elastic foundation solutions (in equation, K = elastic foundation modulus and FK = elastic foundation modulus factor; n = number of half waves in y direction; known analytical solutions were calculated using equation given in Bulson (1969)).*

to the top plate edge. Cases 1 and 2 are supported at all edges, case 1 with all edges simply supported and case 2 with all edges clamped. Cases 3 and 4, however, are supported at only two edges. These cases both resemble shear blade type configurations; in fact case 4 is the same as case 2 of figure 3. The only difference is that in figure 16 the buckling constant CKB is given along with the buckling constant CKA.

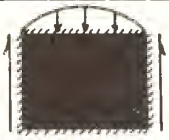
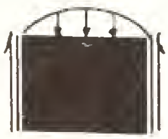
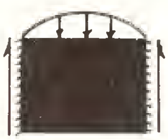
Case No.	Plate Configuration	B/A	CKA = $\frac{\sigma_{cr}\ t\ (2A)^2}{\pi^2\ D}$	CKB = $\frac{\sigma_{cr}\ t\ (2B)^2}{\pi^2\ D}$
1		0.5	12.20898	3.05224
		1.0	7.38091	7.38091
		2.0	7.20327	28.81308
2		0.5	36.10814	9.02703
		1.0	19.09650	19.09650
		2.0	17.76844	71.07375
3		0.25	0.87438	0.05465
		0.33	1.09146	0.11886
		0.50	1.50201	0.37550
		0.67	1.78303	0.80040
		0.75	2.00720	1.12905
		1.0	2.10034	2.10034
		1.5	2.20323	4.95726
		2.0	2.21380	8.85519
	μ = 0.3	3.0	2.21470	19.93233
4		0.25	1.57461	0.09841
		0.33	2.00768	0.21864
		0.50	2.81051	0.70263
		0.67	3.33195	1.49571
		0.75	3.50014	1.96882
		1.0	3.82011	3.82011
		1.5	3.92528	8.83188
		2.0	3.94223	15.76893
	μ = 0.3	3.0	3.94124	35.47114

Figure 16.--*Plates loaded on one edge.*

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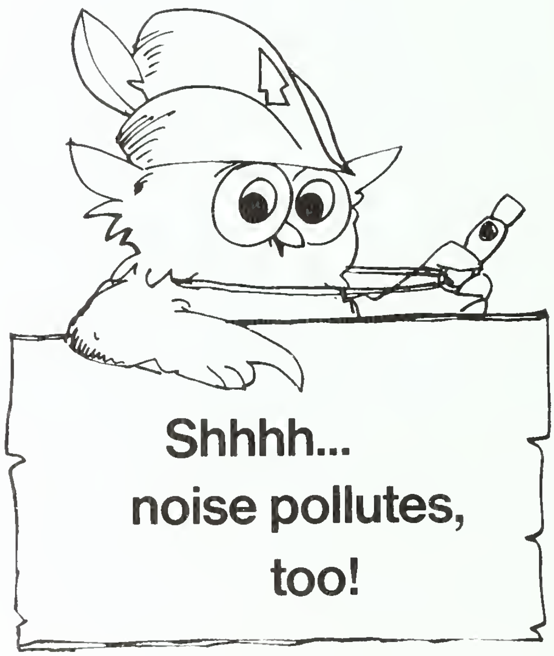
Shhhh...
noise pollutes,
too!