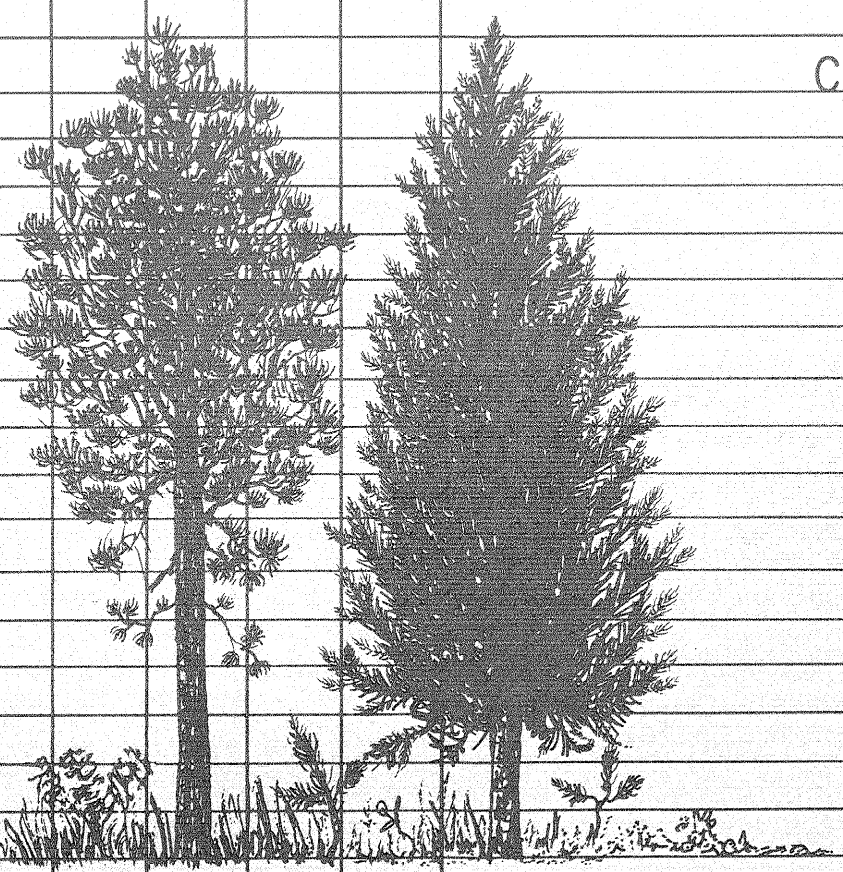
USDA
FOREST SERVICE
RESEARCH PAPER NC-84
1972

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

North Central Forest Experiment Station
John H. Ohman, Director
Forest Service – U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55101

(Maintained in cooperation with the University of Minnesota)
Manuscript approved for publication July 11, 1972

THE AUTHORS: At the time of this study both Rodney W. Sando and Charles H. Wick were Associate Fire Control Scientists for the Station. Both authors are now with the University of Minnesota–Sando with the College of Forestry and Wick with the College of Biological Sciences.

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*

TREES LARGER THAN 1 INCH D.B.H.

Species		Equation	N	R^2	Standard error of the estimate
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.

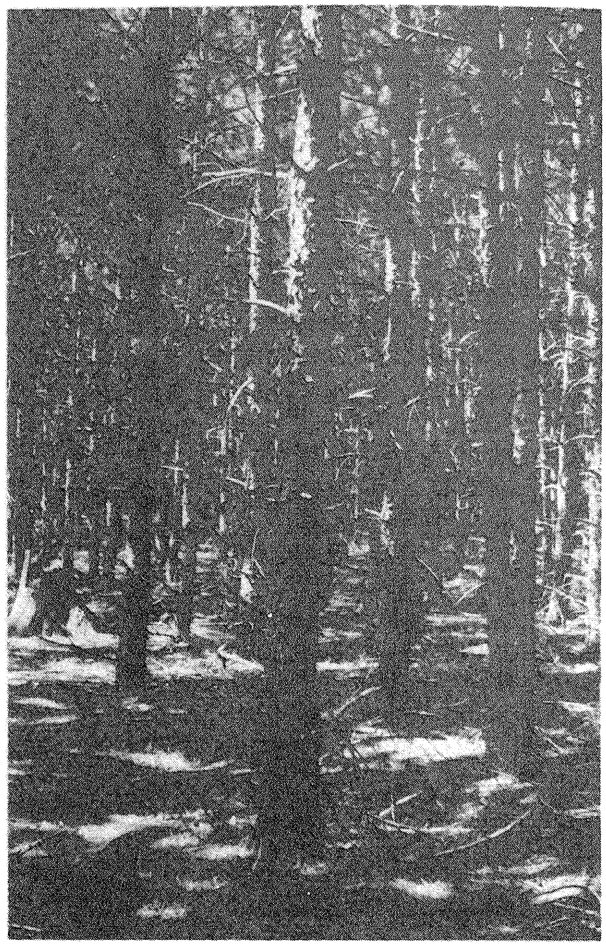


Figure 1.—Thirty-two-year-old red pine plantation.

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.

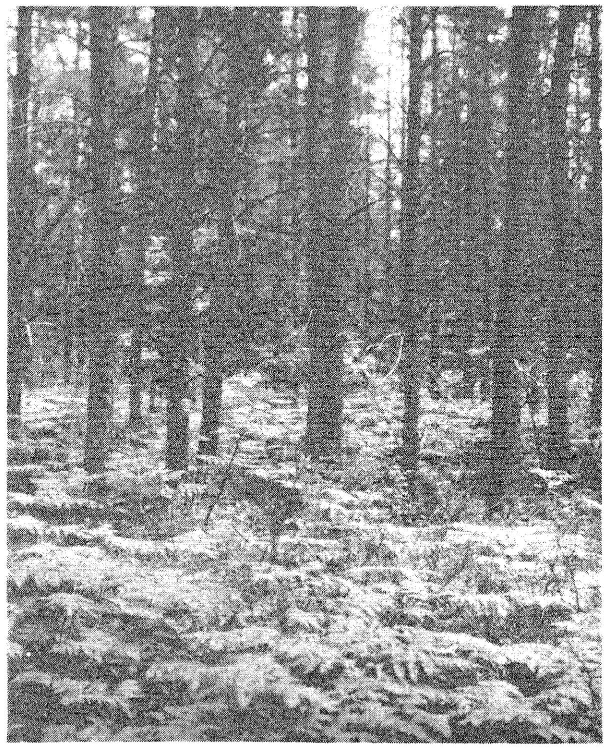


Figure 4.—Forty-year-old jack pine stand of natural origin.

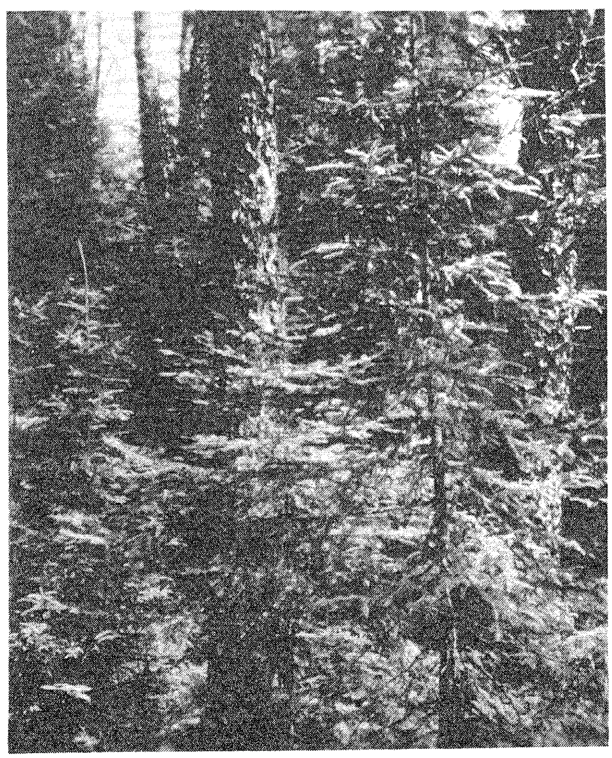


Figure 5.—One-hundred-five-year-old jack pine stand with spruce-fir understory.

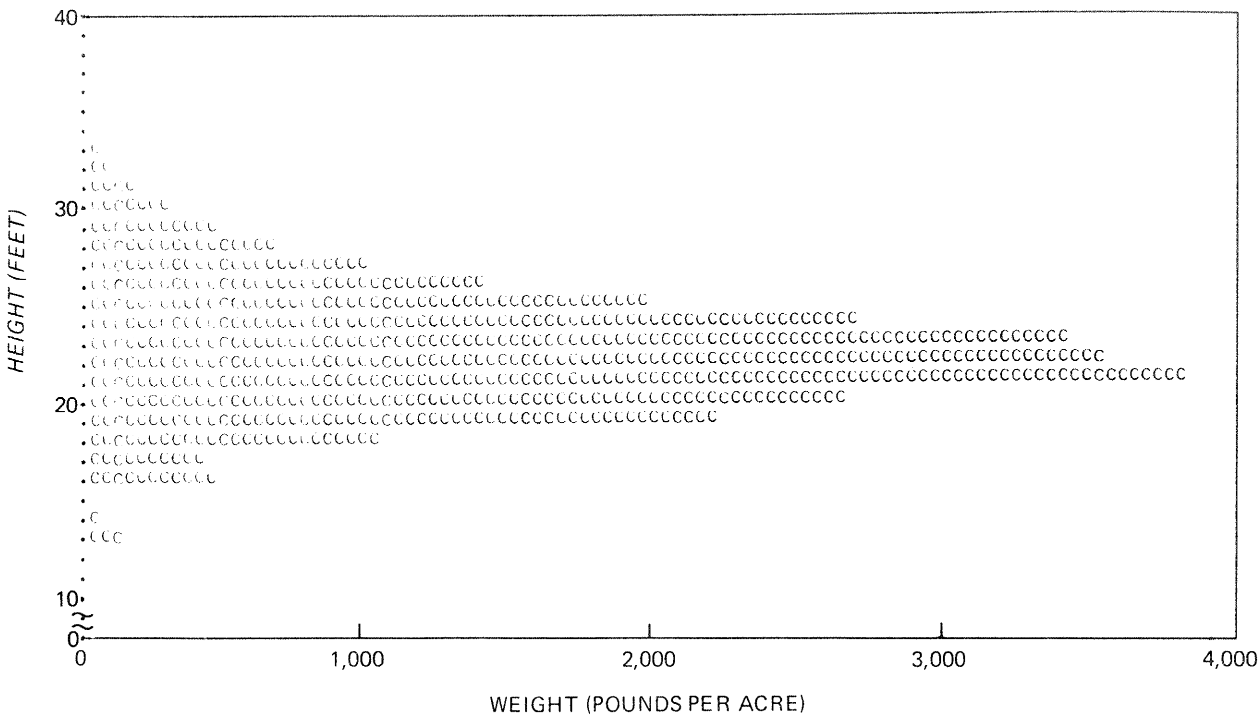


Figure 6.—Graph of crown weight in 32-year-old red pine plantation.

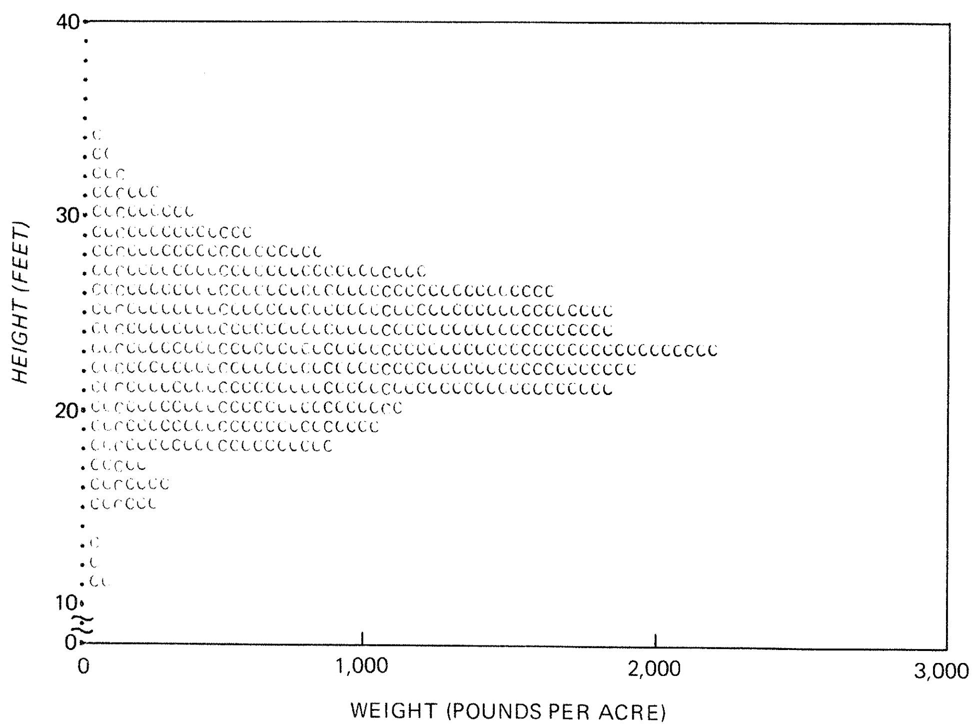


Figure 7.—Graph of crown weight in commercially thinned 32-year-old red pine plantation.

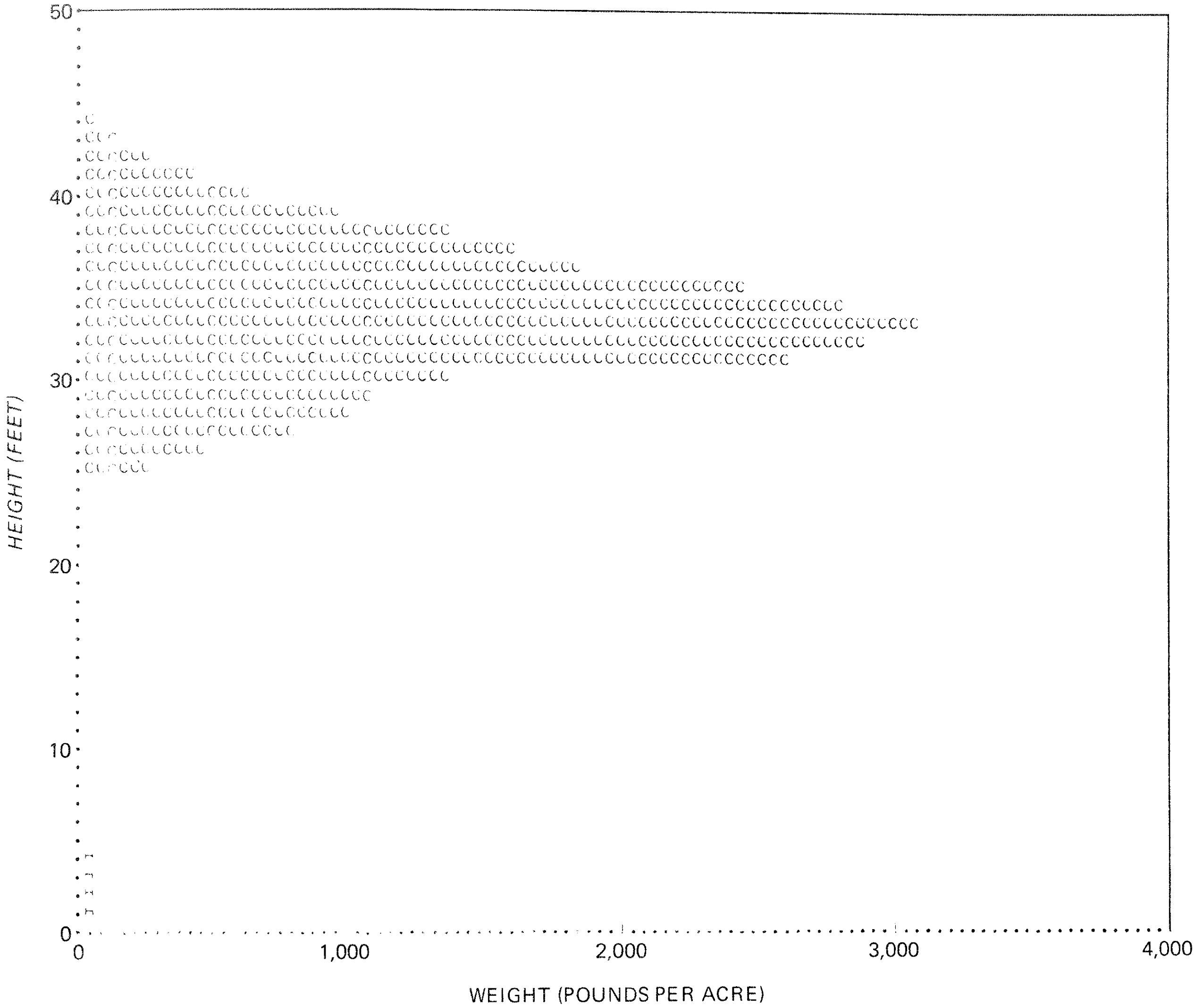


Figure 8.–Graph of crown weight in 50-year-old red pine plantation.

have left 14,070 pounds per acre of slash on the ground. We then used the fire model developed by Rothermel (1972) to determine the impact this slash would have on fire behavior. The fire model showed that a 35-fold increase in fire intensity could be expected under the ambient conditions of 4-percent fine fuel moisture content and winds of 10 m.p.h. It is apparent that a wide variety of forest management alternatives could be evaluated in the same manner. Some logical alternatives to evaluate would be various levels of thinning, pruning to different heights, changing plantation species composition by including hardwoods or by mixing conifer species, and 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

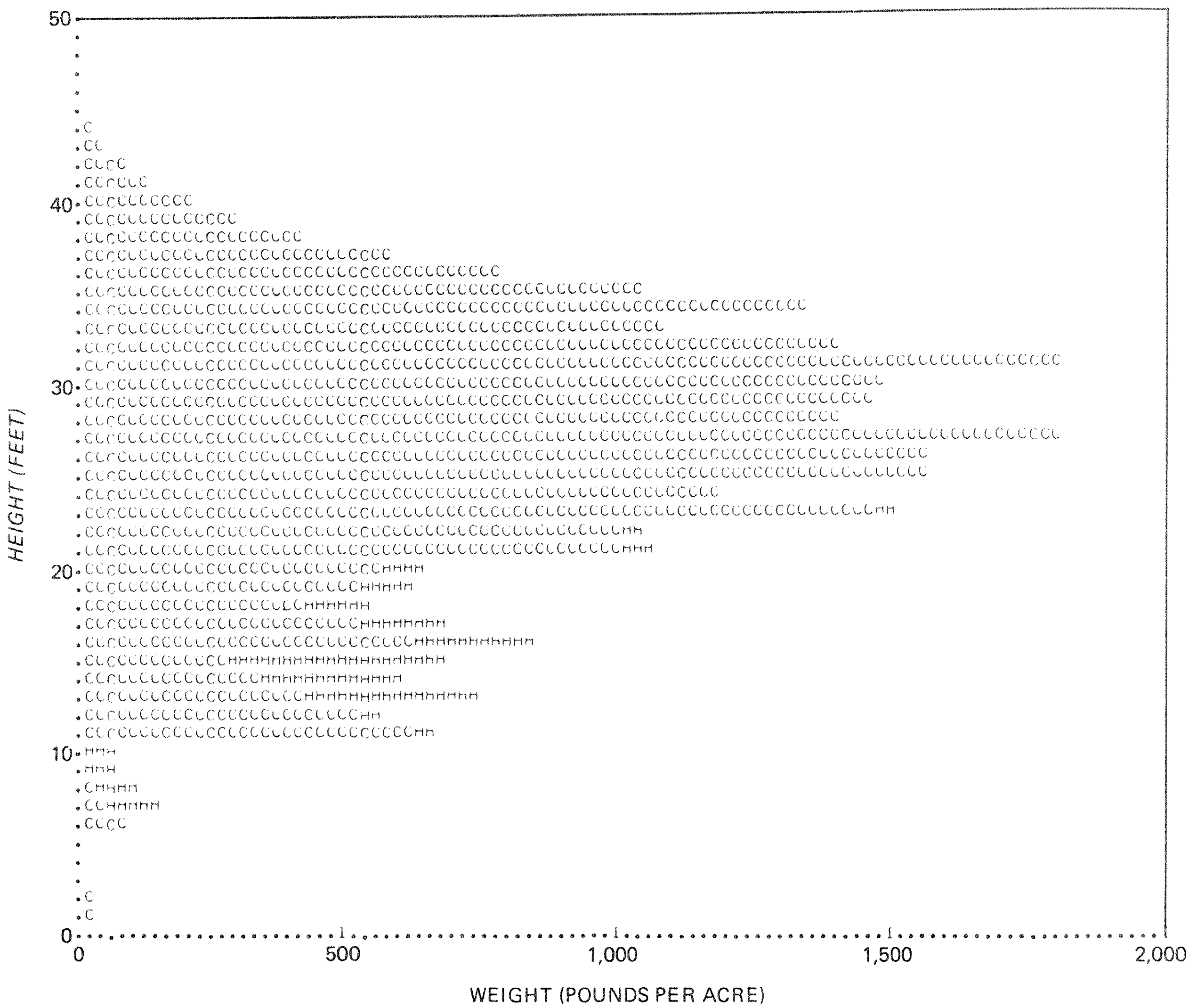


Figure 9.—Graph of crown weight in 40-year-old jack pine stand.

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 crown volume ratio, is calculated to characterize the fuel bed porosity of the stand.

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

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.

LITERATURE CITED

Anderson, Hal E. 1969. Heat transfer and fire spread. USDA For. Serv. Res. Pap. INT-69, 20 p. Intermt. For. & Range Exp. Stn., Ogden, Utah.

Baskerville, G. L. 1965. Dry-matter production in immature balsam fir stands. For. Sci. Monogr. 9, 42 p.

Brown, James K. 1963. Crown weights in red pine plantations. USDA For. Serv. Res. Note LS-19, 4 p. Lake States For. Exp. Stn., St. Paul, Minn.

Brown, James K. 1965. Estimating crown fuel weights of red pine and jack pine. USDA For. Serv. Res. Pap. LS-20, 12 p. Lake States For. Exp. Stn., St. Paul, Minn.

Countryman, Clive M., and Charles W. Philpot. 1970. Physical characteristics of chamise as a wildland fuel. USDA For. Serv. Res. Pap. PSW-66, 16 p. Pac. Southwest For. & Range Exp. Stn., Berkeley, Calif.

Deeming, John E., and James W. Lancaster. 1971. Background, philosophy, implementation—National Fire Danger Rating System. USDA For. Serv. Fire Control Notes 32(2): 4-8.

Deeming, John E., James W. Lancaster, and Michael A. Fosberg. 1971. National Fire Danger Rating System, 1971 field trials. USDA For. Serv., Rocky Mtn. For. & Range Exp. Stn., 39 p.

Fahnestock, George R. 1960. Logging slash flammability. USDA For. Serv., Intermt. For. & Range Exp. Stn. Res. Pap. 58, 67 p.

Fahnestock, George R. 1970. Two keys for appraising forest fire fuels. USDA For. Serv. Res. Pap. PNW-99, 26 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Hornby, L. G. 1936. Fire control planning in the Northern Rocky Mountain Region. USDA For. Serv., Rocky Mt. For. & Range Exp. Stn. Rep. 1, 188 p.

Kiil, A. D. 1967. Fuel weight tables for white spruce and lodgepole pine crowns in Alberta. Can. Dep. For. & Rural Dev. Publ. 1196, 13 p.

Kiil, A. D. 1968. Weight of the fuel complex in 70-year-old lodgepole pine stands of different densities. Can. Dep. For. & Rural Dev. Publ. 1228, 9 p.

Kittredge, Joseph. 1944. Estimation of the amount of foliage of trees and stands. J. For. 42: 905-912.

Loomis, Robert M., Robert E. Phares, and John S. Crosby. 1966. Estimating foliage and branchwood quantities in shortleaf pine. For. Sci. 12(1): 30-39.

Muraro, S. J. 1971. The lodgepole pine fuel complex. Can. For. Serv., Pac. For. Res. Cent. Inf. Rep. BC-X-53, 50 p.

Rothermel, Richard C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115, 40 p. Intermt. For. & Range Exp. Stn., Ogden, Utah.

Rothermel, Richard C., and Hal E. Anderson. 1966. Fire spread characteristics determined in the laboratory. USDA For. Serv. Res. Pap. INT-30, 34 p. Intermt. For. & Range Exp. Stn., Ogden, Utah.

Storey, Theodore G. 1969. Tree weights and fuel size distribution of pinyon pine and Utah juniper. Project Flambeau—an investigation of mass fire (1964-1967). Pac. Southwest For. & Range Exp. Stn. Final Rep. III, 90 p.

Storey, T. G., W. L. Fons, and F. M. Sauer. 1955. Crown characteristics of several coniferous tree species. USDA For. Serv. Interim Tech. Rep. AFSWP-416, 93 p.

Storey, T. G., and W. Y. Pong. 1957. Crown characteristics of several hardwood tree species. USDA For. Serv. Interim Tech. Rep. AFSWP-968, 36 p.

Tufts, W. P. 1919. Pruning young deciduous fruit trees. Calif. Agric. Exp. Stn. Bull. 313, 37 p.

USDA Forest Service. 1938. North Central Region representative fuel types—descriptions and ratings for use in fire control planning. 47 p.

USDA Forest Service. 1956. Glossary of terms used in forest fire control. U.S. Dept. Agric., Agric. Handb. 104, 24 p.

USDA Forest Service, Region 6. 1968. Guide for fuel type classification. 48 p.

Wade, Dale D. 1969. Estimating slash quantity from standing loblolly pine. USDA For. Serv. Res. Note SE-125, 4 p. Southeast. For. Exp. Stn., Asheville, N. C.

☆U.S. Government Printing Office: 1972 – 761-061

SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

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 & 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.

The Changing Market for Hardwood Plywood Stock Panels, by Gary R. Lindell. USDA For. Serv. Res. Pap. NC-78, 7 p., illus. 1972.

Size of Oak Advance Reproduction: Key to Growth Following Harvest Cutting, by Ivan L. Sander. USDA For. Serv. Res. Pap. NC-79, 6 p., illus. 1972.

An Improved Growth Intercept Method for Estimating Site Index of Red Pine, by David H. Alban. USDA For. Serv. Res. Pap. NC-80, 7 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.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

For more than 60 years, the Forest Service has been serving the Nation as a leading natural resource conservation agency.