VALIDATING THE OVERWINTERING EFFECT ON THE DROUGHT CODE IN ELK ISLAND NATIONAL PARK

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1. INTRODUCTION

The Drought Code (DC) is one of the three moisture codes in the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987). The DC is an index of water storage in the soil (Turner 1966, 1972), making it different from the Fine Fuel Moisture Code and Duff Moisture Code, which are moisture content tracking indices. The DC was found to be well suited to reflect moisture contents of slow-drying fuels such as those found in deep, compact duff layers (Muraro and Lawson 1970, Van Wagner 1974).

Van Wagner (1987) reports the DC as having the following properties: a time-lag (time to lose approximately two-thirds of free moisture above equilibrium) of 53 days (corrected from the documented 52), a water capacity of 100 mm, a nominal depth of 18 cm, and a nominal fuel load of 25 kg/m^2.

The DC was originally based upon the Stored Moisture Index (SMI), which directly expressed the moisture equivalent in hundredths of an inch up to a maximum of 800 (i.e., 8 inches of water). To capture the exponential drying characteristics of deep soils, the SMI was converted to the DC as follows

$$DC = 400 \ln (800/Q) \qquad (1)$$

where Q is the moisture equivalent or the former SMI. The constant represents a theoretical maximum moisture content of 400%.

The effects of rainfall on the DC are as follows:

$$r_d = 0.83\, r_o - 1.27 \qquad (2)$$

and

$$Q_r = Q_o + 3.94\, r_d \qquad (3)$$

where r_o and r_d are the actual and effective rainfall (ignored if $r_o < 2.8$ mm), Q_o is the original moisture equivalent and Q_r is the adjusted moisture equivalent, with 3.94 representing a moisture retention efficiency (Van Wagner 1987).

With a time lag of 53 days and a high water capacity, the DC has a capability of retaining high fall levels through the winter and into the spring, depending upon the amount of winter snowfall and the timing of the spring rains. Turner and Lawson (1978) devised a scheme to overwinter the DC based on the amount of total precipitation between the date of the last DC calculation in the fall and spring starting date. The new spring DC is calculated by first converting the fall DC to a fall moisture equivalent Q_f. The spring moisture equivalent Q_s is then calculated from the fall value and the overwinter precipitation P (measured in millimetres water equivalent) as

$$Q_s = a\, Q_f + b\, (3.94\, P) \qquad (4)$$

where a is the carryover fraction of fall moisture (1.00, 0.75 or 0.50) and b is the precipitation effectiveness fraction (0.50, 0.75 or 0.90). Values for a and b are chosen based upon field experience.

Lawson and Dalrymple (1996) reported that the moisture content of deep soil layers can be calculated from the DC. In their report, fuel samples were studied from three geographic locations, where each location represents a different forest floor. From weekly samples, the DC was regressed against observed moisture contents. The resulting relationships are shown in Table 1.

Table 1. DC to moisture content calibration equations (Lawson and Dalrymple 1996).

Site	Stand	Equation
DC standard	not applicable	$Q = 800 / e^{(DC/400)}$
Mission, BC	Coastal cedar-hemlock	$MC = 351 / e^{(DC/390)}$
Nelson, BC	Southern Interior BC	$MC = 285.8 / e^{(DC/304.5)}$
White-horse,YK	White spruce duff	$MC = 488.4 / e^{(DC/267.9)}$

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In 2000, Alberta Lands and Forest Services contracted out a study (Ember Research Services Ltd. 2000) to verify the extremely high spring DC values. For the study 15 locations throughout the province were chosen using mature white spruce stands as sample sites. Fall DCs ranged from 315 to744 and overwinter precipitation amounts ranged from 47 to 115 mm of water equivalent precipitation. In this study, moisture contents as measured through destructive sampling closely matched the coastal cedar-hemlock moisture equation (Table 1) supporting the use of 1.0 and 0.5 for *a* and *b* terms as used by the province.

The purpose of this study is to examine the current overwintering procedure in several mature white spruce stands located in central Alberta. This is an ongoing study conducted over the course of several years to determine the sensitivity of the *a* and *b* terms. This paper presents the preliminary results from 3 years of data.

2. METHODOLOGY

Validating the overwintering of the DC consists of two distinct parts. The first is to examine the effects of the winter's snowfall on the moisture content of the forest floor as measured through destructive sampling. The second part of the study is to relate the moisture content measurements to DC values as calculated at a nearby weather station.

Elk Island National Park was chosen as the study area. Environment Canada runs a climatological station at the Warden's Office providing complete meteorological data. This data includes snow depth and water equivalent measurements.

Elk Island National Park (Figure 1) lies 35 km east of Edmonton Alberta. The 195 km^2 park is primarily aspen and grasslands, though there are several stands of black spruce in low lying areas. One stand of mature white spruce was chosen as the study site.

Three sample sites were chosen within the study stand. Site A is centrally located among the sites. Original sampling was conducted within a no slope area but this was later expanded to include a 10% sloped area (treated as two distinct sites and indicated as A slope and A flat). Site B is the southern site and has a 10% slope with an east exposure. Site C is the northern site laying on gently undulating terrain. All three sites were mesic with 75% crown closure or more and little in the way of under story vegetation.

Several core samples were taken at each site with a drill auger (Nalder and Wein 1998). A core sample was 4.8 cm diameter and > 10 cm in depth. Depths of the litter, fermentation and humus (L, F and H) layers were recorded and the core sample was then cut into 2.0-cm layers as per Lawson and Dalrymple (1996) and stored in tins for moisture and mineral content calculations (Kalra and Maynard 1991).

Figure 1. Elk Island National Park

3. RESULTS

3.1 *Site Characteristics*

The forest floor characteristics of the three sites within the stand are shown in Table 2. These characteristics are the averages and standard deviations of the core samples take at the three sites. Characteristics include the depths of the L, F and H layers, as well as the bulk densities and the mineral contents of the 2 cm layers.

The three sites show some variation in their characteristics. Site A flat has a deeper duff layer, with the combined L, F, and H layer often exceeding 10 cm, while the other sites are typically only 5 to 6 cm. Likewise, the depths of the L and F layer at Site A flat (2 and 6 cm from the surface) were nearly twice as deep as those at B and C.

The bulk densities of the three layers appear to be consistent among the three sites, with 1.6-1.9, 2.0-3.0 and 3.0-6.0 gm/cm^3 for the bulk densities of the L, F and H layers. The mineral contents show less conformity, though. The deeper F and H layer samples from sloped sites had nearly twice the mineral content of those of site A flat.

Table 2. Site Characteristics.

		Site A							
		Flat		Slope		Site B		Site C	
		Value ± σ	n	Value ± σ	n	Value ± σ	n	Value ± σ	n
Depths (cm)	L	1.8 ± 1.3	41	1.7 ± 0.6	25	1.3 ± 0.6	45	1.4 ± 0.5	36
	F	6.3 ± 2.7	41	4.5 ± 6.6	25	4.3 ± 1.4	45	3.8 ± 1.2	36
	H[1]	9.4 ± 2.3	43	6.6 ± 1.7	25	7.0 ± 1.9	47	6.4 ± 1.8	38
Bulk density[2] (gm/cm^3)	0-2 cm	0.159 ± 0.041	46	0.171 ± 0.40	25	0.180 ± 0.072	47	0.194 ± 0.148	37
	2-4 cm	0.210 ± 0.113	46	0.256 ± 0.123	25	0.277 ± 0.189	47	0.364 ± 0.283	38
	4-6 cm	0.252 ± 0.166	46	0.540 ± 0.357	25	0.410 ± 0.272	47	0.675 ± 0.361	38
	6-8 cm[1]	0.396 ± 0.355	46	0.900 ± 0.429	25	0.642 ± 0.345	47	0.920 ± 0.359	38
	8-10 cm[1]	0.577 ± 0.454	46	0.577 ± 0.392	25	0.925 ± 0.399	47	1.170 ± 0.369	37
Mineral content (fraction)	0-2 cm	0.131 ± 0.059	11			0.159 ± 0.050	8	0.193 ± 0.043	6
	2-4 cm	0.193 ± 0.132	11			0.361 ± 0.189	9	0.469 ± 0.175	6
	4-6 cm	0.192 ± 0.083	11			0.515 ± 0.167	9	0.718 ± 0.271	6
	6-8 cm[1]	0.355 ± 0.241	11			0.701 ± 0.186	9	0.855 ± 0.156	6
	8-10 cm[1]	0.532 ± 0.299	11			0.806 ± 0.223	9	0.957 ± 0.036	6

[1]H layer shown in grey
[2]Mineral content included in bulk density calculation

3.2 *Winter of 2000-2001*

Core samples were taken at the sites on October 13, 19, and November 2, 2000. The first snowfall of 8.2 cm arrived on November 5. The DC of the previous day was 536. The last day of measurable snowfall occurred on March 26 and a total of 47.3 cm fell between November 5 and March 26. Sampling was resumed in the spring on April 4 and again on April 11, 2001, when the snow cover was gone. The FWI calculations were resumed April 25, 2001.

Table 3 shows the percent change in the average fall moisture conditions (average of the three dates at each depth) to the average spring conditions. At site A there is a 36% and 16% increase in moisture content for 6-8 and 8-10 cm layers, respectively.

Results for sites B and C were not as expected. The over-winter change in moisture content for site B was a 47% increase and a 13% decrease at 4-6 and 6-8 cm depths, and a 71% decrease for site C at a 4-6 cm depth. The discrepancy of having the humus layer dry over winter may be the circumstantial result of natural variability across the landscape and the few samples taken at sites B and C. As a result, the number of samples taken was increased for the following years.

Overall, it appears that the 47.9 mm of water-equivalent over-winter snowfall had little (47% increase) to no effect on the moisture content of the humus layer.

3.3 *Winter of 2001-2002*

Core samples were taken on October 10 before the first snowfall on October 22, 2001. After three days, warm weather melted the snow and samples were taken again on November 7 and 21. The second snowfall arrived November 25. This snow cover lasted until April 13, when FWI calculations were resumed; however, this was followed by a 25-cm snowfall 2 days later. Calculations were continued, though startup conditions (three successive days of 12°C or warmer weather) did not reoccur until May 12. Sampling was conducted on April 24, May 1 and 9. During this sampling, the frozen ground was significant in preventing a full set of samples being taken for the first two dates.

Table 3. Mean Overwinter Moisture Change

Site	Depth (cm)	Moisture content change (100% Q_s/Q_f)		
		2000/2001	2001/2002	2002/2003
A	1			162
slope	3			264
	5*			292
	7			443
	9			581
A	1	440	189	126
flat	3	294	204	211
	5	199	200	199
	7*	136	229	247
	9*	116	195	443
B	1	620	288	156
	3	163	431	245
	5*	147	476	344
	7*	87	334	480
	9	62	295	499
C	1	202	280	81
	3	84	235	127
	5*	29	206	144
	7	29	215	161
	9	48	340	352

*H layer shown in grey

The total over-winter precipitation was 88.9, 93.1 and 93.8 mm of water-equivalent snowfall, measured from November 25, 2001 to the three spring sampling dates. The winter of 2001-2002 saw nearly twice as much snow at the previous winter and this is reflected in the results. Here average increases in moisture content ranged from a 95 to 376%.

3.4 *Winter of 2002-2003*

Samples were taken October 8 and 17 with the first snow arriving on October 21, 2002. This snow melted and was followed by a second snowfall on November 9. Ten days later, this snow melted and no lasting snow came until January 15, 2003. During this period, temperatures on most days were below freezing.

By April 8, the snow cover had melted. Startup conditions occurred on April 21 and sampling was conducted on April 24. A 39.7 cm snowfall occurred on April 27 and sampling was conducted on May 1 after the snow had melted. On May 5 and 6, yet another 30 cm of snow fell and again sampling was conducted May 14.

The total over-winter precipitation was 140.9, 188.0 and 231.2 mm of water equivalent snowfall from October 21 to each of the sampling dates, respectively.

The significant spring snowfalls that occurred between each sampling period provided a good range of data points from 140.9 mm to 231.2 mm of precipitation, again more than twice the amount of snow seen in the previous 2 years. During the 2002-2003 winter, the increase in the humus layer moisture ranged from 140% to nearly 500%.

4. DISCUSSION

4.1 *Overwinter Effects on the Moisture Content*

Results from the study can be transformed to conform with the format of equation 4 so a linear regression can be conducted to determine the *a* and *b* terms. Figure 2 shows the transformed data with P/Q_s as the overwinter precipitation over the spring moisture equivalent and Q_s/Q_f as the fractional moisture equivalent change between spring and fall.

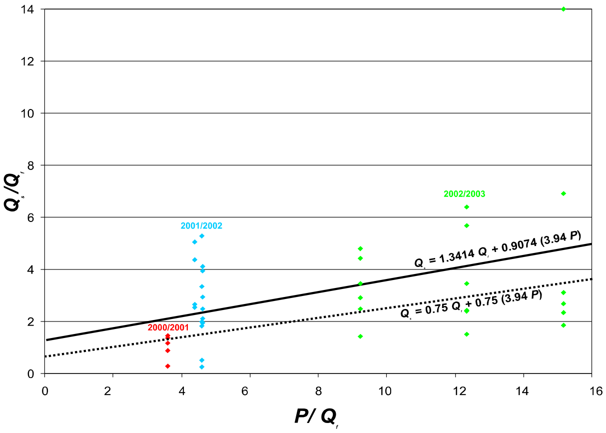

Figure 2. Fractional change in moisture equivalent within the humus layer (Q_s/Q_f) versus the effects of the overwinter precipitation (P/Q_s).

A regression line (solid) through the data reveals values of 1.3414 and 0.9074 for the *a* and *b* terms of equation 4. This is different from the values of 0.75 and 0.75 currently being used at the park (dashed), which is lower than most of the data points, and 1.0 and 0.5 currently being used by the province (not shown), which would be even lower.

Still there are problems with the calculated values. The *a* term suggests the spring conditions will be 34% wetter than the fall values if no precipitation occurs. This can be adjust to 1.00 without affecting the relationship much, leaving a *b* term of 0.9, suggesting a 90% efficiency in overwinter precipitation entering the ground.

The most significant problem though is the poor correlation. With an r^2 of 0.1681, it is hard to draw any clear conclusions from this data at this time. Still, the trend is appropriate and the result is useful in helping to understand the overwintering problem.

4.2 *Moisture Content vs Drought Code*

Figure 3 shows the data points for pure H layer labeled by site (with *F* for site A flat and *S* for site A slope). The curves generated from the equations on Table 1 are shown for reference (thin lines). Clearly, none of these curves describe the observed data; therefore, a new relationship was built for the reported Drought Code and the moisture content measured within this white spruce stand.

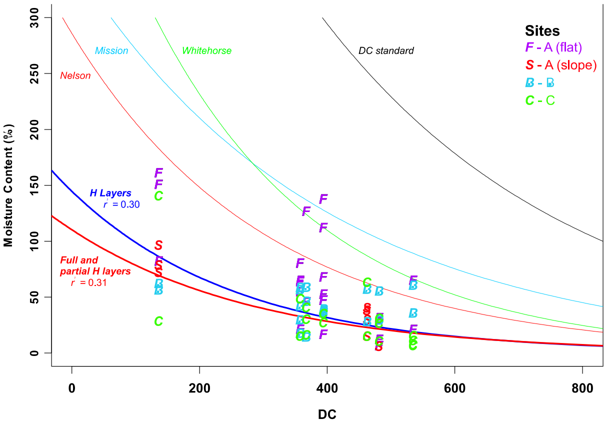

Figure 3. Relationship of DC to moisture content. Characters indicate field measurements, thin curves show previous equations while thick curves indicate regression results.

A non-linear regression analysis was conducted using the $Y = a / \exp(X / b)$ form to follow those used for the previous equations. Observations from the flat portion of site A were removed from the analysis as the scatter plot shows the moisture contents are much higher than those from the three sloped sites and thus must be following different dynamics.

Two regressions were conducted: one using data points of pure H layer samples, the second using these as well as partial H layer samples (with portions of F and mineral soil in the sample). The two resulting curves (thick) are shown on Figure 3. Given nearly similar r^2 values (0.30 and 0.31, respectively), the pure H layer equation may be best at representing the moisture content/DC relationship (a regression on the entire duff layer, as done by Lawson and Dalrymple for Nelson BC, yielded an r^2 of 0.18).

Table 4. DC to moisture content calibration equations for study site.

H layer	$MC = 144.6 / e^{(DC/263)}$
Full and partial H layer	$MC = 110.2 / e^{(DC/294.4)}$

Judging from the regression, it appears that the H layer of this stand has a maximum moisture content of approximately 140%. This is lower than those reported by Lawson and Dalrymple (285 - 488%), probably due to the high mineral content found in the stand. High mineral content leaves less organic material to hold water.

4.3 Stand Characteristics

A question that arises is the appropriateness of the white spruce stand used in this study. It is shallower and holds less water than those previously studied by Lawson and Dalrymple (1996). The bulk densities and mineral contents are also higher than those in other studies (Anderson 2000). This probably has a significant effect on moisture retention, explaining the difference between Lawson and Dalrymple's calibration curves and the one from this study.

The results for the effects of the overwintering snow fall appear to be opposite of what would be expected: that a shallower duff layer should dry more rapidly, hence retain less moisture. Given the correlation, this is a weak conclusion, but it does suggest that mineral content plays a significant role in moisture dynamics.

5. SUMMARY

This study set out to validate the overwintering effect on the Drought Code. To do this a site was selected in Elk Island National Park composed of primarily white spruce. Samples were taken of the forest floor in the fall and in the spring and compared with the overwinter snowfall.

Results from three winters give values of 1.0 and 0.9 for the *a* and *b* terms of equation 4. These are much higher than the values of 0.75 and 0.75 currently being used by the park and 1.0 and 0.5 currently being used by the province. This suggests higher than expected retention of the fall conditions and snow melt – 100% and 90% respectively.

A calibration curve was developed for the white spruce stand to convert DC to moisture content. The curve shows the duff of this stand holds much less water than those previously studied. It was found that the mineral content of this stand was higher than those previously studied, explaining the lower moisture retention.

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