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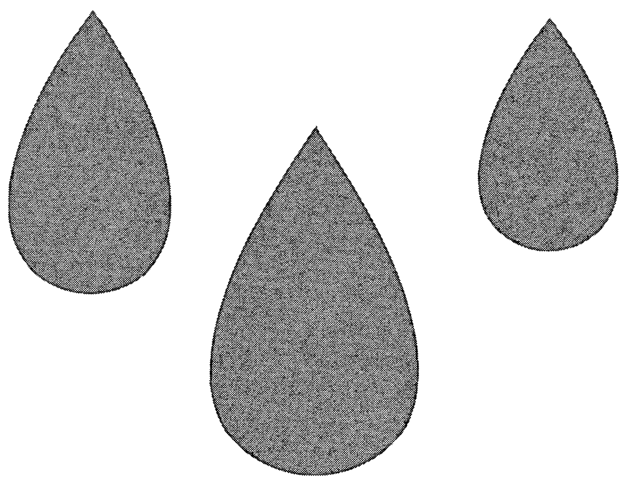

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SUMMER MOISTURE CONTENTS OF UNDERSTORY VEGETATION IN NORTHEASTERN MINNESOTA

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The behavior and effects of forest fires are often influenced by the character of the living understory vegetation. Grasses, ferns, shrubs, mosses, tree reproduction, and herbaceous plants may either contribute actively to the energy of a fire, or they may serve as a heat sink and retard fire propagation and intensity. This can mean the difference between a beneficial, easily managed fire, and a detrimental fire that is difficult to control. Whether living surface fuels play an active or passive role in the combustion process depends largely on their abundance and moisture content. These factors are quantitatively addressed in state-of-the-art models of fire behavior (Rothermel 1972, Albini 1976) and in the National Fire Danger Rating System (Deeming *et al.* 1977).

Although ongoing research holds promise for developing the capability to simulate live fuel moisture changes through knowledge of physical processes governing plant-water relations (Howard 1978, Running 1978), currently available methods of predicting live fuel moisture content, without actual field measurement, are somewhat primitive. The algorithm proposed by Deeming *et al.* (1977) for fire danger rating represents the most comprehensive effort to date to provide a generally applicable model. It considers the predominant type of vegetation (annual or perennial), the phenological stage of development, vegetative adaptation to moisture stress as reflected in the humidity provinces of Thornthwaite (1931), and antecedent precipitation and evaporative demand of the atmosphere. This method seems to work well in the northern Rocky Mountains and in other portions of the western United States, but it has not been thoroughly validated.

Measured moisture contents of tree and shrub foliage have been reported in several studies representing diverse geographic areas (Olsen 1960, Philpot 1963, Reifsnyder 1961, Jameson 1966, Johnson 1966, Van Wagner 1967, Blackmarr and Flanner 1968, Gary 1971, Countryman 1974, Russell and Turner 1975). Herbaceous moistures, on the other hand, are not as well documented. Although many ecologists, range and wildlife scientists, plant physiologists, and fire scientists measure herbaceous moisture contents regularly, little of this information is formally reported. The few published studies indicate that moisture contents of grasses and forbs growing under generally similar conditions are related (Turner 1972) and that many plants common to the West show "a decided decrease in moisture content" as the growing season advances (Richards 1940). The degree to which these observations apply in other geographic regions, however, has not been fully established.

To assess the potential flammability of forests in the Boundary Waters Canoe Area (BWCA) in northeastern Minnesota (Roussopoulos 1978), moisture contents and fresh-to-dry weight conversion factors were required for common grasses, herbs, mosses, and small shrubs.[1] This paper presents and examines summer moisture content measurements for 21 groups of understory plants that are common to the Great Lakes Forest Region (Rowe 1959). Results are useful for a variety of fire management activities including estimating living fuel biomass and predicting fire control difficulty and/or fire effects for actual or anticipated fires. They also offer a preliminary basis for validating the National Fire Danger Rating System herbaceous moisture model (Deeming *et al.* 1977) in the upper Midwest.

METHODS

Field sampling of living herbs, mosses, and small shrubs for gravimetric moisture content determination was conducted in mature forest stands about 20 km south of Ely, Minnesota (47° 50′ N, 91° 45′ W). Sampling began on June 24, after the period of primary plant growth, and ended on August 26, 1976. Throughout this period, plants representing 21 plant categories (individual species, genera, or groups of related species) found commonly in upland forest communities of the area were collected at intervals of one to several days. Forty-two subsamples were taken between 2:00 and 4:00 p.m. each sample day (3 subsamples each from 14 plant groups). Sampling frequency for individual species or species groups varied approximately in proportion to the percent cover each represented.

Each subsample consisted of at least 5 grams fresh weight of a single species or plant group. All above-ground plant parts were included. Subsamples were sealed in metal cans and transported at once to the laboratory where they were weighed, dried at 105C for at least 16 hours, and reweighed to the nearest 0.1 gram. Dry weight conversion factors (CF) were computed for each subsample (dry weight/fresh weight) and a daily average was determined for each subsample triplet. These were converted to moisture contents (MC) by:

$$MC = \frac{100}{CF} - 100 \qquad (1)$$

At the end of the sample period, the time series of daily moisture content percentage values were examined and compared on the basis of magnitude and seasonal trend. Graphical analysis, t-tests, and regression analysis were the principal analytical methods used.

RESULTS AND DISCUSSION

The number of sample days for each sampling category ranged from 3 for starflower (*Trientalis borealis*), false solomon's seal (*Smilacina racemosa*), and twinflower (*Linnaea borealis*) to 21 for large-leaved aster (*Aster macrophyllus*) and wild sarsaparilla (*Aralia nudicaulis*) (table 1). Sample size reflects the relative contribution to understory plant cover in the sampling vicinity.

Averages of seasonal moisture content percents ranged from 138 for Labrador tea (*Ledum groenlandicum*) to 1,027 for bluebead-lily (*Clintonia borealis*).

Scatter diagrams showed downward seasonal trends in moisture content values for most plant groups, which reflects the influence of phenological development as well as the 1976 summer drought (Dickson 1976). Collections were made during the afternoon, the time of day when moisture stress with decreased moisture content would be most likely to occur due to an imbalance between absorption and transpiration rates. Despite the drought, however, the observed trends were generally more subtle than has been reported for western plants (Richards 1940). Linear regression equations fit the time series data reasonably well and had significant correlation coefficients for Labrador tea, large-leaved aster, and for bluebead-lily (fig. 1). Many species, such as wild lily-of-the-valley (*Maianthemum canadense*) on the other hand, showed no significant seasonal trend (fig. 1). To gain a clearer picture of the seasonal moisture responses by sampling group, average moisture content values and corresponding conversion factors for all sampled plant groups were stratified by early (June 24 - July 24) and late (July 25 - August 26) sampling periods (table 1).

[1]*Moisture content is weight loss expressed as a percentage of oven-dry weight: moisture content percent =*

$$\left(\frac{\text{green weight—ovendry weight}}{\text{ovendry weight}}\right) \times 100$$

The conversion factor is the number that, when multiplied by green weight, yields oven dry weight: (conversion factor = oven dry weight ÷ green weight).

Table 1.—*Moisture content of some grasses, forbs, mosses, and small shrubs in northeastern Minnesota*[1]

Plant group	All (June 24-Aug. 26)				Early (June 24-July 24)				Late (July 25-Aug. 26)			
	Sample day	Moisture content	Conversion factor	Standard error of the mean	Sample day	Moisture content	Conversion factor	Standard error of the mean	Sample day	Moisture content	Conversion factor	Standard error of the mean
	No.	Percent			No.	Percent			No.	Percent		
Labrador tea (*Ledum groenlandicum*)	10	138	(.42)	7	3	160	(.38)	13	7	128	(.44)	7
Blueberry[2] (*Vaccinium* spp.)	17	151	(.40)	6	12	157	(.39)	7	5	136	(.42)	7
Clubmoss[3] (*Lycopodium* spp.)	15	153	(.40)	8	11	156	(.39)	10	4	144	(.41)	11
Grasses[4]	10	170	(.37)	13	6	189	(.35)	17	4	142	(.41)	10
Rubus[5] (*Rubus* spp.)	4	208	(.32)	22	—		( )		4	208	(.32)	22
Spreading dogbane (*Apocynum androsaemifolium*)	6	217	(.32)	22	4	197	(.34)	27	2	259	(.28)	26
Twinflower (*Linnaea borealis*)	3	239	(.29)	41	2	270	(.27)	47	1	178	(.36)	
Bracken fern (*Pteridium aquilinum*)	13	248	(.29)	10	10	258	(.28)	11	3	211	(.32)	18
Wild sarsaparilla (*Aralia nudicaulis*)	21	253	(.28)	6	13	258	(.28)	7	8	244	(.29)	11
Strawberry[6] (*Fragaria* spp.)	11	258	(.28)	14	8	271	(.27)	14	3	224	(.31)	34
Bunchberry (*Cornus canadensis*)	17	261	(.28)	7	12	270	(.27)	6	5	237	(.30)	12
Bush honeysuckle (*Diervilla lonicera*)	5	290	(.26)	31	5	290	(.26)	31	—		( )	
False solomon's seal (*Smilacina racemosa*)	3	304	(.25)	28	3	304	(.25)	28	—		( )	
Pearly everlasting (*Anaphalis margaritacea*)	4	319	(.24)	49	2	390	(.20)	36	2	247	(.29)	53
Other ferns[7]	5	326	(.23)	30	2	388	(.20)	12	3	284	(.26)	29
Wood horsetail (*Equisetum sylvaticum*)	4	340	(.23)	9	1	335	(.23)		3	342	(.23)	13
Starflower (*Trientalis borealis*)	3	369	(.21)	7	3	369	(.21)	7	—		( )	
Large-leaved aster (*Aster macrophyllus*)	21	380	(.21)	15	14	418	(.19)	12	7	305	(.25)	17
Dwarf solomons seal (*Maianthemum canadense*)	17	393	(.20)	14	11	403	(.20)	17	6	374	(.21)	23
Sweet coltsfoot (*Petasites spp.*)	4	560	(.15)	70	2	523	(.16)	147	2	597	(.14)	72
Bluebead-lily (*Clintonia borealis*)	15	1,027	(.09)	35	10	1,071	(.09)	34	5	939	(.10)	69

[1]Moisture content percent equals (100 × moisture content ÷ oven dry weight). Conversion factor equals (oven dry weight ÷ green weight); dry weight = conversion factor × green weight.

[2]*Vaccinium myritilloides* and *V. angustifolium* are predominant.

[3]*Lycopodium clavatum* and *obscurum* are predominant.

[4]*Carex* spp. and *Oryzopsis asperifolia* are predominant.

[5]*Rubus strigous* and *R. pubescens* are predominant.

[6]*Fragaria vesca* and *F. virginiana* are predominant.

[7]*Athyrium* spp., *Onoclea sensibilis*, and *Osmunda cinnamomea* are predominant.

For all sampling groups represented by at least three sample days in each half of the season, moisture content was lower during the late sampling period. The difference between the early and late mean moisture contents (expressed as a percentage of the seasonal average) for the groups with at least 10 sample collections ranged from 7 percent for wild lily-of-the-valley to 30 percent for large-leaved aster—with a mean of 16 percent. Groups showing less than 10 percent difference between early and late means were club-mosses (*Lycopodium* spp.), wild sarsaparilla, and wild lily-of-the-valley. Groups with a difference between early and late means of from 10 to 20 percent were blueberry (*Vaccinium* spp.), bracken fern (*Pteridium aquilinum*), strawberry (*Fragaria* spp.), bunchberry (*Cornus canadensis*), and bluebead lily. And those groups with a difference of more than 20 pecent between early and late means were Labrador tea, grasses, and large-leaved aster. These substantial variations among sampling groups may be due in part to species-related differences in morphology, phenological development, rooting characteristics, stomatal activity, etc., as well as micro-environmental preference.

Admittedly, our sample was not adequate to conclusively identify and characterize seasonal moisture responses. It is also possible that the late

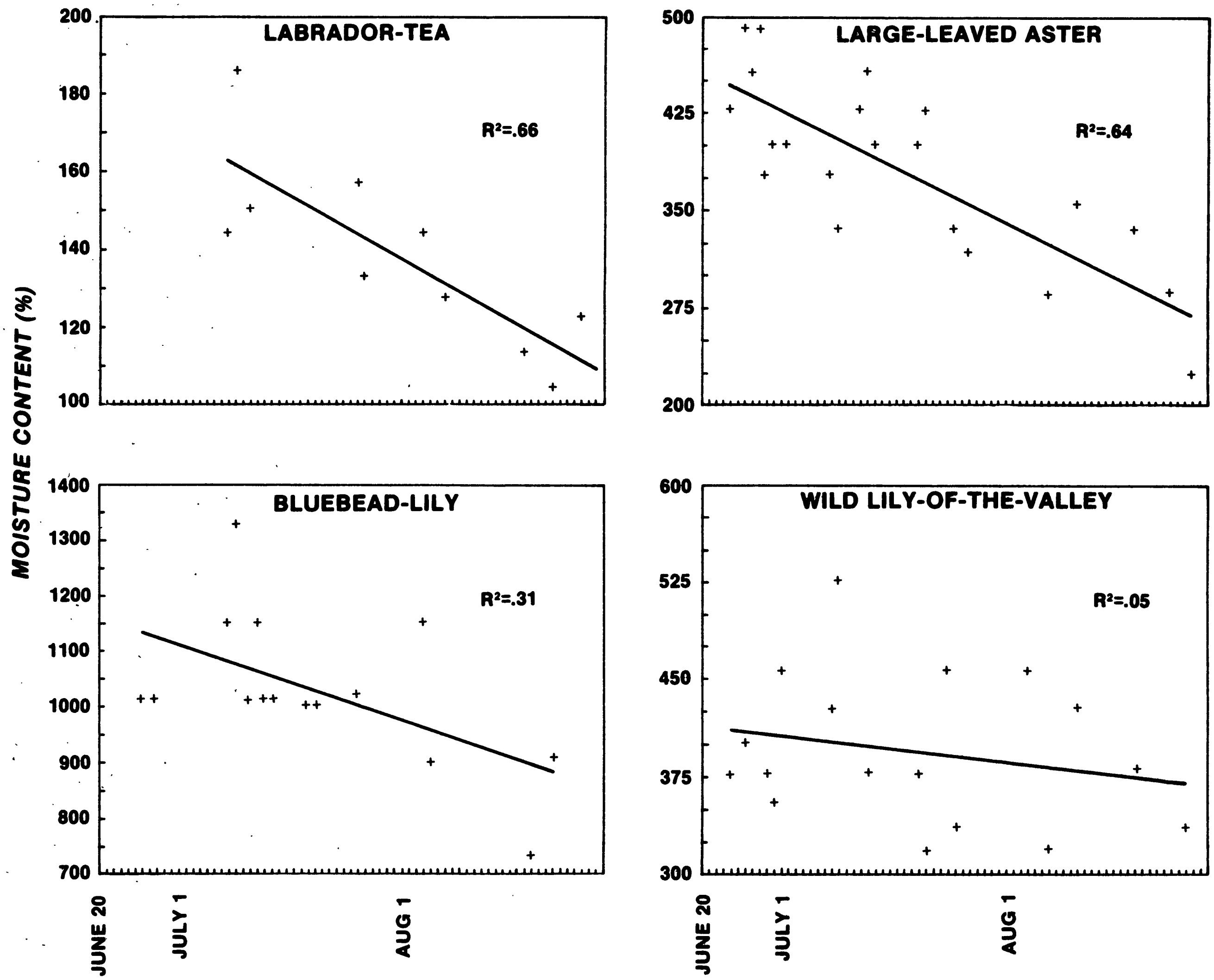

Figure 1.—*Plant moisture content percentages for some species found under mature upland stands in northeastern Minnesota.*

summer drought of 1976 produced atypical plant moisture trends in the sample area. Nonetheless, the average moisture content values obtained here compare favorably with reported values for similar environments of the U.S.S.R. (Svanidze and Khidasheli 1973), and they may be useful in developing crude estimates of dry-weight biomass from field-fresh weights or in predicting forest fire behavior and effects.

One question frequently asked by land managers concerns the suitability of the National Fire Danger Rating System (NFDRS) herbaceous fuel moisture algorithm (Deeming *et al.* 1977) for predicting actual fire behavior or evaluating fuel flammability. Available methods of predicting fire spread rates, intensities, and flame lengths (Rothermel 1972, Albini 1976) require that quantitative estimates of living fuel moisture be developed where these fuels are significant. Use of a simple plant moisture model such as that employed for fire danger rating would be desirable if acceptable accuracy could be achieved. Because fire danger rating is concerned mainly with identifying relative levels and trends in fire potential for the most serious situations anticipated on broad rating areas, it is uncertain whether the NFDRS herbaceous moisture algorithm would be appropriate for other, possibly more demanding, applications. To gain insight on this question, we computed the

NFDRS herbaceous moisture at weekly intervals (Burgan *et al.* 1977) using 1976 observations from the nearest fire weather station. Herbaceous moisture values were computed for all four "climate classes" and plotted for the entire sampling period (fig. 2). All four of these curves show only slightly reduced moisture contents in the late season, which is what we observed for most of the plant groups sampled.

To facilitate comparison with the field results, average calculated moisture contents were determined for the season and for both early and late sampling periods (table 1). In addition, corresponding observed plant moisture contents were calculated as a weighted mean of the moisture content values for all plant groups (table 2). The relative contribution of each plant group to total understory biomass (dry weight) from a broadscale fuel inventory conducted roughly 50 km from the sample area (Roussopoulos 1978) provided the weighting coefficients for this computation. The mean NFDRS moisture contents for each climate class were also computed for this period and are substantially lower than the observed values. The approximate prediction errors are -63 percent, -66 percent, -70 percent, and -75 percent, respectively, for NFDRS climate classes 1, 2, 3, and 4. The fact that climate class 3 yielded the second largest underprediction is especially significant because it is the one recommended for rating fire danger in the eastern United States (Deeming *et al.* 1977).

Examination of the seasonal moisture trends, on the other hand, reveals slightly better agreement. The difference between the early and late weighted measurement means was roughly 18 percent of the seasonal average, while the NFDRS computations yielded corresponding values of 6, 9, 10, and 15 percent, respectively, for climate classes 1 through 4. The NFDRS herbaceous moisture algorithm is much better at representing relative changes—the principal intent of fire danger rating—than it is at predicting actual values. The errors identified above should be closely examined to determine their significance in applications requiring absolute plant moisture content predictions.

For the NFDRS fuel model G (dense conifer forest with heavy detritus accumulations), we predicted selected fire behavior properties using both measured and calculated mean herbaceous moisture contents (table 2). Fire behavior estimates were computed for climate class 1 and 4 to present the range produced by NFDRS. Fire behavior prediction errors resulting from the use of calculated moisture contents were expressed as percentages of the predictions based on measured moisture:

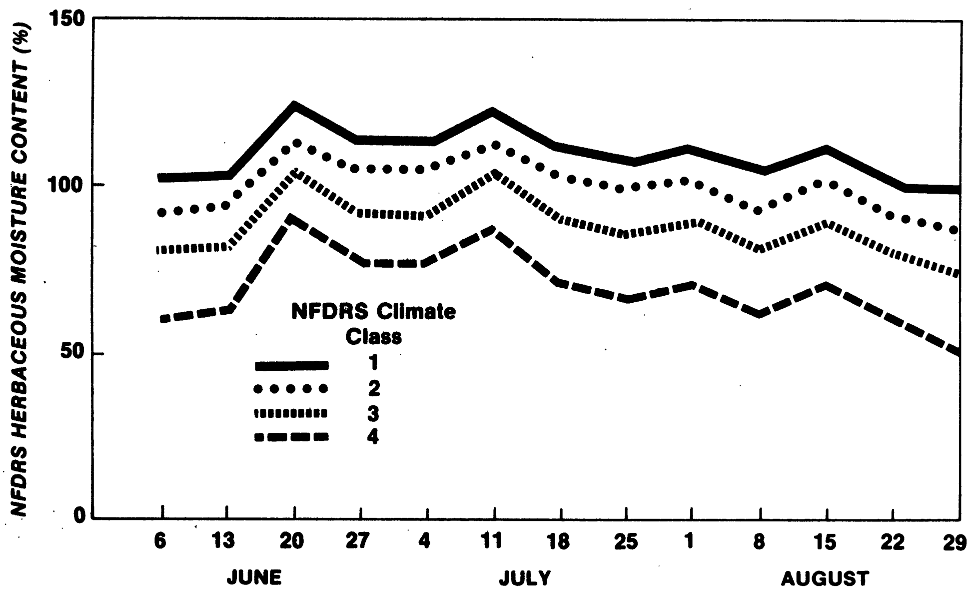

Figure 2.– Manually calculated National Fire Danger Rating System (NFDRS) herbaceous moisture contents for all four climate classes at Ely, Minnesota, 1976.

Table 2.—*Average measured moisture contents and National Fire Danger Rating System (NFDRS) herbaceous moisture predictions by sampling period*

(In percent)

Sampling period	Weighted mean of measured moisture contents	NFDRS herbaceous moisture content			
		Climate Class 1	Climate Class 2	Climate Class 3	Climate Class 4
All (June 24-August 26)	299	112	103	91	74
Early (June 24-July 24)	319	115	107	95	78
Late (July 25-August 26)	264	108	98	86	67

$$E(\%) = \frac{V_c - V_m}{V_m} \bullet 100 \qquad (2)$$

Where: E=the percentage error in a predicted fire behavior characteristic (e.g. spread rate, flame length, etc.) using the NFDRS herbaceous fuel moisture

V_c=the predicted value obtained using the calculated NFDRS herbaceous fuel moisture

V_m=the predicted value obtained using the corresponding weighted mean of measured moisture contents (table 2).

Fuel moistures for the 10, 100, and 1,000 hour timelag fuels were assumed constant at 10, 15, and 15 percent, respectively, for all computations. For 1 hour timelag fuel moisture contents ranging from 5 to 15 percent and effective windspeeds ranging from 4 to 9 m/sec (10 to 20 m.p.h.), forward spread rate (m/min) was overestimated by roughly 55 to 100 percent using the NFDRS climate class 1 herbaceous moisture content, and by 70 to 150 percent using the climate class 4 value. Estimated spread rate for a 1 hour timelag fuel moisture of 5 percent and a windspeed of about 9 m/sec (20 m.p.h.) was 2.4, 4.9, and 6.1 m/min (7.9, 16.1, and 20.0 ft/min) for measured, estimated climate class 1, and estimated climate class 4 fuel moisture values, respectively. Energy release component was overestimated by about 5 to 15 percent and 15 to 25 percent, respectively, for climate class 1 and climate class 4, while corresponding error ranges for flame length predictions were overestimated by 25 to 45 percent and 35 to 75 percent. Estimated flame length predictions for a 1 hour timelag fuel moisture of 5 percent and a windspeed of about 9 m/sec (20 m.p.h.) were 1.2, 1.7, and 2.0 meters (3.8, 5.6, and 6.6 feet) for measured, estimated climate class 1, and estimated climate class 4 fuel moisture values, respectively. Indiscriminant use of the calculated live fuel moistures to predict fire behavior for some planning and operational activities, therefore, would likely result in overly conservative decisions—possibly leading to inefficient use of fire management resources.

The moisture content prediction errors noted above do not significantly compromise the usefulness of the NFDRS herbaceous moisture algorithm for fire danger rating in the Lake States in terms of its intended purpose. Predicted and measured relative herbaceous moisture trends agree. Thus, the NFDRS algorithm may be used to estimate relative fire behavior trends for a season. Uses requiring greater precision, such as comparisons of Lake States fuel moistures with western species, or estimation of absolute values for rate of spread and intensity are questionable unless actual field fuel moisture measurements are obtained. The average moisture content values reported here are appropriate when general estimates are needed for planning over broad areas in Great Lakes conifer forests.

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