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Measuring Fuel Moisture Content in Alaska: Standard Methods and Procedures

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Abstract

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Methods and procedures are given for collecting and processing living and dead plant materials for the purpose of determining their water content. Wild-land fuels in Alaska are emphasized, but the methodology is applicable elsewhere. Guides are given for determining the number of samples needed to attain a chosen precision. Detailed procedures are presented for collecting fuel samples in the field, transporting them safely, and handling them in the laboratory. General guidelines for all live fuels and specific techniques for individual species are given.

Keywords: Fuel moisture content, fuels (forest fire), fire (forest), Alaska.

Contents

Introduction

Almost every facet of modern fire management requires some estimate of fuel moisture content. Recently developed guidelines for prescribed burning call for accurate values for the moisture content of the fuels (Countryman and Dean 1979, Norum 1975). The National Fire Danger Rating System (NFDRS) uses or calculates as many as five fuel moisture contents. Depending on the fuel model involved, the current U.S. Fire Behavior System (Rothermel 1983) may require as many as three integrated dead fuel moisture contents and may also call for a value for live fuels. For calculating fire behavior, the fuel complex involved and the fire behavior and effects sought dictate which fuels must be sampled to determine their moisture content.

Small diameter dead fuels carry the fire and determine the rate of spread and fireline intensity in most cases, so their moisture content is extremely important. Various means and methods have been used to measure or compute dead fuel moisture content. Some analogs have been tried, and one (the standard 1/2-inch diameter fuel moisture indicator sticks described by Fischer and Hardy 1976) is standard equipment at all NFDRS sampling stations. Although some experienced fire managers have found these fuel moisture indicator sticks useful for judging the behavior of planned fires (Morris 1966), others (Beaufait and others 1977, Peck 1969) have shown that there is little correlation between moisture content shown by a fuel stick measurement and that of many natural fuels of similar size collected nearby. The usefulness of fuel moisture sticks must be experimentally determined for any fuel type before they are used as a true direct measure of moisture content and an indirect measure of the flammability of local fuels.

For many reasons, duff, the partially decomposed organic matter on the forest floor, is often sampled for its moisture content. The NFDRS uses duff moisture at a depth of 4 inches and greater below the surface as one measure of 1,000-hour timelag fuels (Deeming and others 1977). Duff moisture content is very important because of the way it influences the impacts and final results of a fire. Many plant parts—rhizomes, roots, tubers—reside in duff. The depth of burning of the duff is instrumental in the survival of many plants and their subsequent resprouting. The burning of the forest floor, as with other fuels, is known to depend on its moisture content (Miller 1977, Norum 1977, Shearer 1975). Readers are encouraged to study the literature and to consult experts on the effects of fire on the ecosystems of interest. The desired depth of burning of the forest floor should be chosen based on this advice; the duff samples most directly related to these important fire effects should then be collected and handled as described.

Although soil is usually not considered to be a fuel, some surface soil samples are often collected for moisture content determination because sprouting parts of many species of plants are concentrated in the surface soil rather than in the duff.

Live plants may either suppress combustion or contribute to it, depending on their moisture content and the flammability of chemical compounds contained in the plant. The NFDRS uses environmental variables to estimate the moisture contents of shrubs and herbaceous plants. These are then used in calculating the ignition component, spread component, and energy release component. Our experience, however, shows that the moisture content of shrubs and herbaceous plants in Alaska is primarily controlled by species physiology and time of year and is little influenced by weather; consequently, it cannot be accurately calculated

from such external variables. Data on file at the Institute of Northern Forestry indicate that, although spring weather can alter the date when vegetation breaks dormancy, the moisture content levels and patterns for individual shrub and grass species are essentially the same during both very wet and very dry spring seasons. Patterns vary considerably among species, however.

The moisture content of conifer needles has a marked influence on fire behavior. Norum (1975) in Montana, Stashko and McQueen (1976) in Alberta, and others found that many conifers readily support crown fires in spring. Firefighters have noted that black spruce *(Picea mariana* (Mill.) B.S.P.[1/]) trees in Alaska readily support fire whenever flames from surface fires reach into the lower branches. The low moisture content of the needles appears to be determined mainly by species physiology. Data on file at the Institute of Northern Forestry show that black spruce foliar moisture content is not very sensitive to daily weather conditions and, compared with other nondeciduous conifers, is relatively insensitive to seasonal differences. Some differences in moisture content caused by seasonal and site differences do exist, however; because they could have an effect on flammability, particularly late in a fire season, they may be worth monitoring.

In contrast, some live fuels in Alaska are extremely sensitive to short-term changes in weather. The feathermosses and lichens commonly found in the understory of most black spruce forests of interior Alaska quickly respond to changes in relative humidity (Mutch and Gastineau 1970). When these live fuels become dry, they support fire similar to the way finely divided dead fuels do. Because the feathermosses and lichens dry and wet rapidly and because black spruce foliage is almost always in a flammable condition, fire can escalate very quickly in such a fuel complex. Similar feathermosses and lichens are found in some hardwood stands as well as in coastal white spruce *(Picea glauca* (Moench) Voss), western hemlock (*Tsuga heterophylla* Raf. Sarg.), and western red cedar *(Thuja plicata* D. Don) forests. These forest types are generally considered much less flammable than black spruce forests, but in some situations the mosses and lichens are abundant enough to propel a fire through them. Furthermore, even when mosses and lichens are sparse in hardwoods, they are commonly concentrated at the bases of trees, forming a fuel bed that supports a fire of sufficient intensity to kill the trees.

For some fuels, no computational procedure yet developed is adequate to estimate their moisture content. Direct sampling of the fuels is the best alternative. Even when computational procedures are developed, they must mimic the values determined from the field sampling of fuels under various conditions. Regardless of the purpose of fuel moisture sampling, a standard procedure for collecting, processing, and calculating the moisture content of samples is greatly needed. Errors in estimating representative moisture content on a site creep in during every step of the process if a strict regime is not followed. Further, the collection of proper material must be standardized if accurate estimates are to be achieved. Data from many locations could then be compared.

[1/]Taxonomic nomenclature follows that of Hultén.

The purpose of this paper is to present a standard procedure for collecting and handling samples from various fuel complexes, with particular emphasis on selected fuels in Alaska.

The definition of moisture content used here is the ratio of the weight of the water contained to the dry weight of the material, expressed as a percentage. The simple formula is:

$$\frac{(\text{Weight of water in sample})}{(\text{dry weight of sample})}(100) = \frac{(\text{sample wet weight} - \text{sample dry weight})}{\text{sample dry weight}}(100)$$

$$= \text{moisture content in percent.}$$

Sampling Procedure

People Qualified To Collect Fuel Samples

Regardless of the reason for determining fuel moisture content, the sampling must be done to rigid standards. Sloppy sampling and handling procedures can lead to poor results or even serious mistakes. Only trained, skilled people should sample and handle the fuels, and they must strictly adhere to proper procedures. Greater consistency of results is often achieved when the same person does all the sampling on a given area.

Material To Be Collected

The goal is to sample the moisture content of the organic materials that influence the way a fire in those fuels will burn. For some purposes, only fuels influencing the behavior of a fire at its head are of interest. In other cases the effects of the fire are crucial, *so* fuels leading to impacts on the site are the most important. It is not our goal to give examples in specific fuel complexes or to suggest which fuels to sample. The choice of fuels to sample varies with the reason for sampling and the fuel type. Guidance in choosing the fuels to be sampled may be gained from printed guidelines, previous experience, experts, direct observation, or other sources.

The fuels to be sampled and processed may include one or more of the following:

1. Dead fuels
   a. Small diameter down and dead woody fuel, 0 to **1/4** inch in diameter
   b. Larger (branch wood) down and dead woody fuel, 1/4 to 1 inch in diameter
   c. The partially decomposed organic mat on the surface of mineral soil (commonly called duff)
   d. Dead grasses, forbs, mosses, and lichens
   e. Surface litter, such as fallen leaves and needles

2. Live fuels
   a. Conifer needles
   b. Twigs and leaves of shrubs
      (1) Evergreen
      (2) Deciduous
   c. Green (live) grasses, sedges, and forbs
   d. Mosses
   e. Lichens

Other fuels may be important in some situations, but the sampling and processing procedures described here will be appropriate for almost any fuel complex in Alaska.

When Samples Should Be Collected

For information to be used as input to the National Fire Danger Rating System, fuels must be sampled throughout the fire season, beginning as soon as snow melts in spring and ending late in summer when no possibility of fire remains. The standard time for NFDRS weather observations is at 1400 hours, usually the warmest part of the day. Fuel moisture samples should also be collected at that time. Down and dead woody fuels, litter, and mosses and lichens should be sampled daily because of their quick response to changes in weather. Biweekly sampling is adequate for shrubs, grasses, herbaceous plants, duff, and conifer foliage because of the slower changes in moisture level of these fuels.

The seasonal period and frequency of sampling before prescribed burning is different for each situation, but some guidelines can be given. Some information may be obtained by sampling fuels throughout the fire season 1 or more years before a prescribed fire. Because weather conditions differ markedly among years, however, it is quite possible that the only useful seasonal fuel moisture trends are those of the live fuels. If the fire must be conducted during a particular part of the summer, such as early August, live fuels could be sampled in late July and early August of the previous summer to get an estimate of their possible moisture levels and thereby their influence on fire behavior at that time of year.

If the fire must be conducted during a particular part of the season, fuels need be sampled only before and during that period until prescribed fuel moisture conditions are met. If the prescription requires a specific set of weather and fuel moisture conditions, then sampling should begin a few weeks before the prescribed fire is likely to be burned. The frequency of sampling should be increased from weekly early in the season to daily as the proposed date of the fire approaches, or when the set of required moisture conditions is met and it is time to burn.

Fuels can be sampled at intervals throughout the day to determine when conditions are nearest to those called for in the prescription. If the fire will be staged at a certain time of the day, such as late afternoon, the fuel moisture samples should be collected during that period daily before the fire. Evening hours in midsummer and late summer when temperatures and humidities often change rapidly can be critical.

Where Samples Should Be Collected

The number of samples collected is less important than their quality and how well they represent the sampled area. Regardless of the fuels to be sampled, they should span the range of conditions, elevations, positions, and situations each fuel experiences on the area expected to burn. The samples should be collected within the area to be burned. A line-transect across representative topographic and microclimatic variations within the area to be burned is often a good way to get representative samples. For example, if the sampling area is on a slope, the samples should usually be taken at points distributed between the highest and lowest elevations within the burn area. Similarly, samples should be collected from all directional aspects within the area. Notably wet and dry locations should be sampled, along with the areas between them. The same applies to shaded and exposed spots, greater and lesser concentrations and depths of fuel, older and younger stands, and any other within-plot variations that might influence fuel moisture content.

If the purpose of the sampling is part of the preparations for a prescribed fire and if the fuels surrounding the fire area are notably different from those within it, the

surrounding fuels should also be sampled. Differences in anticipated fire behavior within and outside the intended fire area help to determine the needed contingency suppression forces in case the fire escapes.

The Number of Samples To Collect

Samples cost money, but so do errors in estimating how a fire will behave. The variability of the moisture content of a particular fuel across a burn unit at any given moment, along with the required precision, combine to determine how many samples are needed. When the fire is to be a prescribed fire, the procedure is fairly straightforward. Since sampling will be done regularly before the burn date, prefire samples can be used to determine how many samples must be collected to guarantee the needed precision. Some basic statistics may help. The sampler must decide from prescription guidelines or calculation models and an acceptable risk how accurate the estimate of fuel moisture content must be. The tolerable range in the estimate of fuel moisture in a specific situation is called the acceptable error (€).

For example, for small diameter dead fuels that usually carry a fire, the sampler might wish to have an estimate within 1 percent of the true value and to be 90 percent sure the estimate is within that range. On the other hand, for live needles it may be adequate to be only 80 percent certain that the sampled moisture content falls within 20 percent of the true average value for the burn area. The sampling densities required for the two fuels are likely to be quite different.

In any event, an estimate of the variation across the burn area is needed. Help can be found in the prefire samples as they are regularly collected and processed. You can use these samples with the procedure that follows.

The standard deviation is calculated:[2/]

$$s = \sqrt{\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1}} \; ; \qquad (1)$$

where:

s = standard deviation;
x = moisture content of each sample;
n = number of samples collected;
Σ = summation.

The acceptable error is E and the required number of samples m. The derivation for the equation for m is in appendix **A.** The result is:

$$m = \frac{(t^2 s^2)}{E^2} \; ; \qquad (2)$$

where t is a common statistic that depends on the number of samples and the confidence level you will accept. **A** table of t values can be found in statistics texts or manuals (for example, Freese 1967).

[2/] Many low-cost, hand-held calculators are programmed to calculate the standard deviation and many of the statistics mentioned.

As a hypothetical example, suppose the acceptable precision for small diameter dead fuel is ±1 percent of true value, with a 90-percent assurance that a set of samples will have an average value within that range. The values for a previously collected set of samples of moisture content are those under *x*.

	x	x^2
	7	49
	9	81
	8	64
	7	49
	6	36
	8	64
	9	81
	10	100
	9	81
	8	64
	7	49
	6	36
Total	94	754

Each sample value is multiplied by itself and listed as x^2. There are 12 values of *x*, so $n = 12$. One can now determine how many samples to take to be 90 percent sure the result is within ±1 percent of the true value of fuel moisture content.

First, the standard deviation is calculated by the use of equation (1):

$$s = \sqrt{\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1}}; \qquad (1)$$

$$s = \sqrt{\frac{754 - \frac{(94)^2}{12}}{12-1}} = 1.267.$$

E is ±1 percent. The only remaining value needed to solve for *m* in equation (2) is a value for *t*. Two things are needed to enter a *t* table. They are degrees of freedom *(df)* and a probability.

Degrees of freedom equals the number in the sample minus one. Therefore:

$df = 12 - 1 = 11.$

Probability is:

$$\frac{(100 - \text{desired confidence level})}{100} = \frac{(100 - 90)}{100} = \frac{10}{100} = 0.1.$$

In a t table, at the intersection of a df of 11 and a probability of 0.10 is found the value $t = 1.796$.

From equation (2), the necessary number of samples is:

$$m = \frac{t^2 s^2}{E^2} = \frac{(1.796)^2\ (1.267)^2}{(1)^2} ,$$

$m = 5.178$.

To be sure enough samples are taken, round the value of m to the next highest integer, or 6. Six samples of this particular fuel from the burn area are needed to be 90 percent sure that the average value of the moisture content will be within 1 percent of the true value.

The worksheets shown in appendix B have been designed as an aid for determining how many samples should be taken to achieve a certain precision with a chosen level of confidence. Before using such a worksheet, the user needs:

1. To know how much error can be tolerated for the job.
2. To know how sure he or she wants to be that the results will be within that error limit.
3. To have a set of pilot data (samples previously collected).

The example just worked out is shown on the worksheets in appendix B. Blank worksheets are in appendix C.

When no pilot data are available, judgment and experience must replace reliable calculations to determine how many samples to collect. When the fuels are uniform and homogeneous on a smooth slope on one aspect, as few as three samples of each fuel may be enough for 100 acres. Where fuels and site conditions vary considerably within the area to be burned, as many as 20 samples may be required for a unit that size. Experience in Alaska black spruce forests comprised of fairly homogeneous stands indicates that 10 samples carefully collected to represent all significantly varying conditions on a site up to 100 acres in size are enough to give an average value, with an error acceptably small enough for even the most meticulous prescribed fire treatment. This, however, is only cursory advice, and each user should keep a record of all samples collected in a given fuel type to serve as a guide for future sampling. The procedure just described can be used to determine the proper sampling densities in a new fuel type.

Collecting and Processing the Samples

Equipment Needed for Fuel Sampling

Containers.—Containers for fuel moisture samples should have tight-fitting lids and be rustproof, permanently numbered, and of a material that can be put directly into a drying oven. From our experience, the best containers are drawn aluminum soil sample cans. The tight-fitting lids limit evaporation, and they do not oxidize, which is important in preventing errors caused by reduction in the weight of cans. Cans 2½ inches in diameter and 1⅝ inches high work well for all fuels except large-leaved shrubs, such as prickly rose *(Rosa acicularis* Lindl.) and highbush cranberry ***(Viburnum edule*** (Michx.) Raf.). For these species, a can 3¼ inches in diameter by 2 inches high is better. Glass jars are too heavy and fragile. Paint cans eventually lose their tight-fitting seal and are too large for most sampling purposes. Plastic containers tolerant of high temperatures are suitable in some cases.

Both the lids and the sides of containers should be permanently identified with a number. Each empty container and lid should be weighed together, to the nearest 0.1 gram (tare weight[3]), and the identification number and weight permanently recorded in your files.

Sample carrying case.—A carrying case (fig. 1) for sample cans should be constructed from plywood or other sturdy material. The case should hold the samples securely, have a hasp or other type of latch and a carrying handle, and provide a place to put field data sheets (an envelope taped to the inside of the case works well). The size of the case depends on the dimensions of the sample cans and the number of samples to be collected each time, but the case should be easy to carry through vegetation and compact enough to fit in vehicles and aircraft.

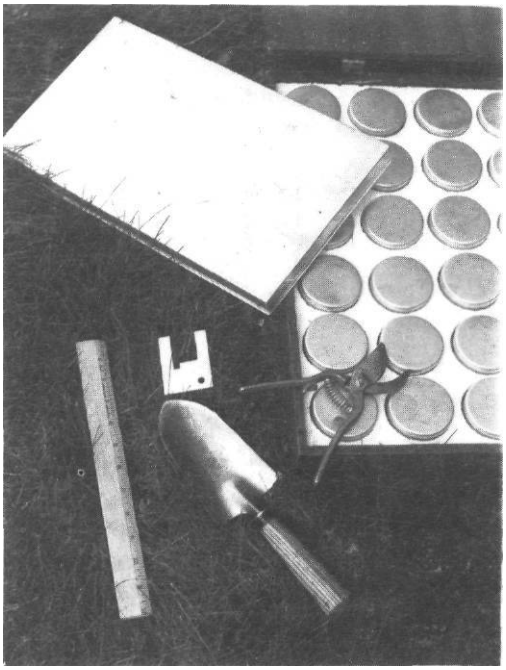

Figure 1.—A carrying case for sample cans should hold the samples securely. A covered notebook, clippers, trowel, ruler, and fuel gage are standard sampling equipment.

Clippers.—Good quality pruning shears (fig. 1) with two curved sharp blades are most effective for clipping fuels. At least two pair should be used: one for dead woody fuels and the other for live fuels. Sharpening may be necessary during the field season.

Garden trowel.—A trowel (fig. 1) with a heavy shank and a sharp blade is used for duff and soil moisture sampling.

Fuel gage.—Cut from rolled steel or heavy aluminum, a fuel gage (fig. 1) is used to check the diameter of a particle of dead woody fuel.

Ruler.—A ruler that resists breakage and repels water and is long enough to measure duff depths should be included.

[3] The weight of the empty clean container

Tape.—One-half-inch-wide drafting tape is the best tape for sealing sampling cans because it can be readily removed from the can. Masking tape can be used, but it frequently leaves a residue that is hard to remove, particularly if the exterior of the can becomes damp or hot. Wide rubber bands or cross sections of motorcycle tire inner tubes have also been used successfully and are reusable.

Clipboard.—A covered clipboard for holding the data sheets, field notes, or this sampling guide is a great aid in the field.

Gloves.—Heat-resistant gloves with a fair amount of flexibility are needed to remove heated samples from the drying oven.

Data sheets.—All data sheets should be designed specifically for a particular sampling job. Two sheets are required: one for field use (see appendix D) and one for fuel moisture calculations in the laboratory (see appendix E). The field data sheets are used to list the locations, dates, sampling times, name of person doing the sampling, all fuels to be collected, the number of each sample can, and any observations or comments. Because the field sheets often become smudged and rumpled, the laboratory sheets should be used for recording drying times and calculations of sample weights and moisture content of the fuel. Both sheets are retained for transferring and documenting data.

Drying oven.—An electric oven specifically designed for drying samples should be obtained. The best type is a mechanical convection oven with a built-in fan to circulate the heated air and ventilate the oven. Fuels dry more uniformly and rapidly than in a gravity convection oven. This agrees with guidance given by Countryman and Dean (1979). The oven must be able to maintain a regulated temperature of 100 °C and have adequate volume to allow air to circulate freely around all samples. Depending on the number of samples to be processed at one time and the size of the oven, an extra shelf and mounting brackets can be purchased to increase the capacity of the oven without impairing its performance.

Scale.—A scale is needed for weighing the samples. The same scale should be used both times the sample is weighed. A top loading, beam or torsion balance scale, capable of accurately measuring to the nearest 0.1 gram, is adequate for weighing most fuel samples. If an electronic balance is available, the job can be done more accurately and quickly. The cost, however, is justified only if many samples will be processed over a long period or if greater precision is necessary

The scale should be checked for accuracy before the field season and regularly during use. The calibration of beam or torsion balances must be performed according to the manufacturer's directions, using the calibration weights provided. Almost without exception, precision electronic scales must be adjusted by the manufacturer.

The scale must be placed on a firm, level surface such as a heavy table or counter top. The area must be free from drafts that cause movement of the scale mechanism and lead to inaccurate readings.

Collecting the Sample

On arrival at the sampling site, place the sample case in a shady spot and prepare the field data sheet. Record the site number, date, time, name of observer, and the can number for each fuel sample to be collected.

Do not collect live fuels if waterdrops are present on leaves or stems. Such free surface water will cause large errors in calculated values of moisture content. Shaking the leaves to remove excess water is not adequate because enough free water can remain to bias the sample. If rain prevents collection of certain samples, write rain in the space where the can number for these samples would be recorded. If no rain has fallen for several hours, the moisture may have evaporated from some of the plants, and sampling can proceed. Dead fuel samples and lichens and mosses may be collected if recent precipitation has occurred, but the presence of any free surface water should be recorded on the data sheet. Duff and organic layer samples may be collected even if rain is falling, but great care must be taken to prevent raindrops from getting into the sample can.

Materials such as mosses, lichens, shrubs, herbaceous plants, grasses, and grass and leaf litter become fairly stiff as they dry, and they may spring from their cans while in the drying oven. This makes the lid difficult to replace, and some of the sample may fall out. For this reason, pack mosses, lichens, leaf litter, organic layer material, and duff loosely in the sample cans. Never compress them to get additional material into the can. It is better to fill several cans than to force too much into one can. Collect an adequate amount of sample material, filling the can about three-fourths full.

Cut the stems of each shrub and herbaceous plant into small pieces as they are dropped into the can. Clip all of the sample again after it is in the can. Cutting the plants into smaller pieces also allows a greater amount of material to fit into a can. Clip grass and sedge leaves from various plants, holding the entire sample in one hand. Then cut all leaves together into short sections as they are dropped into the can (fig. 2).

Figure 2.—While holding the grass and sedge sample material in one hand, clip all blades into a size that will fit into the can without bending them.

Stack the large leaves from such shrubs as rose or highbush cranberry in one hand and cut them into halves, then quarters or smaller sections as shown in figure 3. Do not **drop** the cut sections of leaves into the can—place each stack of leaves on its side in the can. This is important because the leaves curl as they dry, greatly increasing both the space they occupy and the chance of losing part of the sample in the oven.

As you move about the site and collect material, replace the lid on the can to cover materials already collected. When the can is filled, immediately replace the lid tightly and seal it by encircling the lid with **one** layer of drafting tape (fig. **4).** It is easier to remove the tape if a small length of the end is folded onto itself, to form a tab. Be sure no dirt or debris clings to the outside of the sample container. Any comments or observations about plant phenology (as discussed later) should be recorded on the field data sheet.

Arrange the cans in numerical order in the carrying case, along with the field data sheets. Keep the samples cool and dry until they are weighed. If the collected samples receive even moderate heat, some moisture will evaporate, possibly escaping the can, or else remain as vapor and be lost when the sample is opened, yielding an error. Further, decomposition could begin, again causing a loss in weight of the sample and an error. Refrigerate the samples if they cannot be weighed the same day as collected.

Figure 3.—Cut a stack of large leaves into smaller segments and carefully fit them into the sample can.

Figure 4.—Use **one** layer of drafting tape to seal the sampling can. Be sure to tape around the entire lid.

Weighing the Sample

Preheat the drying oven to 100 °C. Transfer the information from the field data sheet to the laboratory calculation sheet. Remove the tape from the can lid. Make sure no tape or other debris is stuck to the outside of the can. Adjust the scale to zero. Place a can on the center of the scale platform. Read the scale and record it as the "wet" weight on the laboratory calculation sheet. Check to see that the identification and contents of the can match those recorded on the field and laboratory sheets. Remove the can from the scale and replace the lid. If any sample material falls out during weighing or when placing it in the oven, weigh the sample again.

Repeat this procedure until all samples are weighed. Be sure to set the scale to zero before each sample is weighed, because the adjustment can be changed by minor vibrations and movement of the scale, causing errors.

Remove the lid and place it under the can as you put the sample in the drying oven. Arrange the cans in numerical order, with numbers facing toward you. Space the samples evenly in the oven so that air circulates freely around every can. If few samples are being dried, center them on the middle rack of the oven. Record the date and time that the samples were put into the oven.

Drying the Sample

Dry the sample for 24 hours at 100 °C, or 18 hours at 100 °C if only live fuels are being processed. Large samples of very wet duff should dry 48 hours. **Do not** put additional samples into the oven while drying a set of samples. If you do, the original samples will absorb moisture from the new samples and must then be dried an additional 24 hours.

At the end of the required drying time, take the samples from the oven and quickly replace the lid tightly as each can is removed. This prevents the absorption of moisture from the air. **Do not** leave the oven door open. It should be opened only long enough to remove a few samples, because moisture from the room will enter the oven and will be quickly absorbed by the dried samples inside. Enough moisture could easily be added to the samples to cause a significant

error. If any sample material falls from a can during the drying process, throw the sample away unless you know which can it fell from and you can replace all of it in the right can.

Allow the covered cans to cool to room temperature before weighing them. Hot air in the can causes buoyancy and may result in a weighing error, particularly if the samples are very light. If you cannot wait for the samples to cool, remove the lid just before each sample is weighed, place the lid beneath the can and then put the sample on the scale. Weigh the sample quickly and record its (dry) weight. If the sample was cooled to room temperature before it was weighed, it can be weighed with the lid on. In either case, check the can number and its contents before you record the dry weight on the laboratory sheet. Check the scale for a zero weight setting before weighing the next sample.

After each dried sample is weighed, replace the lid tightly on the can and save the sample until the fuel moisture content is calculated. If an obvious error appears in the calculation, the sample can be weighed again and the source of the error may be found. Once fuel moisture calculations have been made, discard the sample and clean the cans for reuse. Remove **all** sample and tape residue from the cans. Wiping with a clean rag is sometimes enough to clean the insides of the cans, but they must be washed and scrubbed frequently. Containers must be free of soap residue and completely dry before the lids are replaced and the cans are stored for future use. Air drying is more effective than wiping the cans dry.

Calculating Moisture Content

The formula for calculating percent moisture content is:

$$\frac{\text{Weight of water in sample}}{\text{dry weight of sample}} (100) = \text{percent moisture content.}$$

This is equal to:

$$\frac{\text{Wet weight of sample} - \text{dry weight of sample}}{\text{dry weight of sample}} (100) = \text{percent moisture content.}$$

This is most easily done by the following formula:

$$\frac{\text{Wet sample weight} - \text{dry sample weight}}{\text{dry sample weight} - \text{container tare weight}} (100) = \text{percent moisture content.}$$

Here is an example:

Wet sample weight = 48.2 grams. Dry sample weight = 46.9 grams. Container tare weight = 38.1 grams. By the formula above:

$$\frac{(48.2 - 46.9)}{(46.9 - 38.1)} (100) = \frac{1.3}{8.8} (100) = 0.1477 (100) = 14.77 \text{ percent}$$

or: $\approx$ 14.8 percent moisture content.

If the averages of many similar samples are to be calculated, one decimal place should be kept, to maintain precision, rather than rounding to the nearest whole number.

If a programable calculator capable of storing information in three registers is available, the writing of a program for this procedure will greatly increase the speed and accuracy of the calculations. Whether the computations are done by hand or with a calculator, **repeat** the calculations to be sure they are correct. **A** list of the most common sources of error while processing samples is included in a separate section at the end of the paper.

Collecting Dead Fuels

Down and Dead Woody Fuels

Samples of 0- to 1/4-inch- and 1/4- to 1-inch-diameter down and dead woody fuels should be taken from several branches resting on the ground. Do not collect the entire sample from one location or from a single branch. Collect twigs of as many sizes as possible within the size class. **All** samples must be collected from dead wood that is detached from its growth point. Do not collect parts buried in the litter, duff, or moss. Do not collect dead branches attached to the bases of live trees or detached branches inclined more than 45" from the horizontal. Do not sample from trees or branches that have recently fallen. Cut several 1- to 1½-inch-long sections from each 0- to 1/4-inch diameter down, dead branch. Collect only one piece from each 1/4- to 1-inch down, dead branch (fig. 5). Remove all lichen or other debris and very loose pieces of bark from the samples. The wood collected does not have to be completely sound but should not be decayed to the point of being easily rendered into powder or splinters when rubbed between your fingers. Some splitting caused by drying is acceptable. Wood in various stages of decay should be collected in proportion to its presence on the site, as long as the rules just stated are followed.

Figure 5.—When collecting 1/4- to 1-inch down and dead woody fuels, cut one piece about 1 to 1% inches long from each dead branch on the forest floor.

Duff

Moisture content of the duff has important influences on the depth of burning of the forest floor. It must be sampled carefully and selectively if the impacts and results of the fire are to be predicted well. For duff samples, the depth is very important and should be measured, not estimated (fig. 6), with the base of the moss and lichen or litter layer as a reference point. It may be necessary to collect several duff samples at one spot, each at a distinct depth, to accurately represent moisture conditions; the upper layers of duff wet and dry at a faster rate than deeper, more compact duff layers and may have a significantly different moisture content. Select spots that are representative of the area. Duff samples should not be taken from elevated mounds of moss or thick patches of lichens unless they are representative of the area.

Figure 6.—When collecting duff samples, measure the depth below the bottom of the moss and lichen layer; **do** not estimate it.

The duff layer can be differentiated from the layer of mosses and lichens or leaf litter above it because the plant material in the duff layer is so decomposed that the plant species are not readily identified. Another common characteristic of the duff layer is the presence of a dense network of fungal hyphae, very fine hairlike strands, usually white or very light gray.

Remove all live plant stems, roots, rhizomes, other parts of living plants, and animal droppings from the sample. Be especially careful to avoid including mineral soil or stones in the duff sample, but do not let this caution prevent you from sampling duff near its maximum depth. The presence of mineral soil can often be detected by rubbing questionable soil between your fingers. Soil particles are fine enough (in the silty soils of interior Alaska) to fill the indentations in your fingertips. When mineral soil is found in a sample, discard it, go to another location, and start sampling again.

Mineral Soil

It may be necessary to collect soil moisture samples to predict the survival, after a fire, of roots and rhizomes distributed in upper soil layers. Procedures for Sampling mineral soil are similar to those for collecting duff. Collect samples from representative spots, and measure the depth below the surface of the mineral soil. The samples should contain no living or decomposing plant material or stones.

Hardwood Leaf Litter

Gather leaf litter from both sunny and shady spots within a stand. If the canopy is uniform, visit only a few locations. Collect only uncompacted dry leaves. Usually the upper one-half inch of leaf litter has whole, undecomposed leaves suitable for collection. In stands with a sparse canopy cover or thick stands of grass, collect leaf litter samples both from exposed areas and from spots where the grass cover is meager.

Dead Grasses and Other Grasslike Plants

Collect the sample from 15 to 20 plants. Clip dead blades from all vertical portions of tall grasses, such as bluejoint (*Calamagrostis canadensis* (Michx.) Beauv.), and from tops and sides of cottongrass *(Eriophorum* spp.) tussocks. Collect blades that are brown or tan, not gray or decomposed. If rain has recently fallen, collect only blades of grass that are in a fluffy, loosely compacted arrangement and have no drops of water on them. Collect the entire sample and then clip it into short pieces as you place it into the sample can.

Collecting Live Fuels

Most major changes in the moisture content of live plants are associated with physiological events in their annual life cycles. Noting the occurrence of these events each time a live fuel sample is collected gives you useful information for describing their flammability. The kinds of events that should be recorded include:

Shrubs:
- End of dormancy—buds bursting; beginning of shoot growth.
- New shoot growth complete—new stems darkening; new terminal bud apparent.
- Autumn leaf color.
- Leaves falling off twigs.
- All leaves gone—winter dormancy.

Forbs and grasses:
- Sprouting of plants.
- Plants attaining full size; no new growth apparent.
- Presence of ripe berries or seed heads.
- Curing of foliage.
- Cured foliage.

Conifers:
- Bud break—beginning of new needle and stem growth.
- Active shoot and needle growth.
- Ending of growth period—terminal bud developing at end of the current year's shoot.
- Terminal bud and new stems brown and hardened for winter.

Mosses and Lichens

The procedure for collecting mosses and lichens requires some subjective judgment. Carefully gather and inspect some of the plants before collecting any samples. A close look with a hand lens or binocular microscope will make these sampling guidelines easier to follow.

Feathermosses and associated ground lichens can be sampled separately or included as part of a composite sample containing each in proportion to its presence on the site. Gather mosses and lichens from exposed locations on the forest floor, not beneath tree crowns or dense shrubs.

Many species of mosses and lichens grow in the interior of Alaska, but only feathermosses and fruticose lichens should be collected. Feathermosses have a fairly upright form, many small branches, and a fluffy, feathery appearance (fig. 7). A mature stand of feathermosses usually forms a loose, springy, interwoven mat on the forest floor. Fruticose lichens have upright, thin stalks, frequently with many finely divided branches (fig. 8). Fruticose lichens may form pure lichen mats or may be intermixed with feathermosses on a site. There is a common group of lichens with a flat, leaflike form that grow on top of the moss layer. Do not include them in a sample.

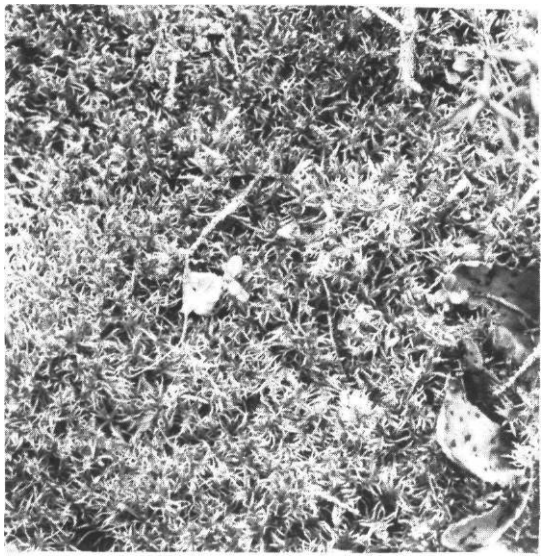

Figure 7.—*Hylocomium splendens* is a commonly occurring species of feathermoss. Be sure to remove dead leaves, grasses, and twigs from the sample.

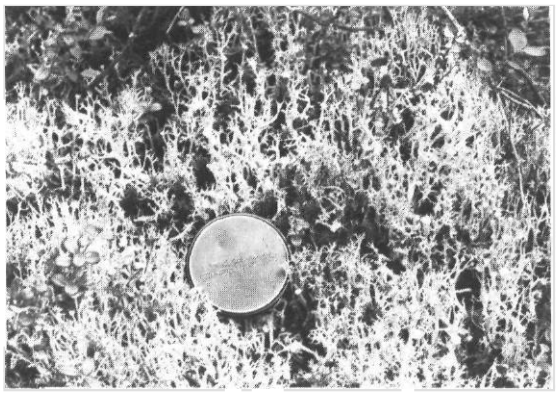

Figure 8.—Several species of commonly occurring fruticose lichens.

Lichens and mosses grow continuously from the same stem. Each year new material forms at the top, and part of the base dies. A thick mat of mosses and lichens forms, with a thin layer of live mosses and lichens on top of and connected to a thick layer of dead mosses and lichens. If a deep moss and lichen layer is present, the upper living parts of the mosses and lichens may have a distinctly different moisture content than the lower dead parts; the upper part of the moss and lichen layer is much fluffier and receives more direct exposure to the elements than the lower part of the layer. For this reason, collect separate samples of living lichens and mosses in the upper part of the layer and the dead lichens and mosses beneath them.

Here are some guidelines to help differentiate between living and dead segments of these plants. The living parts of the moss plants are pale green. The dead part is pale brown and may be slightly decomposed, but not so much so that its species characteristics are lost. Farther down the stem, decomposition removes the fine branches of the moss plant, leaving only a dark brown stalk with a few branch remnants.

Differences in color between live and dead lichens are usually subtle, although the dead base of one common species group turns orange. Some dead lichen parts become gray. Other lichens become very porous. Many of the finely divided branches of dead lichens decompose and break off. **As** decomposition advances, lichens become dark gray or black and are very mushy when wet. These decayed, dark lichens and the dark brown mosses are considered part of the duff layer and should not be included in the moss and lichen sample.

To collect the sample, grasp a few mosses and/or lichens and gently pull them from the moss and lichen layer. Clip off the highly decomposed dark brown moss (fig. 9) and the dark or obviously decomposed lichens (fig. 10) at the base of the layer. Pinch off the plants at the boundary between the upper and lower layer. Then separate the living plants from the dead ones by pulling or clipping them apart. Repeat this process at several locations until the two sample cans are full.

Remove all twigs, undecomposed leaves, live and dead club mosses, and plant stems and rhizomes. Note on the field data sheet if free water is present on the mosses and lichens.

Do not mix sphagnum moss (fig. 11) with feathermosses in your sample, even though they grow together on the site. Sphagnum has a noted ability to retain free water, and it rarely burns except in special cases such as when cured logging debris on top of it is burned.

Figure 9.—Use clippers to remove the highly decomposed dark brown moss from the sampled material.

Figure 10.—Clip off and discard the decomposed base of the lichens.

Figure 11.—Because sphagnum moss has a very dense growth form that allows it to retain free water, it rarely dries enough to burn and therefore should not be included in the feathermoss and lichen sample.

Shrubs

Shrubs are classified into three groups according to their height: large shrubs 6 to 20 feet tall; medium shrubs 2 to 6 feet tall; and small or low shrubs up to 2 feet (Viereck and Little 1972). Most of the mass of large shrubs is above the carrier fuel layer and has little influence on the behavior or characteristics of fires. Consequently, tall shrubs are seldom sampled; however, fire spread can be influenced by the moisture content of shrubs of low and medium height. Because medium shrubs have much higher levels of moisture content than low shrubs (data on file at the Institute of Northern Forestry, Fairbanks), you should sample the two groups separately. Evergreen shrubs have a seasonal moisture cycle that is very different from that of deciduous shrubs, so a separate sample is needed.

Make a composite sample of all the species within each shrub group (that is—medium or low, evergreen or deciduous), sampling each species in proportion to its presence on the site. If individual plants are very large, with large leaves, a separate collection for each species should be made unless a very large sample can is used.

When sampling shrubs, collect only the new, small diameter stems and their associated leaves. Many shrubs tend to produce most of their growth on upper branches. Some twigs do not produce new stems. The amount of material collected from each shrub species should be proportional to its presence on the site. Only one section of stem should be clipped from any plant. Collect samples from both exposed and shaded locations. Eliminate all dead twigs or twigs with diseased or insect-infested leaves. Do not include flower buds, flowers, seed pods, or berries in any stage of development.

Here are some guidelines for collecting samples of some of the major shrub species of Alaska:

Highbush cranberry.—New leaves grow on the new shoots as well as on stem sections formed during recent years. Collect new stems and those 1 and 2 years old, along with their leaves. Each year's growth can be readily identified by a bud scar that encircles the stem. Include the long shoots at the top of the plant and the very short shoots on the sides of stems that often bear only two leaves.

Prickly rose.—All of the leaves and flowers on this species of rose are located on the new stems produced each spring. Do not collect old, stiff stems. New stems are pale green and can be readily differentiated from older stems for most of the summer. The new stems turn darker as autumn approaches and begin to resemble older ones. Clip entire new stems with their associated leaves from the plant at the point where new growth and previous growth meet.

Buffaloberry (*Shepherdia* canadensis (L.) Nutt.).—Collect foliage and twigs produced during the current year and the previous 2 years. No bud scars separate each year's growth, but distinct differences in stem diameter and color identify the age of growth. Early in the season, new stems are very pale brown. The 2 older years' growth becomes increasingly darker in color and thicker in diameter. Tiny, star-shaped clusters of hairs are much more apparent on the new growth. Later in summer, the stems formed 2 years ago will turn gray and be difficult to distinguish from older growth.

Blueberry (***Vaccinium uliginosum* L.** subsp. ***alpinum* (Bigel.)** Huh.).—The leaves of blueberry are found only on new stems. Collect this material and the stem segments produced the previous season (fig. 12). Stem sections 2 years old and older are much darker and have shaggier bark than younger stems. New stem growth is pale green, becoming darker green as the growing season passes. A bud scar separates each year's growth but is sometimes difficult to see. The tip of a stem frequently dies during winter, and new growth develops from the uppermost lateral bud. These dead stem tips may help you distinguish between last year's growth and older stem growth. Green berries can be easily overlooked among the leaves but must be found and removed, as well as all flowers and ripe berries.

Figure 12.—Collect the blueberry stems bearing leaves and the segment of stem produced the previous year.

Shrub birch (***Betula glandulosa* Michx.).**—Sample stem and leaf material produced this year and last year. New stems of shrub birch are very pale brown early in the season, and they slowly darken to gray brown during the summer. After the 2d year of growth, twigs become gray, and the glandular dots on the stem surface become much less obvious. A bud scar encircling the stem marks the end of each year's growth.

Spiraea ***(Spiraea beauverdiana* Schneid.).**—Spiraea leaves occur only on the current year's growth. Include only that material in the sample. Do not collect older stems. Cut the stem where it is connected to the previous year's growth, which is marked by small, clasping leaves. Spiraea has two growth forms. One has very thin, multibranched twigs; a less common type has fairly thick, single stems. The latter are basal sprouts which develop one year and branch during subsequent years. Collect both forms in proportion to their presence on the site. The single stem form is very succulent early in the growing season, so do not include too high a proportion of this material or it will bias the sample toward a moisture content that is too high.

Labrador tea (***Ledum palustre*** L. subsp. ***decumbens*** **(Ait.) Hult.** and ***Ledum palustre*** **L.** subsp. ***groenlandicum*** (Oeder) **Hult.).**—Labrador tea is an evergreen shrub that retains its leaves for two growing seasons, rarely three. Leaves formed one year usually begin to change color in July of the next year. Collect the current and previous years' stem growth and any attached leaves (fig. 13). Do not include stem sections and leaves that are more than 2 years old. Age can be determined from bud scars separating each year's growth.

Labrador tea has two kinds of stems; those that only produce leaves (fig. 14) and those that also flower. The flower bud is pale brown, covered with scalelike, overlapping leaves, and is notably larger than the vegetative bud. Several lateral, leafy branches sometimes form on the flowering stems after the seed development process is nearly complete. Collect both leafy and flowering shoots, but remove all flower buds, flowers, seed capsules, and remnant seed stalks.

Mountain cranberry and lingonberry (***Vaccinium vitis-idaea*** L. subsp. ***minus*** (Lodd) HUH.).—Mountain cranberry is a low-growing evergreen shrub that retains its leaves for several years. Some stems produce new shoots with leaves, others develop flowers, and some stems produce no new growth at all. Sample all three kinds of stems. Growth may begin several weeks later than for most other shrubs, and it is sometimes difficult to determine when new growth has occurred. New stems and leaves are pale green, and older stem material is yellow green or pale reddish brown. Clip the stem just above the moss layer and include the section of the stem with healthy leaves. Discard flowers and all green or ripe berries.

Bearberry ***(Arctostaphylos uva-ursi*** (L.) Spreng. var. ***uva-ursi*****).**—Bearberry is an evergreen shrub with a growth form similar to mountain cranberry. Sample bearberry in the same manner, including only portions of stems bearing leaves and omitting flowers and berries. Include stems with older leaves showing signs of fall color but not sections of stems retaining gray leaves that died in previous years.

Crowberry **(*Empetrum nigrum*** L. subsp. ***hermaphroditum*** (Lange) **Böcher).**—Crowberry is another low-growing evergreen shrub that keeps its leaves for several growing seasons. Sample the younger stem sections with green leaves, along with older sections with leaves that have turned yellow during the current season. Include new stems in proportion to their occurrence, but remove all flowers or berries.

Herbaceous Vegetation

Some herbaceous plants sprout from roots, rhizomes, or overwintering basal leaves several weeks after the shrubs have leaves. Therefore, the mix of species of herbaceous plants collected may change markedly the first few weeks of the growing season.

Forbs.—Collect the entire plant of small, single-stemmed forbs, such as wintergreen *(Pyrola* spp.) or bunchberry (*Cornus canadensis* L.), by clipping the stem at ground level. If a species, such as lousewort *(Pedicularis* spp.), has multiple stems, cut one stem with leaves from each plant. Also, cut leaves or sections of leaves and stems from other plants that are common to the site but few in number. If a large volume of sample material is being collected, take the entire stem of a large plant like fireweed (*Epilobium angustifolium* L.). Remove and discard all flowers and fruits in any stage of development from all herbaceous plants.

Figure 13.—When sampling Labrador tea, collect current and previous years' growth.

Figure 14.—New vegetative growth of Labrador tea begins in early June to mid-June, several weeks after deciduous shrubs break dormancy.

Grasses and grasslike plants.—Collect only the leaves of grasses and sedges. Do not collect stems, seed heads, or succulent white or pale-green leaf bases. For tall grasses such as bluejoint, clip the leaves from all vertical portions of the plants, cutting the blades near their point of attachment to the stem. This is particularly important late in the season, because the lower blades begin to dry and cure earlier than those near the top of the plant.

For low-growing bunchgrasses, clip blades of different lengths from each clump; include only the leafy material and not the base of the leaves. Clip several blades from each clump of cottongrass *(Eriophorum vaginatum* L. subsp. *vaginaturn)* or

other sedges (usually *Carex* spp.). Because the leaves form continuously from the same growth point for several seasons, some live blades may have gray, shriveled material at their tips which died the previous year. Clip off and discard gray tips.

Individual blades die back during the summer, starting at the tip. Do not remove this reddish brown part of the leaf because it is part of the seasonal growth. Later in the season, when entire blades are cured, include them in the sample in proportion to their presence on the site. Do not collect seed heads.

Black Spruce Foliage

Gather needles and twigs from a minimum of eight 1-year-old black spruce trees in a stand (these methods are suitable for white spruce also). Collect needles from all sides and at various reachable heights of the tree. Needles formed in sequential years are separated by a bud scar located at the end of each year's growth. The needles attached just below the scar are inclined at a more acute angle to the branch than are the other needles (fig. 15). Also, the stem of 1-year-old growth is much lighter brown than the dark and slightly woody stem segment that grew the previous year. Collect the foliage by clipping the twig at the bud scar between the 1- and 2-year-old needles.

Remove and discard all this year's growth from each twig, including swollen buds. Buds begin to swell in late May. They are pale brown and turn pale green as the new needles increase in size. The new stems are also pale green, contrasting with the pale or medium brown of 1-year-old stems. New needles and stems become darker throughout the summer but remain readily distinguishable. Some branches do not produce new needles every year, so it is important to learn the characteristics of the new growth.

An easy way to remove buds and very young needle clusters is with the tip of a set of clippers. When new stems and needles are larger, you can grasp the cluster between two fingers and pull gently, separating it from the 1-year-old growth. You will see a pale brown concave scar if all new growth has been removed (fig. 16). If any new needles are still attached to the 1-year-old needles, the center of the new stem will be evident (fig. 17).

Be sure to remove all new buds and needles because their moisture content is many times higher than that of the 1-year-old needles. If they are included in the sample, the estimate of moisture content will be biased toward a much higher value.

Figure 15.—The point on a black spruce twig that separates each year's growth is marked by several needles located just below a bud scar; these needles are inclined at a more acute angle to the twig than are adjacent needles.

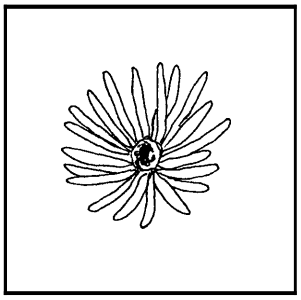

Figure 16.—If all new needle and stem growth is removed from the end of the branch, a brown concave scar, marking the end of the previous year's growth, should be evident.

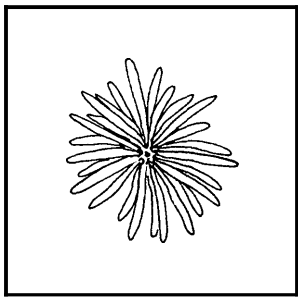

Figure 17.—If new growth is not completely separated from the l-year-old stem and needles, the center of the new stem will be obvious. Carefully remove the new growth.

Common Sources of Errors

Some of the most common sources of error while collecting samples are:

Field Errors

1. The sample is placed in a can with a different number than is listed on the field data sheet. (The numerical sequence is frequently switched by accident when similar fuels, such as 0- to 1/4-inch and 1/4- to 1-inch down and dead wood are collected.)
2. An incorrect lid is placed on a can.
3. The can number is recorded incorrectly on the data sheet.
4. Drops of rain or other free water are allowed to fall into the can.
5. Sphagnum moss is included in the sample of lichens and feathermosses.
6. Stems, roots, and leaves of forbs or shrubs are included in the moss and lichen sample.
7. Soil, small rocks, animal droppings, and other material are included in duff samples.
8. The 1-year-old spruce needle sample is contaminated with the buds, needles, or stems of the current year's growth or that of previous years.
9. Berries are included in the sample.
10. An inadequate amount of material is collected. (Fill the can at least three-fourths full.)
11. Failure to collect material from several spots, plants, or limbs on a site. (Do not collect all of it from one spot.)

Laboratory Errors

Some common sources of error in the laboratory are:

1. Failure to check the can numbers against the sample contents as recorded on the laboratory calculation sheet (frequently initiated by switching the sequence of can numbers while in the field).
2. The material springs from the can while drying.
3. Failure to set the scale to zero before weighing a sample
4. The can is not placed in the middle of the scale platform.
5. The scale is misread.
6. Errors are made during the entry of values into the calculator or while doing the calculations (possibly the greatest single source of error; **double-check!).**

Metric Equivalents

1 inch = 2.540 centimeters
1 pound = 453.6 grams
5/9 (°F − 32) = °C

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Appendix A

Derivation for *m:* The Number of Samples To Collect

From the value for s, the standard deviation, a second statistic called the standard error ($S\bar{x}$) can be calculated:

$$S\bar{x} = s/\sqrt{m}.$$

This value can be used to describe a set of sampled values that has an average value ($\bar{x}$) and some distribution of values around that average. The concept is expressed simply by:

(The average of the sample) $\pm$ (standard error) $(t) = x \pm (S_{\bar{x}})(t) = x \pm E;$

where t is a common value that depends on the number of samples (m) and the confidence level you will accept. Note that the acceptable error (E) is

equal to $(Si)(t)$.

$$E = (S\bar{x})(t),$$

but $S\bar{x} = s/\sqrt{m},$

so $E = (s)(t)/\sqrt{m};$

solving for m.

$$m = (t^2 s^2)/E^2.$$

Appendix B

Sample Density Worksheet Example

I. Previous data (fuel, 0- to 1/4-inch down and dead wood).

A. How many prefire samples have been collected? $n =$ 12

B. How close must your value of fuel moisture content be for your intended project? ± 1 percent.

C. Using your prefire samples, list one set of collected moisture content samples below:

	x	x^2		x	x^2
1.	7	49	11.	7	49
2.	9	81	12.	6	36
3.	8	64	13.		
4.	7	49	14.		
5.	6	36	15.		
6.	8	64	16.		
7.	9	81	17.		
8.	10	100	18.		
9.	9	81	19.		
10.	8	64	20.		

D. Add all the values of x: $\Sigma x =$ 94

E. Multiply each value by itself (x^2) and add all the values:

$\Sigma x^2 =$ 754

F. Multiply the value in D by itself and divide by the value in A:

$(\Sigma x)^2/n =$ 94 X 94/12 = 736.3

Appendix B—Continued

Sample Density Worksheet Example - - Continued

G. Subtract the value in F from the value in E:

$\Sigma x^2 - (\Sigma x)^2/n =$ 17.7

H. Subtract 1 from the value in **A:** $(n - 1) = df =$ 11

I. Divide the value in G by the value in H: $(\Sigma x^2 - (\Sigma x)^2/n) / (n - 1)$

$= s^2 =$ 17.7/11 = 1.6

J. What is your acceptable moisture content error? ± 1 percent.

K. How sure (percent) do you want to be that you will be within your range of acceptable error? $P =$ 90 percent.

L. Take the value in K, subtract it from 100, and divide the result by 100:

$(100 - P) / 100 =$ probability = (100 − 90)/100 = 0.10

M. Go to a *t* table and down the left-hand column under "*df*" to the value in H, and across to the right to the column under the probability value in L.

List the value at the intersection: $t =$ 1.796

N. Multiply the value in J by itself: $E^2 =$ 1

O. Multiply the value in M by itself: $t^2 =$ 3.23

P. Multiply the value in I by the value in O and divide by the value in N:

$(t^2 s^2) / E^2 = m =$ 5.2

Q. Round to the next higher integer 6

This is the number of samples you must collect next time to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

Appendix C

Sample Density Worksheet

I. Previous data (fuel, _____).

A. How many prefire samples have been collected? $n =$ _____

B. How close must your value of fuel moisture content be for your intended project? ± _____ percent.

C. Using your prefire samples, list one set of collected moisture content samples below:

	x	x^2		x	x^2
1.			11.		
2.			12.		
3.			13.		
4.			**14.**		
5.			15.		
6.			16.		
7.			17.		
8.			18.		
9.			19.		
10.			20.		

D. Add all the values of x: $\Sigma x =$ _____

E. Multiply each value by itself (x^2) and add all the values:

$\Sigma x^2 =$ _____

F. Multiply the value in D by itself and divide by the value in **A:**

$(\Sigma x)^2/n =$ _____

Appendix C—Continued

Sample Density Worksheet—Continued

G. Subtract the value in F from the value in E:

$\Sigma x^2 - (\Sigma x)^2/n =$ _____

H. Subtract 1 from the value in **A:** $(n - 1) = df =$ _____

I. Divide the value in G by the value in H: $(\Sigma x^2 - (\Sigma x)^2/n) / (n - 1)$

$= s^2 =$ _____

J. What is your acceptable moisture content error? $\pm$ _____ percent.

K. How sure (percent) do you want to be that you will be within your range of acceptable error? $P =$ _____ percent.

L. Take the value in K, subtract it from 100, and divide the result by 100:

$(100 - P)/ 100 =$ probability = _____

M. Go to a *t* table and down the left-hand column under "*df*" to the value in H, and across to the right to the column under the probability value in L.

List the value at the intersection: $t =$ _____

N. Multiply the value in J by itself: $E^2 =$ _____

O. Multiply the value in M by itself: $t^2 =$ _____

P. Multiply the value in I by the value in O and divide by the value in N:

$(t^2 s^2) / E^2 = m =$ _____

Q Round to the next higher integer _____

This is the number of samples you must collect next time to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

Appendix D

Data Sheet for Field Use

Location _____ Fuel moisture, black spruce sites

Site No. _____

Observer _____

Date _____
Month/day/year

Time _____

Material	Can number
Upper moss + lichens	
Lower moss + lichens	
Upper duff (2 to 2.5 inches)	
Lower duff (4.5 to 5 inches)	
Blueberry	
Cranberry	
Labrador tea	
Black spruce	
Phenology	
Blueberry	
Cranberry	
Labrador tea	
Black spruce	
Comments:	

Appendix E

Data Sheet for Laboratory Use

Location _____ Fuel moisture calculations, black spruce sites

Site No. _____

Date in oven _____

Date out of oven _____
Month/day/year

Observer _____

Time in _____

Date collected _____

Time out _____

Time collected _____

Material	Can No.	Tare weight	Wet weight	Dry weight	Moisture content
Upper moss + lichens					
Lower moss + lichens					
Upper duff					
Lower duff					
Blueberry					
Cranberry					
Labrador tea					
Black spruce					

Comments:

Norum, Rodney A.; Miller, Melanie. Measuring fuel moisture content in Alaska: standard methods and procedures. Gen. Tech. Rep. PNW 171 U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984**. **34 p.**

Methods and procedures are given for collecting and processing living and dead plant materials for the purpose of determining their water content. Wild-land fuels in Alaska are emphasized, but the methodology is applicable elsewhere. Guides are given for determining the number of samples needed to attain a chosen precision. Detailed procedures are presented for collecting fuel samples in the field, transporting them safely, and handling them in the laboratory. General guidelines for all live fuels and specific techniques for individual species are given.

Keywords: Fuel moisture content, fuels (forest fire), fire (forest), Alaska.

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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