

CANADA  
DEPARTMENT OF FORESTRY  
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Progress Report  
Project B.C. 603

DEVELOPMENT OF A METHOD FOR THE EVALUATION OF FOREST  
FUELS IN THE SOUTHERN INTERIOR OF BRITISH COLUMBIA

by  
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## Progress Report

# Project B.C. 603 - Development of a Method for the Evaluation of Forest Fuels in the Southern Interior of British Columbia

by

S. J. Muraro

### Introduction

During the 1961 field season the fuel complexes associated with interior dry belt stands of Douglas fir and ponderosa pine were investigated to determine an index of the fuel complex using various stand parameters. The fuel components were separated and weighed by size classes and location on 41 paired, square, milacre plots. **Forty-one pairs of plots were established** near Kamloops, 26 in the Douglas fir type and 15 in the ponderosa pine type.

### Area

This preliminary study was conducted near Paul Lake which lies approximately 15 miles northeast of Kamloops within the M1 (ponderosa pine and Douglas fir) section of the Montane Forest Region of Canada<sup>1</sup>. The fir stands investigated lie roughly midway between the lower savannah ponderosa pine type and the higher lodgepole-aspen types. The elevation of the sample plots ranged from approximately 1,300 feet in the pine type to approximately 3,500 in the fir type.

The physiography of the area changes from glaciated, broad valleys through steeply to very-steeply-rolling country to high, gently-rolling plateau areas.

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<sup>1</sup> Rowe, J. S. Forest Regions of Canada. Canada Dept. of Northern Affairs and National Resources Bulletin 123, 1959.

## Procedure

### Plot Location and Cover Type

Cover types were selected from twenty-chain scale aerial photographs with the aid of the B. C. Forest Service, Inventory Division's, forty-chain scale cover type maps. Primary plots were located on the ground on the basis of a subjective selection of the "worst average" fuel complex during a short reconnaissance of the cover type. The plot was located on the photograph and pin punched; the plot number was then recorded on the back of the photograph. The "worst average" was selected because this is the fuel complex which would be of most concern to a fire control organization. By stratifying the sampling to one level of the fuel complex within a cover type, in theory the upper quartile, the number of samples may also be reduced. However, since most statistical methods are based on a random sample of the population, the sampling method used presented difficulties in the analysis of the data. Secondary plots were established mechanically from the selected plot by measuring a distance of two chains in that cardinal direction which would maintain the second plot in the largest area of the cover type being sampled. The secondary plot was employed in an attempt to establish a measure of the variability within the cover type. After locating each plot, photographic, mensurational and fuel data were recorded along with physiographic and plot description on the field sheet shown in Figure 1.

### Photographic

The photographic record of each cover type and its fuel complex consists of three sets of photographs, two taken in the field and the third extracted from the aerial photographs. Ground stereo pictures of the plot were taken to illustrate the fuel complex while panoramic pictures were included to illustrate the general appearance of the cover type. Stereograms

FUEL CLASSIFICATION FIELD SHEET

Ground Photo. Roll # \_\_\_\_\_ Picture # \_\_\_\_\_  
 Date \_\_\_\_\_ Hour \_\_\_\_\_ Plot # \_\_\_\_\_ Region # \_\_\_\_\_ Comp. # \_\_\_\_\_  
 Cover } Upper \_\_\_\_\_ Age \_\_\_\_\_ Mat. Imm. Rep. Actual \_\_\_\_\_ ft. Invent. \_\_\_\_\_ ft.  
 Type } species \_\_\_\_\_ yrs. (circle one) Height \_\_\_\_\_ Height \_\_\_\_\_  
 Lower \_\_\_\_\_ Age \_\_\_\_\_ Mat. Imm. Rep. Actual \_\_\_\_\_ ft. Invent. \_\_\_\_\_ ft.  
 species \_\_\_\_\_ yrs. (circle one) Height \_\_\_\_\_ Height \_\_\_\_\_  
 Type # \_\_\_\_\_ Flight # \_\_\_\_\_ Air Photo \_\_\_\_\_ and \_\_\_\_\_ Density: D M S  
 B.C.F.S. Ours # \_\_\_\_\_ (circle one)

Remarks \_\_\_\_\_  
 Elevation \_\_\_\_\_ ft. Aspect \_\_\_\_\_ Slope % \_\_\_\_\_ Physio. \_\_\_\_\_ describe

Soil \_\_\_\_\_ describe  
 Station R.H. \_\_\_\_\_ Dry Code \_\_\_\_\_ Dro. Ind. \_\_\_\_\_ Wind \_\_\_\_\_ D. Index \_\_\_\_\_ Haz. Ind. \_\_\_\_\_  
 Plot R.H. \_\_\_\_\_ " \_\_\_\_\_ " \_\_\_\_\_ " \_\_\_\_\_ " \_\_\_\_\_ " \_\_\_\_\_

Remarks \_\_\_\_\_

Size Class	# of Pieces	Depth ft.	Plot Wt.	Tin #	Tin Wt.	Sample Wt. grams	O.D. Wt. grs.	% M.C.	O.D. Plot Wt.	O.D. Wt./Acre	Remarks
Lower Litter											
Upper Litter											
Fine Fuels 1" or < } Conif.											
Herb.											
Dead											
Intermed. Fuels 1.1" - 4" } Dead											
Live											
Heavy Fuels 4.1"-10"											
Large Fuels > 10.1"											
Total Dead											
Total Live											
TOTAL											

Vertical Break \_\_\_\_\_ ft. Bridge Fuels \_\_\_\_\_ Av. #/ft. Type \_\_\_\_\_ Fine \_\_\_\_\_ Med. \_\_\_\_\_ Coarse \_\_\_\_\_  
 Aerial Zone: Top \_\_\_\_\_ ft. Bottom \_\_\_\_\_ ft. Depth \_\_\_\_\_ ft.  
 Density of Crown \_\_\_\_\_ Dense \_\_\_\_\_ Mod. \_\_\_\_\_ Sparse \_\_\_\_\_ Crown Closure \_\_\_\_\_ Dense \_\_\_\_\_ Mod. \_\_\_\_\_ Sparse \_\_\_\_\_  
 Snags/Acre \_\_\_\_\_ # Approx. Percentage Which Are + \_\_\_\_\_ 0 \_\_\_\_\_ - \_\_\_\_\_  
 Flash Fuels \_\_\_\_\_ Description and Quantity \_\_\_\_\_

(OVER)

FIGURE 1.

of the plots extracted from the aerial photographs completed the photographic record.

#### Mensurational Data

Mensurational data of the stand were collected from circular plots having common centres with the milacre fuel plots. In mature and immature stands one-tenth acre plots were used, while one-hundredth acre plots were used in reproduction stands. All trees in the plots were tallied by two-inch diameter classes. The age and height of one dominant tree on each plot was recorded for site index determinations. The average height from the ground to the base of the green crown for the cover type was also determined from field measurements.

The fuel complex was measured by separating the fuel components into three classes determined by location -- litter, ground fuels and bridge fuels. Litter was classed as that material occurring at the lowest level of the surface zone and consisted of needles, leaves and branchwood having an average diameter less than one-tenth of an inch. Initially this class was to contain two sub-classes -- lower litter and upper litter. The upper litter consisted of unconsolidated material which had not decomposed to such a degree that its identity was erased, while the lower litter consisted of the consolidated material in a more advanced stage of decomposition. Separation of these two classes was generally effected with little difficulty in the pine stands, a very definite zone of demarcation being evident.

The litter occurring under the fir cover types was much more homogenous in vertical distribution making the separation of the zones quite difficult and time-consuming. This difficulty dictated that a crude method of raking the looser surface material with the fingers be used and the



abandonment of the lower litter measure. The occurrence of moss beds also compounded the measure of litter in the fir type. A measure of weight of this fuel was not attempted because of the difficulty of separating soil from moss.

Ground fuels were classed as those fuels having an average diameter of more than one-tenth of an inch. This class of fuels was composed of four sub-classes determined by the average diameter of the fuel components.

The more important sub-class was termed fine fuels. This consisted of fuels less than one inch in diameter and was composed of three types -- living coniferous, living herbaceous and dead fuels.

The next larger size class of surface fuels was termed intermediate fuels. The diameter of these fuel components ranged from 1.1 inches to 4.0 inches. This size class of fuels occurred on only nine of the 30 plots established in the pine types, but occurred on 36 of the 52 plots established in the fir types. Only two types of fuel, living and dead, were noted in this sub-class.

Two other size classes were recognized -- those fuels having diameters from 4.1 to 10.0 inches were termed heavy fuels, while those having a diameter more than 10.1 inches were termed large fuels. No differentiation according to fuel condition was made within these two sub-classes. Large fuels did not occur on any of the established plots, while heavy fuels occurred once in the pine type and ten times in the fir type.

Bridge fuels were those fuel components which occurred as dead branches on the boles of trees between the upper level of the surface fuel components and the lower limit of the green crown or aerial zone. It is these fuels which determine to a large degree the ease of fire access to

the aerial zone. These fuel components were removed to a height of seven feet above the ground and weighed.

Weight of fuel is the most convenient objective measurement of fuel quantity that can be made under field conditions. The weight was determined using spring balances calibrated in kilograms. An estimate of the average depth of the fuel components was also made although in practice little confidence can be applied to these measurements. **All measurements** for each plot were recorded on the field form shown in Figure 1. Samples of each size class of fuel were removed and oven dried for moisture content determinations and subsequent correction to oven dry weight.

#### Distribution of Samples

To the disadvantage of this pilot study, the area selected for work had a limited variability of stand conditions which were readily accessible. The distribution of height and age classes is shown in Table I. Notice is drawn to the frequent occurrence of multimodal distributions in the Douglas fir data. This is a reflection of the two dominant stands which constitute the Douglas fir type in the area.

The younger stands are very dense, small crowned, and generally exhibit symptoms of suppression. As a reflection of this suppression their site index is usually low, site index class 51-60 being the population mode. The 41-50 foot class was the modal height class, while the age modal occurred in the 61- to 80-year-old class. The population of site index is the only parameter not having a bimodal distribution. The modal and bimodal classes for each parameter are shaded in the fir data distribution on Table I.

The veteran segments of the fir type are generally the residuals of high grade logging during the early Thirties. These stands are of generally



TABLE I. DISTRIBUTION OF PLOTS BY CLASSES OF HEIGHT, SITE, DENSITY  
AND AGE\*

Height Classes									
11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total
Fir		4	15	7	5	8	9	3	51
Pine	2	5	9	7	3	2	2		30

Site Index Class									
Fir		3	4	13	11	11	6	3	51
Pine			4	8	10	4		4	30

Density Index Class									
0-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	160+	Total
Fir	14	8	16	7	3	2	1		51

Age Classes									
Fir		5	26	1	5	1	12	1	51

\* The shaded blocks represent the modal or bimodal classes of the various parameters.

higher site index, lower density, and greater height than the younger cover type.

A density index was computed in order to combine the effect of both tree size and number of stems. The density index distribution shown in Table I is the average diameter times the number of stems per 1/100 acre. A bimodal distribution is also shown for this population.

### Observations

In the 1961 field work it was found that inventory maps of the Paul Lake area, where the work was conducted, were generally very inaccurate as far as height estimations were concerned, errors of 100 per cent being not uncommon. It is realized in this study that the maps were being put to a use for which they were never intended. The newer series of inventory maps are of decidedly better quality and should adequately serve this project in future work. Aerial photographs of good quality are another prerequisite for this type of endeavour.

Land use appeared to be one of the greater causes of discrepancy in the system. In the case of the 1961 location, apparently untouched stands which had been slated for sampling had to be discarded because of excessive trampling and use as shelter areas by stock. This use does not exhibit itself in the stand characteristics discernible from the aerial photographs but can be picked up by skilled interpreters from the direction of stock trails on surrounding open range land.

### Statistical Evaluation and Discussion of Data

The statistical evaluation of data gathered in a heterogenous manner must be treated with caution. Initially we must state the null hypothesis, i.e., that there is no real difference between the selected plots and the mechanically spaced plots. That is to say that differences in samples of the fuel complex between the paired plots is due strictly to chance and not to a bias in plot selection.

Strictly speaking, we may compare the method of sampling used in this project to the procedure of comparing the means of "n" randomly selected, numbered items from each of two containers. One container is assumed to hold

items numbered from 1 to 100 representing the total population, and the other container is assumed to hold items numbered from 60 to 80 representing a replicate of a portion of the population on either side of an upper quartile point. We would expect that the mean values of "n" items selected from each of these two containers would be significantly different. If, upon analyzing the samples, it was determined that a significant difference did not occur either in the means or the variances of the samples, we must conclude that the populations are actually the same.

The first procedure was to test the paired plots in order to determine if the data may be grouped and treated as a single population or if the two sets of plots are representative of two discrete populations. Parameters of the stand to be analyzed were height of dominant trees, density of stand in number of trees per one-tenth acre, average diameter and basal area per acre. Measures of the fuel complex to be analyzed were weight of lower and upper litter, weight of fine fuels less than one inch, weight of intermediate fuels, and the weight of bridge fuels to a height of seven feet. The significance of the variation in means of values from each set of plots was tested using Student's "t" test. The variance of each set of data was tested using the variance ratio test. In both cases the Bessel correction for small samples was used. Table II shows the computed values of t and F as well as the means and variances of the various measures of stand and fuel from the two sets of plots. Significant values of "F" and "t" at the five and one per cent probability level are shown below the title head. From the results of the "t" test shown in Table I, we can assume that significant differences in the means are not present and thus we must accept the presented hypothesis in all but two cases. We cannot accept the null hypothesis regarding the

TABLE II. STATISTICAL COMPARISON OF STAND PARAMETERS AND WEIGHTS OF FUEL ON  
SELECTED AND MECHANICALLY SPACED PLOTS. (Fuel weights in kilograms  
per milacre.)

Fir t with 46 D.F., 5% = 2.02; 1% = 2.69: F with 23 D.F., 5% = 2.01; 1% = 2.72  
Pine t with 28 D.F., 5% = 2.05; 1% = 2.76: F with 14 D.F., 5% = 2.48; 1% = 3.70

Stand Parameter	Means - t Test				Standard Deviation <sup>2</sup> - F Test		
		Selected	Mech.	Computed "t"	Selected	Mech.	Computed "F"
Ht. of domin- ants, ft.	Fir	60.4	61.7	.26	283.2	301.6	1.07
	Pine	-	-		-	-	-
Basal area, ft. <sup>2</sup> /A	Fir	152.4	174.2	.86	4774.7	9900.1	2.07*
	Pine	97.2	89.3	.33	3017.5	3097.7	1.03
Density, # trees/1/10 A.	Fir	92.9	99.4	.31	5085.1	4715.8	1.08
	Pine	72.8	77.1	.17	3857.1	4496.5	1.17
Mean diameter	Fir	6.36	6.47	.12	8.52	10.60	1.24
	Pine	6.57	6.77	.16	9.74	11.56	1.19
<u>Wt. of Fuel</u>							
Lower litter kg./MA.	Fir	-	-	-	-	-	-
	Pine	6.53	6.03	.52	7.39	6.01	1.21
Upper litter kg./MA.	Fir	3.08	2.96	.22	9.32	7.47	1.25
	Pine	4.57	4.43	.19	2.74	5.34	1.95
Fine fuels < 1" kg./MA.	Fir	2.76	2.70	.15	1.82	2.06	1.13
	Pine	.27	.33	.71	.04	.063	1.56
Intermediates 1.1 - 4.0" kg./MA.	Fir	3.11	1.63	1.59	16.53	3.03	5.46**
	Pine	-	-	-	-	-	-
Bridge fuels kg./MA.	Fir	.75	.71	.17	.60	.56	1.07
	Pine	.94	.76	.71	.50	.41	1.22

\* Significant at 5% level of probability (probably significant)

\*\* Significant at 1% level of probability (definitely significant)



difference in mean values of basal area and intermediate fuels since the variance ratio test indicates that the standard deviations of these two populations are significantly different and thus we are not justified in using the "t" test.

The data show that the mean values of fuel quantities of various sizes are not significantly different between sets of plots from a statistical standpoint, i.e., at the five per cent level. However, upon examination of the difference in variance we find that highly significant differences appear in the standard deviation of the intermediate fuels; thus, we must say that the population of fuels of this size are definitely different between sets of paired plots. In fact, one may say that it is probably on the basis of this size class of fuels that the worst average was selected.

The data on fuel quantity appear to be contradictory. The means of the selected plot data are generally greater than those of the mechanically located plots. One would also expect a lesser variance in the selected data since some measure of stratification was exercised; however, the opposite was found to be true.

With the foregoing discussion and the data presented in Table I we may accept the conclusion that the samples of the tested variables of cover type and fuel complex are drawn from the same population, with the exception of the two parameters discussed. Thus, pooling of the data from the selected and mechanically spaced plots for further analysis may be allowed.

Since we are interested in correlating the fuel complex with stand parameters which are readily identifiable from aerial photographs, we shall concentrate our analysis on the three stand parameters of site index, height and density. Initially, a comparison of the populations of three fuel

components -- upper litter, fine fuels, and bridge fuels -- between the two species will be made. The same type of analysis as was used for the comparison of the populations arising from the two methods of plot location will be used; the results are shown in Table III. In the analysis of bridge fuels, only immature stands of both species were considered because of the absence of bridge fuels in mature stands of both species, while the complete populations of both species were analyzed for the other two fuel components. Intermediate and heavy fuels were not analyzed because of their noticeable scarcity in the pine types. The great difference in fine fuel quantity between the two species is immediately apparent from Table III.

TABLE III. STATISTICAL COMPARISON OF STANDARD DEVIATIONS AND MEANS OF FUEL WEIGHTS IN KILOGRAMS PER MILACRE, UNDER DOUGLAS FIR AND PONDEROSA PINE STANDS

Fuel Components	Mean			Variance		
	Pine	Fir	t	Pine	Fir	F
	in kilos/MA			in kilos/MA		
Upper litter	4.49 kg.	3.02 kg.	2.23*	4.13 kg.	8.91 kg.	2.14*
Fine fuels	.30 "	2.78 "	9.46**	.05 "	1.94 "	36.66**
Bridge fuels, immature only < 65' tall	1.06 "	1.19 "	.74	.42 "	.41 "	1.05

\* Significant at 5% level of probability (probably significant)

\*\* Significant at 1% level of probability (definitely significant)

It now seems reasonable to attempt to show that differences in fuel weight within the species occur and also to attempt to isolate the stand parameters



which best show these differences. An analysis of the variances of the weights of upper litter, fine fuels and intermediate fuels, using two classes of height, density index and site index of the fir stands, were calculated. The class separation for height occurred at 65 feet, a definite break in the data occurring at this point, only four of the 51 plots falling within the 61 to 70 foot height class. Site index of 64 feet was used as the criteria for separating the two site classes. The division for the two classes of density occurred at the density index of 50.

These class divisions provided a natural split of the data. The division by height provided 29 plots in the lower class and 22 plots in the upper class; while division by density index placed 27 plots in the lower density class and 24 in the higher class and the division by site index allowed a 26 to 25 ratio of lower site to upper site plots. However, because of interrelationships a very warped distribution of site or density occurred within each height class. Herein lies the difficulty of subjecting this distribution of data to variance tests. The lower height class was composed of 22 poor site plots and eight moderate and good site plots, whereas the higher height class was composed of only four poor site plots and 22 moderate and good site plots. The opposite situation was true for the analysis combining height and density although not to such an extreme. This type of distribution is not ideal for analysis of variance and interaction because one class of any of the three parameters tested does not occur in sufficient quantities within any class of the other two parameters.

The results of these analyses can be summarized as follows: In the analysis of variance of fine fuels and intermediate fuels using height and site as variables, variance caused by height was significant in both cases at the one per cent probability level while variance attributable to site

was significant at the five per cent probability level. Neither variable was shown to have a significant effect on the distribution of upper litter. In the analysis of the same three fuel components using height and density index as variables, the same degree of significance was attributable to height as in the former case for the same fuel components. The variance accountable to density was not significant for any of the three fuel components.

### Graphical Analysis

A graphical analysis of the data was attempted as an alternative method of arriving at the best parameters by which variation in fuel components may be determined.

The method of graphical analysis used is based upon the assumption that if the weight of each fuel component tested were consistent throughout the species, the percentage of fuel occurring within a class of the species will be consistent with the percentage of plots occurring within the same class. If the cumulative class percentage of fuel is plotted on the vertical axis and the cumulative class percentage of plots is referenced to the horizontal axis a "no variation" relationship should yield a perfect 1:1 relation resulting in a straight line reclining at an angle of 45 degrees. Figures 4 to 7, show the cumulative and individual percentage of both fuel weight and number of plots lying within each class of the independent variable. The consistency of variation of the dependent variable is indicated by the slopes of the lines connecting class limits, while the degree of deviation of the dependent variable from the assumed "no variation" line is shown by the deviation of the actual line from the theoretical "no variation" line. The parameters of height, density, site and age were tested

by this method for the fir stands, while only height and site were tested for the pine stands. For the fir data the five fuel components of upper litter, fine, intermediate, heavy and bridge fuels were tested. In the case of pine only lower litter, upper litter, fine and bridge fuels were tested. Only curves showing total fir ground fuels (exclusive of litter) and fir bridge fuels plotted according to height and site are included in this report.

#### Discussion of Curves

Upon perusal of the surface fuel and bridge fuel curves classed according to height and site, one is immediately aware of the similarity of the curves. This similarity could be caused by a close correlation between height and site. An examination of Figure 2 shows that this is indeed true although differences in the cumulative curves, particularly for bridge fuels, are felt to be of sufficient importance to maintain site as a parameter of measurement, if only as a safeguard. However, the close correlation between site and height theoretically nullifies the use of one of these parameters as an independent variable in the analysis of variance. The correlation of height and density is shown in Figure 3. The scatter of the points in this graph indicates that these two functions may be used as independent variables.

Tables IV and V show the mean value of bridge fuels occurring in the lower seven feet and the total ground fuels exclusive of litter, by ten foot classes of height and site index, respectively. The trend of values in the two tables are quite similar although height appears to show a more consistent variation especially in the case of the bridge fuels.

The per cent weight of ground fuel by classes of height and site shown in Figures 4 and 5 indicates that the lower classes (class limits

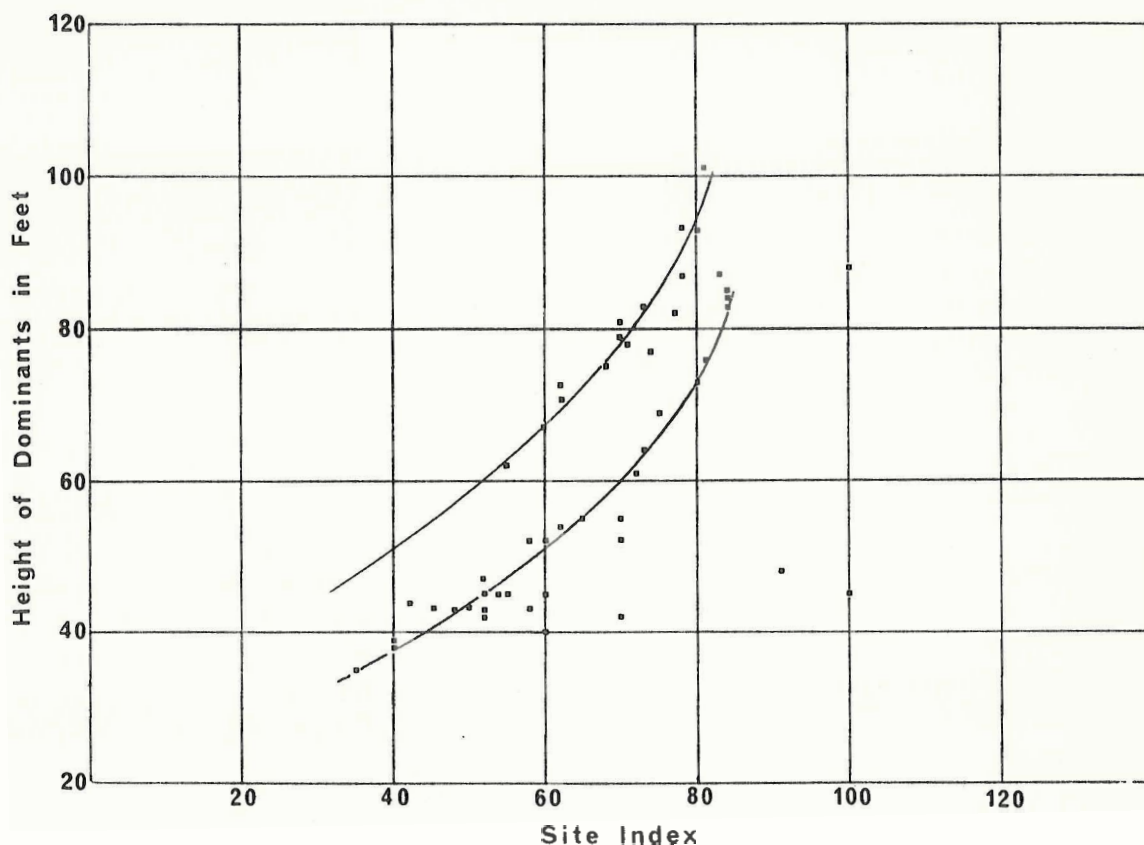


Figure 2. Height of dominants plotted against site index to illustrate the close association of these two variables. The upper curve represents the veterans while the lower sites represent the immature stands.

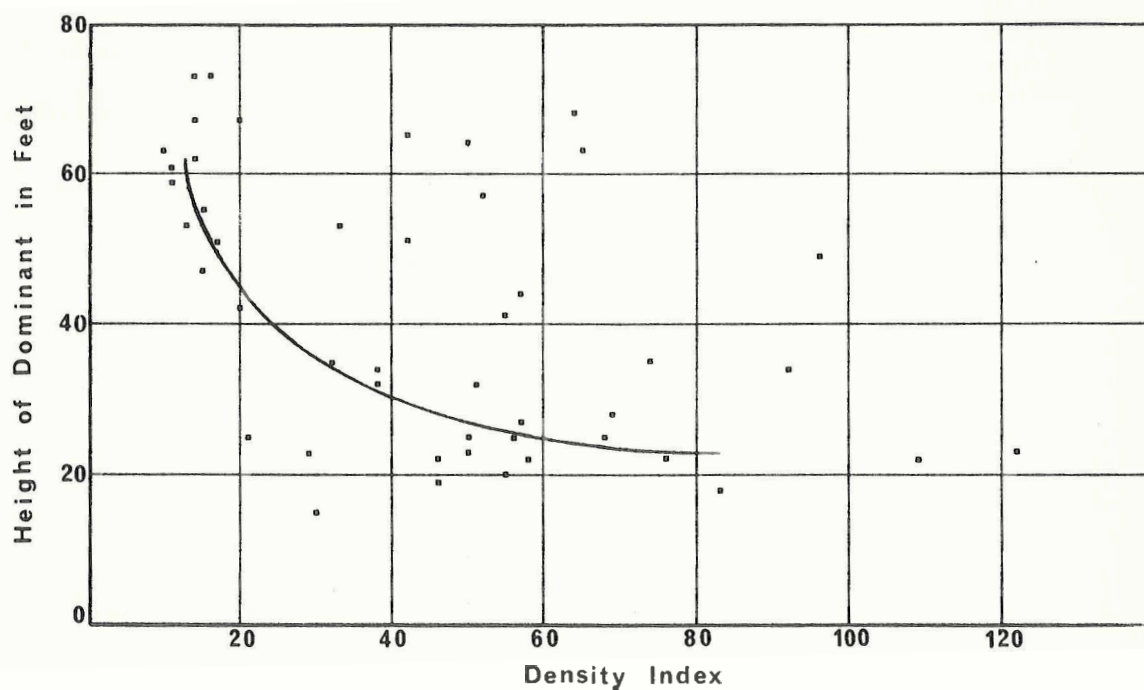
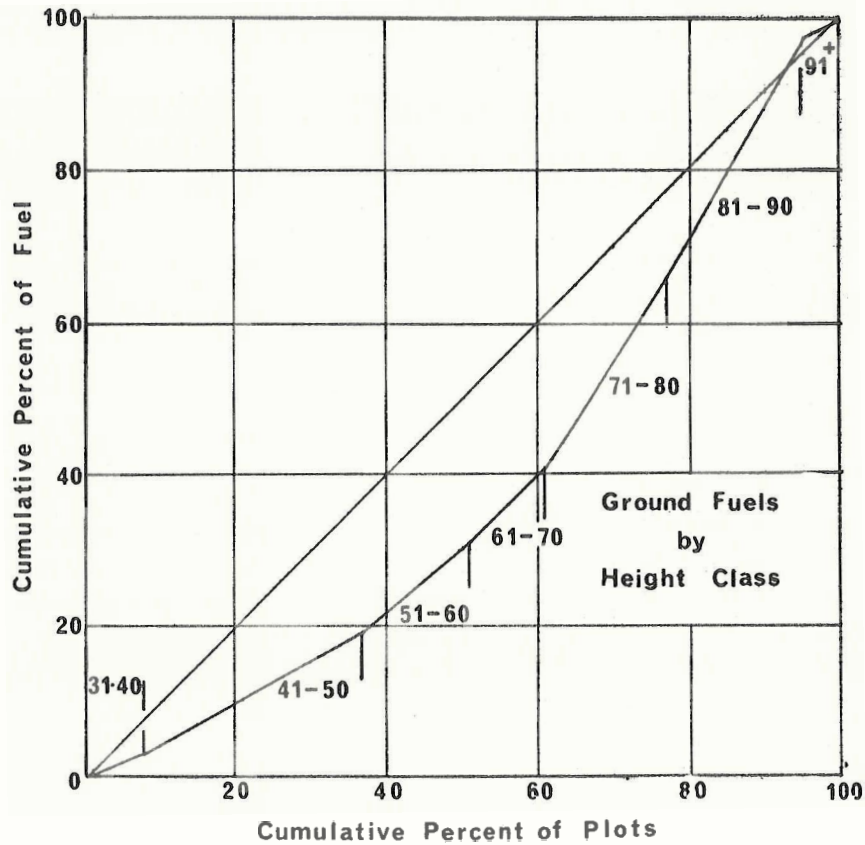
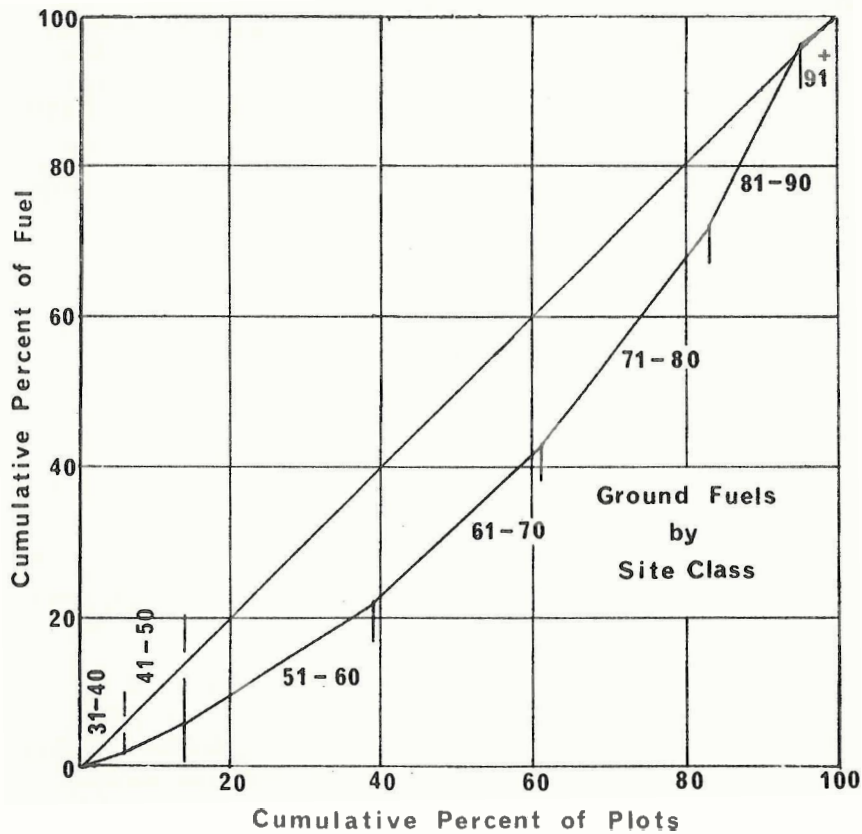


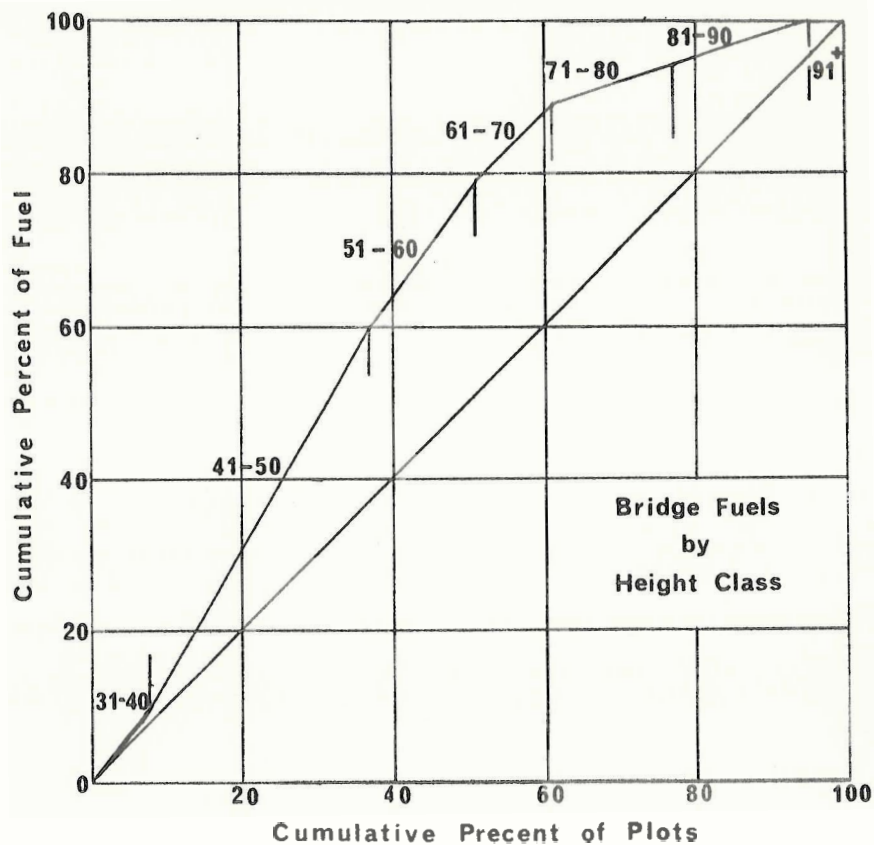
Figure 3. Height of dominants plotted against density index to determine association of these two variables.



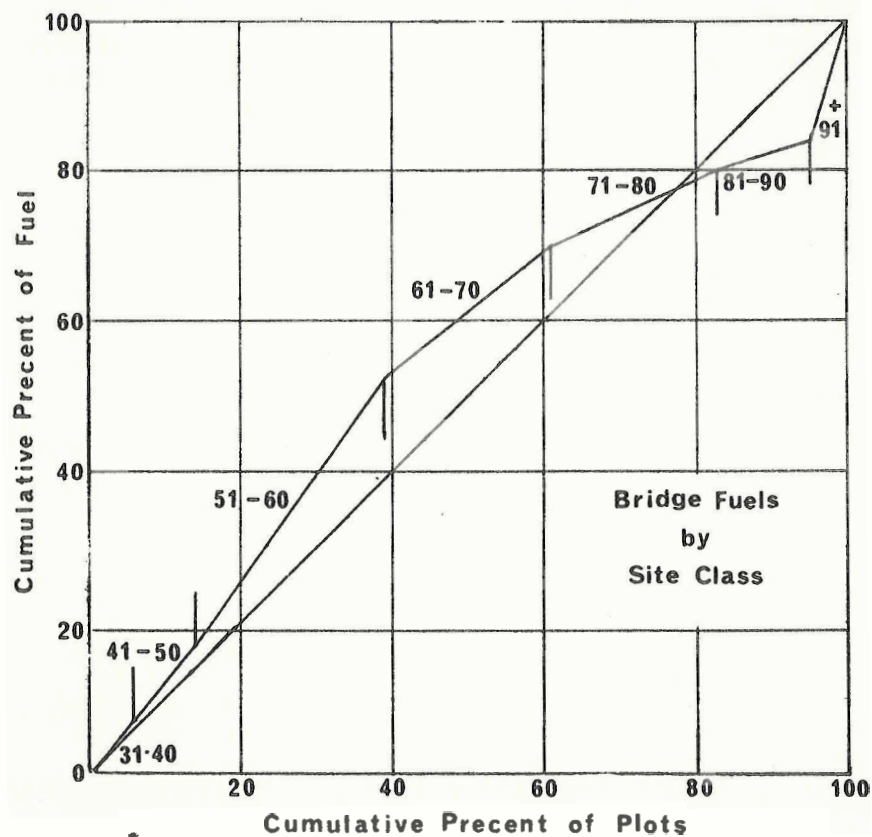
Figures 4 and 5. Cumulative percentage of ground fuel weight exclusive of litter plotted against cumulative percentage of plots by height classes (upper Figure) and by site classes (lower Figure).







Figures 6 and 7. Cumulative percentage of bridge fuel weight plotted against cumulative percentage of plots by height classes (upper Figure) and by site classes (lower Figure).





denoted by the vertical lines) have the lesser weight of ground fuels. This is indicated by the slope of the fuel weight line being less than the 45 degree "no variation" line. The two central height classes 51-60 and 61-70 in the height curve show almost the same slope as the "no variation" line indicating that those classes of the stand contain close to the mean weight of ground fuels of the total population (see mean weight of ground fuels Tables IV and V). The next two classes in both curves, 71-80 and 81-90, show a line much steeper than the "no variation" line, indicating that the bulk of the ground fuels are concentrated in these two height classes. In both curves, the last class appears to be inconsistent with the trend; this is probably due, in part at least, to the poor sample from this class.

The per cent weight of bridge fuels shows the opposite general trend in the curve for height (Figure 4) and for site (Figure 5) although in this case the height curve definitely shows a better relationship. From the height curves we see that the greatest weight of bridge fuels is concentrated in the 41-50 foot height class and decreases slightly in the 51-60 foot class during which the actual line is parallel to the "no variation" line indicating the class in which the population average lies (see Table IV). The last three classes all show lines having much shallower slopes than the "no variation" line indicating that the mean weight of fuel in the upper classes is less than the mean weight. The site curve indicates the same trend with the exception of the discrepancy in the last class.

#### General Discussion and Conclusions

From an examination of the mean weights of fuel in Tables IV and V and from the foregoing discussions it is immediately apparent that the mean

TABLE IV. SUMMARY OF BRIDGE FUELS AND GROUND FUELS EXCLUSIVE OF LITTER  
IN DOUGLAS FIR BY HEIGHT CLASSES SHOWING MEAN TOTALS, CUMULATIVE  
PERCENTAGE OF PLOTS AND FUEL COMPONENTS AND MEAN HEIGHT TO  
LOWER LIMIT OF CROWN. (All weights are in kilograms per milacre.)

		Height Class						Total
		31-40	41-50	51-60	61-70	71-80	81-90	
No. of Plots		4	15	7	5	8	9	51
Cum. %		8	37	51	61	77	95	100
Fines	kg./MA	8.24	33.55	17.83	15.09	24.92	35.04	140.79
Inter.	"	.89	14.96	15.54	4.96	35.90	43.63	121.42
Heavy	"	-	2.72	3.86	11.04	19.75	21.53	58.90
Σ of Ground	kg./MA	9.13	51.23	37.23	31.09	80.57	100.20	321.11
Cum. %		3	19	31	41	66	97	100
Ground Mean	kg./MA	2.28	3.42	5.36	6.21	10.05	11.35	6.21
Bridge	kg./MA	3.93	18.89	7.37	3.71	1.96	2.20	38.06
Cum. %		10	60	79	89	94	100	100
Bridge								
Mean	kg./MA	.98	1.26*	1.05	.74	.20	.24	.75
Mean Ht. to Crown		18	24	37	31	30	34	31

\* This is probably a more realistic peak of a downward trend.

TABLE V. SUMMARY OF BRIDGE FUELS AND GROUND FUELS EXCLUSIVE OF LITTER  
IN DOUGLAS FIR BY SITE INDEX CLASSES SHOWING MEAN TOTALS AND  
CUMULATIVE PERCENTAGE OF PLOTS AND FUEL COMPONENTS. (All  
weights are in kilograms per milacre.)

		Site Class							Total
		31-40	41-50	51-60	61-70	71-80	81-90	91-100	
No. of Plots		3	4	13	11	11	6	3	51
Cum. %		6	14	39	61	83	95	100	100
Fines	kg./MA	6.44	7.71	29.07	29.88	30.71	28.31	8.68	140.79
Inter.	"	.89	4.89	19.27	22.42	40.30	28.34	5.31	121.42
Heavy	"	-	-	2.72	15.46	19.19	21.53	-	58.90
Σ of Ground	kg./MA	7.33	12.60	51.06	67.76	90.20	78.18	13.99	321.11
Cum. %		2	6	22	43	72	95	100	100
Ground Mean	kg./MA	2.45	3.15	3.94	6.15	8.21	12.87	4.67	6.21
Bridge	kg./MA	2.48	3.75	13.16	6.70	3.98	1.69	6.30	38.06
Cum. %		7	10	35	18	10	4	16	100
Bridge									
Mean	kg./MA	.83	.78	1.01*	.61	.36	.28	2.10**	.75

\* This is probably a more realistic peak of a downward trend.

\*\* Due to low heavy limbs on wolf tree.

weight of all ground fuel components, with the exception of litter, varies directly with height and site class, while the bridge fuel component varies inversely with the same parameters.

However, one cannot assume that these figures can be transposed immediately into a relative index of fire behaviour. From experience and observations on wild fires, it is evident that the crowning potential is probably one of the better indices of the workload involved on any timberland wildfire. The crowning potential of a stand of timber is dependent on three important fuel factors. Initially there must be a source of heat at the surface zone; however, the amount of available fuel energy which is necessary to produce a vertical fire movement is dependent on the distance separating the crown zone from the surface zone. The greater the vertical separation, the greater the amount of surface fuel which must be available for combustion. In the presence of a large vertical separation, crowning may still occur with moderate to low amounts of surface zone fuels if sufficient bridge fuels are present, thus maintaining a continuous vertical fuel bed.

In this study it has been shown that there is approximately five times the amount of surface zone fuels in mature stands as there is under immature stands; more detailed mention of fuel weights other than those in Tables IV and V are not included because more work is necessary in the Douglas fir and ponderosa pine types. The differential associated with height and/or age may be even greater when one considers that reproduction stands were not sampled. However, experience has clearly indicated that the reproduction and immature stands are usually the better fire propagators. The problem now presented is to determine the relative weight which should be attached to the relatively small quantity of bridge fuels in relation to ground fuels and also the determination of effective vertical separations as a function of various weights of ground fuels and weather.



The integration of these important variables into a usable index is a paramount requisite for objective fuel type mapping. These fuel factors should be paramount when evaluating the fuel complex of, especially, the Douglas fir and lodgepole pine cover types. In both stands, situations are very common where a combination of the absence of bridge fuels in sufficient quantities and light surface zone fuels prohibits fire access to the crowns. The threshold quantity is quite definite; in many situations the difference is only a few miles of wind. Even more striking, on slopes of 15 to 30 per cent, the difference in direction of spread may dictate the occurrence of crowning (in the high to extreme danger index class).

Fortunately, the fuel complexes of the "dog hair" fir thickets which make up the lower height classes in the pilot study do not usually contain large amounts of surface zone fuels. These fuel complexes are characterized by relatively large vertical intervals, heavy concentration of bridge fuels, from 1.5 - 2.0 tons per acre, and light surface zone fuels, 3 to 4 tons per acre, the greater part of which is in the fine class. The absence of larger fuel components to produce a heat bank prevents vertical spread in this type except under weather conditions ideal for fire propagation. The consoling nature of these observations is not meant to placate fire control personnel. If anything, it is a warning of an impending powder-keg in which a downslope-backing fire, which is to all appearance inoffensive, can be transformed almost without warning into a difficult fire control situation. For this reason line construction and preliminary mop-up should be an integrated operation in these fuel types. "Burning out", although sometimes necessary, in most cases only compounds the final mop-up job.

During the course of this study it was evident that the methods of evaluating fuel complexes must be flexible to allow consideration of

factors associated with different species. Again the bridge fuel component is presented as an example when comparing Douglas fir and lodgepole pine types. In fir, the bridge fuel component, i.e., the fuel agent which conveys the fire from the ground to the crown, is the fine dead branches which, in some stands, extend as a nearly solid front from the crown to the ground, whereas the bark of living trees is almost a negative fuel. In lodgepole pine the opposite is true; the bark with its characteristic flaky nature is the principal means of fire conveyance, limby bridge fuels close to the ground usually being absent.

From the results of this pilot study it is immediately apparent that the scope of the problem was much too broad. In this conclusion lies one of the benefits of this pilot study. The parameters of the cover type to be measured have been limited to the three which appear to be most useful -- average height of dominants and co-dominants, site, and density. Due to inadequate sampling, density was not shown to have a significant effect. However, the measure of density will be maintained because of its effect upon the microclimate of the stand, the vertical separation and crown weights.

#### Summary

During the 1961 field season, work on the use of stand parameters to objectively determine indices of the fuel complex was started near Kamloops. Interior dry belt stands of Douglas fir and ponderosa pine were studied. From statistical and graphical analysis it was determined that height and site may be used as parameters of the fuel complex within the stand. Land use, in this case excessive stock use, was found to hamper the usefulness of this method to evaluate fuels.

The most important result of the study was to emphasize the lack



of basic knowledge in the field of fire propagation in forest fuels and the need for detailed basic laboratory research in this field.

#### Future Work

This study is to be carried on in the lodgepole pine of southern British Columbia during the 1962 field season under more diversified stand conditions than was possible in the fir types. The lodgepole pine study is to result in the first of a series of technical notes dealing with the fuel complexes of important Interior species. Upon completion of the work in lodgepole pine when the method is proven to have definite value, work will be continued during following years in other Interior cover types.