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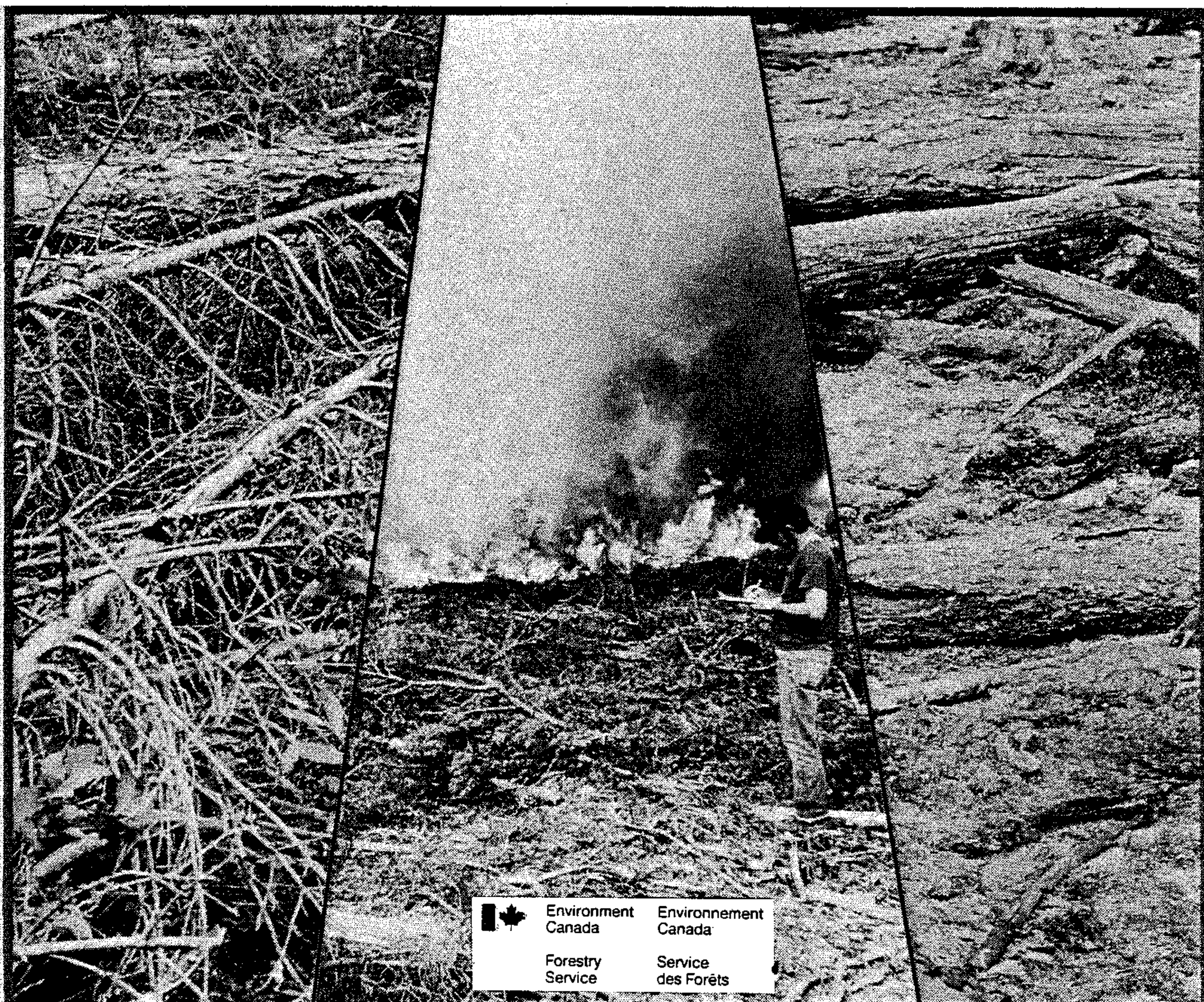
MEASUREMENT AND DESCRIPTION OF FUELS AND FIRE BEHAVIOR ON PRESCRIBED BURNS: A HANDBOOK

DOUGLAS J. McRAE, MARTIN E. ALEXANDER AND BRIAN J. STOCKS



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GREAT LAKES FOREST RESEARCH CENTRE

SAULT STE. MARIE, ONTARIO

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ABSTRACT

This report provides detailed instructions for documenting fuel and fire behavior characteristics on prescribed burns in northern Ontario slash complexes. It is divided into three major sections: preburn procedures, observations during the fire, and postburn procedures. Methods for determining preburn fuel loading and depths, fuel consumption, rate of spread, frontal fire intensity, depth of burn, and fuel moisture contents are outlined. Examples and sample calculations are provided. A selected bibliography and copies of forms that can be used for recording data are included.

RÉSUMÉ

Ce rapport fournit des instructions détaillées pour documenter les caractéristiques des combustibles et le comportement du feu lors de brûlages dirigés dans des complexes de rémanents dans le nord de l'Ontario. Il se divise en trois sections: procédés préalables au brûlage, observations durant le brûlage et procédés subséquents au brûlage. On a mis l'accent sur les méthodes permettant de déterminer avant le brûlage la charge et la profondeur du combustible, la consommation de combustible, la vitesse de propagation du feu, l'intensité du feu de front, la profondeur du brûlage et la teneur en humidité. Des exemples et des calculs types sont fournis. On trouvera aussi une bibliographie choisie et des copies de formules à utiliser pour l'enregistrement des données.

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of numerous Ontario Ministry of Natural Resources personnel who field tested a draft of the handbook in 1978. Their comments, criticisms, and suggestions were all considered in the preparation of the final report. We would also like to thank Mr. C.E. Van Wagner, Research Scientist at the Petawawa National Forestry Institute, Chalk River, Ontario, Mr. Kevin C. Ryan, Research Forester with the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Seattle, Washington, and Mr. William H. Fransden, Research Physicist with the USDA Forest Service, Northern Forest Fire Laboratory, Missoula, Montana, for their helpful reviews. Credit is due T.W. Blake, Research Technician, Great Lakes Forest Research Centre, for preparation of illustrations.

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INTRODUCTION

Prescribed burning has been defined by the Canadian Committee on Forest Fire Control (Anon. 1976) as follows:

> "The burning of forest fuels on a specific area under predetermined conditions so that the fire is confined to that area to fulfill silvicultural, wildlife management, sanitary or hazard reduction requirements."

The primary use of prescribed burning in Ontario is for silvicultural purposes, namely site preparation required for planting and seeding. On certain sites, prescribed fire is an economically and ecologically attractive alternative to other methods of site preparation.

Fuel characteristics (e.g., quantity, moisture content) and subsequent fire behavior are intimately linked with the silvicultural effectiveness of prescribed fire. The way a prescribed fire behaves represents the combined and interrelated effects of fuel characteristics, past and present fire weather, and topographic features. Preburn sampling of fuels offers a means of quantifying the initial loading and depth. Fuel characterization can aid in prescription formulation by permitting the comparison of fuels to expected fire behavior (fuel consumption, depth of burn, rate of spread, etc.) when utilizing fuel moisture codes and fire behavior indices of the Canadian Forest Fire Weather Index System (Van Wagner 1974, Anon. 1978). Postburn fuel sampling allows for quantification of the degree of achievement of burn objectives. The resulting effects of fire (e.g., seedbed receptivity) are directly related to fuel and fire conditions. If all of these factors are taken into consideration, one can devise a system for gauging the success of the burn in relation to the purpose of the burn (Kiil 1964).

This handbook was designed specifically to meet the needs of Ontario Ministry of Natural Resources (OMNR) personnel in measuring and describing fuels and fire behavior characteristics on prescribed burns in silviculturally created slash situations in northern Ontario. The size of the handbook may overwhelm the reader at first, but it should be kept in mind that this is a complete package. A substantial amount of illustrative and explanatory material has been included to assist the user. The handbook is divided into three major sections: (1) preburn procedures, (2) observations during the fire, and (3) postburn procedures. It is essential to familiarize oneself with all three sections in order to derive full benefit from the handbook. We recognize that manpower resources and time schedules may not permit the use of this handbook in its entirety. Personnel may use only the preburn and postburn procedures or may record selected observations during the burn. Assigned work should be a joint effort on the part of fire and timber management personnel.

The handbook has been developed for sampling the following species:

Pj jack pine (*Pinus banksiana* Lamb.)

S black spruce (*Picea mariana* [Mill.] B.S.P.) and
white spruce (*P. glauca* [Moench] Voss)

B balsam fir (*Abies balsamea* [L.] Mill.)

Po trembling aspen (*Populus tremuloides* Michx.)
bigtooth aspen (*Populus grandidentata* Michx.)
balsam poplar (*Populus balsamifera* L.)

Bw white birch (*Betula papyrifera* Marsh.)

Prescribed burning is a rapidly expanding forest management tool in northern Ontario. It requires planning, and planning is best done on the basis of research, experience, and previous results. The quantification and standardization of data collected on prescribed burns as outlined in this handbook will provide a means of developing and improving existing guidelines. In addition, it will permit the benefits of prescribed burning to be assessed and comparisons between burns in different locales to be made objectively.

Canada's decision to switch to the international system of measurement (metric) is reflected in this handbook. A table of conversion factors is included for the convenience of the user (Appendix I). An electronic calculator with simple arithmetic capability (+,−,x,÷) and memory recall is necessary to perform the required computations. Calculators with a power function (y^x) are preferred but not essential. Copies of forms for recording data are contained in Appendix II.

In developing this handbook we have drawn heavily on our own experience and that of our colleagues. Many published reports have been utilized and are acknowledged accordingly. A brief description of selected aspects of the handbook development is provided in Appendix III. Anyone wishing further details should contact us directly. Included in the bibliography are references for further reading on the subject of fuel quantity and moisture content sampling, fire behavior characteristics, fire weather measurement, prescribed burn case studies, etc.

Since the field of forest fire science is never static, it is anticipated that new techniques or improved values will necessitate the publication of supplements to this handbook. In addition, companion handbooks or reports may be written as the need arises.

PREBURN PROCEDURES

A. *Office Planning*

Step 1. Provide the following information and a description of the prescribed burn site on form PB-1 (Appendix II).

(a) Prescribed burn name and/or number

(b) OMNR Administrative Region and District

(c) Basemap and block number(s)

(d) OMNR Forest Management Unit

(e) Forest Section name and number (refer to Appendix IV)

(f) Site Region and District name and number (refer to Appendix V)

(g) Provincial project number

(h) Burn size (ha)--total and burnable

(i) Burn objective(s)

(j) Prescription (upon completion of fuel sampling)

(k) Burning date(s) (upon completion)

Step 2. Divide the proposed prescribed burn site into sections (possibly 2 to 8) having similar slash fuel patterns, by the use, either alone or in combination, of low-level aerial photography, Forest Resource Inventory (FRI) forest stand map(s), aerial reconnaissance, or ground investigation. Consider natural and/or man-made barriers to fire spread. Prescribed burn site and sections (denoted A,B,C, etc.) should be outlined on a blank FRI map.

Step 3. Record on form PB-1 the precut stand characteristics, history, and size of each section. Use precutting cruise data when available.

(a) Forest type (species and percentage composition)

(b) Age class

(c) Height

(d) Site class

(e) Stocking

(f) Size (ha)

(g) Month(s) and year(s) of cut

(h) Additional observations (e.g., stand density, upland or lowland site, predominant understory vegetation, etc.)

Step 4. Determine sampling intensity per section. At least one equilateral sampling triangle measuring 30 m on a side is required for approximately every 20 ha. This is a rule of thumb, and more sampling triangles may be desired—time and personnel permitting—if the fire manager is concerned about one section on the site because of the possibility of erratic fire behavior, or if slash fuels appear to be quite variable. Approximately 2 hours should be allotted to the establishment and sampling of each triangle. If time does not permit the degree of sampling intensity recommended here, as many sampling triangles as possible should be positioned over the entire site in representative locations.

Step 5. Assemble and check all equipment necessary for fuel sampling prior to any field work (Table 1). Some of this equipment will have to be constructed before any field work takes place.

Table 1. Itemized list and use of field equipment needed for fuel sampling.

Item	Use
Hand compass	triangle layout
Metal ruler or pocket tape (metric)	measuring duff depths and depth of burn
Pocket tape (metric)	measuring slash depth
30 m cloth or metal tape	delineating sample triangle layout
Caliper (metric)	measuring slash pieces 7.0 cm and greater in diameter
Go-no-go gauge[a]	determining size class of borderline pieces
Clinometer or abney level	slope measurement
Line intersect pins[b]	delineating sample triangle layout
Depth-of-burn pins[c]	depth of burn measurements
Hammer and nails	marking slash pieces 7.0 cm and greater in diameter
String[d]	delineating sample triangle
Knapsack and/or vest	storing equipment
Clipboard[e]	recording data
Inventory forms[f] and pencils	recording data
Pocketknife	duff depth measurements
Camera and film	photo documentation of fuel conditions
2 m range pole (optional)	reference scale for photos
Hand counter (optional)	recording data

[a] Refer to Figure 5 on page 9 for details of construction.

[b] 18 pins required per sampling triangle (should carry one extra).

[c] 12 pins required per sampling triangle. Refer to Figure 16 on page 17 for details of style and construction.

[d] Approximately 100 m of string per sampling triangle.

[e] Attach a photocopy of Appendix VI.

[f] Form PB-2 is designed for both pre- and postburn sampling for approximately two triangles.

B. *Fuel Sampling*

All sampling crew members should read this entire section before doing any field work. With experience, proficiency in sampling will improve. While all of the sampling procedures outlined in this section are described individually, many of the procedures can be carried out concurrently. An abbreviated list of pertinent field instructions and a diagram of sample triangle layout that can be photocopied and attached to a clipboard are included in Appendix VI.

1. Loadings. Logging residues and quantities of natural woody fuel are determined by using the *line intersect fuel sampling method* developed by Van Wagner (1965b, 1968) and elaborated upon principally by Brown (1971) and Brown and Roussopoulos (1974). The method involves tallying intersections, by diameter size classes, of slash pieces less than 7.0 cm in diameter which intersect a sample line represented by a vertical plane (Fig. 1). Fuel pieces greater than 7.0 cm in diameter are measured with the use of calipers. The line intersect fuel sampling method is fast and efficient, and involves no destructive sampling or physical weighing. Anyone interested in obtaining loading estimates of understory vegetation (shrubs, grass, herbaceous plants) on sites that warrant this information should contact the authors directly about procedures.

Fig. 1. Representation of one triangle side in the line intersect fuel sampling method.

The line intersect fuel sampling method is best employed in the field with a two-man crew. The division of labor between the two sampling crew members is as follows: one person counts intersections, etc., and the other records data on the inventory form PB-2 (Appendix II) utilizing a "dot tally" system for intersections and later noting the final number. Fuel sampling in slash complexes can be tedious, often taxing the tolerance level of inventory personnel. For this reason it is highly desirable for crew members to switch jobs from time to time. It is generally more efficient to set up the entire sampling triangle prior to any measurements.

Step 1. Locate and mark a starting point for the sampling triangle with a line intersect pin (synonymous with "pigtail" regeneration assessment pin). This starting point can be selected arbitrarily in the field or determined by pacing into the section a set distance from the boundary (Fig. 2). The location of the starting point should be such that when the sampling triangle is laid out, it will not cross any roads or landings. It is important that the sampling triangles be established in representative locations within the sector. *Try to avoid disturbing fuel material.* Accurate estimates require measurements of undisturbed material along the sample line.

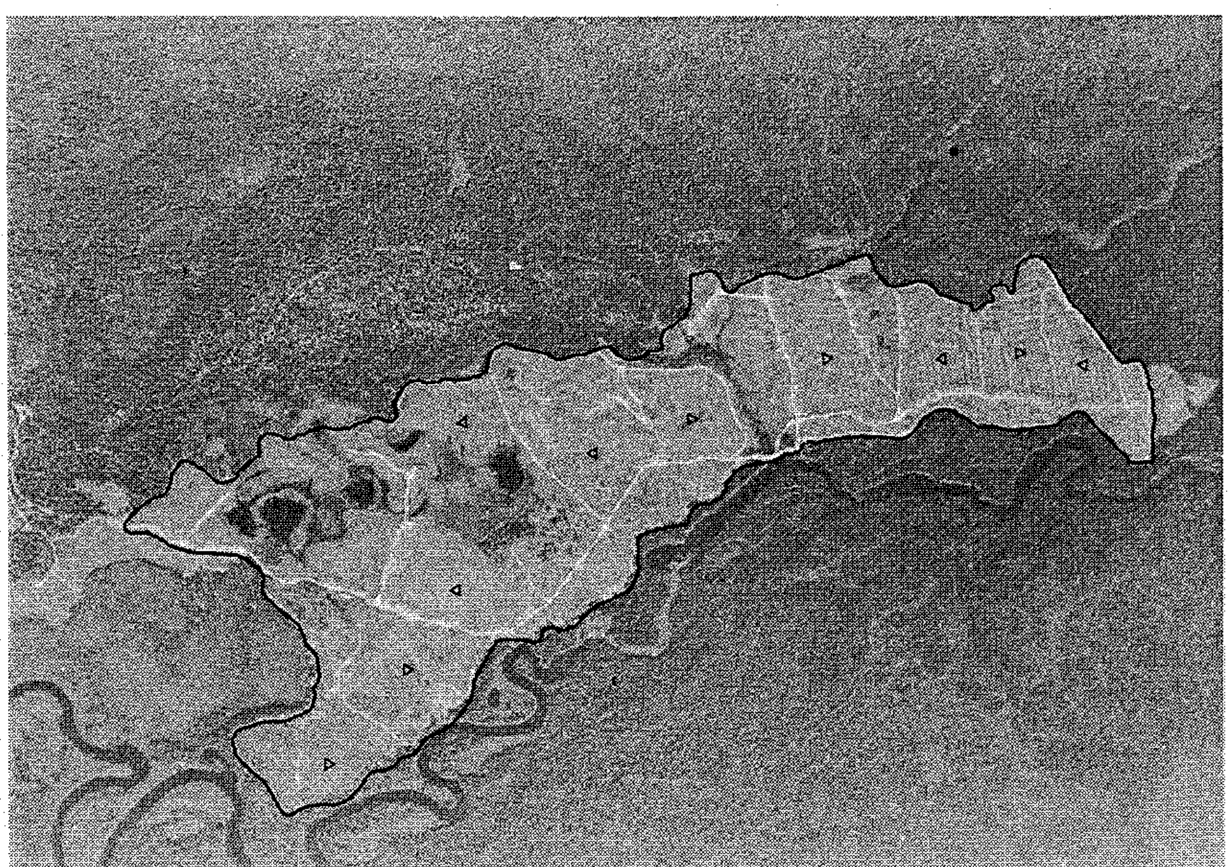


Fig. 2. Symbolic representation of the fuel sampling scheme applied to a proposed 200 ha prescribed burn site.

Once the starting point is located, an equilateral triangle with 30 m sides is created (Fig. 3). A hand compass is useful for laying straight sides and offsetting 60° to locate the side of the sampling triangle. The triangle doesn't have to close completely, but should close within a reasonable distance. The extra line intersect pin is insurance against triangles that do not close completely. Where triangles do not close completely an extra pin can be inserted to fill the space.

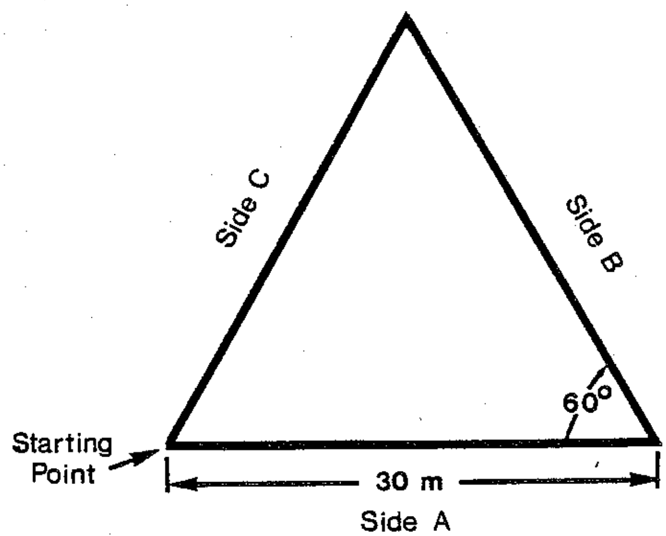


Fig. 3. Overhead view of sampling triangle.

Step 2. Line intersect pins are located during construction of the sampling triangle at 0, 5, 10, 15, 20, 25 and 30 m intervals along each side (Fig. 4). A string is then tied tautly between pins. Use of line intersect pins allows for reconstruction of the sample line (triangle) following the burn in order to sample postburn fuel loadings and ultimately determine fuel consumption. *Line intersect pins must be installed perpendicular to the slope of the ground.*

Step 3. Measure the slope of the sample line (ground slope) on each side of the triangle using a clinometer or abney level to the nearest 5 percent and record on inventory form PB-2.

Step 4. Count the number of woody fuel pieces (twigs, branches, unmerchantable tops, etc.), less then 7.0 cm in diameter, that intersect the sampling line (string) and record, by the following size class diameters (in the appropriate lengths of the sample line), all pieces found above the duff layer for all three sides of the triangle (as illustrated in Fig. 4):

Size class diameters (cm)	Sample line tally length (m)
0.0 - 0.49	0 - 5
0.5 - 0.99	0 - 10
1.0 - 2.99	0 - 15
3.0 - 4.99	0 - 20
5.0 - 6.99	0 - 25

Crew members can keep track of the intersections by using a "dot tally" system in the space provided on inventory form PB-2 (Appendix II) and later noting the final number in the space provided on the form.

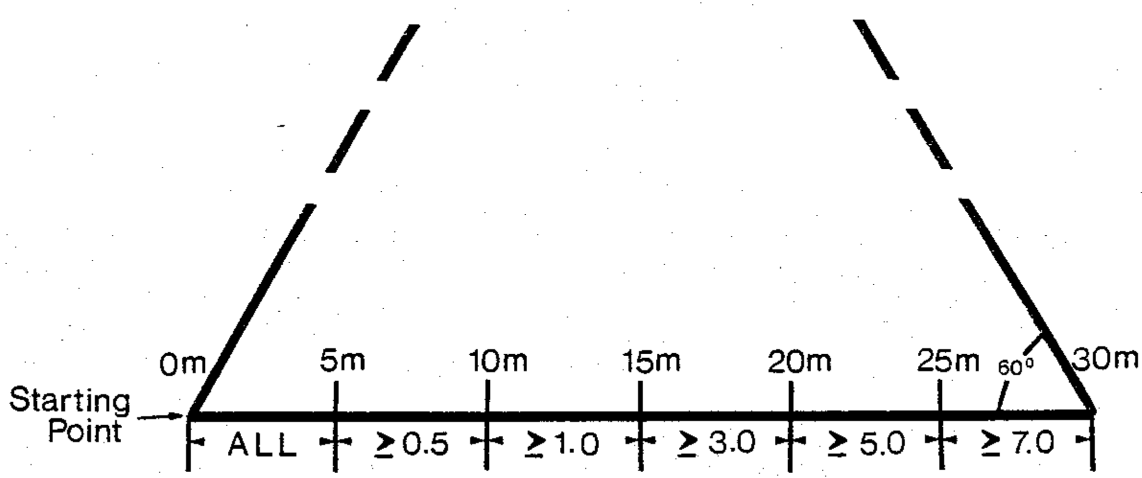


Fig. 4. Overhead view of sample line making up one side of sampling triangle.

The diameter of the particle *at the point of intersection* determines its size class diameter. A "go-no-go" gauge (Fig. 5) with openings of 0.5, 1.0, 3.0 cm, an intermediate length of 5.0 cm, and overall length of 7.0 cm works well for separating borderline slash fuel pieces into size class diameters and for training the eye to recognize size class diameters (Fig. 6).

Observe the tally rules given after step 6.

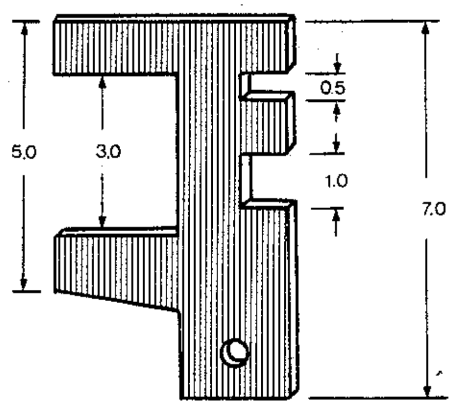


Fig. 5. A "go-no-go" gauge is best cut from sheet aluminum. Cut the notches slightly tight and file smooth to final dimensions (after Brown 1974b).

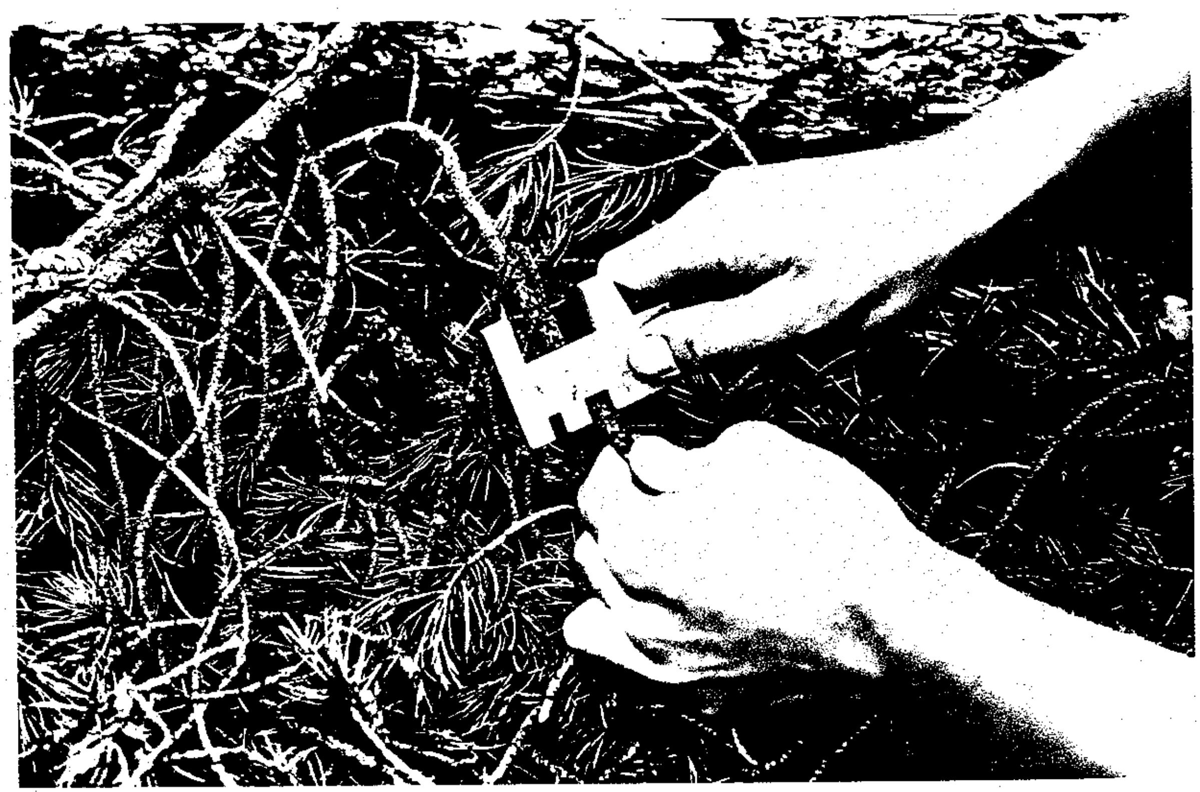


Fig. 6. Using a "go-no-go" gauge to determine size class of borderline pieces.

Step 5. After completing the tally of each sample triangle side, estimate the percent species composition (Pj = jack pine; S = black and white spruce; B = balsam fir; Po = poplar; Bw = white birch) of pieces between 0-0.99 and 1.0-6.99 cm in diameter and record on the inventory form PB-2 (Appendix II).

Step 6. Measure and record on inventory form PB-2 the diameter of all pieces 7.0 cm and greater in diameter that intersect the sample line for all three sides of the triangle by condition. For sound pieces, only species needs to be noted (e.g., 9.2B). Sound pices not identified should be labelled as unknown (e.g., 8.3U). Denote rotten pieces by an "R" (e.g., 10.4R). Consider pieces rotten when the piece at the intersection is obviously not solid and can be kicked apart easily. *With calipers measure diameters at the point of intersection to the nearest 0.1 cm, being sure to avoid parallax* (Fig. 7).

Fig. 7. Using calipers to measure a large slash piece intersecting the sample line.

All pieces 7.0 cm in diameter or greater should have a nail (7.5 cm long) driven in at the point of measurement. Allow approximately 1.0 cm of the nail to remain exposed. Use of nails allows for remeasurement of exactly the same spot on the piece during the postburn sampling, and ensures that only pieces tallied before the burn will be tallied in the postburn sampling. Piece movement is quite common.

Observe the tally rules that follow.

Tally Rules[1]

Rule 1. Particles qualifying for tally include downed, dead woody material (twigs, stems, branches, and bolewood) from trees and shrubs. Dead branches attached to boles of standing trees are omitted because they are not downed fuels. Consider a particle downed when it has fallen to the ground or is severed from its original source of growth. Cones, bark flakes, needles, leaves, grass, and forbs are not counted. *Dead woody stems and branches still attached to standing trees are not counted.*

Rule 2. Twigs or branches lying only above the duff layer are counted (Fig. 8).

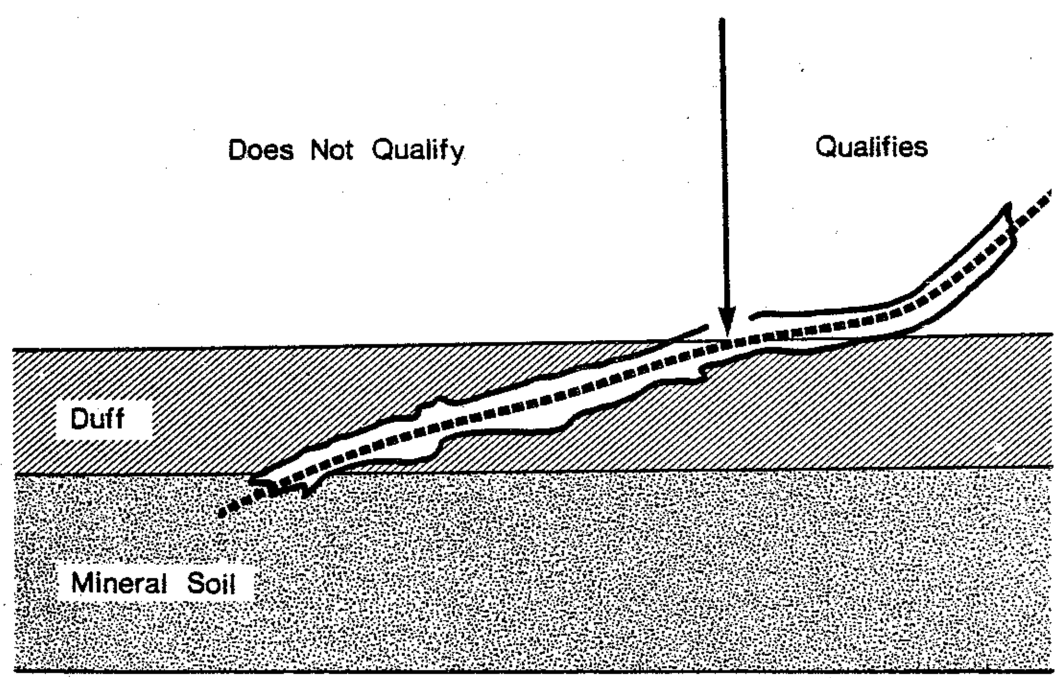


Fig. 8. Regardless of size, pieces are tallied only when intersections lie above the duff layer (right of arrow) (after Brown 1974b).

[1] Tally rules either directly from or adapted from Brown (1974b).

Rule 3. If the sampling line intersects the end of a piece, tally only if the central axis is crossed (Fig. 9). If the line exactly intersects the central axis, tally every other such piece.

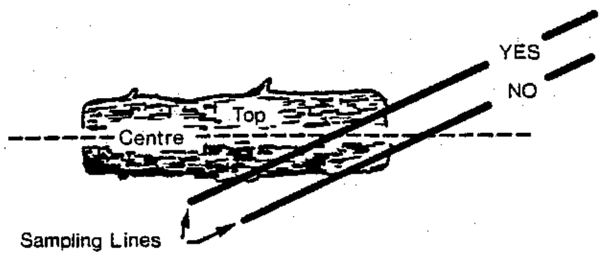


Fig. 9. An intersection at the end of a branch or log must include the central axis to be tallied (adapted from Brown 1974b).

Rule 4. Do not tally any particle with a central axis that coincides perfectly with the sampling line. (This should happen rarely.) (Fig. 10).

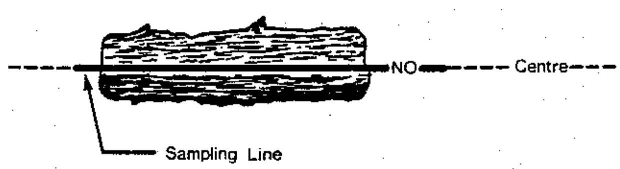


Fig. 10. Do not tally as the central axis of the piece coincides perfectly with the sample line (adapted from Brown 1974b).

Rule 5. If the sampling line intersects a curved or angular piece more than once, tally each intersection (Fig. 11).

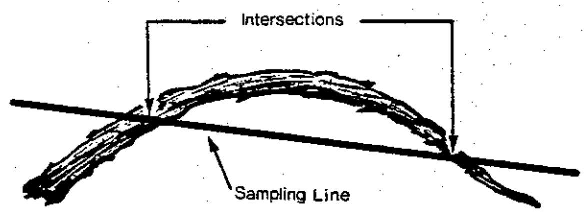


Fig. 11. Tally both intersections for a curved piece intersected more than once by the sampling line (adapted from Brown 1974b).

Rule 6. Wood slivers and chunks left after logging, and rotten logs that have fallen apart, *must be reconstructed visually into a cylinder for determining size class diameters or recording diameters.*

Rule 7. Tally uprooted stumps and roots not encased in dirt. For tallying, consider uprooted stumps as tree boles or individual roots, depending on where the sampling lines intersect the stumps. *Do not tally undisturbed stumps.*

Rule 8. Be sure to look up from the ground when sampling because downed material can be tallied up to any height providing it is not rooted.

2. Depths

i) Duff. Measure vertical depth of duff to the nearest 0.1 cm, to a maximum depth of 20 cm, using a small metal ruler or pocket tape (Fig. 12). Duff as defined here includes the L, F, and H horizons.

Measurements should be taken 1 m to the right of the 5, 10, 20 and 25 m line intersect pins (Fig. 13). Each duff measurement should be recorded on the tally sheet in one of the following categories describing the top layer of duff (e.g., 4, 3 L):

S - sphagnum F - feather moss P - peat L - litter

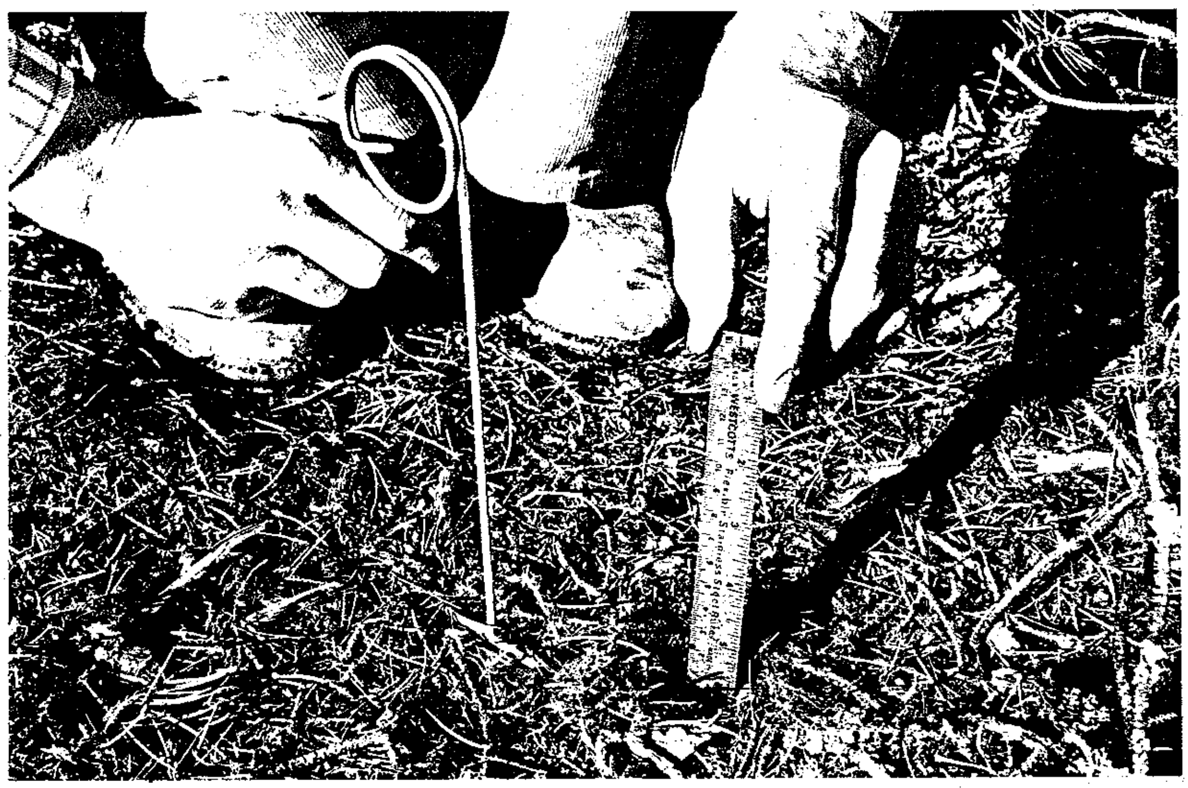


Fig. 12. Using a small steel ruler to measure duff depth adjacent to the depth-of-burn pin. Note that the duff depth measurement is not close enough to the pin to affect the depth-of-burn reading.

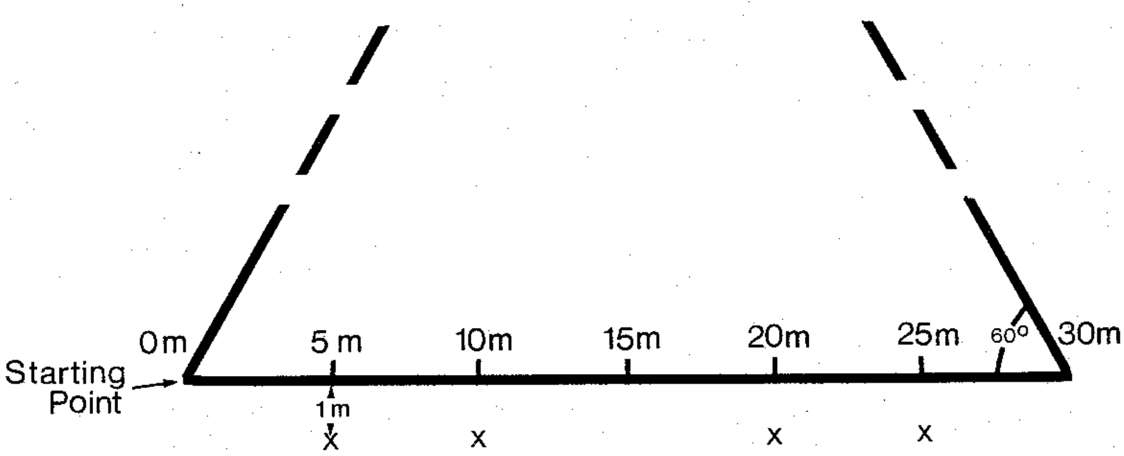


Fig. 13. Overhead view of sample line and positioning of duff measurements.

Carefully expose a profile of the duff layer for the measurements. A pocketknife is useful for exposing the profile. *Avoid compacting or loosening the duff where the depth is measured.* When sound stumps or logs occur at the point of measurement, offset and measure duff depth at a distance of 1.5 m to the right of the line intersect pin. Measure through rotten logs whose central axis is in the duff layer as illustrated in Figure 14.

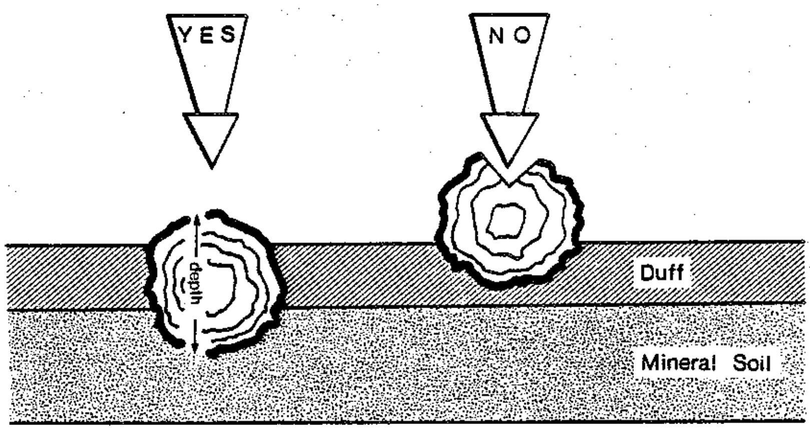


Fig. 14. Duff depth is measured through a rotten log when its central axis lies in or below the duff layer (adapted from Brown 1974b).

ii) Slash. Techniques for measuring slash depths are given here for situations in which this fuel characteristic would be of concern and interest. It is considered an optional measurement.

Take depth measurements, one adjacent to each line intersect pin, of the highest intercept within 15 cm of each intercept pin. Record depths to the nearest cm on inventory form PB-2 (Appendix II) as the vertical distance from the top of the duff to the highest intersected dead slash-fuel piece (Fig. 15). *Only slash fuel pieces less than 7.0 cm in diameter that have been tallied on the sampling line are acceptable.*

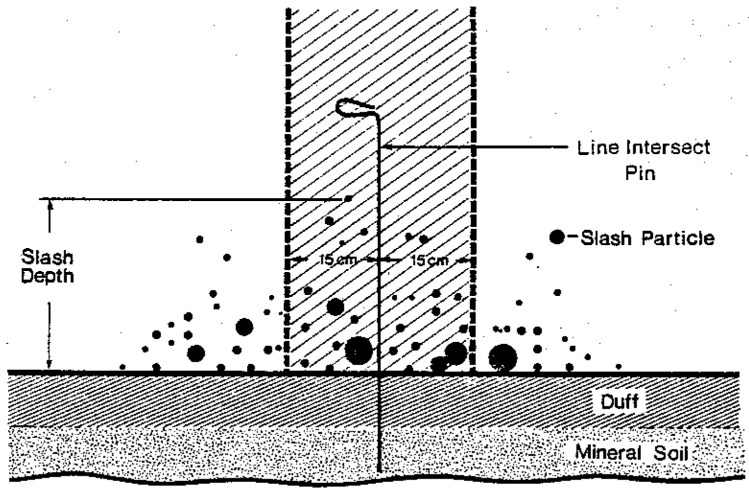


Fig. 15. Cross-sectional view of hypothetical slash fuel bed showing location of slash depth measurements.

C. *Duff Pin Placement*

Depth-of-burn pins are placed on the site prior to burning so that duff removal can be measured. Depth-of-burn pins can be of two types: survey pins with a V-notch filed in the stem or survey pins with a "t" bar welded to the stem (Fig. 16). Both of these pins can be made of No. 9 wire and should have an overall length of 40 cm. The notch or bar should be placed in the middle of the pin. The "t" bar survey pin is considered superior because it is more visible after burning and measurements can be taken more easily with it. All pins should extend into the duff/soil layer at least 20 cm (deeper than expected depth of burn). On shallow soil sites some design modifications may be necessary when one is constructing pins.

Depth-of-burn pins are located adjacent to the duff depth measurements approximately 15 cm away from the sampling plane to avoid the influence of the depth measurement holes. Depth-of-burn pins may be placed on the site in conjunction with duff measurements. If left on the site for an extended period of time (3 or more months) they should be examined to see that placement specifications are still met.

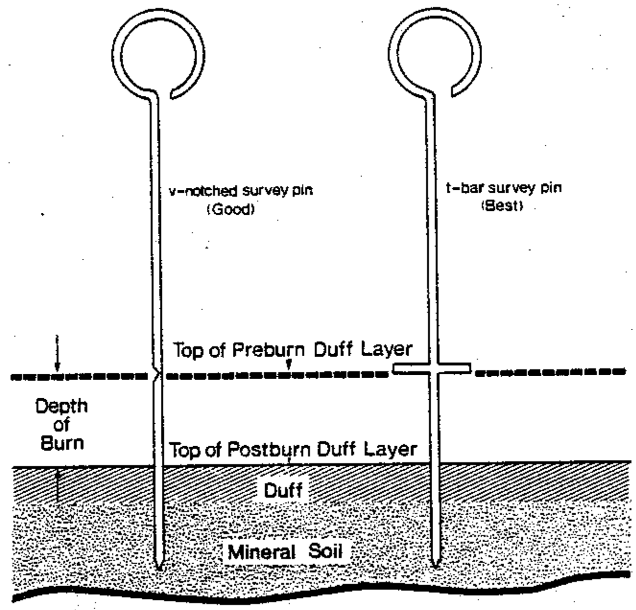


Fig. 16. Two types of depth-of-burn pins.

Avoid compacting or loosening the duff layer around the pins when placing pins in position or when taking duff depth measurements. Pins must be placed in the duff in a vertical position, such that the notch or t-bar is level with the top of the duff layer (Fig. 16). Slash fuel particles on the duff measured by the line intersect fuel sampling method should not be part of this measurement.

If the pins are placed in a duff layer category differently than outlined in these procedures, it should be noted on the inventory form.

D. *Photography (optional)*

Color transparencies (35 mm slides) are helpful in documenting preburn and postburn fuel conditions (Fig. 17). Transparencies may prove useful in planning, in training sessions, in making comparisons with other burns, etc. Prescribed burn name and/or number, section number, sample triangle number and side should be noted in the field and recorded later on the transparency. To maintain continuity, take photographs approximately 10 m from the 0 m starting point. The 2.0 m range pole suggested in Table 1 can be placed in the field of view for scale. The range pole should be placed at the far end of the triangle side, and the location at which the photograph was taken must be noted if it is anticipated that postburn photographs will be taken. Review Koski and Fischer (1978), Maxwell and Ward (1976a, 1976b), and Anon. (1974b) for further details on photo documentation of slash fuel complexes.

Fig. 17. Documentation of both pre- and postburn fuel conditions.

E. *Calculations*

1. Slash loading. The steps for calculating slash loadings are outlined below.

Step 1. Add the number of slash fuel piece intersections by size class diameter for each sample triangle. Calculations of needle bearing and total intersections in the 0.0–0.49 cm size class should be made separately so that foliage loadings can be calculated later.

Step 2. Determine the average species composition values for the 0–0.99 and 1.0–6.99 cm diameter categories from the three field estimates per sample triangle. Then calculate the number of pieces by species in each size class from the total (no. pieces/species/size class = average % x total no. pieces).

Step 3. From Table 2, obtain the appropriate multiplication factor for species, slash age (fresh or 1 year and older), and size class, and multiply this factor by the number of intersections for that species and size class to obtain the "uncorrected" slash fuel loading (kg/m^2). Continue to do this for all species and for each size class below 7.0 cm.

Table 2. Multiplication factors for use in calculating fuel loadings (kg/m^2) for a sample triangle having 30 m sides.

Slash age	Size diameters (cm)	Species: Jack pine	Spruce[a]	Balsam fir	Poplar[b]	White birch
Fresh	0.0–0.49	0.0006	0.0004	0.0005	0.0007	0.0007
	0.5–0.99	0.0011	0.0011	0.0011	0.0010	0.0012
	1.0–2.99	0.0044	0.0067	0.0034	0.0046	0.0060
	3.0–4.99	0.0158	0.0173	0.0124	0.0130	0.0208
	5.0–6.99	0.0333	0.0330	0.0217	0.0237	0.0336
1 year and older	0.0–0.49	0.0005	0.0003	0.0004	0.0006	0.0005
	0.5–0.99	0.0010	0.0011	0.0010	0.0009	0.0011
	1.0–2.99	0.0044	0.0067	0.0034	0.0046	0.0060
	3.0–4.99	0.0158	0.0173	0.0124	0.0130	0.0208
	5.0–6.99	0.0333	0.0330	0.0217	0.0237	0.0336

[a] black spruce and white spruce

[b] trembling aspen, bigtooth aspen, and balsam poplar

Step 4. Determine the sum of diameter square values for all sound pieces 7.0 cm and greater for each species and multiply by their respective multiplication factors found in Table 3 to obtain their fuel loading (kg/m^2). For rotten pieces, the multiplication factor is 0.0004.

Table 3. Multiplication factors for use in calculating fuel loadings (kg/m^2) for pieces 7.0 cm or greater in diameter for a sample triangle having 30 m sides

Species	Multiplication factor
Jack pine	0.0006
Spruce[a]	0.0006
Balsam fir	0.0005
Poplar[b]	0.0005
White birch	0.0008
Unknown	0.0006

[a] black spruce and white spruce

[b] trembling aspen, bigtooth aspen, and balsam poplar

Step 5. From Table 4, choose the slope correction factor corresponding to ground slope as described in step 4 of field procedures. Determine an overall slope correction factor for the sample triangle by averaging the slope correction values for each side.

Table 4. Slope correction factors for converting fuel loadings on a slope basis to loadings on a horizontal basis. Use the equation given for slopes greater than 60 percent.

Slope (%)	Correction factor[a]	Slope (%)	Correction factor[a]
0	1.000	35	1.059
10	1.005	40	1.077
15	1.011	45	1.097
20	1.020	50	1.118
25	1.031	55	1.141
30	1.044	60	1.166

[a] Correction factor = $\sqrt{1 + (\text{Percent slope}/100)^2}$

Step 6. Multiply the slope correction factor by the slash fuel loadings given in steps 3 and 4 to obtain the final loadings (kg/m^2). See Example 1 for complete illustration of calculations for estimating slash loadings by sample plane.

Step 7. Slash loadings may be averaged to give one value for the entire prescribed burn or for each prescribed burn section.

2. Foliage loading. Jack pine and balsam fir may retain their needles for a number of year after logging. Black spruce, on the other hand, loses its needles very quickly. For this reason, only jack pine and balsam fir foliage are considered here.

Step 1. Estimate the percentage of coniferous foliage retained on the branches using Figure 18.

Step 2. Obtain the slash fuel loadings for each slash fuel type (jack pine and balsam fir only) for the 0.0-0.49 size class.

Step 3. Multiply the value in step 1 by the value in step 2, and multiply by the following needle-to-slash fuel weight ratios to obtain foliage loadings (kg/m^2) (See Example 2):

Species	Ratio
Jack pine	2.03
Balsam fir	1.61

Example 1. Calculating preburn slash fuel loadings (kg/m^2) using the line intersect sampling method.

Slash fuel size class (cm)	Species composition (%) Jack pine	Black spruce	Poplar	Number of intersections
0.0-0.49	40	60	0	673
0.5-0.99	40	60	0	105
1.0-2.99	0	95	5	60
3.0-4.99	0	95	5	27
5.0-6.99	0	95	5	12

Species	Diameters 7[+] cm
All sound black spruce	9.5, 13.4, 10.8, 17.9, 7.6, 7.3, 12.4, 8.1, 22.4, 9.0, 7.2, 11.9, 7.0, 9.9, 13.3, 8.6, 18.6, 7.9, 10.3, 20.3

Sample triangle side	Slope (%)	Slope correction factor
A	0	1.00
B	0	1.00
C	20	1.02

Age = 2 years old

Calculations

Part A - Calculating number of intersections by species

Slash fuel size class (cm)	Number of intersections by species Jack pine	Black spruce	Poplar
0.0-0.49	269	404	0
0.5-0.99	42	63	0
1.0-2.99	0	57	3
3.0-4.99	0	26	1
5.0-6.99	0	11	1

Part B - Calculating slash loading

jack pine	0.0-0.49	269 x .0005 = 0.135
jack pine	0.5-0.99	42 x .0010 = 0.042
black spruce	0.0-0.49	404 x .0003 = 0.121
black spruce	0.5-0.99	63 x .0011 = 0.069
black spruce	1.0-2.99	57 x .0067 = 0.382
black spruce	3.0-4.99	26 x .0173 = 0.450
black spruce	5.0-6.99	11 x .0330 = 0.363
aspen	1.0-2.99	3 x .0046 = 0.014
aspen	2.0-4.99	1 x .0130 = 0.013
aspen	5.0-6.99	1 x .0237 = 0.024
black spruce	7.0 +	3137.9 x .0006 = 1.883
		3.496

Intersections or sum of 7.0 + diameters squared (↑ first factor)

Factors used from Tables 4 and 5 (↑ second factor)

Slash fuel loading (kg/m^2) (without slope correction factor) (↑ 3.496)

Total slash fuel loading (kg/m^2) with slope correction factor = $3.496 \times \frac{1.00 + 1.00 + 1.02}{3} = 3.496 \times 1.007 = 3.520$

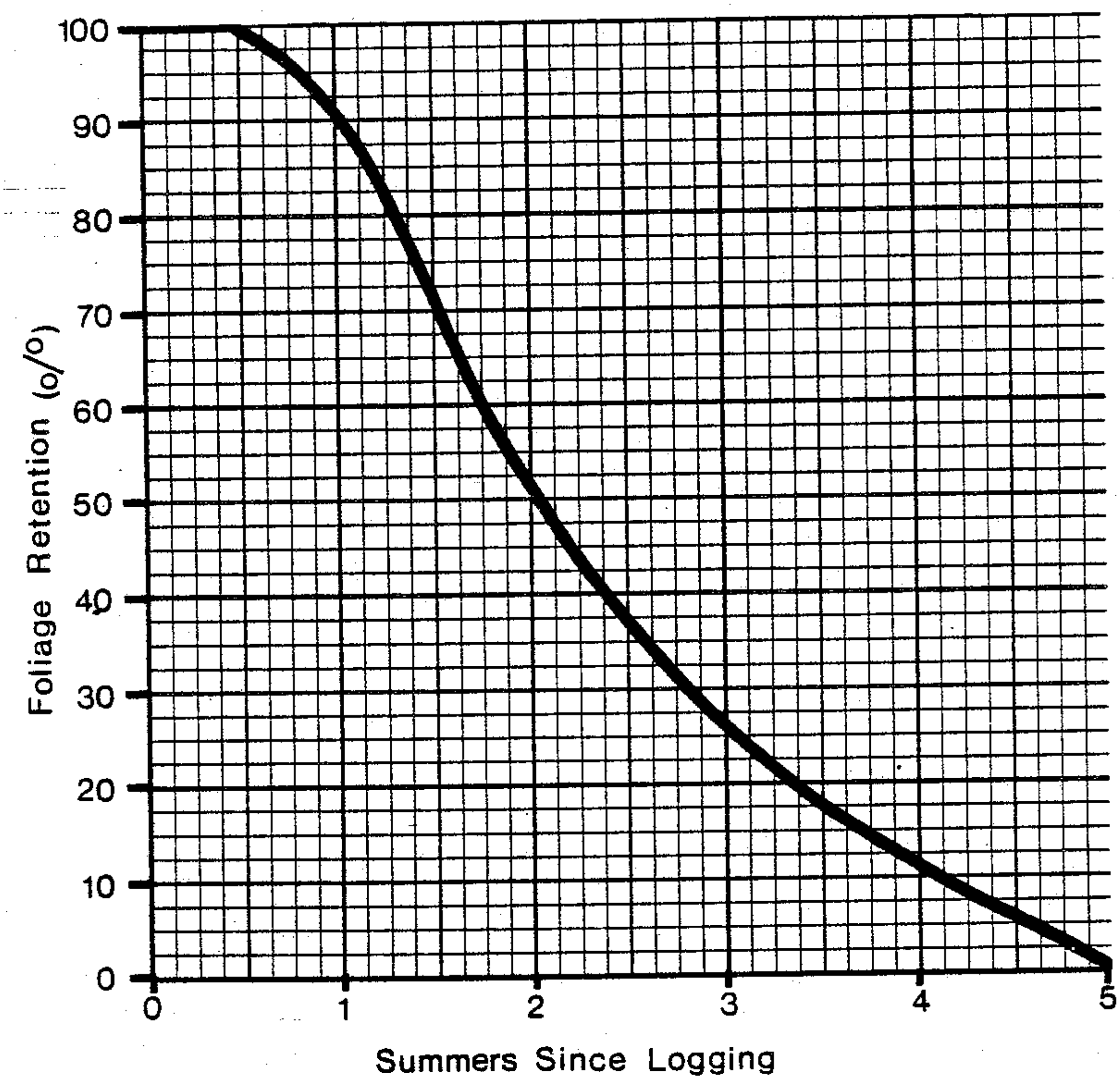


Fig. 18. Relationship between foliage retention (%) on branches and slash age (summers since logging) for jack pine and balsam fir.

Example 2. Calculation of foliage loadings.

For the same fuel sampling triangle as is given in Example 1, all the 0.0-4.49 cm jack pine size class intersections were found to be needle-bearing pieces. This loading is 0.136 kg/m² slope-corrected. The prescribed burn site has undergone two summers of weathering.

Needle retention for 2-year-old jack pine is 50 percent (from Fig. 16).

$$\text{Foliage loading} = \underset{(loading)}{0.136} \times \underset{(ratio)}{2.03} \times \underset{(foliage\ retention)}{0.50} = 0.138\ kg/m^2$$

Step 4. Foliage loadings may be averaged to give one value for the entire prescribed burn or for each prescribed burn section.

3. Duff depth and loading. The steps for calculating duff depth and loading are given below.

Step 1. Calculate the percentage of each duff type for each section.

Step 2. Determine the average duff depth for each sampling triangle by duff type.

Step 3. Using this average duff depth, determine the duff loading (kg/m^2) either by the graph method (Fig. 19) or by means of the equation (Example 3). For Figure 19, lowland black spruce refers to a spruce/feather moss or spruce/sphagnum site while upland black spruce is a drier site having a distinct duff composed of soil horizons made of decomposing materials (L, F, and H horizons).

Example 3. Calculation of duff loadings.

The site from which Example 1 was taken was considered an upland black spruce site with an average duff depth of 7.4 cm.

Duff loading as read from Figure 19 for an upland black spruce site with an average depth of 7.4 cm is 7.495 kg/m^2.

Step 4. Duff loadings may be averaged to give one value for the entire prescribed burn or for each prescribed burn section.

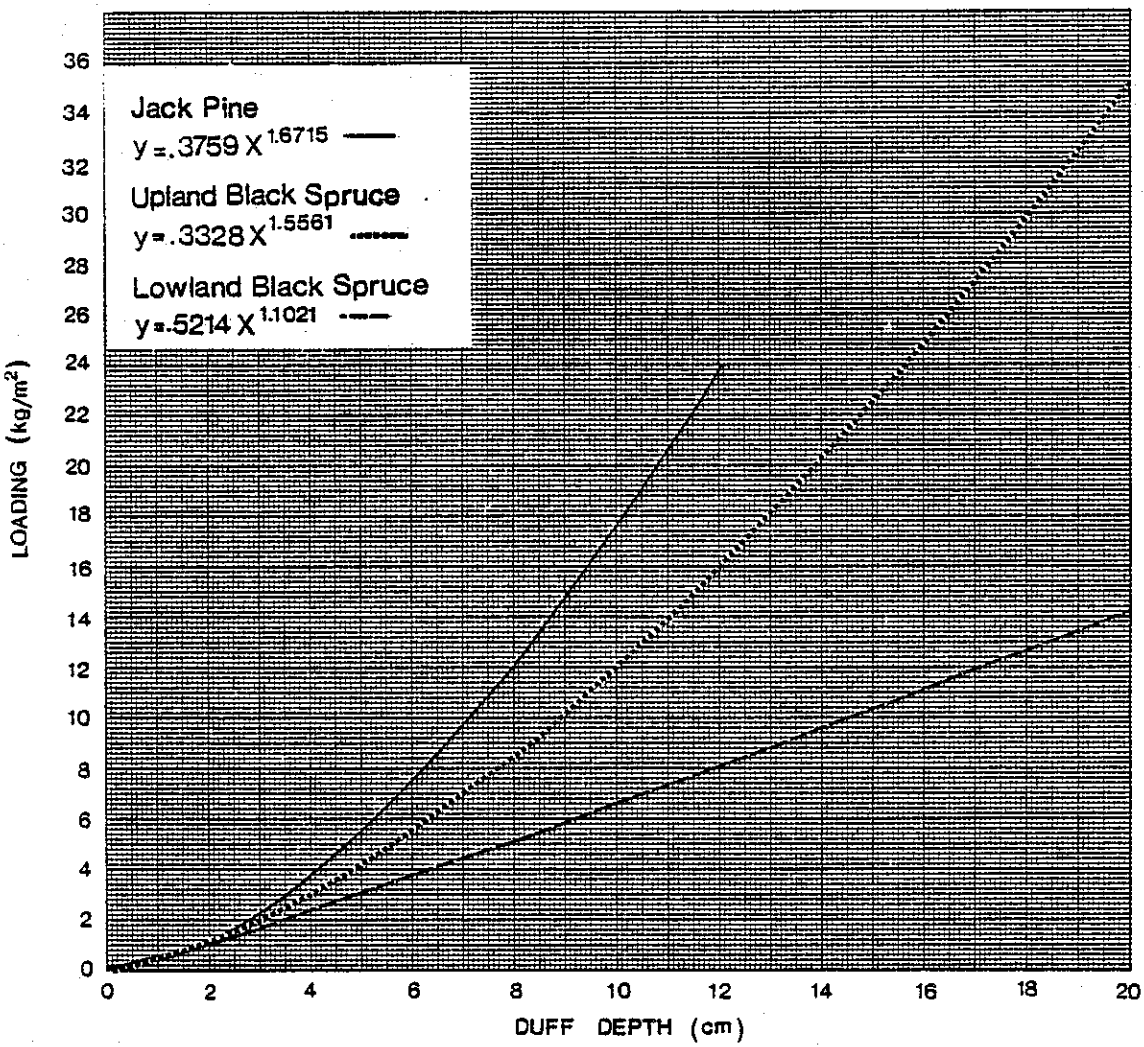


Fig. 19. Relationship between duff fuel loading and duff depth for three different sites. Use upland black spruce for mixedwood sites.

4. <u>Total loading</u>. Fuel loadings are summarized from examples 1-3 as follows:

$$\text{TOTAL FUEL LOADING (kg/m}^2\text{)} = \underset{\textit{slash}}{3.520} + \underset{\textit{foliage}}{0.138} + \underset{\textit{duff}}{7.495}$$

$$= 11.153 \text{ kg/m}^2.$$

5. <u>Slash depth</u>. If slash depths are measured, determine the average values for each section or for the entire burn area. A more realistic average depth can be calculated if one realizes that the sampling method used measures the highest slash intercept depth, by multiplying by the factor 0.638 (Albini and Brown 1978). The average depth calculated by means of this multiplication factor is known as the bulk depth.

Finally, recheck all calculations and complete Form PB-1 (Appendix II).

OBSERVATIONS DURING THE FIRE

Personnel taking measurements or observations during a prescribed burn should work independently of ignition and suppression crews. In this way, they can devote full attention to their task without having to worry about operational work.

All monitoring personnel should synchronize their watches prior to ignition to prevent errors resulting from inaccurate timing. Fire observers working near the flaming front gathering information should be very familiar with the ignition pattern (with safety routes noted), should wear proper clothing (non-synthetic clothing, gloves, bandanna), and should be in two-way radio communication with the fire boss.

Photography using a 35 mm camera is helpful in documenting many aspects of flame front characteristics. Location and time should be recorded for each photo.

A. *Rate of Spread*

Rate of spread measurements may be taken on prescribed burns with ignition patterns that include headfires, backfires, and flank fires. Rate of spread measurements are almost impossible to document on prescribed burns with a centre or perimeter firing pattern, and narrow strip headfires. Rate of spread measurements can best be made on a moving fire originating from a line.

A number of methods for measuring rate of spread are available, and all have both advantages and disadvantages. Those requiring a minimum amount of equipment are discussed below. Several rate of spread measurements for a section, when averaged, would give a representative rate of spread for the section as a whole. Recording of rate of spread measurements in a pocket notebook should also include section location (closest sample triangle number) and time of measurement.

Method 1. Often observers of prescribed fires will take rate of spread measurements, especially on slow moving fires, by visual observation and pacing of distances. The use of a stopwatch to determine how long the fire takes to cover a certain distance gives a rate of spread in that particular area and at that particular time.

Method 2. When rates of spread are expected to be very fast (> 10 m/min), a grid marking system may be employed. This method involves measuring out a grid pattern on the prescribed burn site before ignition occurs. The simplest grid is a single row of equally spaced markers placed on the site. More elaborate grid systems may involve a number of rows. Spacing of markers should be related to rate of spread (i.e., they should be farther apart for higher expected rates of spread). Table 5 is a guide for establishing distances between markers.

Table 5. Guide for establishing distances between rate of spread markers.

Potential rate of spread (m/min)	ISI prescription	Minimum grid distance (m)
5.0	4	5
10.0	6	10
15.0	8	15
20.0	11	20
25.0	13	25
30.0	15	30

Markers may be flagging tape tied to branches or poles painted with orange tree paint. Times are recorded with a stopwatch or wristwatch as the fire burns past each marker, and rate of spread values are recorded.

Method 3. On prescribed burns covering large areas, one approach is to sketch the moving fire front at convenient time intervals (e.g., 15 minutes) from a stationary (e.g., hill top, tree) or moving (e.g., helicopter) vantage point relative to landmarks (Fig. 20). With this method, rate of spread (m/min) may be calculated later by dividing the distance (m) between two different landmarks or recording times by the time (min) it took to cover this distance.

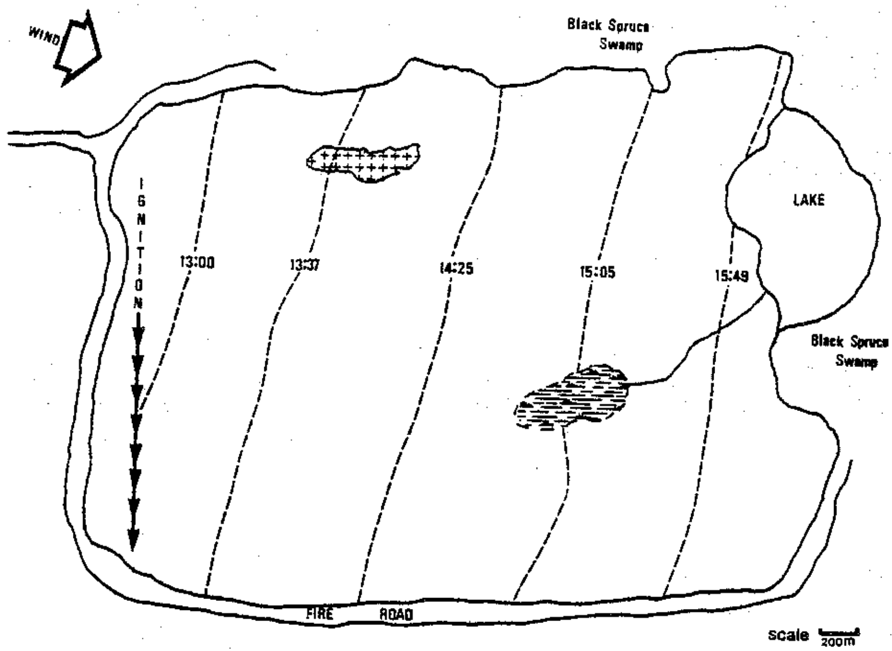


Fig. 20. A sketch map illustrating fire front advancement at particular time periods as drawn from a helicopter. Known time intervals and distances can be used to estimate rate of spread. Rate of spread for this burn was approximately 16 m/min.

B. *Spotting*

If spotting does occur outside the prescribed burn perimeter, the time of occurrence, distance (in metres) from the suspected fire front (measured if necessary after burning has been completed), and location of the prescribed burn map should be noted.

C. *Fire Weather*

According to OMNR Fire Weather Station Manual regulations (Anon. 1974a), a fire weather station should be set up near the prescribed burn site at least 3 weeks before burning. This period permits the codes and indices of the Canadian Forest Fire Weather Index System to reflect local fuel moisture conditions adequately. The fuel moisture codes from the nearest permanent fire weather station or an average of surrounding stations should be used as starting values.

Fire weather observations can be obtained by setting up a semipermanent unit at the site. A semipermanent station (e.g., Holohan 1977) should consist of a Stevenson screen, dry and wet bulb thermometers with fan, rain gauge, and anemometer. Refer to Fischer and Hardy (1976) and Turner and Lawson (1978) for further details on recording fire weather.

While fire weather observations are required at 1300 hours each day, additional observations should be taken and recorded at half-hour intervals immediately preceding and during the prescribed burn.

D. *Fuel Moisture*

The methodology for determination of fuel moisture contents is presented here for those who have access to a forced-air drying oven. Fuel moisture samples should be taken for several fuels found on the prescribed burn site:

(a) slash fuel particles (0.0-0.99 cm size class)

(b) slash fuel particles (1.0-2.99 cm size class)

(c) slash fuel particles (3.0-4.99 cm size class)

(d) slash fuel particles (5.0-6.99 cm size class)

(e) surface litter (cones, bark flakes, dead needles)

(f) duff layer (0-6 cm)

Fuel moisture samples of foliage and slash pieces with larger diameters may also be taken, if desired. If sound pieces greater than 7.0 cm are taken they should be split into smaller units.

Fuel moisture samples should be taken just prior to the prescribed burn. Samples are kept in seamless tin fuel moisture containers (often called soil sampling tins) (227 gram size). Sample tins should be numbered with heat resistant paint for identification purposes. Tins should be sealed with masking tape to prevent moisture exchanges after collection. All fuel moisture tins should be labelled with (1) prescribed burn number, (2) prescribed burn section, (3) closest sample triangle, (4) sample contents (type of fuel), (5) date, and (6) time of collection on form PB-3 (Appendix II). Six samples should be taken each time for every fuel type sampled.

The collection of slash fuel particle samples is best done with hand pruners to cut fuel into convenient sections 2-3 cm long. For duff collections, a pocketknife is essential for cutting out a section of the duff. Recording of duff fuel moisture samples should include the duff classification as listed in field procedures for taking duff depths (page 13). It is wise to take duff samples representing major duff material types that occur on the prescribed burn.

POSTBURN PROCEDURES

A. *Fuel Sampling and Calculations*

1. Slash loadings. The quantity of logging slash fuel not consumed by the prescribed fire may be estimated according to the line intersect fuel sampling method (Fig. 21). The procedure is exactly the same as that used for taking preburn logging slash fuel loadings. This time, however, sampling planes are already positioned because line intersect pins were placed out on the site for the preburn sample. Once the line intersect pins are located the sampling planes can be delineated by restringing between pins.

Fig. 21. Restringing the sample triangle after the burn in preparation for resampling slash loadings.

Charred but still solid pieces should be resampled along with all unburned pieces. The postburn tally of the 0.0-6.99 size classes is similar to the preburn inventory. Particles 7.0 cm and greater should be remeasured at the nail point. Inventory form PB-2 (Appendix II) has been designed for use in both the pre- and postburn sampling. This ensures that if, for example, only six slash pieces 7.0 cm and greater were tallied before the prescribed fire, no more than six pieces are measured after the fire. Some log movement during the fire is common and could result in the inclusion in the postburn tally of pieces that had not qualified for preburn measurement. Care must be taken to avoid this.

Postburn loadings by species may be obtained by using the preburn inventory species ratio. The species of pieces 7.0 cm or greater should be identified easily by taking a count of logs with nails and comparing this with the preburn count, using the inventory form PB-2. Methods for calculating postburn slash loadings are similar to those used for preburn slash loadings. Postburn loadings may be averaged to give one value for the entire prescribed burn or for each prescribed burn section. Remove all pins from the site except the starting point pin; these can be used in the next prescribed fire. The permanent placement of the starting point pin will provide a reference point in the field for any future assessment related to the burn.

2. Duff removal. Procedures for removing duff are outlined below.

Step 1. Measure each depth-of-burn pin from either the mid-point of the V-notch or the bottom of the "t"-bar to the top of the unburned duff layer, or to the top of mineral soil if it is exposed (refer to Fig. 15 on page 16). Make sure to scrape the ash away to get to the unburned duff layer. If the "t"-bar survey pin is used (Fig. 22), two measurements should be taken, one on either side of the "t", and averaged to obtain one value. Remove all pins from the site.

Step 2. Determine the average depth of burn for each sampling triangle.

Step 3. Duff consumption (kg/m^2) is determined from the graph in Figure 19 by using the average depth of burn to obtain the weight of duff consumed by the fire (Example 4).

Step 4. Postburn duff loading (kg/m^2) is obtained by subtracting duff consumption from preburn duff bulk loading (Example 4).

POSTBURN DUFF LOADING (kg/m^2) = PREBURN DUFF LOADING - DUFF CONSUMED

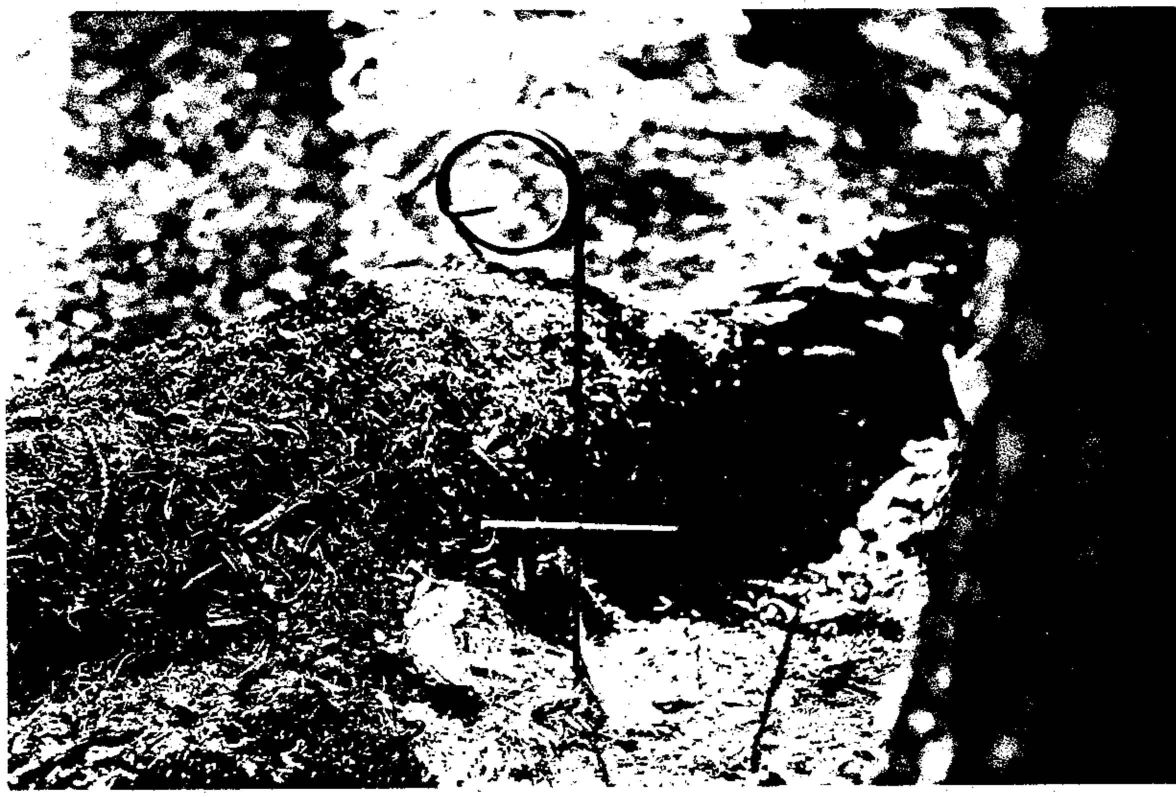


Fig. 22. Postburn view of a "t"-bar depth-of-burn pin.

Example 4. Calculations of postburn duff loadings

The site from which examples 1 and 3 were taken (upland black spruce) had a depth of burn of 4.2 cm.

The duff consumption for the sample triangle is 3.105 kg/m^2 as read from Figure 19.

$$\text{Postburn duff loading} = 7.495 \text{ (from Example 3)} - 3.105$$
$$= 4.390 \text{ kg/m}^2$$

B. *Fire Behavior Calculations*

1. Fuel consumption. i) Slash. Procedures for calculating slash consumption are outlined on the following page.

Step 1. Subtract the postburn slash loading from the preburn slash loading for the total loading of pieces in the 0.0-6.99 cm size classes inclusive and for pieces 7.0 cm and greater in diameter. Obtain the slash consumption as follows (see Example 5):

SLASH CONSUMPTION (kg/m^2) = PREBURN SLASH LOADING-POSTBURN SLASH LOADING

Step 2. Calculate the percent slash consumption for the total loading of pieces in the 0.0-6.99 cm size classes inclusive and for pieces 7.0 cm and greater as follows (see Example 5):

$$\text{SLASH CONSUMPTION (\%)} = \left[\frac{\text{PREBURN SLASH LOADING - POSTBURN SLASH LOADING}}{\text{PREBURN SLASH LOADING}}\right] \times 100\%$$

Example 5. Calculating slash consumption (SC).

Given

Preburn slash loading (0.0-6.99 cm) = 1.613 x 1.007 (slope correction factor)
= 1.624 kg/m^2

Preburn slash loading (7.0 + cm) = 1.883 x 1.007 (slope correction factor)
= 1.896 kg/m^2

Postburn slash loading (0.0-6.99 cm) = 0.102 x 1.007 (slope correction factor)
= 0.103 kg/m^2

Postburn slash loading (7.0 + cm) = 1.124 x 1.007 (slope correction factor)
= 1.131 kg/m^2

Calculations

SC (0.0-6.99 cm) = 1.624 - 0.103 = 1.521 kg/m^2

% SC (0.0-6.99 cm) = ([1.624 - 0.103]/1.624) 100% = 94%

SC (7.0 + cm) = 1.896 - 1.131 = 0.765 kg/m^2

% SC (7.0 + cm) = ([1.896 - 1.131]/1.896) 100% = 40%

ii) Foliage. In most cases, if a prescribed fire can be completed, all foliage (100%) should be consumed by the fire.

iii) Duff. Duff consumption has already been calculated on pages 31-32. Calculate the percent duff consumption as follows:

$$\text{DUFF CONSUMPTION (\%)} = \left[\frac{\text{PREBURN DUFF LOADING} - \text{POSTBURN DUFF LOADING}}{\text{PREBURN DUFF LOADING}}\right] \times 100\%$$

In addition, duff depth reduction can be expressed for silvicultural purposes. Calculate the percent duff reduction for each sample triangle as follows:

$$\text{DUFF DEPTH REDUCTION (\%)} = \left[\frac{\text{DEPTH OF BURN}}{\text{PREBURN DUFF DEPTH}}\right] \times 100\%$$

iv) Total. Total fuel consumption can be calculated as follows:

Step 1. Add the slash, duff and foliage consumption values determined previously and calculate as follows:

$$\begin{aligned}\text{TOTAL FUEL CONSUMPTION (kg/m}^2) &= \text{SLASH} + \text{FOLIAGE} + \text{DUFF}\\ &= 2.286 + 0.138 + 3.105\\ &= 5.529\end{aligned}$$

Step 2. Calculate the total fuel consumption in percent for each sample triangle as follows:

$$\begin{aligned}\text{TOTAL FUEL CONSUMPTION (\%)} &= \left[\frac{\text{TOTAL PREBURN} - \text{POSTBURN FUEL LOADING}}{\text{TOTAL PREBURN FUEL LOADING}}\right] \times 100\%\\ &= \frac{11.060 - 5.529}{11.060} \times 100\%\\ &= 50\%\end{aligned}$$

2. Total heat release. Total heat release (Albini 1976) is expressed in S.I. units as kilojoules per square metre (kJ/m^2), and is an estimate of total heat or energy release on a unit area. Total heat release (T) in kJ/m^2 is calculated as follows for each fuel type:

$$T = (\text{Fuel Low Heat of Combustion, kJ/kg}) \times (\text{Fuel Consumption, kg/m}^2)$$

Fuel low heat of combustion values are given in Table 6. Use the unknown value for calculating T for rotten pieces. Total heat release values should be calculated for each sample triangle (Example 6).

Table 6. Low heat of combustion values (kJ/kg) for each fuel component by species.

Fuel component	Low heat of combustion (kJ/kg) by species					
	Jack pine	Spruce[a]	Balsam fir	Poplar[b]	White birch	Unknown or rotten
Foliage	19874	-	20093	-	-	-
Slash	20083	20083	20083	18409	19246	19581
Duff	Jack pine		Lowland spruce		Upland spruce	
	18409		19246		19246	

[a] black spruce and white spruce

[b] trembling aspen, bigtooth aspen, and balsam poplar

Example 6. Calculation of total heat release.

$$T = \underbrace{[20083 \times 2.286]}_{\textit{slash}} + \underbrace{[19784 \times 0.138]}_{\textit{foliage}} + \underbrace{[19246 \times 3.105]}_{\textit{duff}} = 108399 \text{ kJ/m}^2$$

3. Frontal fire intensity. Frontal fire intensity (synonymous with Byram's fire intensity) is expressed in S.I. units as kilowatts per metre (kW/m) and signifies the amount of heat energy produced by fuel combusted per second per metre of fire front. Frontal fire intensity (I) in kW/m is calculated as follows (from Byram 1959):

I = (Low of Heat Combustion, kJ/kg) x (Fuel Consumption, kg/m^2) x (Rate of Spread, m/s)

or

I = (Total Heat Release [T]) x ([Rate of Spread, m/min] ÷ 60)

Frontal fire intensity values should be calculated for each section. Measured rate of spread values used in the equation should be representative of the fuel sampling triangle areas. See Example 7 below for illustration of frontal fire intensity calculation.

> Example 7. Calculation of frontal fire intensity.
>
> The average rate of spread measured on the section during the prescribed burn was found to be 40 m/min.
>
> Frontal Fire Intensity = I
>
> I = Total Heat Released (kJ/m^2) x (Rate of Spread [m/min]/60)
> = 108399 x (40/60)
> = 72266 kW/m

4. Fuel moisture content determination. For determining fuel moisture contents a forced air drying oven and a weighing balance are needed. To determine fuel moisture, proceed as follows:

Step 1. Remove masking tape from tin. Obtain the weights (GM) of sample tin and "green" fuel sample together for all samples taken.

Step 2. Oven-dry samples in their tins, with lids off, at a constant 100°C for 24 hours except for duff layer samples, which should be dried for 48 hours.

Step 3. Obtain the weights (GD) of both sample tin and "dry" sample for all samples taken.

Step 4. Obtain the weight (tare) of each sampling tin alone after emptying out dried material.

Step 5. Obtain the "green" weight (GW) by subtracting weight of sampling tin from weight obtained in step 1 for each sample.

Step 6. Obtain the "dry" weight (DW) by subtracting weight of sampling tin from weight obtained in step 3 for each sample.

Step 7. Moisture content (%) is determined by the formula:

$$\text{MOISTURE CONTENT (\%)} = \left[\frac{(GW - DW)}{DW}\right] \times 100$$

All measurements taken for determining fuel moisture content should be recorded on form PB-3.

BIBLIOGRAPHY

Adkins, C.W. and Clements, H.B. 1976. Photographic measurements of flame size over flat terrain. Funct. Photo. 11(6):32-34.

Albini, F.A. 1975. An attempt (and failure) to correlate duff removal and slash fire heat. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-24. 16 p.

Albini, F.A. 1976. Estimating wildfire behavior and effects. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-20. 92 p.

Albini, F.A. and Brown, J.K. 1978. Predicting slash depth for fire modeling. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Pap. INT-206. 22 p.

Anderson, H.E. 1978. Graphic aids for field calculation of dead, down forest fuels. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-45. 21 p.

Anon. 1955. Wood handbook. USDA Agric. Handb. 72. 528 p. (Rev. Aug. 1974).

Anon. 1974a. Fire weather manual. Ont. Min. Nat. Resour., For. Fire Control Br., Toronto, Ont. 17 p.

Anon. 1974b. National fuel classification and inventory system (preliminary draft). USDA For. Serv., Div. Fire Manage., Washington, D.C. 23 p. + appendices.

Anon. 1976a. Glossary of forest fire control terms. (3rd ed.). Nat. Res. Counc. Can., Ottawa, Ont. NRCC Publ. 15520. 44 p.

Anon. 1976b. Southern forestry smoke management guidebook. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, N.C. Gen. Tech. Rep. SE-10. 140 p.

Anon. 1978. Canadian Forest Fire Weather Index tables. Dep. Environ., Can. For. Serv., Ottawa, Ont. For. Tech. Rep. 25. 47 p.

Bailey, G.R. 1969. An evaluation of the line-intersect method for assessing logging residue. Dep. Fish. For., Can. For. Serv., For. Prod. Lab., Vancouver, B.C. Inf. Rep. VP-X-23. 41 p.

Bailey, G.R. 1970a. A simplified method of sampling logging residue. For. Chron. 46:288-294.

Bailey, G.R. 1970b. Speedier estimates of logging residue. Can. For. Indust. 90(12):33-35.

Bailey, G.R. and Lefebvre, E.L. 1971. Estimating volume distribution of logging residue from intersected-sampled data. Dep. Environ., Can. For. Serv., Ottawa, Ont. Bi-mon. Res. Notes 27:4-5.

Barney, R.J., Noste, N.V. and Wilson, R.A. 1978. Rates of spread of wildfire in Alaskan fuels. USDA For. Serv., Pacif. Northwest For. Range Exp. Stn., Portland, Oreg. Res. Note PNW-311. 12 p.

Beaufait, W.R. 1966. An integrating device for evaluating prescribed fires. For. Sci. 12:27-29.

Beaufait, W.R., Hardy, C.E. and Fisher, W.C. 1977. Broadcast burning in larch-fir clearcuts: the Miller Creek-Newman Ridge study. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Pap. INT-175 (Rev.). 53 p.

Beaufait, W.R., Marsden, M.A. and Norum, R.A. 1974. Inventory of slash fuels using 3 P subsampling. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-13. 17 p.

Benson, R.E. and Johnson, C.M. 1976. Logging residues under different stand and harvesting conditions, Rocky Mountains. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Pap. INT-181. 15 p.

Bevins, C.D. 1976. An evaluation of the slash fuel model of the 1972 National Fire Danger Rating System. M.SC. Thesis, Univ. Wash., Seattle. 104 p.

Bevins, C.D. 1978. Fuel particle diameters of western hemlock. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Note INT-243. 3 p.

Britton, C.M., Karr, B.L. and Sneva, F.A. 1977. A technique for measuring rate of fire spread. J. Range Manage. 30:395-397.

Brown, J.K. 1970. Vertical distribution of fuel in spruce-fir logging slash. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Pap. INT-81. 9 p.

Brown, J.K. 1971. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17:96-102.

Brown, J.K. 1972. Field test of a rate-of-fire spread model in slash fuels. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Pap. INT-116. 24 p.

Brown, J.K. 1974a. Reducing fire potential in lodgepole pine by increasing timber utilization. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Note INT-181. 6 p.

Brown, J.K. 1974b. Handbook for inventorying downed woody material. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-16. 24 p.

Brown, J.K. and Roussopoulos, P.J. 1974. Eliminating biases in the planar intersect method for estimating volumes of small fuels. For. Sci. 20:250-256.

Byram, G.M. 1959. Combustion of forest fuels. p. 61-89 *in* K.P. Davis, *Ed.* Forest fire: control and use. McGraw-Hill, New York.

Chrosciewicz, Z. 1976. Burning for black spruce regeneration on a lowland cutover site in southeastern Manitoba. Can. J. For. Res. 6:179-186.

Chrosciewicz, Z. 1978a. Slash and duff reduction by burning on clear-cut jack pine sites in southeastern Manitoba. Dep. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Inf. Rep. NOR-X-199. 11 p.

Chrosciewicz, Z. 1978b. Slash and duff reduction by burning on clear-cut jack pine sites in central Saskatchewan. Dep. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Inf. Rep. NOR-X-200. 12 p.

Chrosciewicz, Z. 1978c. Large-scale operational burns for slash disposal and conifer reproduction in central Saskatchewan. Dep. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Inf. Rep. NOR-X-201. 11 p.

Dell, J.D. and Ward, F.R. 1971. Logging residues on Douglas-fir Region clearcuts--weights and volumes. USDA For. Serv., Pacif. Northwest For. Range Exp. Stn., Portland, Oreg. Res. Pap. PNW-115. 10 p.

Egglestone, J.N. 1975. A general theory on common point intersect sampling with special application to downed woody particles. M.Sc. Thesis, Univ. B.C., Vancouver. 115 p.

Fahnestock, G.R. 1960. Logging slash flammability. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Pap. 58. 67 p.

Fahnestock, G.R. and Dieterich, J.H. 1962. Logging slash flammability after 5 years. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Res. Pap. 70. 15 p.

Fischer, W.C. and Hardy, C.E. 1976. Fire-weather observer's handbook. USDA, Washington, D.C. Agric. Handb. 494. 152 p.

Hedin, A. and Turner, T. 1977. What is burned in a prescribed fire? Wash. Dep. Nat. Resour., Olympia, Wash. DNR Note 16. 7 p.

Hills, G.A. 1959. A ready reference to the description of the land of Ontario and its productivity. Ont. Dep. Lands For., Maple, Ont. Res. Div., Prelimin. Rep. 142 p.

Hills, G.A. 1961. The ecological basis for land-use planning. Ont. Dep. Lands For., Toronto, Ont. Res. Rep. 46. 210 p. (Repr. 1966).

Holohan, T. 1977. Portable fire weather kit MK III. Ont. Min. Nat. Resour., Toronto, Ont. Fire Manage. Bull. 74. 3 p.

Hough, W.A. 1969. Caloric value of some forest fuels of the southern United States. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, N.C. Res. Note SE-120. 4 p.

Howard, J.O. 1978. A technique for predicting logging residue volumes in the Douglas-fir region. USDA For. Serv., Pacif. Northwest For. Range Exp. Stn., Portland, Oreg. Res. Pap. PNW-235. 14 p.

Howard, J.O. and Ward, F.R. 1972. Measurement of logging residue--alternative applications of the line intersect method. USDA For. Serv., Pacif. Northwest For. Range Exp. Stn., Portland, Oreg. Res. Note PNW-183. 8 p.

Irving, F.D. and French, D.W. 1971. Control by fire of dwarf mistletoe in black spruce. J. For. 69:28-30.

Kiil, A.D. 1964. On describing and measuring locality, fuels and fire intensity of prescribed burns. Paper presented at Rocky Mount. Sec., Can. Inst. For. Meet., Edmonton, Alta., 11 Apr., 1964. 16 p. [available as Can. Dep. For., For. Res. Br., Mimeogr. Rep. 64-A-11.]

Kiil, A.D. 1966. Three prescribed burns in 1-year-old white spruce slash. Can. Dep. For. Rur. Dev., For. Br., For. Res. Lab., Calgary, Alta. Int. Rep. A-6. 20 p.

Kiil, A.D. 1968. Changes in the physical characteristics and moisture content of pine and spruce-fir slash during the first five years after logging. Can. Dep. For. Rur. Dev., For. Br., For. Res. Lab., Edmonton, Alta. Int. Rep. A-14. 40 p.

Kiil, A.D. 1969. Fuel consumption by a prescribed burn in spruce-fir logging slash. For. Chron. 45:100-102.

Kiil, A.D. 1970. Distribution of moisture in spruce-fir duff and its relevance to fire danger rating. Dep. Fish. For., Can. For. Serv., For. Res. Lab., Edmonton, Alta. Int. Rep. A-34. 14 p.

Kiil, A.D. 1970. Effects of spring burning on vegetation in old partially cut spruce-aspen stands in east-central Alberta. Dep. Fish. For., Can. For. Serv., For. Res. Lab., Edmonton, Alta. Inf. Rep. A-X-33. 12 p.

Kiil, A.D. 1971. Prescribed fire effects in subalpine spruce-fir slash. Dep. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Inf. Rep. NOR-X-3. 30 p.

Kiil, A.D. 1971. Fire hazard from large block clearcutting in Alberta. p. 75-94 *in* Some implications of large-scale clearcutting in Alberta: literature review. Dep. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Inf. Rep. NOR-X-6.

Koski, W.H. and Fischer, W.C. 1978. Photo series for appraising precommercial thinning slash in North Idaho. USDA For. Serv., Intermount. For. Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-46.

Little, E.C. 1973. Foolproof timer measures rate of spread. Fire Manage. 34(4):10-11.

Maxwell, W.G. and Ward, F.R. 1976a. Photo series for quantifying forest residues in the: coastal Douglas-fir-hemlock type, coastal Douglas-fir-hardwood type. USDA For. Serv., Pacif. Northwest For. Range Exp. Stn., Portland, Oreg. Gen. Tech. Rep. PNW-51. 102 p.

Maxwell, W.G. and Ward, F.R. 1976b. Photo series for quantifying forest residues in the: ponderosa pine type, ponderosa pine and associated species type: lodgepole pine type. USDA For. Serv., Pacif. Northwest For. and Range Exp. Stn., Portland, Oreg. Gen. Tech. Rep. PNW-52. 73 p.

McRae, D.J. 1979. Prescribed burning in jack pine logging slash: a review. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-289 (in press).

Ménard, M. and Dionne, J. 1972. Essai d'une méthode par transects pour estimer le volume de bois non utilisé lors d'une exploitation forestière. [Trial of a method employing transects to estimate the volume of wood not utilized during the course of forest harvesting.] Min. Terres For., Québec, P.Q. Serv. Rech. Note 2. 9 p.

Muraro, S.J. 1967. Prescribed fire--evaluation of hazard abatement. Can. Dep. For. Rur. Dev., Ottawa, Ont. Dep. Publ. 1231. 28 p.

Muraro, S.J. 1971. Prescribed-fire impact in cedar-hemlock logging slash. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. 1295. 20 p.

Muraro, S.J. 1975. Prescribed fire predictor. Dep. Environ., Can. For. Serv., Pacif. For. Res. Cent., Victoria, B.C. Misc. Publ.

Pickford, S.G. and Sandberg, D.V. 1975. Using motion pictures for data collection on prescribed burning experiments. USDA For. Serv., Pacif. Northwest For. Range Exp. Stn., Portland, Oreg. Res. Note PNW-259. 7 p.

Ponto, R.L. 1972. Procedures for ovendrying forest slash components and organic matter: study carried out in Alberta, 1967-1971. Dep. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Misc. Rep. NOR-Y-9. 9 p.

Quintilio, D. 1970. Preliminary guidelines for prescribed burning in lodgepole pine slash. Dep. Fish. For., Can. For. Serv., For. Res. Lab., Edmonton, Alta. Int. Rep. A-30. 16 p.

Quintilio, D. 1972. Fire spread and impace in lodgepole pine slash. M.Sc. Thesis, Univ. Mont., Missoula. 69 p.

Randall, A.G. 1966. A prescribed burn following a clearcut in the spruce type. Univ. Maine, Agric. Exp. Stn., Orono, Maine. Misc. Publ. 675. 12 p.

Roussopoulos, P.J. and Johnson, V.J. 1973. Estimating slash fuel loading for several Lake States tree species. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-88. 8 p.

Roussopoulos, P.J. and Johnson, V.J. 1975. Help in making fuel management decisions. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-112. 16 p.

Rowe, J.S. 1972. Forest regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. 1300. 172 p.

Schroeder, M.J. and Buck, C.C. 1970. Fire weather...a guide for application of meteorological information to forest fire control operations. USDA Agric. Handb. 360. 229 p.

Schmidt, R.G. 1975. A hazard appraisal system for southwest Oregon. M.Sc. Thesis, Univ. Wash., Seattle. 149 p.

Steele, R.W. 1964. Effects of prescribed burning on forest duff depth. West. For. Conserv. Assoc. Annu. Meet. Proc. 1964:20-21.

Steele, R.W. and Beaufait, W.R. 1969. Spring and autumn broadcast burning of interior Douglas-fir slash. Univ. Mont., Sch. For., Mont. For. Conserv. Exp. Stn., Missoula, Mont. Bull. 36. 12 p.

Stocks, B.J. and Walker, J.D. 1972. Fire behavior and fuel consumption in jack pine slash in Ontario. Dep. Environ., Can. For. Serv., Sault Ste Marie, Ont. Inf. Rep. O-X-169. 19 p.

Turner, J.A. and Lawson, B.D. 1978. Weather in the Canadian Forest Fire Danger Rating System: a user guide to national standards and practices. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BC-X-117. 40 p.

Van Wagner, C.E. 1965a. Describing forest fires--old ways and new. For. Chron. 41:301-305.

Van Wagner, C.E. 1965b. The line intersect method of fuel sampling. Can. Dep. For., Petawawa For. Exp. Stn., Chalk River, Ont. Int. Rep. PS-1. 3 p.

Van Wagner, C.E. 1966. Three experimental fires in jack pine slash. Can. Dep. For., Ottawa, Ont. Publ. 1146. 22 p.

Van Wagner, C.E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14:20-26.

Van Wagner, C.E. 1972. Heat combustion, heat yield, and fire behavior. Dep. Environ., Can. For. Serv., Petawawa For. Exp. Stn., Chalk River, Ont. Rep. PS-X-35. 7 p.

Van Wagner, C.E. 1974. Structure of the Canadian Forest Fire Weather Index. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. 1333. 44 p.

Van Wagner, C.E. 1978. Metric units and conversion factors for forest fire quantities. Dep. Fish. Environ., Can. For. Serv., Petawawa For. Exp. Stn., Chalk River, Ont. Inf. Rep. PS-X-71. 6 p.

Van Wagner, C.E. and Wilson, A.L. 1976. Diameter measurement in the line intersect method. For. Sci. 22:230-232.

Warren, W.G. and Olsen, P.F. 1964. A line intersect technique for assessing logging waste. For. Sci. 10:267-276.

Williams, D.E. 1955. Fire hazard resulting from jack pine slash. Can. Dep. North. Aff. Nat. Resour., For. Br., For. Res. Div., Ottawa, Ont. Tech. Note 22. 14 p.

Williams, D.E. 1958. Two control burns in jack pine cut-overs. Pulp Pap. Mag. Can. 59:332-338.

APPENDICES

APPENDIX I. Selected S.I./English Unit Conversion Factors (adapted from Van Wagner 1978).

If units are:	Multiply by:	To obtain:	Inverse factor[a]
Area			
Hectares (ha)	2.4711	Acres	0.40469
Length and Depth			
Centimetres (cm)	0.3937	Inches	2.54
Metres (m)	3.2808	Feet	0.3048
Loading			
Kilograms/square metre (kg/m^2)	4.46098	Tons/acre	0.22417
Rate of Spread			
Metres/minute (m/min)	3.2808	Feet/minute	0.3048
Heat Release			
Kilojoules/square metre (kJ/m^2)	0.088114	Btu/square foot	11.349
Kilowatts/metre (kW/m)	0.28909	Btu/foot/second	3.4592

[a] To convert English values to S.I. units multiply by inverse factor.

APPENDIX II

MASTER COPIES OF FORMS

Photocopies can be made from these originals:

Form	Name
PB-1	Prescribed Burn Summary Report (Part A)
	Prescribed Burn Summary Report (Part B)
PB-2	Fuel Sampling Tally Sheet
PB-3	Fuel Moisture Content Determination

PRESCRIBED BURN SUMMARY REPORT

Form PB-1
Part A

P.B. Name & No. ____________________ OMNR Region & District ____________________
Base Map & Block Nos. ____________________ OMNR Forest Mgmt. Unit ____________________
Forest Region/Section Name & No. ____
Site Region/District Name & No. ____
Provincial Project No. ____________________ P.B. Size ________ ha Total ________ ha burnable

Burn Objectives ____

____

Prescription ____

Burning Date(s)

SITE INFORMATION	Section	Section	Section	Section	Section	Section	Section
Forest Type							
Age Class							
Height							
Site Class							
Stocking							
Size (ha)							
Cut Month & Year							

Additional Observations ____

FUELS DESCRIPTION

SLASH														
% Species Comp. 0-1 cm/1-7 cm: Jack Pine														
Spruce														
Balsam Fir														
Poplar														
White Birch														

Loading: 0.0-0.49							
0.5-0.99							
1.0-2.99							
3.0-4.99							
5.0-6.99							
Total 0-6.99							
≥ 7.0 cm loading: Jack Pine							
Spruce							
Balsam Fir							
Poplar							
White Birch							
Unknown							
Rotten							
Total							
Total Slash							

PRESCRIBED BURN SUMMARY REPORT

Form PB-1
part B

	Section	Section	Section	Section	Section	Section	Section
	FUELS DESCRIPTION (cont.)						
Foliage Loading							
Slash Age							
Slash Depth							
DUFF							

% Type & Depth														
Sphagnum														
Feathermoss														
Peat														
Litter														

Mean Depth							
Preburn Loading							
TOTAL LOADING							
Postburn Duff Depth							
	FIRE BEHAVIOR CHARACTERISTICS						
%Slash Consumption (<7cm)							
%Slash Consumption (≥7cm)							
% Duff Consumption							
% Duff Depth Reduction							
Depth of Burn							
Rate of Spread							
Total Heat Release							
Frontal Fire Intensity							

Spotting ☐ yes ☐ no If yes, how far from the fire front ______

FIRE DANGER & WEATHER

CFFWIT Codes & Indices ______ FFMC ______ DMC ______ DC ______ ISI ______ BUI ______ FWI

Fire Weather Obs. ______ °C Temp. ___ RH ___ km/h Wind Days since ___ 0.6 ___ 1.5 ___ 2.9 mm of rain

☐ yes ☐ no on-site weather station. If no, on-site rain gauge used ☐ yes ☐ no

FUEL MOISTURE CONTENTS

Collection Time:

Slash 0-0.99 cm		Slash 3.0-4.99 cm		Litter					
Slash 1.0-2.99 cm		Slash 5.0-6.99 cm		Duff					

P.B. RESULTS & COMMENTS ______

Report prepared by: Title: Date:

FORM PB-2
form ___ of ___

FUEL SAMPLING TALLY SHEET

DISTRICT ____________ P.B. NAME & NO. ____________ DATE(S) ____________ INVENTORY CREW ____________

BURN INVENTORY	SIDE / TRIANGLE #	NUMBER OF INTERSECTS <7.0 cm BY SIZE CLASS: 0 - 0.49 [0 - 5 m]	0.5 - 0.99 [0 - 10 m]	1.0 - 2.99 [0 - 15 m]	3.0-4.99 [0 - 20m]	5.0-6.99 [0 - 25m]	DIAMETERS OF 7.0 + cm INTERSECTS BY SPECIES & CONDITION [0-30 m]	DUFF DEPTH & DEPTH OF BURN (cms.)	% SPECIES COMP 0-0.99 / 1.0-6.99: Pj	S	B	Po	Bw	SLASH DEPTH (cms.)
PRE-														
POST-														% SLOPE -
PRE-														
POST-														% SLOPE -
PRE-														
POST-														% SLOPE -
PRE-														
POST-														% SLOPE -
PRE-														
POST-														% SLOPE -
PRE-														
POST-														% SLOPE -
PRE-														
POST-														% SLOPE -
PRE-														
POST-														% SLOPE -

FORM PB-3

FUEL MOISTURE CONTENT DETERMINATION

P.B. Name & No. ______________________ Sample Triangle ________________ Year __________

Samples Taken by: ______________________ Determinations by: ______________________________

Fuel Type	Date	Time	Tin No.	G.M.	G.D.	Tare	G.W.	D.W.	Content (%)

APPENDIX III. Documentation of Handbook Development

Fuel Diameter Size Classes

The weight of downed woody fuel is more meaningful when viewed as weight by size class distribution than as total load. This necessitates some uniform system of delineation according to fuel diameter so that the percent contribution of each category to the total weight can be visualized. In April 1976, Mr. Z. Chrosciewicz, a research scientist at the Northern Forest Research Centre in Edmonton, Alberta, proposed the following basic diameter size class breakdown for data presentation: 0-1, 1-3, 3-7, $\geq$ 7 cm. These classes were based on the following considerations: (1) sampling convenience (class limits in whole centimetres), (2) sampling economy (four main classes only), and (3) sampling progression (geometric by classes)[a]. Chrosciewicz noted also that sub-classes may be desired. The classification scheme outlined above has been accepted by the Canadian Forestry Service fire research community for use across the country.

Line Intersect Fuel Sampling

The general format for preburn fuel sampling was adapted principally from Brown (1974b) and to a lesser extent from several other published handbooks (Roussopoulos and Johnson 1973; Anon. 1974; Beaufait et al. 1974). Certain features were modified or expanded and others were added in order to adapt procedures to northern Ontario slash fuel complex conditions.

The basic theory behind the line intersect method is that fuel volumes are estimated, then weight is calculated from volume by applying the specific gravity of woody material. The equation for calculating to fuel loading is as follows (after Van Wagner 1968; Brown 1971; Brown and Roussopoulos 1974):

$$W = \frac{0.1234 \times (n \times d_q^2) \textit{ or } \Sigma d^2 \times s \times a \times c}{N \times l}$$

---

[a] Z. Chrosciewicz, Nov. 2, 1976, pers. comm.

(continued)

where:

W = fuel loading, kg/m^2

0.1234 = a constant to convert volume to kg/m^2

n = number of intercepts per size class less than 7.0 cm in diameter

d_q^2 = squared, quadratic-mean diameter, cm^2

Σd^2 = sum of squared diameters for intercepts 7.0 cm and greater in diameter, cm^2

s = specific gravity of fuel size class g/cm^2

a = correction factor for nonhorizontal angle of fuel pieces

c = slope correction factor ($c = \sqrt{1 + (\text{Percent Slope}/100)^2}$)

N = number of fuel transects

l = length of the fuel transect, metres

The multiplication factors given in Tables 2 and 3 were derived from the above equation. Solving the equation required values for d_q^2, s, and a, by size class, species and slash age. Quadratic-mean diameters (dq) were determined in the field by actual measurement to the nearest 1 mm of approximately 22,000 pieces from a variety of sites. Specific gravity values were obtained from the literature (e.g. Anon. 1955, Roussopoulos and Johnson 1973). Correction factors for non-horizontal angle for the size classes less than 7.0 cm (for 7.0 + cm pieces 1.0 is assumed) were taken from Brown and Roussopoulos (1974). In the latter two cases, regression analysis of the literature data was required to determine values. Total length of sampling line per size class represented by $N \times l$ corresponds to amount of line (90 m) per triangle. The finer the fuel pieces the shorter the line required.

Sampling Intensity and Design

The total length of sample line required per 20 ha is based on suggestions by Brown (1974b, p. 3) and on experience in northern Idaho and western Montana. The time required for field sampling was also considered. Individual prescribed burns in northern Ontario commonly vary from 120 to 200 ha, and occasionally are as large as 800 ha.

The equilateral triangle scheme as a sampling design was adopted on the suggestion of Mr. C.E. Van Wagner, Research Scientist, Petawawa National Forestry Institute, Chalk River, Ontario[b]. The three angle directions provide adequate protection against orientation bias.

[b] Dec. 21, 1978, pers. comm.

(continued)

Foliage Loading

The weight of coniferous needles can be estimated according to Brown (1970, 1974a) by the following equation:

$$W_f = F \times R \times w$$

where

W_f = foliage loading, kg/m^2

F = foliage retention, %

R = ratio of needle weight-to-twig weight

W = twig loading, kg/m^2

Needle weight-to-twig weight ratios for jack pine and balsam fir were adapted from values given by Roussopoulos and Johnson (1973). Twig size was regarded as being in the 0-0.49 cm diameter class. The foliage retention curve noted in Figure 18 was approximated through logical relations and assumptions, a review of previous studies in western North America (Fahnestock and Dieterich 1962, Kiil 1968, Albini and Brown 1978), and from observations in the literature (e.g., Williams 1955, 1958, Van Wagner 1966).

Duff Loading vs Depth

The curves noted in Figure 19 were derived through regression analyses from field measurements of depth and duff sample collections. For jack pine, data from Stocks and Walker (1972) were used. Data for upland and lowland black spruce sites were obtained during the 1978 field season.

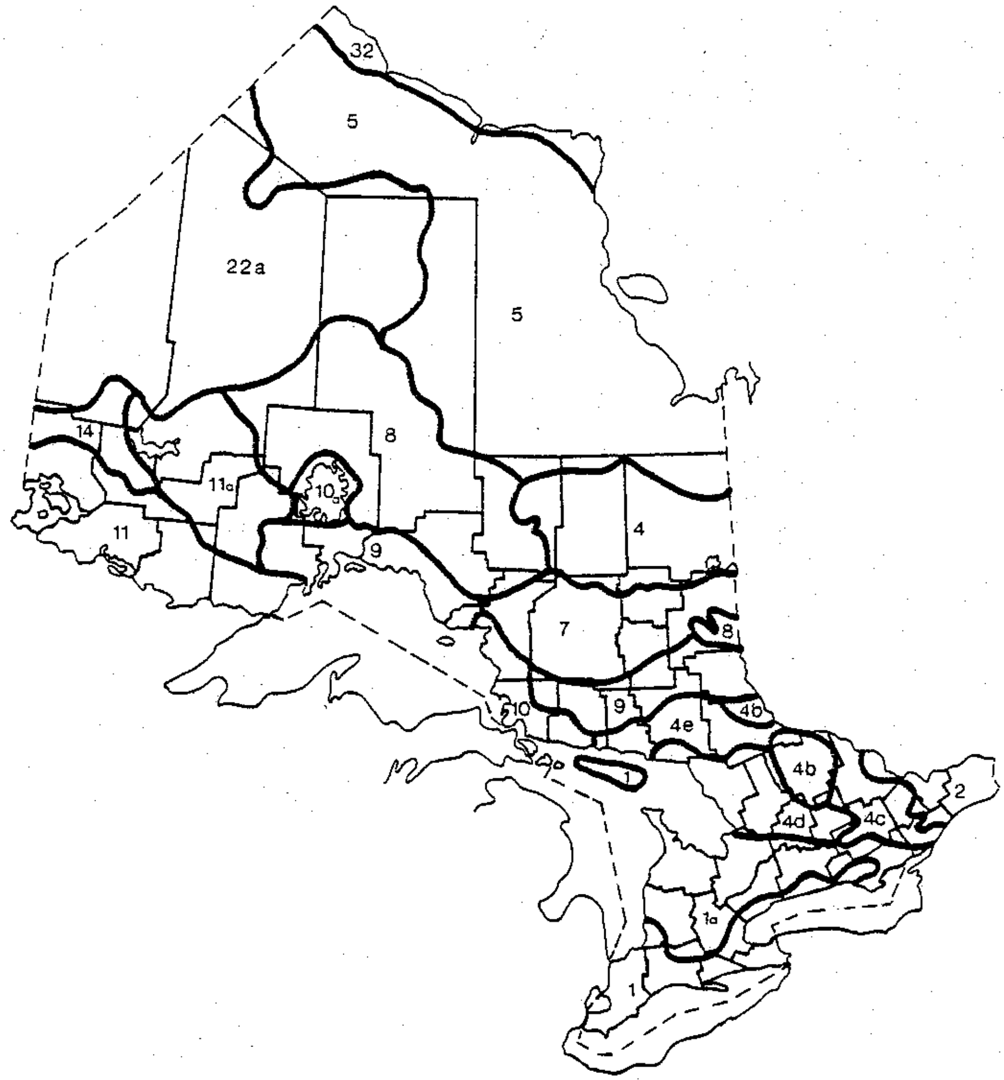
Rate of Spread Markers

Table 5 was developed from the relationship of Initial Spread Index to fire rate of spread given in Stocks and Walker (1972). The potential rate of spread and minimum grid distance markers are directly related.

Heat of Combustion

Fuel low heat of combustion values were obtained from the literature (e.g., Hough 1969; Van Wagner 1972) and through personal correspondence. Means were determined from all sources according to fuel type category.

APPENDIX IV. Forest Regions and Sections of Ontario.



Forest regions and sections of Ontario from south to north (Rowe 1972) are:

DECIDUOUS FOREST REGION:
1. Niagara

GREAT LAKES-ST. LAWRENCE FOREST REGION:
1a. Huron-Ontario
2. Upper St. Lawrence
4b. Algonquin-Pontiac
4c. Middle Ottawa
4d. Georgian Bay
4e. Sudbury-North Bay
8. Haileybury Clay
9. Timagami
10. Algoma
11. Quetico
12. Rainy River

BOREAL FOREST REGION:
4. Northern Clay
5. Hudson Bay Lowlands
7. Missinaibi-Cabonga
8a. Central Plateau
9. Superior
10a. Nipigon
11a. Upper English River
14. Lower English River
22a. Northern Coniferous
32. Forest Tundra

OMNR administrative district boundaries are provided on the above map for ease of reference.

APPENDIX V. Site Regions and Districts - Map

Site regions and districts after Hills (1959, 1961 [reprinted 1966]) are:

Site Region 2W Big Trout Lake

Site District 1 Sandy Lake
2 Lower Sachigo River
3 Wunnummin Lake

Site Region 3W Lake Nipigon

Site District 2 White Water Lake
3 Savanne
4 Black Sturgeon
5 Geraldton
6 Schreiber

Site Region 3S Lake St. Joseph[a]

Site Region 4S Wabigoon Lake

Site District 1 Sydney Lake
2 Lac Seul
3 Sunstrum
4 Dryden
5 Manitou

Site Region 5S Lake of the Woods

Site District 1 Kenora
2 Rainy River

Site Region 4W Pigeon River

Site District 1 Quetico
2 Kakabeka

Site Region 2E James Bay

Site District 1 Albany
2 Moose River
3 Kesagami

Site Region 3E Lake Abitibi

Site District 1 Smoky Falls
2 Hornepayne
3 Cochrane
4 Tip Top Mountain
5 Folyet
6 Kirkland Lake

Site Region 4E Lake Timagami

Site District 1 Michipicoten
2 Batchawana
3 Mississagi
4 Timagami
5 New Liskeard

Site Region 5E Georgian Bay

Site District 1 Thessalon
2 Gore Bay[b]
3 Lake Cloche
4 Sudbury
5 North Bay
6 Tomiko
7 Parry Sound
8 Huntsville
9 Algonquin Park
10 Brent
11 Bancroft
12 Renfrew

OMNR administrative district boundaries noted on the map on the following page for ease of reference.

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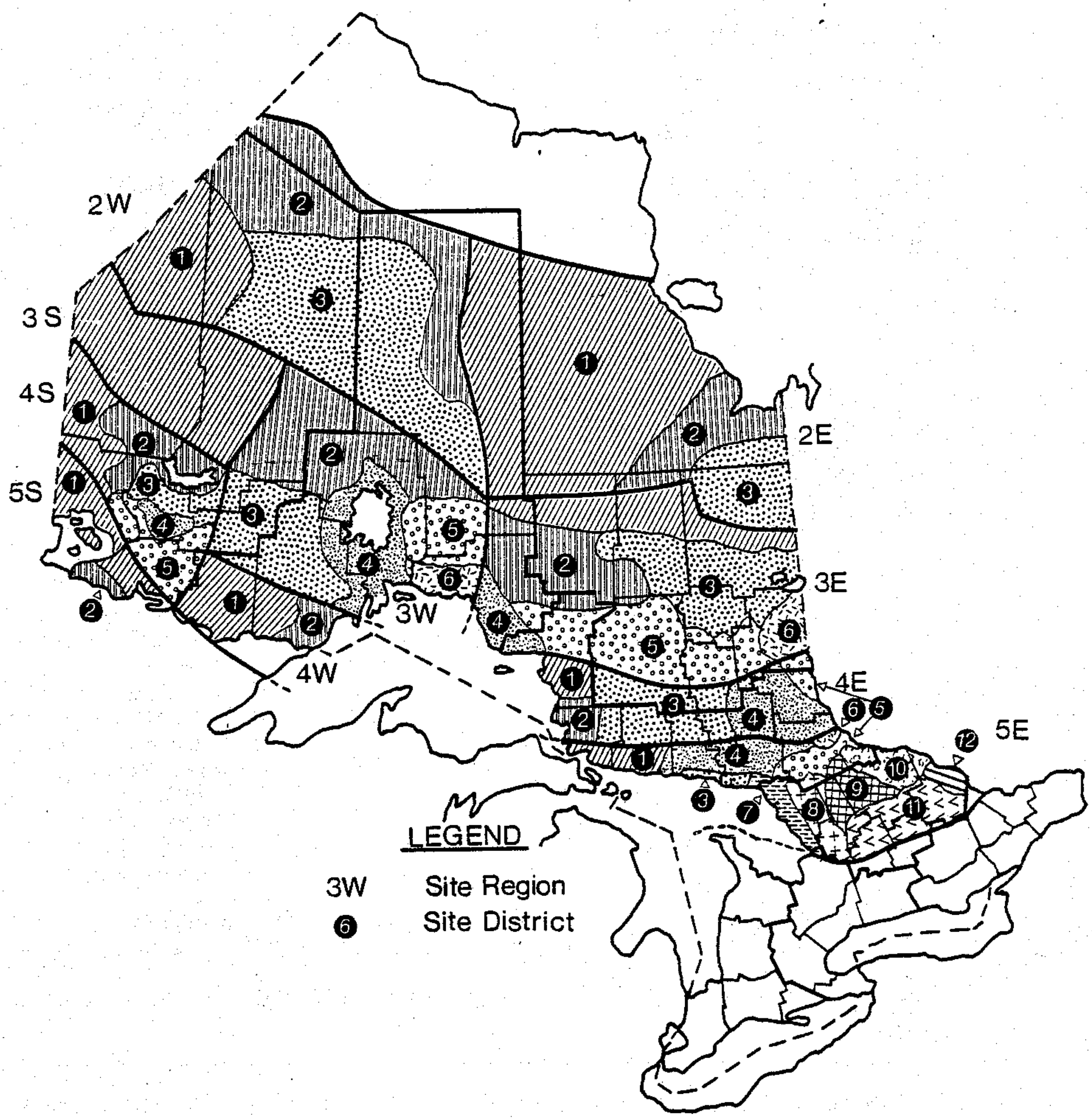
[a] Formerly Site District 1 (Cat Lake) of Site Region 3W. (G. Pierpoint, Ont. Min. Nat. Resour., Ont. For. Res. Centre, Maple. Mar. 29, 1979, pers. comm.)

[b] Not shown on the map. Includes the islands in Lake Huron.

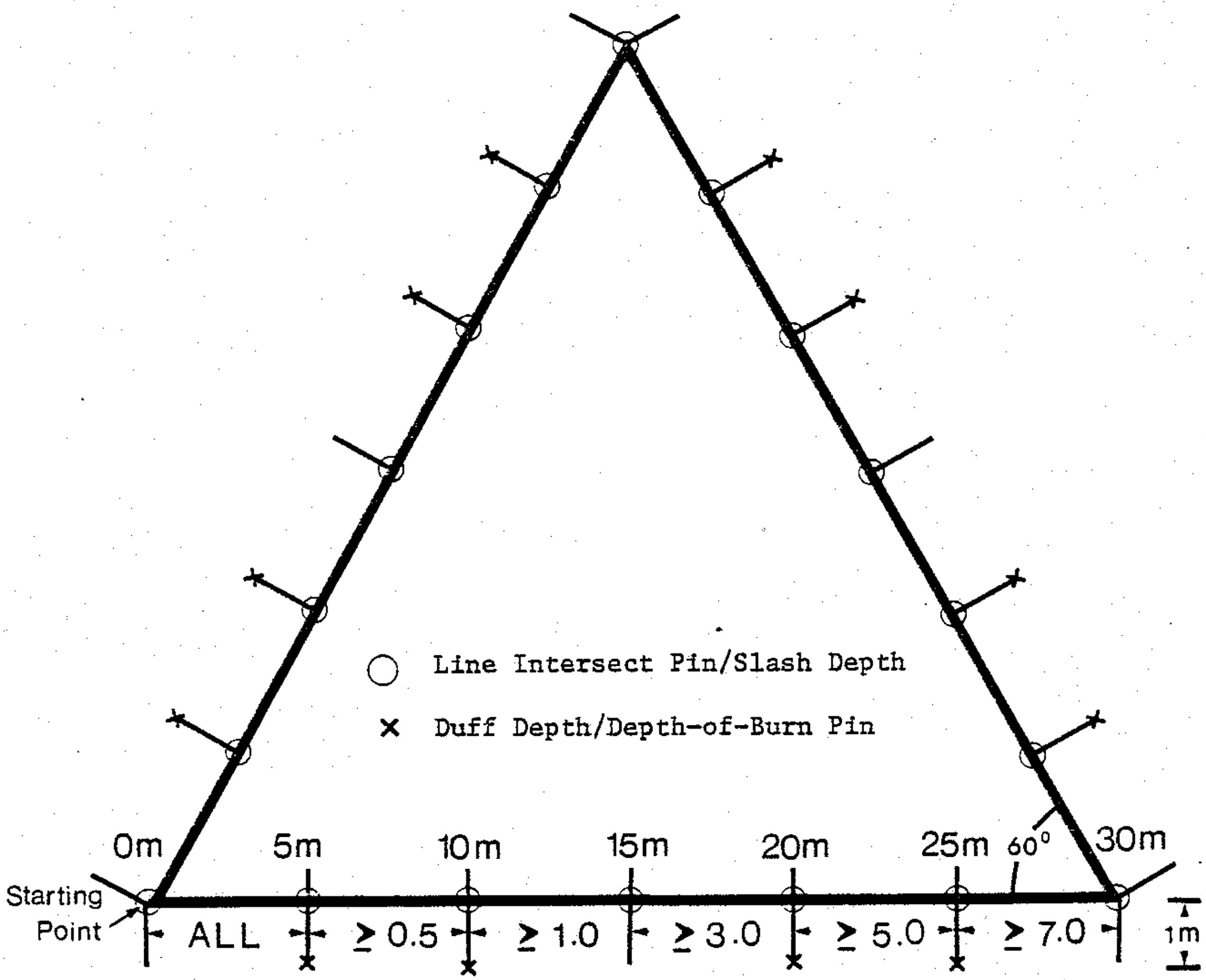
(continued)

APPENDIX V. Site Regions and Districts - Map (concluded)



APPENDIX VI. Pertinent Field Instructions and Plot Layout

7.0+ cm Size Class Conditions	Species	Duff Types
Sound - by species; U = unknown	Pj - Jack pine	S - Sphagnum
R = rotten	S - Spruce	F - Feather moss
	B - Balsam fir	P - Peat
	Po - Trembling aspen	L - Litter
	Bw - White birch	



Reminders

1. Slope measurement of each triangle side to nearest 5 percent.
2. Estimate species composition of 0-1.0 and 1.0-7.0 composite size class.

McRae, D.J., Alexander, M.E. and Stocks, B.J.

1979. Measurement and description of fuels and fire behavior on prescribed burns: a handbook. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-287. 44 p. + Appendices, illus.

This report provides detailed instructions for documenting fuel and fire behavior characteristics on prescribed burns in northern Ontario slash fuel complexes.

McRae, D.J., Alexander, M.E. and Stocks, B.J.

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