THE LODGEPOLE PINE FUEL COMPLEX

by
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Abstract

Mensurational parameters of a range of lodgepole pine stands were correlated with loading of individual fuel components and the total fuel complex. Except for the aerial fuel components consisting of dead and living foliage, predictive equations for other components of the fuel complex were considered inadequate for the modern fire control organization. Inability to document conditions at the time of stand establishment and subsequent stand history were considered most responsible for the poor correlations. Recommendation for simulation of the forest fuel complex and a means of visually comparing the vertical distribution of fuel components are provided.

Introduction

Knowledge of fuel quantity and distribution in wildland fuel complexes has long been recognized as a critical requirement for predicting fire behavior. In the early days of fire control, extensive effort was concentrated on developing fuel-type maps to determine the speed and strength of initial attack and for fire control planning (Hornby 1935, 1936). Dealing with the need for fuel classification for optimum use of fire control resources, Hornby said, "When a given level of burning severity extends over a large area the same speed and strength of attack is not necessary for all fuel types." The value of fuel classifications as an attack guide is reduced if air detection is employed, when local fuels and fire behavior can be described by the observer. More recent attempts of fuel classification (Kiil 1968) have been oriented toward use as a guide for long-term fire control planning. The important present day requirements for fuel measurements are oriented to the need for introducing the fuel component of the fire environment into a comprehensive fire behavior rating system.

This study was initiated in 1961 to determine if components of the forest fuel complex could be correlated with stand characteristics to provide useful predictors of fuel loading and distribution. Specifically, the objectives were to:

(a) Correlate characteristics of the fuel complex with species, age and density of the cover type;

(b) Provide a pictorial display of the fuel complexes sampled.

On the basis of preliminary work in the ponderosa pine (<u>Pinus ponderosa</u> Laws.) and Douglas fir (<u>Pseudotsuga</u> <u>menziesii</u> (Mirb.) Franco) cover types (Muraro 1962), the results reported in this paper are confined to lodgepole pine (Pinus contorta Dougl. var latifolia Engelm) cover types.

Area

The study area was located on a glaciated plateau between elevations of 3500 and 5000 feet (M.S.I.), 20 miles southeast of Merritt, British Columbia, at 50° 00' north latitude and 120° 00' west longitude. The soils were of glacial origin, generally of gravelly sandy loam on a gently rolling topography exhibiting characteristics of glaciated land surfaces (Spilsbury et al. 1963).

Lodgepole pine was the major forest tree species in this transition zone between the ponderosa pine—Douglas fir (M1) section and the interior subalpine (SA_2) section (Rowe 1959). The majority of the stands consisted of two age classes, one resulting from a wildfire in 1940; the other from a wildfire that occurred about 60 years previously (Fig. 1).

Field Measurements

One hundred and sixty sampling points in a variety of lodgepole pine associations were located on 20-chain scale aerial photographs. The points, located on the ground, were numbered, and surrounded by a string plot boundary to provide a sample of the stand. One-tenth-acre square plots were designated in mature stands and 1/20-acre square plots in regeneration. The following stand characteristics were measured.

(1) Age of three dominant trees in years.

(2) Height of three dominant trees in feet.

(3) Height in feet of crown base above ground from three dominant trees.

(4) Number of living stems by two-inch diameter (dbh) classes.

(5) Number of dead trees by two-inch diameter (dbh) classes.

(6) A measure of stand density determined by the distance required to count 20 trees on a plot 13.2 feet wide (Keser 1964).

In addition, vegetal and physiographic characteristics of the plot area were recorded.

Two 4-chain baselines bisecting each other at the center of the stand appraisal plot were used as the basis of measuring the fuel complex associated with the stand. A variable sampling design best suited to particular fuel components was applied in the following manner.

(1) Dead surface fuels $\leq$ 0.5-inch diameter - gravimetric sampling from sixteen 1/10,000-acre plots spaced at 33 ft intervals along each transect line.

(2) Dead surface fuels > .5-inch diameter - number of fuel components intersecting the 8-chain baseline by three diameter classes; 0.51 to 1.5 inches, 1.51 to 4.0 inches and > 4.1 inches diameter.

(3) Height above ground of the highest dead surface fuel component.

(4) Number of bridge fuels (dead branches occurring in the lowest 6 ft of bole, or below the green crown components) on four trees within the plot boundary having the heaviest concentration of this fuel component.

(5) Weight of bridge fuel components on four trees within the plot boundary having the heaviest concentration of this fuel component.

(6) Number of snags - designated as boles larger than 7.0 inches dbh and exceeding 10 ft in height.

(7) Number of dead trees exclusive of snags.

Crown fuel components occurring on each five feet of tree height were weighed from all trees on one 1/10-acre plot and on 17 plots containing 20 trees each (Fig. 1) (Muraro 1966) to determine the spatial distribution of dead and living aerial fuels.

Ground vegetation occurring on the four predominant vegetation sites (Spilsbury et al. 1963) was clipped, bagged and oven-dried to determine the weight of this fuel. Approximately 25 plots, each measuring ten feet long by one foot wide, were sampled in each vegetation site (Table III).

Depth and sample volume of the organic layer (L, F and H layers) were measured at 20 and five locations, respectively, on 25 stand measurement plots representing a range of stand densities and ages. The samples were oven-dried and then burned in a muffle furnace to determine the quantity of mineral soil incorporated in the sample.

Analysis of Data

Stand and Fuel Relations

Ten independent variables were compiled from the field measurements of the stand and correlated with other stand variables and with 19 dependent variables describing the stand and fuel complex. Simple and multiple correlations of the following variables were conducted.

Y_{10} X_1 mean height of dominants (feet)

Y_9 X_2 mean age of dominants (years)

Y_8	X_3	site index at 80 years
Y_7	X_4	stand density by 20-tree method (feet) (Keser 1964)
Y_6	X_5	product of number of trees /0.01 acres x dbh
Y_5	X_6	number of living trees per acre
Y_4	X_7	mean dbh of living trees (inches)
Y_3	X_8	Volume per acre (Ccf)
Y_2	X_9	land productivity class[1/]
Y_1	X_{10}	Basal area in square feet/acre
	Y_{11}	number of dead trees per acre
	Y_{12}	mean dbh of dead trees
	Y_{13}	number of snags per acre
	Y_{14}	oven-dry loading (tons/acre) of surface fuels < 0.5 inch diameter
	Y_{15}	oven-dry loading (tons/acre) of surface fuel 0.51 to 1.50 inch diameter
	Y_{16}	oven-dry loading (tons/acre) of surface fuel 1.51 to 4.0 inch diameter
	Y_{17}	surface oven-dry loading (tons/acre) of surface fuel > 4.0 inch diameter
	Y_{18}	total surface fuel loading (tons/acre)
	Y_{19}	bridge fuel loading (tons/acre)
	Y_{20}	height of lowest bridge fuel component above ground (feet)
	Y_{21}	Maximum height above ground (feet) of bridge fuel
	Y_{22}	length of live crown (feet)

1/ Land productivity classes provided by Dr. D. S. Lacate, University of British Columbia.

The ability to predict characteristics of the fuel complex from stand density and height of dominants was tested to determine if stand inventory data could be used as a basic for estimating the fuel complex. Photographic interpretations of stand density and height of dominants from 20-chain scale photography classified each plot into one of ten types (Table I). Means and standard deviations of stand and fuel measurements were determined for the plots in each type. Variance ratios between those types considered to be most similar were calculated and tested by the F test to determine significance of population differences.

Table I - Distribution and Description of Stands Interpreted from Aerial Photographs.

Type	No. of Plots	Description	Illustrated by Figure No.
0	10	Regeneration < 30 ft - extremely dense	5
1	11	Regeneration < 30 ft - dense to moderately dense	6
2	4	Regeneration < 30 ft - moderately dense to open	7
3	13	Suppressed < 50 ft - dense older stands	8
4	32	Moderately tall - dense	9
5	16	Moderately tall - open	10
6	30	Tall - dense	11
7	31	Tall - open	12
8	8	Mature lodgepole with spruce-balsam understory	13
9	6	Veteran Douglas fir with pine understory	14

The plots were similarly categorized into 13 types according to height and density classes from the measurements made on the ground to determine type differences (Table II). Normal stocking was determined from yield tables for British Columbia (Table XIII, XVIII, Smithers 1961).

Table II - Distribution and Description of Stands from Ground Measurements

Height Ft	Stocking Class: Normal	Dense	Very Dense
< 30	Type 1 (n = 10) < 4000 trees/acre	Type 2(n = 8) 4000 to 10,000 trees/acre	Type 3 (n = 7) > 10,000 trees/acre
31-50		Type 4(n = 7) < 3000 trees/acre	Type 5 (n = 10) > 3000 trees/acre
51-60		Type 6(n = 16) < 2000 trees/acre	Type 7 (n = 20) > 2000 trees/acre
61-70	Type 8 (n = 17) < 800 trees/acre	Type 9(n = 15) 800 to 1500 trees/acre	Type 10 (n = 7) > 1500 trees/acre
> 71	Type 11 (n = 7) < 500 trees/acre	Type 12(n = 20) 500 to 800 trees/acre	Type 13 (n = 17) > 800 trees/acre

Herbaceous vegetation

Mean loading of all species in each of the four most predominant vegetation types (Spilsbury et al. 1963, Table IV) were calculated. Because of the distribution of species no statistical analysis was done nor was there any attempt to correlate ground vegetation and stand characteristics.

Organic Layer

Mean loading of the organic layer under each stand was calculated from the 20 measurements of depth and the mean bulk density calculated from the five volumetric samples of the organic layer. Standard deviations of depth for each group of samples were calculated. Graphical analysis of bulk density, loading and depth as dependent variables of stand height, age, site index and density for both the stand and dominant trees was conducted. The weight of mineral content determined by the muffle furnace treatment was deleted from oven-dry weight for all calculations.

Crown Weight

Multiple regressions of living and dead crown fuel components and their distribution on individual trees were conducted with fuel weight, uncorrected for moisture content, and individual tree parameters.[1]

The weight of live and dead crown fuels on each five feet of height from the 18 crown weights plots were converted to an approximate dry weight by assuming 100% moisture content for living crown fuels and 15% for dead crown fuels. The weight and distribution on a per acre basis for each five feet of crown and for individual trees were graphically analysed with stand parameters as independent variables. Compactness ratios (ft^2/ft^3)[2] and fuel loading for each five acre-feet were also calculated (Appendix II).

Results

The distribution of the 160 sample plots, according to various stand parameters, was as follows.

	DISTRIBUTION OF PLOTS BY HEIGHT CLASSES										
HT. IN FT	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100+
NO. OF PLOTS	0	15	10	2	14	32	43	31	10	2	

	DISTRIBUTION OF PLOTS BY DISTANCE REQUIRED TO COUNT 20 TREES									
DIST. IN FT	0-19	20-39	40-59	60-79	80-99	100-119	120-139	140-159	160-179	180+
NO. OF PLOTS	37	53	20	20	11	8	3	3	3	2

1/ Conducted under the direction of Dr. J.H.G. Smith, Faculty of Forestry, University of British Columbia.

2/ Compactness (1/lambda)(ft^2/ft^3) is the relation of the volume of the fuel complex and the size of fuel components and is determined by dividing the surface area (ft^2) of the individual fuel components by the volume of the fuel complex less the volume of the fuel components (ft^3).

DISTRIBUTION OF PLOTS BY AGE CLASSES

AGE IN YEARS	0–29	30–69	70–99	100–129	130–159	160–189	190+			
NO. OF PLOTS	25	4	100	22	5	1	3			

Stand density, determined by measuring the distance required to count 20 trees on a plot 13.2 feet wide (Keser 1964), is related to the number of trees per acre by the relation shown in Figure 2.

Relation of Stand & Fuel Measurements

Appendix I shows the correlation coefficients from the simple regression of fuel characteristics and stand measurements. With 160 pairs of data, correlation coefficients of .4 are significant at the 5% level of probability. In general, correlation coefficients of regressions using stand parameters as independent variable of fuels were less than .4. Exceptions mainly dealt with size, (Y_{11}) number of dead trees (Y_{12}) and snags (Y_{13}). In the opinion of this author, regressions that yield correlation coefficients of .4, explaining 16% of the population variance, are of little use to the modern fire control agency as a means of predicting the fuel complex.

Multiple regressions of stand and fuel measurements did not improve the use of stand parameters as a means of predicting fuel characteristics. As with the simple regressions, the highest correlation coefficients were obtained when stand parameters were related to other stand parameters and when fuel parameters were related to other fuel parameters.

Means values of selected stand and fuel measurements for the plots in each of the types determined from the aerial photographs are shown in Table III.

Population variances of the pairs of types shown in the first column that are different due to chance less than 5 and 1% of the time, are indicated by asterisks. Those not marked by asterisks have more than a 5% chance that the difference of the means is due to chance. Table III verifies the results of the regressional analysis by showing only a few of the fuel parameters to be different, whereas most of the stand parameters are different 99% of the time. The types shown in Table III are illustrated by Figures 5 to 14 with selected measurements of the stand and fuel complexes.

The results of a similar analysis with types derived from ground measurements are not shown, but the differences in the means of a greater number of fuel parameters from these types were due to chance rather than from photographically determined types.

Herbaceous vegetation

Mean values of the herbaceous vegetation, segregated according to species in each vegetation type are shown in Table IV. In general, pinegrass occurs in varying amounts throughout the entire area and under virtually all types of stands.

TABLE III - STAND AND FUEL MEASUREMENTS FROM PHOTOGRAPHIC CLASSIFICATION

Type	n	Age	Dom. Ht	Dom. Crown Length	Avg Dbh (Live)	B.A.	Live Trees	Density	Vol.	Site Index	Dead Trees	Avg Dbh (Dead)	Snags	Ground Fuel <.5 Inch	Total Ground Fuel	Compact- ness (Ground)	Bridge Fuel	Compact- ness (Bridge)
		Years	Ft	Ft	Inch	Ft^2/A	No./A	Ft/20 Trees	Ccf/A	80 Years	No./A	Inch	No./A	T/A	T/A	Ft^2/Ft^3	T/A	Ft^2/Ft^3
0 0x1	10	19	15.2 *	11.1 **	1.18	14 *	18,000 **	5.7 **	4.5	47	218	.80	2	.32	25.59	.651	1.09	.088
1 2x1	11	19	19.4	16.2 *	1.61	75	4,297 **	20.7 **	6.7	57 *	109	.88	6	.29	18.14	.512	.65	.072
2	4	19	23.5	21.0	2.31	33	1,062	58.9	4.3	72	5	1.00	0	.14	9.48	.868	.45	.049
3 3x0	13	81	43.4	16.2 *	2.67	180	4,359 **	11.9 **	34.8	48	2,217 **	2.66	0	.60 *	10.75 *	.185 **	.47 *	.034 **
4 4x3	32	82	55.4 **	19.6 *	3.91 **	208 *	2,344 **	21.9 **	55.7 **	60 **	1,374 **	1.89	9	.40 *	3.82 **	.177	.74	.038
5 5x4	16	84	61.6 **	23.6 **	5.65 **	180	1,029 **	61.3 **	51.4	66 **	246 **	2.26	17	.31	2.52 **	.312 *	.81	.038
6 6x4 6x5	30	94 *	67.4 ** **	25.9 **	5.44 **	201 **	1,216 **	41.6 ** **	63.8 * **	70 ** **	504 ** *	2.29	40	.43	7.26 ** **	.236	.67	.034
7 7x5 7x6	31	103 *	72.3 ** **	31.8 ** **	7.07 ** **	178	615 ** **	96.4 ** **	60.0	73 **	115 * **	2.44	35	.34	9.54	.175	.84	.039
8	8	110	79.3	50.0	6.16	205	540	81.8	75.5	78	134	1.67	34	.46	12.97	.526	1.39	.068
9	6	161	81.7	57.7	2.97	154	2,314	50.6	41.3	73	40	.20	34	.48	13.47	.248	.40	.022

* less than 5% probability that differences are due to chance;

** less than 1% probability that differences are due to chance.

TABLE IV - OVEN-DRY WEIGHT OF VEGETATION ACCORDING TO SPECIES AND VEGETATION SITE[1]

Veget. Plot No.	Applicable Stand Plots	No. of 10 ft^2 Samples	Class and Description[1]	Species	O.D.W. lb/ft^2
VA	137,136	25	III Calamagrostis-Vaccinnium scoparium	Calamogrostis	0.014
				Vaccinnium	0.006
				TOTAL	0.020
VB	160	26	XII Calamagrostis	Calamogrostis	0.030
				Mixed	0.038
				TOTAL	0.068
VC	118,119, 120	25	II Vaccinnium scoparium ledum	Ledum	0.057
				Vaccinnium	0.010
				Calamogrostis	0.001
				TOTAL	0.068
VD	36,38,39, 37,40	28	II Vaccinnium scoparium	Vaccinnium	0.008
				Calamogrostis	0.010
				TOTAL	0.018

[1] Arlidge, J.W.C. Site type map of Minnie Lake--Paradise Lake transect.

Organic Layer

Standard deviations of the 20 measurements of organic depth ranged from 30 to 52% of the means for each sample (Table V). No single stand or site variable satisfactorily explained the variation of organic loading or depth, although stand height and density provided the most useful relation. The associated variables of site and age confounded these relations through their effect on height and density (Lamois 1958). Under stands less than approximately 25 years of age, loading averaged 0.312 lbs/ft^2; 0.486 lbs/ft^2 in 50- to 100-year-old stands and 1.124 lbs/ft^2 in 200-year-old stands of spruce and lodgepole pine. Mineral soil content of individual samples ranged up to 60% of dry sample weight. The relation of loading as a function of depth is shown in Figure 3.

Crown weights

Crown weights in tons per acre with dominant tree characteristics and mean stand characteristics are shown in Table V. Loading of living crown fuels on the average tree is well related to average crown length. Total crown fuel, i.e., dead and living fuels are also dependent on mean stand diameter (Fig. 4). Knowledge of average stand dbh, average crown length and number of stems per acre is required to derive crown fuel loading from Figure 4. None of the numerous stand parameters tested provided a useful independent variable of aerial fuel loading on a per acre basis. Exceptions that could not be logically assigned to stocking, age, site or height occurred in each analysis.

Regression analysis of the data, uncorrected for moisture content, yielded the following relations of crown fuel components and heights in feet and dbh in inches of the individual trees.

(a) $Y_1 = -.0197 + .0490$ (Dbh) $- .0024$ (total height), when Y_1 = weight of dead fuel per foot of occurrence (Kgs/Ft)
$n = 396$ samples $r^2 = .49$

(b) $Y_2 = -.1518 + .30058$ (Dbh) $- .0122$ (total height) when Y_2 = weight of living fuel per foot of live crown (Kgs/Ft)
$n = 405$ samples $r^2 = .74$

(c) $Y_2 = -9.9987 + 10.643$ (Dbh) $- .8563$ (height to live crown), when Y_2 = weight of living fuel per tree (Kgs)
$n = 425$ samples $r^2 = .80$

TABLE V. SUMMARY OF ORGANIC LAYER PLOTS

Plot No.	Age (yrs)	Trees /Acre	STAND Mean DBH (inches)	Crown Length (ft)	B.A. (ft^2)	ORGANIC LAYER Loading (lb/ft^2)	Depth (inches)	±	SD (inches)	Bulk Density (Less Mineral) lb/ft^2
1	97	1030	5.55	25	222	.266	.94	±	.460	4.32
2	86	2760	2.99	17	158	.741	2.49	±	1.273	3.59
3	76	1980	3.69	18	162	.180	.59	±	.209	4.51
4	84	450	7.69	35	157	.301	1.38	±	.459	2.91
5	81	910	6.66	21	244	.286	1.52	±	1.117	2.42
6	86	1500	4.62	22	191	.589	2.03	±	.849	3.88
7	81	2770	4.04	28	214	.501	1.54	±	.708	4.42
8	94	3260	3.40	26	239	.369	.96	±	.372	4.34
9	199	810	6.91	22	182	.523	1.75	±	.639	3.69
10	103	340	10.15	49	231	1.922	4.55	±	1.836	4.91
11	74	2220	2.91	18	118	.506	1.41	±	.471	4.16
12	70	7350	1.95	19	160	.848	2.18	±	.986	4.34
13	19	4080	1.66	14	70	.295	1.13	±	.662	3.94
14	19	8140	1.50	11	110	.330	1.09	±	.362	4.72
15	108	650	5.89	40	141	.422	1.18	±	.402	4.44
16	80	1620	3.66	24	143	.275	1.21	±	.260	2.89
17	81	2610	3.44	25	190	.380	1.53	±	.510	3.62
18	87	500	7.68	39	179	.426	1.62	±	.569	3.27
19	55	1460	3.99	36	148	.491	1.71	±	.545	3.35
20	87	540	7.15	29	160	.409	.92	±	.510	4.72
21	74	360	8.78	36	158	.682	1.59	±	.836	4.09
22	83	2600	2.77	18	125	.763	3.26	±	2.572	3.09
23	82	860	6.07	31	187	.842	3.16	±	1.809	3.08
24	108	570	7.40	32	183	.372	2.27	±	.834	2.69
25	84	3460	2.78	20	175	.715	2.26	±	.955	3.42

TABLE VI STAND CHARACTERISTICS OF CROWN WEIGHT PLOTS

Plot No.	Mean of 3 Dominants			Site Index 80 Years	Stocking % of Normal[1]	Mean of Stand			Total Stems/ Acre	Crown Wt T/A		
	Age	Ht'	Dbh"			Total Ht'	Ht to Green Crown	Stand Dbh		Dead	Living	Total
1	110	80	10.5	70	150	61	35	6.7	650	2.92	11.66	14.58
2	86	73	8.6	70	140	54	32	5.4	710	2.15	7.60	9.75
3	80	53	7.0	50	160	40	22	4.6	1210	3.91	9.37	13.28
4	114	69	9.8	60	80	61	31	7.7	450	.57	11.09	11.66
5	81	50	6.3	50	300	43	28	3.9	2520	3.85	12.99	16.84
6	86	76	11.4	70	60	65	31	9.0	380	2.92	14.85	17.77
7	82	42	4.0	40	450	36	24	3.0	3520	1.57	6.99	8.56
8	74	50	4.1	50	500	41	30	3.4	4080	3.14	10.55	13.69
9	200	78	11.6	60	130	59	41	6.8	670	.65	10.39	11.04
10	74	76	9.4	80	90	69	39	8.4	480	6.42	10.55	16.97
11	80	64	7.0	60	210	55	37	5.2	1410	3.85	9.45	13.30
12	80	36	4.9	40	500	27	18	2.4	4000	2.11	7.20	9.31
13	83	58	6.7	60	150	45	31	4.7	990	2.95	5.73	8.68
14	86	63	8.4	60	75	53	34	6.4	510	3.58	5.14	8.72
15	91	74	8.6	70	160	62	40	6.5	830	5.72	11.37	17.09
16	21	14	1.4	50	400	10	4	.8	20000	.62	5.98	6.60
17	21	17	2.4	60	85	14	5	1.4	3570	.22	4.09	4.31
18	21	22	2.6	70	90	18	5	2.1	2670	.38	5.89	6.27

1/ From Smithers; 1961 Tables XIII to XVIII

(d) $Y_2 = -10.287 + 10.3916$ (Dbh) $- .4738$ (total height), when Y_2 = weight of living fuel per tree (Kgs)

$n = 425$ samples $r^2 = .72$

The dry weight of fuel Y is obtained by the product of $Y_1(.15)$ for dead crown fuels and $\frac{Y_2}{2}$ for living crown fuels.

The length of live crowns were related to total height by a correlation coefficient of .70, but the best correlation was with dbh in the form:

crown length (ft) = 5.22 + 2.70 (dbh) where $n = 425$ and $r = .76$.

The other important spatial parameter of the aerial fuel complex is the height from the ground to the base of the tree crown and is best related to total height by:

height to live crown (ft) = −.35 + .60 (total height) when $n = 425$ and $r = .76$.

The weight per acre of living and dead crown fuel components and the compactness ratios for each five-foot increment of height on each plot are shown in Appendix II. Generally, the greatest weight of living fuel either concurs with or is within five feet of the highest zone of dead fuel.

Visual presentation of fuel complexes

A pictorial catalogue, accompanied by a description of the range of fuel loadings in various zones of the fuel complex, is useful to allow visual association of distribution and fuel loading of complexes that would be expected to react similarly to fire stimuli. This approach could logically be recommended as a first step to deciding priority cover types for development of burning index programs.

The combination of 20-chain aerial photographs and ground photographs of the fuel types in Table III, selected on the basis of photo interpretation, are shown in Figures 5 to 14.

Discussion and Application of Results

This project failed to satisfy the primary objective of determining useful relations of the surface fuel complex as a dependent of stand characteristics. However, the wide range of stands tested and the population of fuel complexes sampled provides a useful reference of the distribution of fuel components within the lodgepole pine cover type in Interior British Columbia. Apart from aerial fuel components, the stand parameters tested provide at best a crude estimate of surface fuel loading that does not justify the effort required for operational implementation.

Importance of stand history

Throughout the field and analysis phases of this study it was realized that the inability to document successional stand history would preclude developing stand-fuel relations with sufficient confidence for specific fire control application.

Smithers (1961) emphasized the importance of fire in both the establishment and subsequent growth of lodgepole pine stands. The type of fire (not necessarily the intensity) has a paramount influence on the stocking and subsequent growth patterns of the stand; however, this is somewhat confounded by the initial stand and moisture conditions and depth of the organic layer. Subsequent to stand establishment, recurring wildfires can result in alterations in stocking and subsequent growth patterns. One important effect of fire history is to make conventional height-age indices useless for defining the true productivity of the site. The nature of the fire responsible for establishing a particular stand influences the resultant ground fuel characteristics in the early years of the succeeding stand.

Subsequent fires tend to deplete the organic fuel component and add to the surface fuel component when killed trees are wind-thrown.

Reasons for the occurrence of a particular stand type and the associated fuel complex require documentation of a number of complex inter-related conditions and events that we were unable to do within the scope of this study.

Some of these conditions are:

(1) the availability and location of fuel components within the fuel complex presented by the original stand;

(2) depth and moisture content of the organic layer under the original stand.

(3) spread and residence characteristics of the destroying fire;

(4) the availability of viable seed after the original stand is destroyed;

(5) subsequent fire history that altered the newly established stand.

(6) productivity of the site.

Appreciation of the effect of these conditions provides a reasonable basis for presentation of a hypothetical example emphasizing the effect of fire behavior on subsequent stand establishment and development. Horton (1953) cited these same factors and their effect on subsequent stand development; however, he did not elaborate on subsequent fuel complexes.

A wide variety of burning conditions are experienced over the course of most large wildfires, especially those associated with establishing the majority of the present pine stands in British Columbia. Fire behavior during periods of damp weather, or to a lesser degree night burning conditions, has a different impact on the regenerative capacity of the site than during periods of hot, windy daytime conditions. Differences in original fuel complexes, availability of seed and freshness of site are other factors influencing the succeeding stand.

A hypothetical example of typical diurnal wildfire behavior in a generally uniform lodgepole pine stand best illustrates the relation of fire to succeeding stand and fuel characteristics. At night, as daytime winds decrease, the tendency to crown will decrease; the fire will creep and smoulder on the surface in a generally erratic fashion, exposing mineral soil where the organic layer is shallow or dry and leaving a residual layer where it is moist. Mortality of the stand under these conditions is primarily from root and stem damage and the occasional "candling" tree. Unless a reburn occurs the following day, a thinned stand may well be the result. Areas involved in this low intensity type fire are characterized by discolored lower crowns and darkened trunks. Subsequent tree mortality is sporadic and mineral soil exposure tends to be spotty. Temperature requirements for serotinous cones in the crowns are not satisfied. Good seed-bed conditions are spotty and no seed has been made available as a result of the fire.

With the onset of the following burning period, flame heights will increase and the surface fire will cover the ground more uniformly. Crowning of individual trees will become more general, dependent on the availability of ground fuels and the proximity of the crowns to the ground fuel. Flame heights will increase with increasing fuel and/or wind until all of the crowns are involved and, unless the crowns are too widely spaced, a fully developed crown fire will result. Tree mortality will be complete at the end of this transition phase. Fires of this type are characterized by red foliage immediately after passage of the fire. Moss and dead needles and the readily volatilized components of living needles are the only crown fuels involved. Mineral soil exposure is uniform except as influenced by differing microsites. Temperatures in the crown have satisfied serotinous cone requirements without necessarily being lethal to seed. Seedbed requirements are generally satisfied and an abundance of seed is available.

If burning conditions continue to worsen, fire behavior is characterized by involvement of a greater proportion of the aerial fuel components. Needles are completely consumed, and branches up to $\frac{1}{2}$ inch and cones are occasionally consumed; temperature lethal to seed are general; smaller trees may be burned off at ground level and some involvement of larger boles occurs. The organic layer is completely removed except in localized wet areas, and physical alteration of the surface mineral soil may occur on dry sites. Areas subjected to this type of fire present generally favorable seedbed conditions except on the severe prefire sites; however, viable seed is destroyed except on the periphery of these areas.

The result of these three levels of fire behavior is, in the first case, a thinned stand; in the second, an extremely dense stand of regeneration, and in the third, a low density stand of regeneration. Fire behavior also influences the fuel complex in a very obvious fashion for a period of years subsequent to the burn. In the first area of low intensity fire, the number of snags will increase as weakened trees die and then slowly decrease as they are wind-blown, increasing the ground fuel loading (Fig. 12). On the area of moderate intensity, initial blowdown where deep burning occurs, and a high protracted rate of downfall as supporting roots decompose, ensure that these areas will experience heavy ground fuel loadings for an extended period of time. In the area of high intensity, generally deeper burning and greater fuel depletion ensure that blowdown is complete within a relatively short period of time or may occur in conjunction with frontal passage. Ground fuel loading is high immediately after the burn, but decomposition of the material tends to be more rapid because of proximity of branchless material to the ground and the increased rate of decomposition in the severely checked material. Only a small proportion of stems remain standing, a condition in which decomposition is slow.

The area of moderate intensity is the first to regenerate but also presents the fuel complex most conducive to destruction. If a second wildfire occurs within a 15-to 20-year period, under extended drought conditions, chances are excellent that a severe site virtually absent of tree growth will result due to total destruction of the limited seed available in stands of this age. The quantity of ground fuel and the proximity of aerial fuels to the surface and the small diameter or living trees would involve all fuels in combustion. Other influences have confounding effects on this simplified model but the scheme presented suggests a natural fuel modification process that discourages secondary fires of high intensity on severely burned areas and enhances ignition (through the presence of snags) and fire growth (because of fuel continuity) on areas experiencing burns of moderate severity. After the first 40 years, other influences such as rate of decomposition, area use and winter snowfall tend to influence the stand-fuel relationship in a confounding manner which must be known if realistic fuel predictions are to be derived from stand characteristics.

Prediction of aerial fuel components via the spatial analysis of crown weights is quite appropriate for predicting fire behavior in these components, but the variability of surface fuels and their spatial relation to the aerial fuels is too uncertain to predict fire behavior in the entire fuel complex.

The foregoing example and the results of the analysis lead to the conclusion that a useable (in terms of the variance between types) fuel classification, derived from indirect measurements, is unattainable if it cannot be achieved in a homogenous forest type such as lodgepole pine. The approach used by Hornby in the 1930's of classifying each area of interest, does not seem economically practical except possibly for limited high value areas such as research forests.

Use of Simulation Techniques

Simulation techniques offer an encouraging method of obtaining useable fuel classification on areas where previous stand history and the severity and type of disturbance can be documented. These qualifications restrict the use of the techniques to areas recently logged and to wildland situations where predisturbance aerial photographs have been supplemented with immediate post-disturbance photographs.

Recently some effort (Kurucz 1969; Smith 1970) has been devoted to simulating growth of forest stands with a specific orientation toward the growing stand as a fuel complex. These efforts have thus far been devoted to the stand and aerial fuel components, i.e., the portion most accurately predicted. To satisfy the requirements of a useable fuel classification via this technique requires a number of subroutines in the simulation program using relatively hard-to-get inputs that must be specifically located in time and space.

Some of the required subroutines and the required considerations are:

I Previous fuel complex (Initial fuel complex)

(1) stand characteristics, dbh, density, height and species.

(2) organic layer, depth and loading.

(3) herbaceous layer, species and loading.

(4) shrub layer, species and loading.

(5) surface fuels, size distribution.

II Intensity and degree of disturbance (Fuel depletion and fire impact)

(1) type of disturbance, fire, logging, logging and burning, blowdown, etc.

(2) effect of disturbance on regenerative potential of herbs, shrubs and stand.

(3) distribution of mortality among size classes.

(4) amount of organic layer and ground fuel depletion.

III Revegetation of site (Fuel appreciation)

(1) rate of downfall and other change of fuel position.

(2) ingrowth and transition of herbaceous vegetation according to species and characteristics.

(3) sprouting and establishment rate of succession of shrubs.

(4) species, and method of conifer establishment with growth rates, fuel loading and spatial characteristics.

(5) buildup or organic layers according to site.

IV Metamorphosis of site (Fuel depreciation)

(1) rate of organic layer decay and incorporation as a soil component.

(2) rate of change and availability of downfall material and surface fuel remnants of previous fuel complex.

Incorporation of these factors, where they apply, are necessary if simulation techniques are to yield fuel classifications applicable by the modern control agency. Relatively few wildland areas, except those experiencing recent change, are sufficiently documented for simulation of development to their current state.

Simulation would provide a means of documenting the fuel complexes presently in the early stages of development on recent and current clear-cut logging operations and wildfires. The ability to determine the required inputs on recently logged areas must be considered in view of the extensive areas of these fuel types; and their increased recreational use afforded by widespread accessibility. All factors pointing to an impending critical fire control problem in areas that justifies the best preventive research effort possible.

Spatial Distribution of Fuels

The spatial distribution of loading (lb/ft^2) of eight of the 10 fuel types illustrated (Figs. 5 to 14) can be compared in Figure 15 to illustrate the difference in crowning potential of the types. Organic fuel loading indicated on the abscissa is shown in the lower left quadrant by lines radiating from the origin to the appropriate depth indicated on the ordinate when zero depth represents the top of the organic layer. Surface fuel loading, including tree litter, herbaceous vegetation and logs, are cumulated by the lines radiating from the origin into the upper right quadrant to a uniform depth of one foot. Cumulated aerial fuel loading (Appendix II) for each five-foot increment of height is originated at the termination of the appropriate indicator of surface fuel loading. The relative ease of crowning is at least partially dependent on the proximity of crown fuels to the surface fuels and the continuity of intervening fuels. The height at which a loading of 0.10 lbs/ft^2 is achieved in the crowns of regeneration types 0, 1 and 2 is 5, 7.5 and 8 ft, respectively, above the surface fuels. The remaining five types consisting of immature and mature stands require 30 to 40 feet of height to attain this loading. Crown weights from types 8 and 9 were not sampled. The favorable vertical fuel distribution in types 0 and 1 is even more hazardous because of the proximity of the heaviest surface fuel loading to the lowest crowns.

Potential to available fuel transformation

A decrease in fuel moisture allows more fuel to be available for combustion at a rate that is dependent on the size, density and physical location of the fuel component. The dotted lines show the hypothetical difference in fuel availability for various drying periods and the resultant flame heights (Fig. 15). The availability of the organic layer is shown by the dashed lines to the right of the zero line and considers the increased depletion of deeper organic layers as drying progresses. The availability of surface fuels is shown by the dashed lines to the right of the zero line reflecting the decrease in rate of depletion with increased drying. Flame heights for a no wind situation are shown by the solid line for drying regime up to 20 days. The flame heights hypothesized are due only to involvement of ground fuel components and illustrate the relatively short drying period required to involve the crowns of all three young stands. Under the conditions shown, crown involvement of the remaining types is doubtful; however, the increases in flame length that occur under the influence of wind would probably involve all crowns at wind speeds exceeding 10 miles per hour with a 20-day drying regime.

Conclusions

1. Young lodgepole pine stands are most hazardous and the hazard increases with stand density due to heavier ground fuel loading and more continuous aerial fuels. Least hazardous are moderate to open advanced immature and mature stands. Hazard increases as stands become overmature when surface fuel loading increases with decadence and invasion of shade tolerant species restablishes vertical fuel continuity.

2. The primary objectives of this project were not achieved; however, information on the spatial distribution of aerial and ground fuel components in the lodgepole pine cover type are presented and discussed in relation to the general problem of fuel classification.

3. Except for crown fuel components, fuel classifications derived from association with stand characteristics in the lodgepole pine stands

tested are not sufficiently accurate to be of value to the fire control decision maker. The uncertainty associated with stand establishment and stand history appear to be the largest source of error.

4. More accurate fuel classifications can most likely be achieved by simulation techniques that include subroutines for initial fuel complexes, types of disturbance, and time related appreciation and depreciation of individual fuel components within the fuel complex. These techniques can best be applied to areas where the stand history is known and are therefore invalid for most wildland fuel complexes.

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APPENDIX I CORRELATION COEFFICIENTS (r) OF STAND AND FUEL CHARACTERISTICS.

Dependent Variable	Independent Variable X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1	.54	.45	.20	–.10	.24	–.18	.37	.82	–.31	
Y_2	.72	–.42	–.73	–.47	.40	.57	–.70	.60		–.31
Y_3	.86	.64	.56	.23	–.27	–.55	.69		–.60	.82
Y_4	.86	.70	.65	.75	–.56	–.75		.69	–.70	.37
Y_5	–.74	–.56	–.69	–.60	–.74		–.75	–.55	.57	–.18
Y_6	–.52	–.38	–.54	–.56		–.74	–.56	–.27	.40	.24
Y_7	.54	.43	.53		–.56	–.60	.75	.23	–.47	–.10
Y_8	.70	.26		.53	–.54	–.69	.65	.56	–.73	.20
Y_9	.78		.26	.43	–.38	–.56	.70	.64	–.42	.45
Y_{10}		.78	.70	.54	–.52	–.74	.86	.86	.72	.54
Y_{11}	–.07	.09	–.38	–.48	.30	.25	–.33	.09	.24	.31
Y_{12}	.62	.55	.38	.34	–.30	–.47	.58	.59	–.42	.41
Y_{13}	.46	.38	.42	.26	–.23	–.33	.48	.42	–.46	.25
Y_{14}	.04	.32	–.23	–.14	.06	.08	–.02	.09	–.06	.15
Y_{15}	–.39	–.18	–.46	–.36	.20	.33	–.45	–.29	.34	.15
Y_{16}	–.59	–.43	–.39	–.25	.24	.39	–.46	–.50	.28	–.42
Y_{17}	–.20	.07	–.19	.06	.26	.23	–.06	–.24	.07	–.13
Y_{18}	–.35	–.05	–.30	–.03	.31	32	–.20	–.36	.15	–.23
Y_{19}	–.01	–.14	.06	–.04	.09	.06	.04	.04	–.02	.09
Y_{20}	.16	.23	–.14	–.23	.11	.11	–.14	.19	.08	.22
Y_{21}	.52	.13	.41	.24	–.16	–.37	.44	.46	–.37	.39
Y_{22}	.69	.47	.68	.68	–.55	–.62	.68	.43	.57	.06

APPENDIX II FUEL LOADING (LB/ACRE) OF DEAD AND LIVING CROWN FUELS AND COMPACTNESS (FT^2/FT^3) BY FIVE-FOOT HEIGHT INCREMENTS

HEIGHT	PLOT 1			PLOT 2			PLOT 3			PLOT 4		
	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT
FT	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3
5	88		.002	40		.001	386		.009			
10	324	11	.009	324	50	.012	1147		.027	16		
15	603	4	.015	404	151	.022	2159		.052	210		.005
20	662	91	.023	681	104	.025	1580	615	.088	286	145	.019
25	629	227	.033	668	175	.030	2057	1149	.142	168	881	.076
30	905	447	.057	569	315	.039	500	2828	.242	206	1272	.108
35	657	503	.057	429	471	.048		4305	.349	139	1664	.138
40	869	855	.090	495	719	.070		4592	.373	72	2420	.198
45	598	1492	.135	384	1334	.119		2912	.235	55	3109	.254
50	312	2390	.201	311	2012	.171		1779	.144		3989	.323
55	45	3410	.278		3303	.268		474	.038		3523	.286
60	113	3892	.319		3190	.259		87	.007		3164	.257
65	37	4008	.326		2104	.171					1526	.124
70	7	3487	.283		1038	.085					496	.040
75		1782	.145		238	.019						
80		631	.051									
85		20	.002									
90												
95												
100												

APPENDIX II FUEL LOADING (LB/ACRE) OF DEAD AND LIVING CROWN FUELS AND COMPACTNESS (FT^2/FT^3) BY FIVE-FOOT HEIGHT INCREMENTS (CON'T)

HEIGHT	PLOT 5			PLOT 6			PLOT 7			PLOT 8		
	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT
FT	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3
5	354		.008	213		.005	131		.003	76		.002
10	638		.015	487		.012	196		.005	305		.007
15	993		.024	772	29	.021	555		.013	532		.013
20	1182		.028	1071	66	.031	881	96	.029	724		.017
25	1489	500	.076	1240	419	.064	1012	442	.060	1295	22	.033
30	2223	1585	.182	1087	764	.088	360	3399	.285	2323	560	.101
35	874	5535	.470	634	1741	.156		5532	.449	990	3786	.331
40		8303	.674	258	3321	.276		4168	.338	39	8066	.656
45		7664	.622	75	4403	.359		345	.028		6901	.560
50		1863	.151		4708	.382					1614	.131
55		542	.044		5291	.429					67	.005
60					4623	.375						
65					2741	.223						
70					1067	.087						
75					452	.037						
80					48	.004						
85												
90												
95												
100												

APPENDIX II FUEL LOADING (LB/ACRE) OF DEAD AND LIVING CROWN FUELS AND COMPACTNESS (FT^2/FT^3) BY FIVE-FOOT HEIGHT INCREMENTS (CON'T)

HEIGHT	PLOT 9			PLOT 10			PLOT 11			PLOT 12		
	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT
FT	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	CROWN	FT^2/FT^3
5				449		.011	79		.002	112		.003
10				1191		.028	475		.011	1010		.024
15				1283		.031	778		.019	1795	154	.055
20				1807	139	.054	1015		.024	1309	1496	.153
25	6			1849	195	.060	1230	163	.043		5610	.455
30	132	37	.006	1952	326	.073	1358	109	.041		4796	.389
35	308	299	.032	1803	272	.065	1529	201	.053		1804	.146
40	315	1340	.116	1604	480	.120	1068	722	.084		528	.043
45	213	2043	.171	825	1732	.162	171	2816	.233			
50	315	2543	.213	86	3115	.255		4995	.405			
55	12	2930	.238		3821	.310		5553	.451			
60		2986	.242		4211	.342		3731	.303			
65		3600	.292		4016	.326		559	.045			
70		2283	.185		2471	.201		61	.005			
75		1965	.160		309	.025						
80		769	.062		21	.002						
85												
90												
95												
100												

APPENDIX II FUEL LOADING (LB/ACRE) OF DEAD AND LIVING CROWN FUELS AND COMPACTNESS (FT^2/FT^3) BY FIVE-FOOT HEIGHT INCREMENTS (CON'T)

HEIGHT	PLOT 13			PLOT 14			PLOT 15			PLOT 16		
	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT	LB/ACRE		COMPACT
FT	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3
5	339		.008	595		.014	201		.005	1252	1558	.159
10	621		.015	849		.020	459		.011		7854	.638
15	850		.020	1058		.025	806		.019		2332	.189
20	823	37	.023	1091		.026	1100		.026		220	.018
25	1033	97	.033	1146	66	.033	1559	36	.040			
30	1024	145	.036	1124	176	.041	2200	110	.060			
35	887	866	.091	1003	805	.089	2291	129	.065			
40	339	3259	.273	253	2171	.182	1669	311	.065			
45		3667	.298	44	2623	.214	954	1705	.161			
50		2280	.185		2491	.202	201	3704	.305			
55		880	.072		1201	.097	14	4290	.349			
60		246	.020		529	.043		4931	.400			
65					187	.015		4749	.386			
70					33	.003		2145	.174			
75								495	.040			
80								9	.001			
85												
90												
95												
100												

APPENDIX II FUEL LOADING (LB/ACRE) OF DEAD AND LIVING CROWN FUELS AND COMPACTNESS (FT^2/FT^3) BY FIVE-FOOT HEIGHT INCREMENT (CON'T)

HEIGHT	PLOT 17			PLOT 18		
	LB/ACRE		COMPACT	LB/ACRE		COMPACT
	DEAD	GREEN	FT^2/FT^3	DEAD	GREEN	FT^2/FT^3
5	433	55	.055	717	276	.040
10		4524	.367	36	4043	.329
15		2912	.236		5674	.461
20		198	.016		1777	.144
25					14	.001

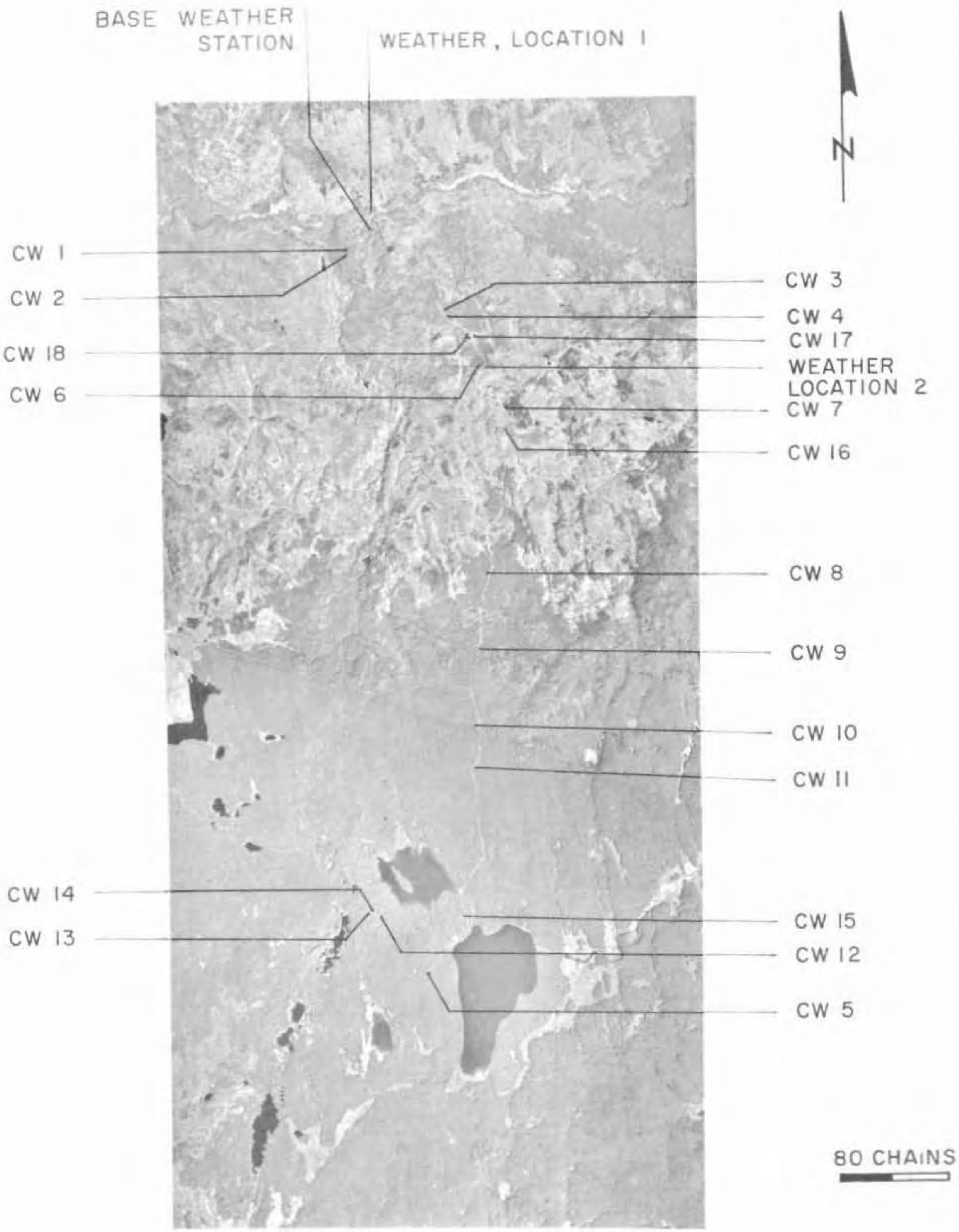

FIGURE I. PARADISE LAKE STUDY AREA SHOWING CROWN WEIGHT PLOTS AND WEATHER STATIONS.

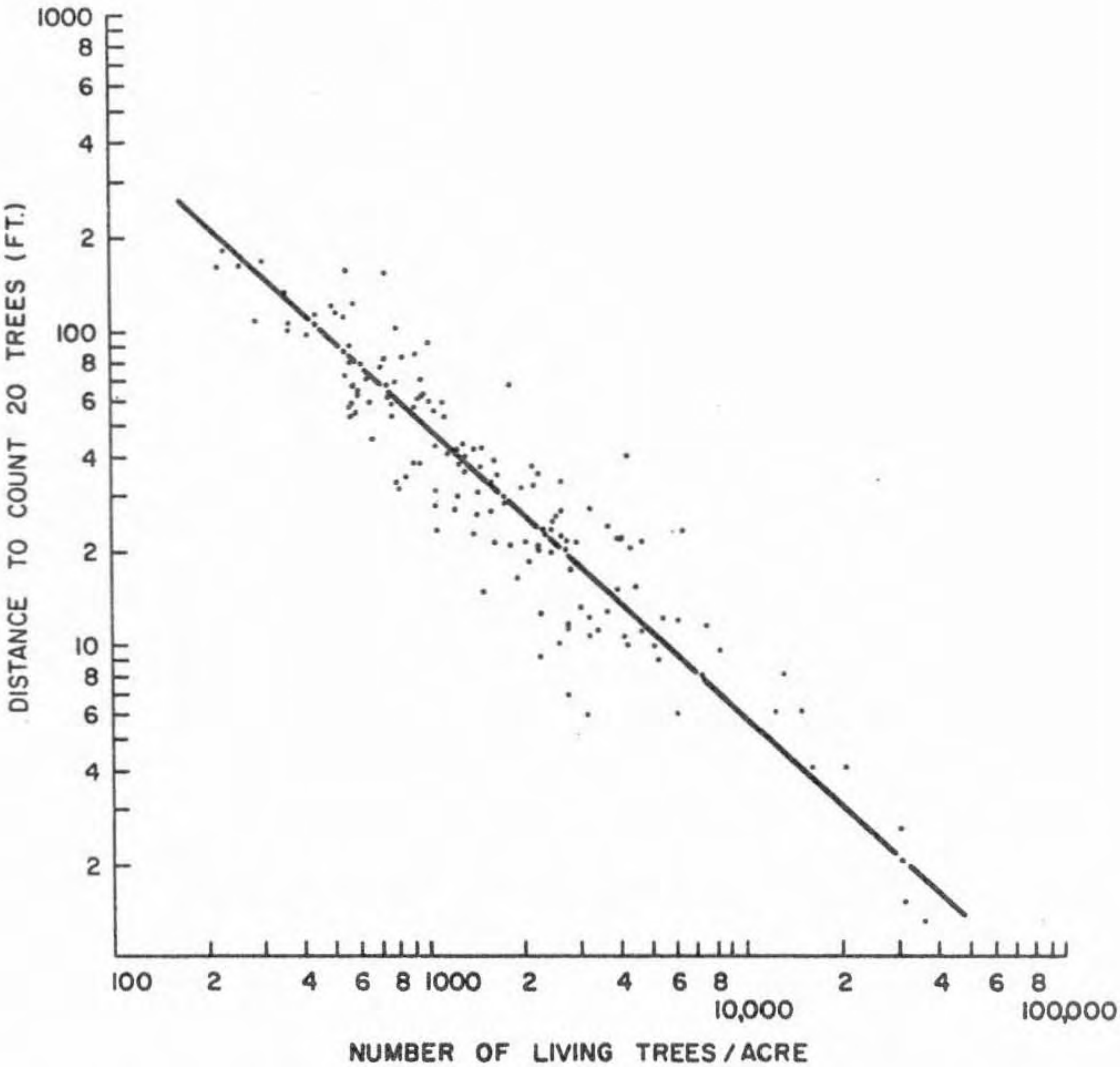

FIGURE 2. RELATION OF DISTANCE REQUIRED TO COUNT 20 LIVING TREES ALONG A STRIP 13.2 FT WIDE WITH NUMBER OF TREES PER ACRE.

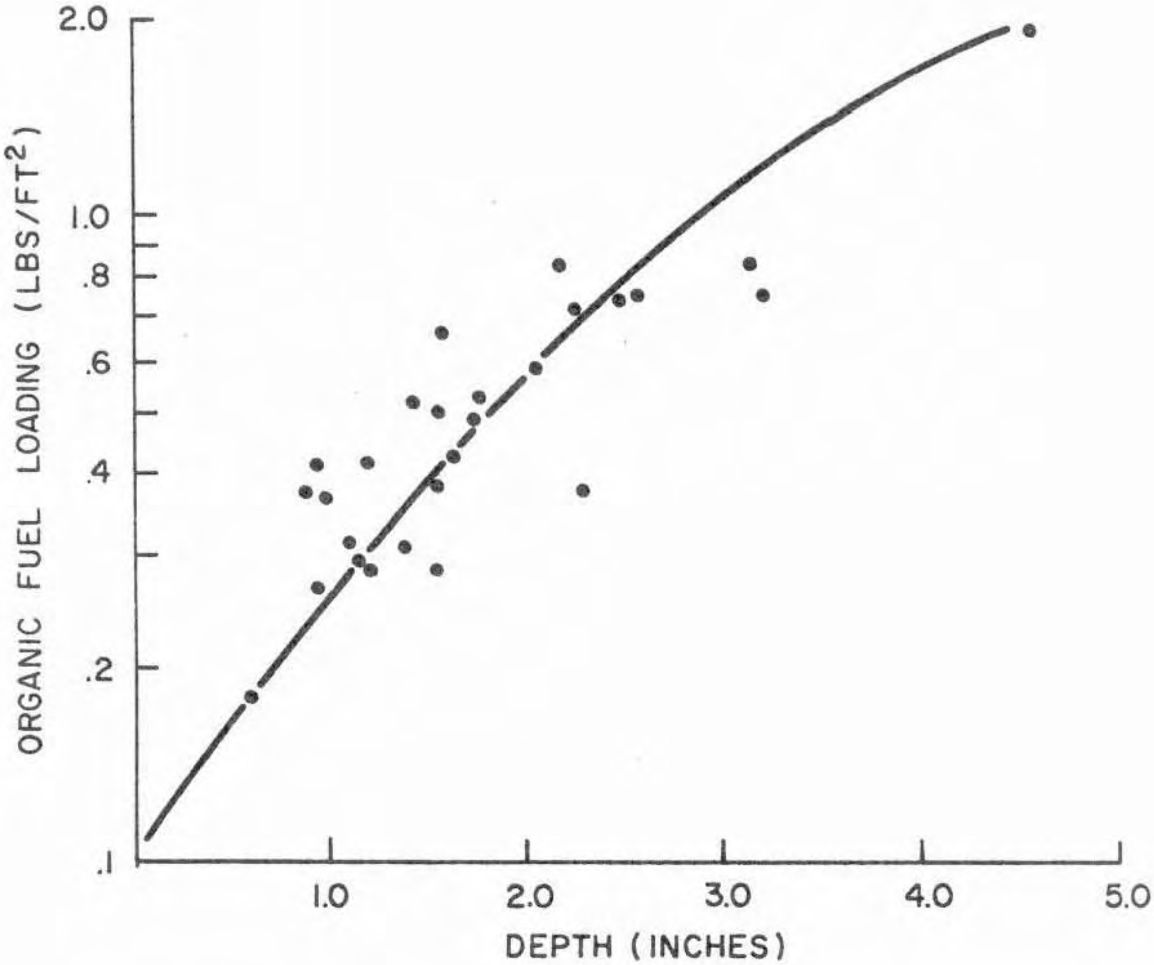

FIGURE 3. RELATION OF ORGANIC FUEL LOADING (LB/FT^2) WITH DEPTH OF THE ORGANIC LAYER (INCHES).

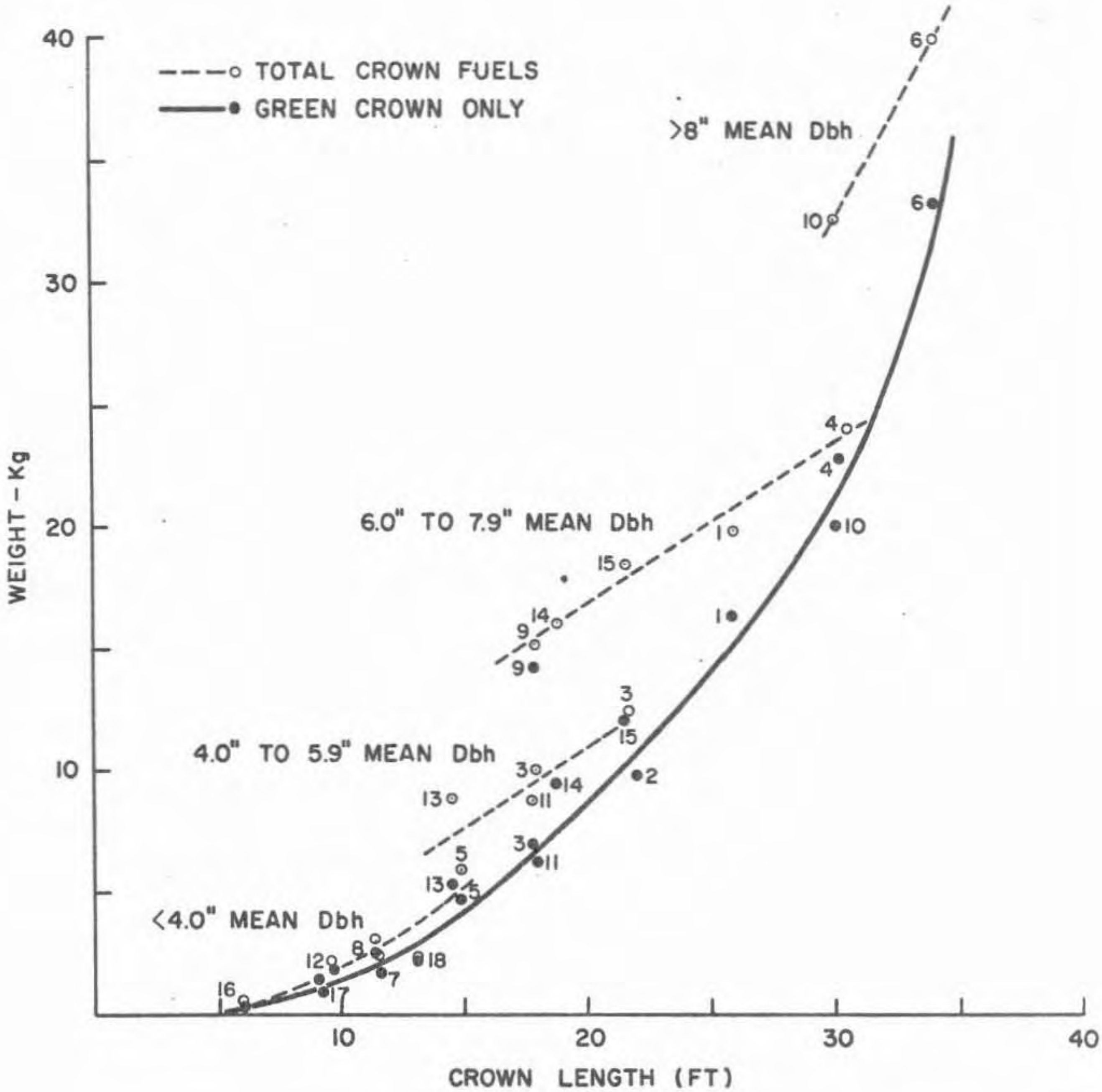

FIGURE 4. MEAN TOTAL CROWN FUEL AS A FUNCTION OF MEAN CROWN LENGTH AND DBH AND MEAN LIVING CROWN FUEL AS A FUNCTION OF MEAN GREEN CROWN LENGTH.

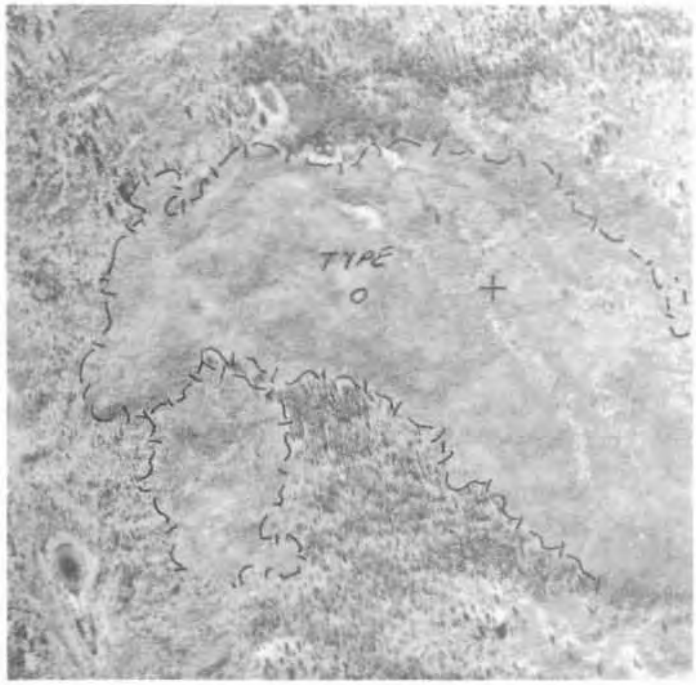

FIGURE 5

TYPE O

Fuel Parameters

Ground Fuels	< .5"	-	.3 ± .2	T/A
	.51 - 1.50"	-	.7 ± .5	T/A
	1.51 - 4.0"	-	7.3 ± 3.1	T/A
	> 4.1"	-	17.3 ± 16.5	T/A
	Total	-	25.6 ± 15.3	T/A
Crown Height		-	4.1	Ft
Aerial Fuels Dead		-	.62	T/A
	Living	-	5.98	T/A
Surface & Aerial Fuel		-	32.20	

Stand Parameters

Age	-	18.9	± 1.7	Yrs
Dom. Ht.	-	15.2	± 4.4	Ft
Ave Dbh	-	1.18	± .25	In
B.A./A	-	140	± 67	Ft^2
Trees/Acre	-	18,000	——	
Vol/Acre	-	4.6	± 4.5	Ccf
Crown Length	-	11.1	± 3.7	Ft

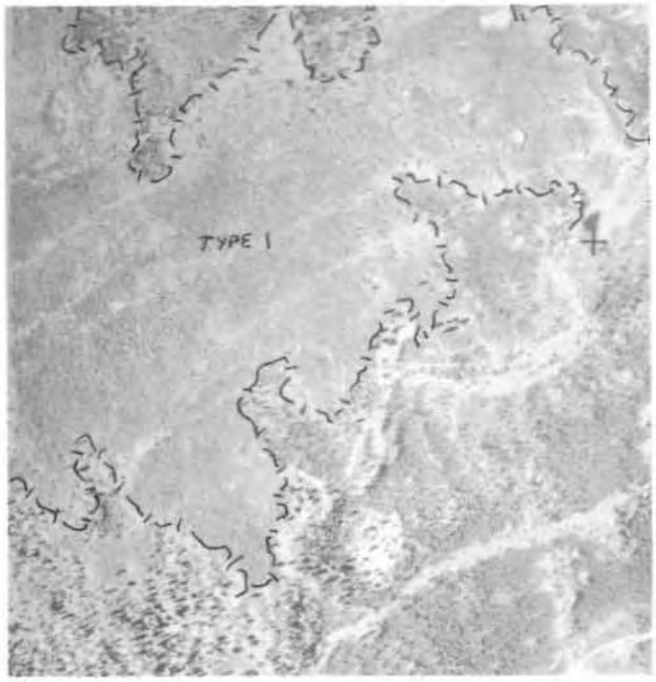

FIGURE 6

TYPE 1

Fuel Parameters

Ground Fuels	< .5	.3	± .2	T/A
	.51 – 1.5	1.2	± 1.4	T/A
	1.51 – 4.0	7.3	± 6.9	T/A
	> 4.1	9.3	± 9.3	T/A
Total		18.2	± 9.1	T/A

Crown Height	3.2	Ft
Aerial Fuels Dead	.22	T/A
Living	4.09	T/A
Surface & Aerial Fuel	22.51	T/A

Stand Parameters

Age	18.6	± 1.9	Yrs
Dom Ht	19.4	± 4.0	Ft
Ave Dbh	1.61"	± .38	In
B.A./A	75	± 38	Ft^2
Trees/Acre	4297	± 1767	
Vol/Acre	6.7	± 5.7	Ccf
Crown Length	16.2	± 4.0	Ft

 

FIGURE 7

TYPE 2

Fuel Parameters

Ground Fuels	< .5"	-	.1 ± .1	T/A
	.51 - 1.5"	-	.3 ± .2	T/A
	1.51 - 4.0"	-	3.9 ± 1.5	T/A
	> 4.1"	-	5.1 ± 4.9	T/A
Total		-	9.4 ± 5.1	T/A

Crown Height	-	2.5 Ft
Aerial Fuels Dead	-	.38 T/A
Living	-	5.89 T/A
Surface & Aerial Fuels	-	15.77 T/A

Stand Parameters

Age	-	18.8	± .5	Yrs
Dom Ht	-	23.5	± 3.0	Ft
Ave Dbh	-	2.33	± .34	In
B.A./A	-	35	± 10	Ft^2
Trees/Acre	-	1063	± 336	
Vol/Acre	-	4.3	± 1.5	Ccf
Crown Length	-	21.0	± 2.9	Ft

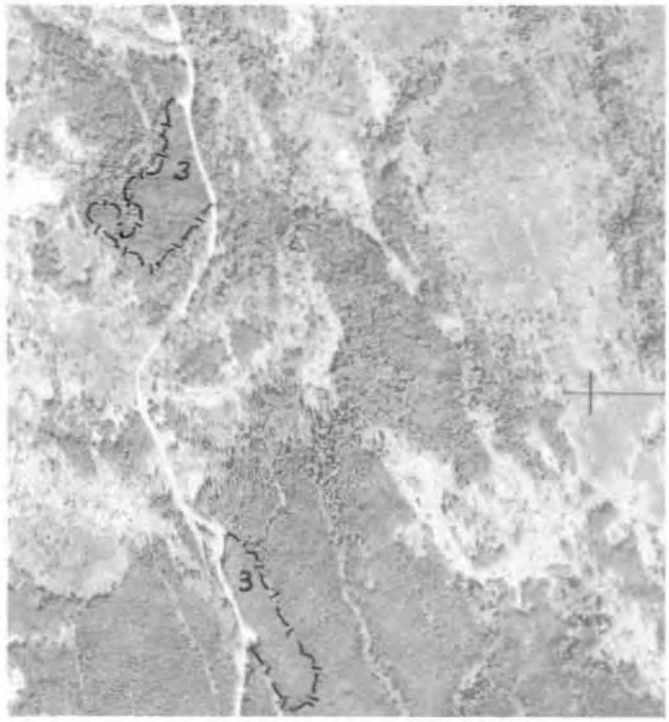

FIGURE 8

TYPE 3

Fuel Parameters

Ground Fuels	< .5"	.7	± .4	T/A
	.51 - 1.5"	1.2	± .8	T/A
	1.51 - 4.0"	1.3	± .8	T/A
	> 4.1"	7.6	± 10.0	T/A
	Total	10.8	± 11.2	T/A

Crown Height	27.2	Ft
Aerial Fuels Dead	1.84	T/A
Living	7.14	T/A
Surface & Aerial Fuels	19.78	T/A

Stand Parameters

Age	81.3	±	7.4	Yrs
Dom Ht.	43.4	±	4.6	Ft
Ave Dbh	2.68	±	.48	In
B.A./A	180	±	26	Ft^2
Trees/Acre	4359	±	1487	
Vol/Acre	34.8	±	7.8	Ccf
Crown Length	16.2	±	5.5	Ft

FIGURE 9

TYPE 4

Fuel Parameters

Ground Fuels	< .5"	- .4 ± .2	T/A
	.51 - 1.50"	- .8 ± .7	T/A
	1.51 - 4.0"	- 1.3 ± .7	T/A
	> 4.1"	- 1.3 ± 1.7	T/A
	Total	- 3.8 ± 2.2	T/A
Crown Height		- 35.8	Ft
Aerial Fuels Dead		- 3.63	T/A
Living		- 10.97	T/A
Surface & Aerial Fuels		- 18.40	T/A

Stand Parameters

Age	-	82.1 ±	6.2	Yrs
Dom Ht	-	55.4 ±	4.7	Ft
Ave Dbh	-	3.96 ±	.73	In
B.A./A	-	209 ±	49	Ft^2
Trees/Acre	-	2309 ±	781	
Vol/Acre	-	55.7 ±		Ccf
Crown Length	-	19.6 ±		Ft

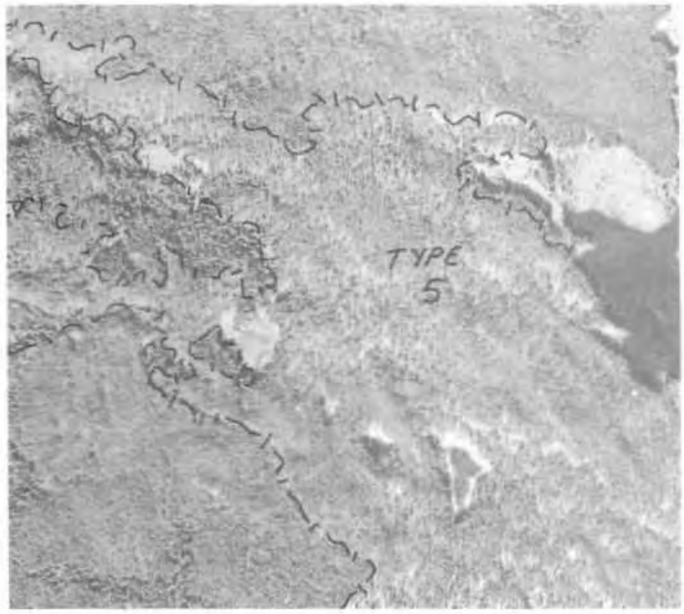

FIGURE 10

TYPE 5

Fuel Parameters

Ground Fuels	< .5"	-	.3 ±	.1	T/A
	.51 - 1.5"	-	.2 ±	.2	T/A
	1.51 - 4.0"	-	.9 ±	.5	T/A
	> 4.1"	-	1.1 ±	1.1	T/A
	Total	-	2.5 ±	2.2	T/A

Crown Height	-	38.0	Ft
Aerial Fuel Dead	-	3.40	T/A
Living	-	7.59	T/A
Surface & Aerial Fuel	-	13.49	T/A

Stand Parameters

Age	-	83.6	±	9.5	Yrs
Dom Ht	-	61.6	±	5.4	Ft
Ave Dbh	-	5.66	±	1.08	In
B.A./A	-	181	±	44	Ft^2
Trees/Acre	-	1029	±	482	
Vol/Acre	-	51.4	±	13.8	Ccf
Crown Length	-	23.6	±	6.4	Ft

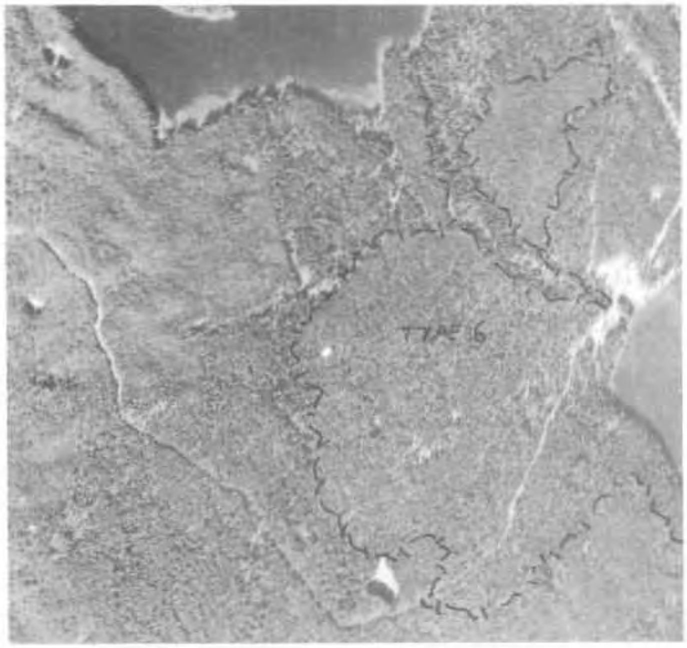

FIGURE 11

TYPE 6

Fuel Parameters

Ground Fuels	< .5"	- .4 ± .2	T/A
	.51 - 1.51"	- .3 ± .4	T/A
	1.51 - 4.0"	- 1.8 ± 1.4	T/A
	> 4.1"	- 4.7 ± 5.4	T/A
	Total	- 7.2 ± 6.6	T/A

Crown Height	- 31.5	Ft
Aerial Fuels Dead	- 2.27	T/A
Living	- 10.11	T/A
Surface & Aerial Fuels	- 19.58	T/A

Stand Parameters

Age	- 93.9	± 25.9	Yrs
Dom. Ht.	- 67.4	± 6.2	Ft
Ave Dbh	- 5.44	± .97	In
B.A./A	- 202	± 42	Ft^2
Trees/Acre	- 1216	± 552	
Vol/Acre	- 63.8	± 14.6	Ccf
Crown Length	- 25.9	± 5.5	Ft

FIGURE 12

TYPE 7

Fuel Parameters

Ground Fuels	< .5"	- .3 ± .2 T/A
	.51 - 1.51"	- .2 ± .2 T/A
	1.51 - 4.0"	- 1.3 ± 1.4 T/A
	> 4.1"	- 7.8 ± 16.8 T/A
	Total	- 9.5 ± 17.8 T/A

Crown Height		- 40.5 Ft
Aerial Fuels	Dead	- 3.96 T/A
	Living	- 10.55 T/A
Surface & Aerial Fuels		- 24.01 T/A

Stand Parameters

Age	- 103.0	± 32.4	Yrs
Dom Ht	- 72.3	± 6.3	Ft
Ave Dbh	- 7.07	± 1.34	In
B.A./A	- 179	± 49	Ft^2
Trees/Acre	- 615	± 233	
Vol/Acre	- 60.0	± 17.6	Ccf
Crown Length	- 31.8	± 7.1	

FIGURE 13

TYPE 8

Fuel Parameters

Ground Fuels	< .5"	- .5	±	.2	T/A
	.51 - 1.5"	- .5	±	.5	T/A
	1.51 - 4.0"	- 2.4	±	1.6	T/A
	> 4.1"	- 9.2	±	11.4	T/A
Total		-13.0	±	12.3	T/A

Crown Ht. - 29.3 Ft.

Aerial Fuels Dead - —

Living - —

Stand Parameters

Age	-	110.4	±	25.1	Yrs
Dom. Ht	-	79.3	±	15.5	Ft
Ave. Dbh	-	6.25	±	2.65	In
B.A./A	-	209	±	26	Ft^2
Trees/Acre	-	1108	±	1067	
Vol/Acre	-	75.5	±	17.1	Ccf
Crown Length	-	50.0	±	17.7	Ft

FIGURE 14

TYPE 9

Fuel Parameters

Ground Fuels	< .5"	- .4 ± .1 T/A
	.51 - 1.5"	- .2 ± 0 T/A
	1.51 - 4.0"	- 1.6 ± .5 T/A
	> 4.1"	- 9.9 ± 7.6 T/A
	Total	- 12.8 ± 7.6 T/A
Crown Ht		- 24.5 Ft
Aerial Fuels	Dead	- —
	Living	- —

Stand Parameters

Age	-	161.7	±	66.8	Yrs
Dom Ht	-	81.7	±	11.9	Ft
Ave Dbh	-	2.95	±	2.39	In
B.A./A	-	150	±	30	Ft^2
Trees/Acre	-	2337	±	1571	
Vol/Acre	-	41.3	±	9.1	Ccf
Crown Length	-	57.7	±	15.5	Ft

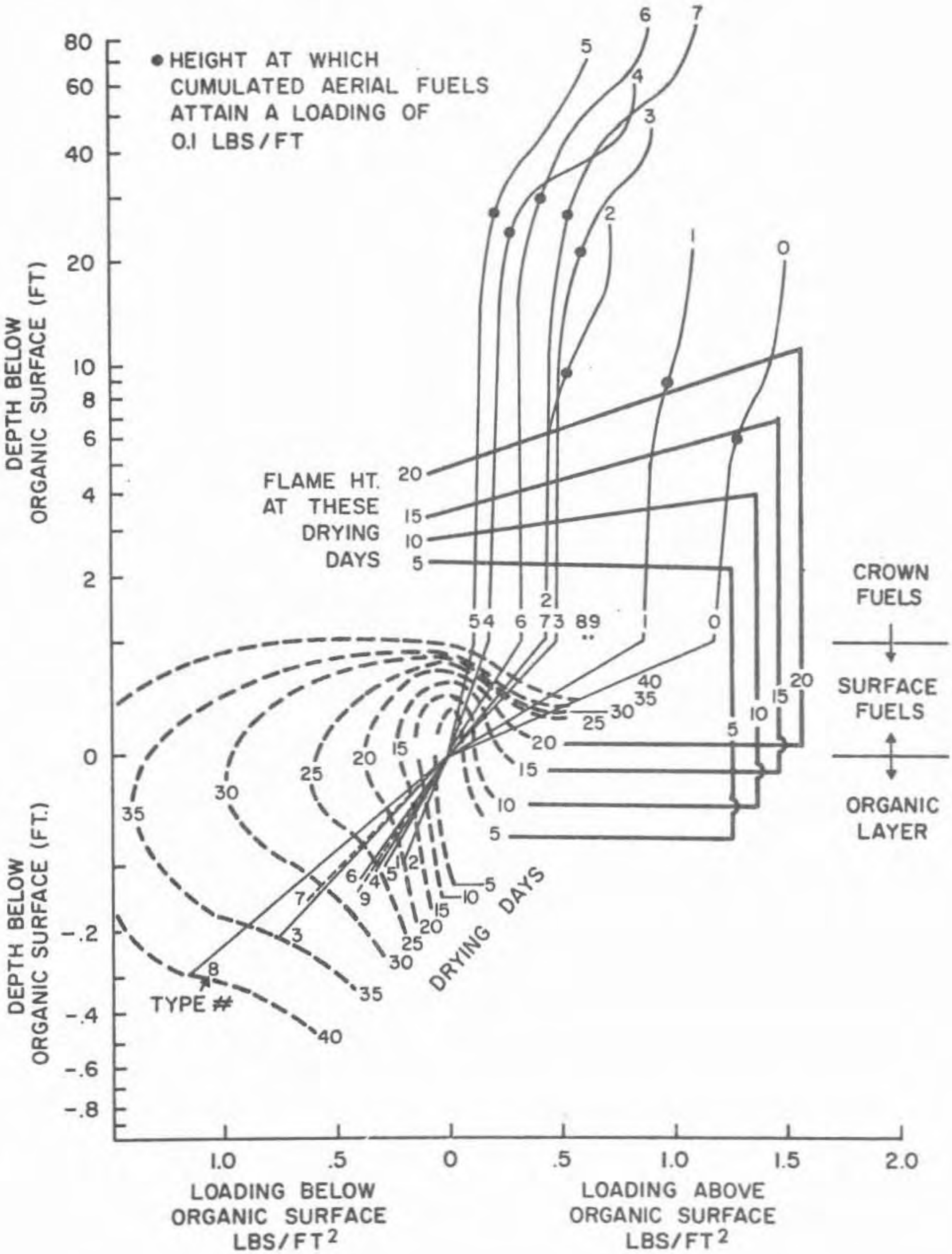

FIGURE 15. COMPARISON OF LOADING AND DISTRIBUTION OF FUEL COMPONENTS IN LODGEPOLE PINE FUEL TYPES WITH HYPOTHETICAL FUEL AVAILABILITY AND RESULTANT FLAME HEIGHT AS A FUNCTION OF DRYING DAYS AT ZERO WING.