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 ASPEN CROWN FUELS IN NORTHEASTERN MINNESOTA

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APPLICATION

Tree crowns are an important source of forest fuel, especially as cutting slash or as debris that may follow wind or ice storms. Quaking aspen (*Populus tremuloides* Michx.) is a major constituent of the mature and overmature upland stands in the Boundary Waters Canoe Area of the Superior National Forest. So to appraise the potential flammability of these stands a method was developed to estimate the crown fuel weights of quaking aspen. The tables given in this section were based on the method that is explained in the following Documentation section.

Although the tables below have been designed primarily to be used in fuel models, they could also be used for estimating productivity of potentially usable fiber. The tables can probably be used satisfactorily anywhere in the Lake States, but with the most confidence in northeastern Minnesota.

ESTIMATING DRY WEIGHTS OF FOLIAGE, BRANCHWOOD, AND BOLE TOPS

Use table 1 to get dry weight estimates of foliage, all live and dead branchwood[1] together, and all live branchwood alone, by tree dbh.

Table 1.—*Dry weight of aspen crown components per tree by d.b.h.*[1]

D.b.h.	Foliage	Live and dead branchwood	Live branchwood
cm		*kg*	
2	0.03	0.1	0.1
4	.15	.5	.3
6	.34	1.3	1.0
8	.62	2.7	2.2
10	1.0	4.8	4.0
12	1.5	7.7	6.5
14	2.0	12.0	9.8
16	2.7	16.0	14.0
18	3.4	22.0	19.0
20	4.3	29.0	25.0
22	5.2	37.0	33.0
24	6.3	47.0	41.0
26	7.4	57.0	51.0
28	8.7	69.0	62.0
30	10.0	83.0	75.0
32	11.5	98.0	89.0
34	13.0	115.0	105.0
36	14.7	133.0	122.0
38	16.5	153.0	141.0
40	18.4	175.0	162.0

[1]Crown branchwood includes bolewood <0.6 cm in diameter. Branchwood and bolewood include all woody parts (wood + bark).

Use table 2 to break down the branchwood tabulations of table 1 into four size classes.

Use table 3 to get dry weights of the bole tops by two size classes. (Weight of bolewood less than 0.6 cm in diameter is given in tables 1 and 2.) These tops are a significant fuel frequently left in the woods following cutting.

[1]*"Branchwood" and also "bolewood" as used in this paper refer to both wood and bark.*

Table 2.—*Dry weight of four diameter classes of aspen branchwood per tree by d.b.h.*[1]

	Live and dead branchwood				Live branchwood			
D.b.h.	0–0.6 cm	0.6–2.5 cm	2.5–7.6 cm	7.6+ cm	0–0.6 cm	0.6–2.5 cm	2.5–7.6 cm	7.6+ cm
cm	- - - - - - - - - - - - *kg* - - - - - - - - - - -				- - - - - - - - - - *kg* - - - - - - - - - - -			
2	0.1	0	0	0	0.1	0	0	0
4	.3	0.2	0	0	.2	0.1	0	0
6	.6	.7	0	0	.5	.5	0	0
8	1.0	1.7	0	0	.8	1.4	0	0
10	1.5	3.3	0	0	1.2	2.7	0	0
12	2.1	4.8	0.8	0	1.7	4.0	0.7	0
14	2.8	6.5	2.3	0	2.3	5.4	2.1	0
16	3.6	8.3	4.4	0	3.1	6.8	4.0	0
18	4.4	10.0	7.3	0	3.8	8.6	6.7	0
20	5.2	13.0	11.0	0	4.6	11.0	10.0	0
22	6.3	15.0	16.0	0	5.6	12.0	15.0	0
24	7.5	18.0	21.0	0	6.6	15.0	20.0	0
26	8.6	21.0	27.0	1.1	7.7	17.0	25.0	1.0
28	9.7	24.0	33.0	2.0	8.7	20.0	32.0	1.9
30	11.0	27.0	41.0	3.3	9.7	22.0	39.0	3.7
32	13.0	30.0	49.0	5.9	12.0	25.0	47.0	5.3
34	14.0	34.0	58.0	8.0	13.0	28.0	57.0	7.3
36	16.0	39.0	68.0	11.0	15.0	32.0	66.0	9.8
38	17.0	43.0	81.0	12.0	16.0	35.0	78.0	13.0
40	19.0	47.0	93.0	16.0	18.0	39.0	89.0	16.0

[1]Branchwood includes both wood and bark.

Table 3.—*Dry weight of aspen bolewood by size class per tree by d.b.h.*[1]

	Bolewood Diameter Class	
D.b.h.	0.6 - 2.5 cm[2]	2.5 - 7.6 cm
cm	- - - - - - - *kg* - - - - - - -	
2	0.27	0
4	.27	1.27
6	.27	1.91
≥8	.27	2.90

[1]Bolewood includes both wood and bark.

[2]Bolewood diameters <0.6 cm are included with branchwood estimates in Table 2.

AN EXAMPLE

The following example summarizes the crown component weight information available from tables 1-3:

An aspen tree 28 cm d.b.h. has been tallied.[2] Table 1 shows the following estimated dry weights:

Foliage	8.7 kg
Live and dead branchwood	69.0 kg
Live branchwood	62.0 kg
Dead branchwood [live & dead (69 kg) minus live (62 kg) = 7 kg]	7.0 kg

Table 2 shows the following estimated dry weights:

Diameter class	*Live and dead branchwood*	*Live branchwood*	*Dead branchwood (live & dead minus live)*
(cm)	. . . . (kg)	. . . .	
0 to 0.6	9.7	8.7	1.0
0.6 to 2.5	24.0	20.0	4.0
2.5 to 7.6	33.0	32.0	1.0
7.6 plus	2.0	1.9	0.1
Totals	68.7	62.6	6.1

Table 3 shows the following estimated dry weight of bolewood:

Diameter class	*Bolewood*
(cm)	(kg)
0.6 - 2.5	0.27
2.5 - 7.6	2.90
Total	3.17

[2]*English-metric equivalents: 1 inch = 2.54 cm; 1 pound = 0.4536 kg.*

DOCUMENTION

Methods for estimating aspen crown weights have been developed by a number of investigators: Sando and Wick (1972), and Schlaegel (1975) in northern Minnesota; Zavitkovski (1971) in northern Wisconsin; MacLean and Wein (1976) in New Brunswick, Canada; and Young *et al.* (1964), and Ribe (1973) in Maine. However, these methods fail to distinguish different branchwood size classes, which are needed to predict fire behavior using the Rothermel (1972) model. Sando and Wick (1972) were concerned with "foliage and that portion of the tree smaller than 2.5 inches (6.35 cm) in diameter"—the parts most significant to fire management—but no further size breakdown was attempted.

Suitable methods for estimating crown weights and size distributions of woody materials are now available for most western species (Brown 1976) but are lacking for most eastern ones. The purpose of the present study was to provide a suitable method for quaking aspen.

METHODS AND RESULTS

Field data were collected during August and September of 1976. Fifteen dominant or codominant aspen trees were selected for destructive sampling on the Superior National Forest in Minnesota. Selected trees ranged from 3 to 38 cm in d.b.h.

Tree measurements included diameter at breast height, total height, length and width of live crown, diameters of all branches 5 cm from the bole (basal diameter), and length of dead branches. A total of 75 sample branches (every tenth branch), 47 live and 28 dead, were cut from the sample trees throughout the length of the crowns to obtain a range of branch sizes.

Ovendry weights of foliage, total branchwood, and branchwood within each of three fuel size groups—0 to 0.6 cm, 0.6 to 2.5 cm, and 2.5 to 7.6 cm in diameter—were determined for sample branches. Weights were determined separately for living and for dead material. Factors for converting field green weight to ovendry were obtained from small samples cut from sample branches and oven dried at 105 C. for 24 hours.

Using branch basal diameter as the independent variable, logarithmic regression analysis yielded good relations on live branches for: weights of foliage, total weights of both live and dead wood, weights of live and dead wood by size classes, weight of live wood only, and weight of live wood by size classes (table 4). Similar regressions were run for dead branches using the product of branch diameter times length as the independent variable (table 4). The addition of branch length significantly improved the estimates for dead branches because many dead branches are broken off at varying lengths. All equations were adjusted for logarithmic transformation bias (Baskerville 1972).

Table 4.—*Equations, coefficients of determination, and number of branches sampled, to estimate various dependent variables in aspen crowns*

Dependent Variable	Equation[1]	r^2	Branches Number
LIVE BRANCHES			
Foliage	$Wf = 10.694\ (Bd)^{2.160}$	0.95	58
Total, Both Live and Dead Wood	$Wtb = 25.552\ (Bd)^{2.794}$	.97	58
Live and Dead Wood Classes:			
0.0 - 0.6 cm	$R_1 = .608\ (Bd)^{-.838}$	.84	47
0.0 - 2.5 cm	$R_2 = 2.167\ (Bd)^{-.856}$	.69	24
0.0 - 7.6 cm	$R_3 = 11.107\ (Bd)^{-1.205}$	1.00	3
Total, Live Wood Only	$Wtb = 25.312\ (Bd)^{2.786}$	.97	58
Live Wood Classes:			
0.0 - 0.6 cm	$R_1 = .614\ (Bd)^{-.850}$	.81	47
0.0 - 2.5 cm	$R_2 = 2.194\ (Bd)^{-.877}$	.62	24
0.0 - 7.6 cm	$R_3 = 11.419\ (Bd)^{-1.218}$	1.00	3
DEAD BRANCHES			
Total Branchwood	$Wtb = 39.547\ (Bdl)^{1.325}$	.92	30
Branchwood Classes:			
0.0 - 0.6 cm	$R_1 = .410\ (Bdl)^{-.686}$	.34	28
0.0 - 2.5 cm	$R_2 = 1.159\ (Bdl)^{-.253}$	.63	11

[1]The abbreviated terms are:
Bd = Branch basal diameter, centimeters
Bdl = Branch basal diameter in centimeters times branch length in meters
Wf = Foliage weight, grams
Wtb = Total branchwood weight, grams
R_1 R_2 R_3 = Ratios of branchwood within a group to total branchwood weight

The size class distribution of branchwood weight for individual branches is represented by estimating the ratio of branchwood weight in each size class to total branchwood weight per branch. Since more than 100 percent of a branch cannot be attributed to a size class (a ratio greater than one), the size class regressions for live branches apply only when the branch diameter is larger than $a^{-1/b}$; where "a" and "b" are the regression coefficients of the appropriate size class equation $R_i = a(\text{Basal diameter})^b$ (table 4). For example, the 0- to 0.6-cm size class equation for "live wood'' applies only to branches with basal diameters greater than 0.56 cm. Below this ''critical diameter'' the entire branch is within the 0- to 0.6-cm size class, and the ratio contribution is therefore 1.0. In general:

$$R_i = \begin{cases} a(\text{Basal diameter})^b, & \text{Basal diameter} \geq a^{-1/b} \\ 1.0, & \text{Basal diameter} < a^{-1/b} \end{cases} \qquad (1)$$

Similarly, for dead branches:

$$R_i = \begin{cases} a(\text{Branch diameter times length})^b, & \text{Branch diameter times length} \geq a^{-1/b} \\ 1.0, & \text{Branch diameter times length} < a^{-1/b} \end{cases} \qquad (2)$$

The equations developed for branches were then used to ''build'' crowns for the 15 sample trees using the respective tallies of branch diameters—and for dead branches—branch lengths. Equations were developed for the weight of foliage alone, foliage and branchwood, live branchwood, and total branchwood using tree dbh as the independent variable (table 5). Additionally, equations were developed to compute ratios of branchwood size-class weights to totals (table 6). Again, these equations are constrained at a value of 1.0 for low dbh trees.

Our crown branchwood estimates include the very topmost section of the bole 0.6 cm in diameter and smaller. Because it is a significant fuel and often left in the woods after cutting, estimates of bolewood within the 0.6- to 2.5- and 2.5- to 7.6-cm diameter classes were prepared separately (table 3). These estimates were based on our data for another study for northern red oak trees, (adjustments for differences in wood specific gravity were made), and on Schlaegel's (1975) estimating methods for weight of boles and the percentage of bolewood within specific diameter ranges for aspen.

DISCUSSION

Our definition of live branchwood is compatible with that of Schlaegel (1975) and Zavitkovski (1971), but they use a second estimator—tree height—in their equations. Using the measured heights and diameters for our sample trees, though, we were able to compute estimates of branchwood weight, and foliage weight, for each tree both by Schlaegel's and by Zavitkovski's equations and compare them with our estimates (fig. 1). Our branchwood estimates were similar to Schlaegel's for Minnesota trees up to about 28 cm d.b.h., beyond which ours became increasingly heavier. Zavitkovski's branchwood equations, developed for his Wisconsin trees, produced estimates much lower than found for our Minnesota sample, and a similar relation was found when foliage estimates were compared. Results of a Russian study by Zukova (1969) were also examined. The weight of live branchwood for 6 aspen trees in the Moscow region was found, for the most part, to fall closer to the Minnesota than to the Wisconsin estimates (fig. 1).

Table 5.—*Coefficients, standard deviations, coefficients of determination, and number of samples used in estimating dry weights of aspen crown components*[1]

Dependent Variable	a	b	$S_{y \cdot x}$[2]	r^2	n
Total Weight	0.0182	2.5094	0.237	0.98	15
Foliage Weight	.0079	2.1012	.264	.97	15
Live Branchwood Weight	.0084	2.6746	.307	.98	15
Total Branchwood Weight	.0125	2.5874	.233	.98	15

[1]Weight (kilograms) per tree by dbh (centimeters), and the general equation $Y = aX^b$.

[2]$S_{y \cdot x}$ (standard deviations about regression) in terms of natural logarithmic values of the variates according to the general form lnY = a + lnX before adjustment for bias.

Table 6.—*Coefficients, standard deviations, coefficients of determination, and number of samples used in estimating the ratio of weight of aspen branchwood per size class to total branchwood weight*[1]

Dependent variable weight size-class branchwood/ weight total branchwood	a	b	$S_{y \cdot x}$[2]	r^2	n
LIVE AND DEAD BRANCHWOOD					
0 to 0.6 cm/Total	1.856	-0.773	0.132	0.95	15
0 to 2.5 cm/Total	5.317	- .718	.128	.88	13
0 to 7.6 cm/Total	1.793	- .185	.015	.87	6
LIVE BRANCHWOOD					
0 to 0.6 cm/Total	1.846	- .771	.146	.94	15
0 to 2.5 cm/Total	6.249	- .784	.132	.89	13
0 to 7.6 cm/Total	1.892	- .202	.015	.88	6

[1]Ratio of weights (kilograms) per tree by d.b.h. (centimeters), and the general equation $Y=aX^b$.

[2]$S_{y \cdot x}$ (standard deviations about regression) in terms of natural logarithmic values of the variates according to the general form lnY = a + b lnX before adjustment for bias.

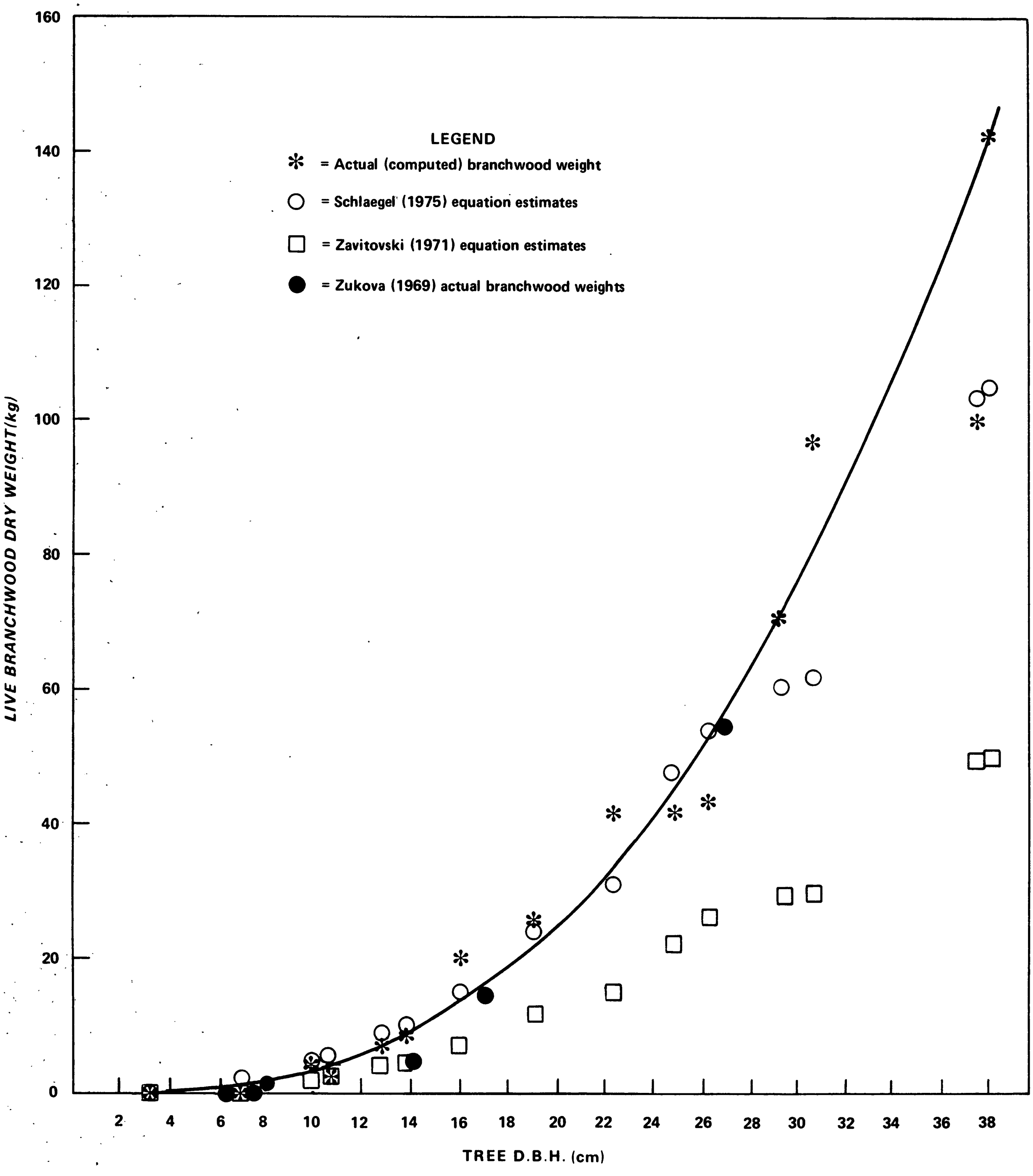

Figure 1.—*Actual live branchwood weights plotted over tree dbh compared with those of Zukova* (1969), *and with Schlaegel's* (1975) *and Zavitkovski's* (1971) *equation estimates. The prediction curve is based on the actual weights. (Data from 15 northeastern Minnesota quaking aspen trees.)*

We compared our estimates of live branchwood with estimates for Maine trees using equations by Young *et al.* (1964) and by Ribe (1973). We also compared aspen crown weights (branches and leaves) estimated by an equation by MacLean and Wein (1976) for New Brunswick, Canada, with our live branchwood plus leaves. These investigators used dbh as the estimator. All three of these estimates were much below ours, as were those of Zavitkovski for branchwood and for foliage.

The estimates by the various investigators may be influenced by several factors, including climate, site, and stand density. The basic data used by Zavitkovski indicates that stand density may strongly influence the estimates. For example, his regression equation was controlled by 48 trees, all from dense stands and less than 20 cm d.b.h. However, two larger sample trees, 24 and 29 cm d.b.h. both from low density stands had actual branchwood weights within the range of the predictions of the Minnesota equations.[3] Our trees were from medium to low density stands; the larger trees particularly had little crown competition.

All our sample trees were quaking aspen. Zavitkovski (1971), however, having sampled both quaking and largetooth aspen (*Populus grandidentata* Michx.), found no obvious difference between the species in the distribution of dry weight among components. This supports the use of our equations for both species.

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[3] *Personal communication with J. Zavitkovski, Institute of Forest Genetics, Rhinelander, Wisconsin, September 9, 1977.*

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