Technical Notes

Stratified Sampling for Determining Duff Moisture in Mountainous Terrain

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There are no published guidelines on duff moisture sampling procedures, yet accurate estimates of duff moisture are necessary for prescribing a given level of duff reduction through burning (Brown et al. 1985). Duff moisture can vary considerably across a given site, particularly in steep, irregular terrain. Adequate sampling to obtain duff moisture estimates can be difficult and time-consuming. We have found that simple random sampling of duff moisture often requires 40 or more observations to obtain desired precision. Stratified random sampling can provide more reliable estimates than simple random sampling with less time and effort. The key is to separate the area into nonoverlapping sites or strata, so that the variation in duff moisture within strata is less than in the area as a whole.

Duff moisture content is closely related to exposure and surface and subsurface drainage in steep, irregular terrain (Potts et al. 1983). In short, topographic position may identify strata to be used in stratified sampling. Based on this premise, we suggest the following sampling procedure for estimating duff moisture in mountainous terrain to provide the best information with minimum time and effort.

SAMPLING PROCEDURE

The first step in stratified duff moisture sampling is to estimate the areal proportions of the site occupied by dry, mesic, or wet strata. Convex areas, such as ridges, are typically dry. Concave areas, particularly draws, are comparatively wet. Slopes between these topographic positions generally have an intermediate, or mesic, moisture regime. Stratification can be done easily with the aid of a large-scale topographic map of the site, and by observation in the field. The efficiency of the procedure results from grouping areas of similar duff moisture, not in the absolute accuracy of the estimated areal proportions. For example, the 34-ac clearcut in Figure 1 is visually stratified into proportions of 0.3, 0.6, and 0.1 for dry, mesic, and wet, respectively.

The midslope or mesic stratum will exhibit the greatest variation in duff moisture. Ridges and draws tend to be more uniformly dry and wet. Because of the large expected variance in the mesic stratum, we recommend a minimum of ten observations from midslope positions. In both the wet and dry strata, a minimum of three observations should be made. Thus, the recommended sampling ratio (dry:mesic:wet) is 3:10:3. In large areas with multiple aspects, it may be desirable to divide the area into two or more subunits based on dominant cardinal aspect. Each subunit should then be sampled independently.

COLLECTING DUFF

Once the three strata have been defined, duff collection may begin. The amount and composition of forest floor material varies within and between sites depending on climate, the type of vegetation present, and stand history. The litter layer consists of freshly fallen needles, twigs, and other debris. Litter is loosely packed and has undergone only slight decomposition. It freely exchanges moisture with the air and is a major source of fuel in a spreading fire. The fermentation layer, or upper duff, is below the litter. Although darker in color and more densely packed than litter, organic material has not decomposed so much that individual needles and twigs cannot be identified. The humus layer, or lower duff, is underneath the fermentation layer. Humus is in an advanced state of decomposition. Dark brown or black in color, individual pieces are no longer distinguishable.

Technically, duff observations should be made at random locations within each stratum. In practice, however, it is considerably easier to estab-

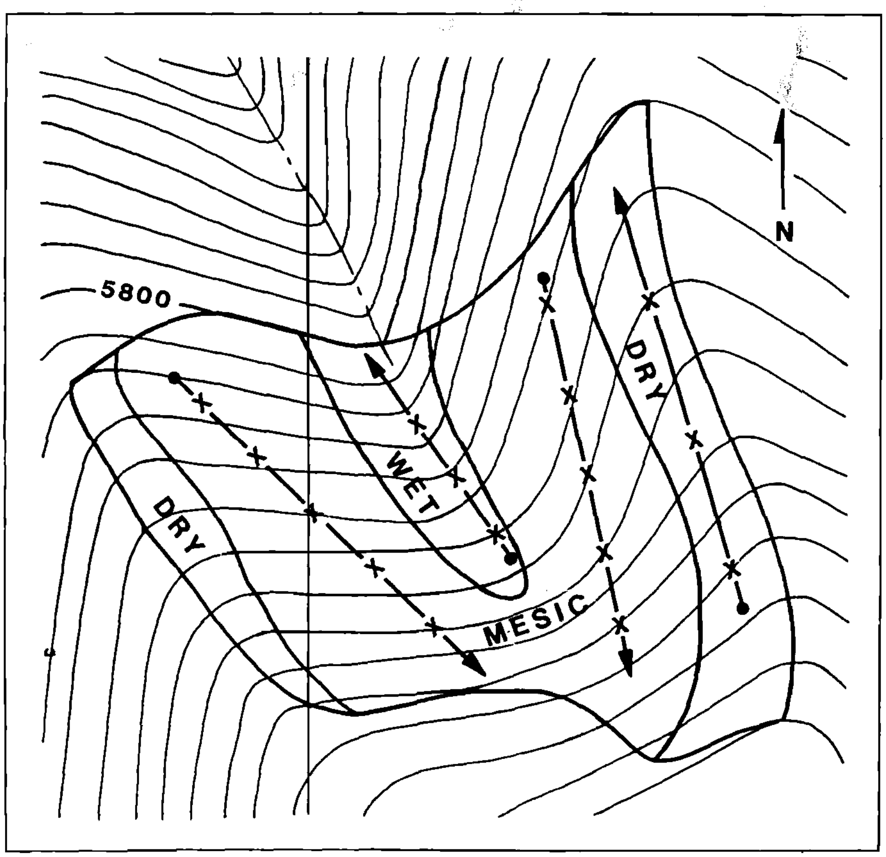

Fig. 1. Stratification of a clearcut into dry, mesic, and wet areas and example duff moisture sampling. Transects with sample points (*x*) at fixed intervals beginning with random starting points (•). (40 ft contours).

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lish a transect across each stratum and make observations at fixed intervals starting from a random point (see Figure 1). Avoid collecting duff where disturbances such as logging or windthrow have recently altered duff structure. Remove freshly fallen, uncompacted litter from the surface. The entire depth of duff may be collected, or the profile may be separated into upper and lower duff. The decision whether to treat the two duff layers separately or as one depends on how the information will be used. Duff consumption models have differing duff moisture data requirements. For example, Norum's (1977) and Sandberg's (1980) models require lower duff moisture estimates, while Brown et al. (1985) have provisions for using either lower duff moisture or total duff moisture estimates. In practice, it is difficult to separate the duff into two layers when it is less than 1-in deep. Avoid contamination with mineral soil as this will lead to erroneously low duff moisture estimates.

Collected duff materials should be immediately sealed in air-tight containers, clearly labeled, protected from temperature extremes, and processed as quickly as possible. Moisture content may be determined gravimetrically or from electrical or chemical properties—personal preference or equipment availability dictate the choice.

Once moisture content (percent by weight) has been determined for each observation, calculate the average moisture content ($\bar{y}$) in each stratum. Mean duff moisture content on the site ($\bar{Y}st$) is then estimated by:

$$\bar{Y}st = N_1 (\bar{y}_1) + N_2 (\bar{y}_2) + N_3 (\bar{y}_3)$$

where N_1, N_2, and N_3 are the proportions of the total site in dry, mesic, and wet strata, respectively $(N_1 + N_2 + N_3) = 1$ and $\bar{y}_1$, $\bar{y}_2$, and $\bar{y}_3$ are the average duff moisture contents observed in the dry, mesic, and wet strata, respectively.

For example, if the average moisture contents observed for the dry, mesic, and wet strata in Figure 1 were 54, 76, and 121% respectively, the estimate of the site's average moisture content would be:

$$Yst = 0.3\,(54\%) + 0.6\,(76\%) + 0.1\,(121\%) = 74\%$$

INTERPRETING AND APPLYING RESULTS

Before using the stratified mean duff moisture content to predict duff consumption on a site, the within-stratum estimates should be inspected. It is possible that burning with the observed moisture contents may result in unacceptable fire effects in one or more strata. If duff is too wet, duff consumption may be too low to accomplish the objectives of the burn. The opposite may occur if the duff is too dry. In the example given above, Brown et al. (1985, equation 9) predict 69, 58, and 34% duff reduction in the dry, mesic, and wet strata, respectively. The manager has the ultimate choice of burning for acceptable results in all strata, or perhaps the best results in one stratum.

The recommended total of 16 observations made for the stratified random sample in a 3:10:3 (dry:mesic:wet) ratio should provide acceptable precision for most burning situations in the Northwest. We have found that site-average duff moisture content can usually be estimated with 90% confidence and ±20% allowable error using the procedure. Managers concerned with the accuracy of their estimates should compute confidence levels based on their data. For further discussion of stratified random sampling, sample size determination, precision, and accuracy, interested readers are advised to consult standard statistics texts (e.g. Snedecor and Cochran 1967).

As stated at the beginning of this discussion, there are no published guidelines or procedures for duff moisture sampling. Some sampling techniques are more efficient than others. Stratified sampling for estimating duff moisture has two distinct advantages over simple random sampling. We have found that stratified duff moisture sampling generally requires half the observations for a given level of confidence and allowable sampling error. Second, and perhaps more important, stratified sampling provides estimates of duff moisture means and variances in the different strata. This gives a clearer picture of how duff consumption and associated fire effects can be expected to vary across a site.

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