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STAND SPECIFIC LITTER MOISTURE CONTENT CALIBRATIONS FOR THE CANADIAN FINE FUEL MOISTURE CODE

B. Mike Wotton* and Jennifer L. Beverly
Canadian Forest Service, Natural Resources Canada

1. INTRODUCTION

The moisture content in fine surface fuels has an important influence on the rate of spread and the sustainability of fire. Models used operationally to predict fire behaviour such as the Rothermel model (Rothermel 1972) and BEHAVE (Andrews, 1986) in the US and the Canadian Fire Behaviour Prediction (FBP) System in Canada (Forestry Canada Fire Danger Group 1992) rely on estimates of fuel moisture to predict both fire spread rate and the consumption of fuels. In the Canadian FBP System fuel moisture is estimated from outputs of the Fire Weather Index (FWI) System (Van Wagner 1987). The FWI System uses daily observations of temperature, relative humidity, wind speed and rainfall to estimate moisture in three layers of the forest floor: fine surface fuels are represented by the Fine Fuel Moisture Code (FFMC); the upper organic layer is represented by the Duff Moisture Code (DMC); and deeper organic layers are represented by the Drought Code (DC). These moisture codes are generated from simple moisture exchange models within the FWI System and are representative of the moisture content of fuels in a mature, closed canopy jack or lodgepole pine stand. In their operational use however these moisture codes are used as relative indicators of fuel moisture in a wide variety of stands throughout Canada. Fire managers understand that an FFMC of 90 in a pine stand represents a different actual litter moisture content than a FFMC of 90 in a mixedwood stand. They account for the differences due to forest type using their experience and with tools such as the FBP System, which allows stand specific predictions of expected fire behaviour.

The following paper describes investigations of relationships between the FFMC and observed litter moisture from a number of important forest types from across Canada. The influences of forest type, stand density and seasonality on the relationship between FFMC and observed litter moisture are examined and models are developed to more accurately predict actual litter moisture from diurnally adjusted FFMC values in specific stands.

In the FWI System the fuel moisture models of the different layers of the forest floor are not linked together. However in reality there is moisture exchange between these layers, and one would expect that a wet organic layer would influence litter moisture on the surface. In this paper we also investigate this relationship and develop a method to adjust FFMC according to the moisture content in the upper organic layer (as represented by the DMC).

* *Corresponding author current address*: Faculty of Forestry, University of Toronto, 33 Willcocks St. Toronto, Ontario, Canada, M5S 3B3; e-mail mike.wotton@utoronto.ca

2. METHODS

2.1 Data

Fuel moisture data for this study were obtained from a Canadian Forest Service database assembled as part of an extensive program of fuel moisture and fuel ignitability testing carried out at research sites across Canada from 1939 to 1961*. This field-based research program involved daily sampling of moisture content of a variety of fuels (litter, duff, mosses, and heavier woody material) and evaluating the ignitability of the litter with small-scale test fires lit with matches (or sometimes small campfires). This program, which began in the early 1930's, lead to the development of the early fire hazard rating systems in Canada, which eventually became the FWI System.

In this current analysis data for fuel moisture and fire weather was used from research sites in the provinces of Manitoba (Whiteshell), Saskatchewan (Bittern Creek), Alberta (Kananaskis and Whitecourt), British Columbia (100 Mile House) and the Northwest Territories (Fort Smith). Stand types included in this analysis were pine, deciduous (aspen), spruce, douglas fir and mixedwood (a mix of deciduous and spruce or pine). In the original field records canopy closure was summarized for each test fire and these summaries were used along with photos and descriptions of the stands to estimate a qualitative rating of stand density (light, moderate, high) for each stand location. Season (spring, summer or fall) was determined from records of overstory greenup and leaf fall at each research site (with the exception of the Whitecourt site where this data was unavailable. At that site all samples taken after May 31 were assigned to the summer category and samples from before that date assigned to the spring category.).

Daily fire weather collected at each research station was used to calculate the components of the FWI System. The Canadian Fire Danger Rating System (CFFDRS) provides methods for adjusting the daily FFMC value to compensate for its diurnal variation (Van Wagner 1972, Lawson et al. 1996): the daily FFMC value represents litter moisture content at peak burning conditions on any day, approximately 1600hrs LST. This method of diurnal adjustment was used to estimate a FFMC value at the approximate time the litter sample was collected. Modelled moisture content was calculated from the diurnally adjusted FFMC using the

*Beverly, J.L. and Wotton, B.M., The Canadian small-scale test database: historical overview and data documentation. Canadian Forest Service Northern Forestry Centre, Information Report. (In preparation).

standard FWI System conversion between FFMC and moisture content [Eq. 1].

$$mc(FFMC) = 147.27\frac{(101 - FFMC)}{(59.5 + FFMC)} \quad [1]$$

2.2 Analysis

Observed moisture content, mc(abs), and modelled moisture content, mc(FFMC), were first plotted to examine their distribution. The points were found to be clustered at the dry end with increasing variability in the relationship between mc(obs) and mc(FFMC) with increasing moisture content. This observation is quite common in fuel moisture studies: for dry conditions the error between model predictions and observations is considerably lower than for moister conditions. From this visualization of the data it seemed clear the moisture content data needed to be transformed to a more normal distribution for proper interpretation of statistical analysis. Both mc(obs) and mc(FFMC) were transformed using the natural logarithm to normalize the variance within increasing dryness.

Analysis of variance (ANOVA) was used to explore relationships between observed and estimated moisture content and the influence of other factors. First the significance of the relationship between observed moisture and predicted moisture was examined alone for all data point. Then forest type was coded into a 5 level categorical variable (FOREST=pine, spruce, fir, mixed, or deciduous) and included in the ANOVA. The influence of stand density was then added to the ANOVA model by inclusion of a 3-level categorical variable describing stand density (DENSITY=Light, Moderate, or Dense). Interaction terms between forest type and estimated moisture, FOREST×ln(mc(FFMC)), and stand density and estimated moisture, DENSITY×ln(mc(FFMC)), were also added to the analysis. The effect of time of year was then tested by adding a 3-level categorical variable for season (SEASON=Spring, Summer or Fall). An interaction term between season and estimated moisture, SEASON× ln(mc(FFMC)), was then added to the model and evaluated

The form of the ANOVA model from these analyses is shown in Eq. 2. While only this model form is shown, each variable (and subsequently its interaction with mc(FFMC)) was tested individually for its influence on the relationship between Mc(obs) and mc(FFMC). These results will not be shown in this paper as they can be generalized with the final model form shown in Eq. 2.

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$$\begin{aligned} \ln(mc(obs)) = \; & \beta_0 + \beta_1 \cdot \ln(mc(FFMC)) + \\ & \beta_2 \cdot FOREST + \beta_3 \cdot DENSITY + \beta_4 \cdot SEASON \\ & + \beta_5 \cdot FOREST \times \ln(mc(FFMC)) \\ & + \beta_6 \cdot DENSITY \times \ln(mc(FFMC)) \\ & + \beta_7 \cdot SEASON \times \ln(mc(FFMC)) \quad [2] \end{aligned}$$

The influence of duff moisture on the general relationship between observed litter moisture and that predicted from the FFMC was then tested in an ANOVA using the simple model form

$$\ln(mc(obs)) = \beta_0 + \beta_1 \cdot \ln(mc(FFMC)) + \beta_2 \cdot mc(DMC). \quad [3]$$

Here mc(DMC) is the moisture content equivalent of the DMC and is calculated using the standard relation for this moisture code from the FWI System given in Eq. 4. A plot of ln(mc(obs)) versus mc(DMC) revealed no significant change in variability throughout the range of mc(DMC) and so this term was left untransformed.

$$mc(DMC) = 20 + e^{-\left(\frac{DMC - 244.72}{43.43}\right)} \quad [4]$$

This analysis showed that DMC did have a significant influence on the relationship between mc(obs) and mc(FFMC) and thus a mc(DMC) term was added to the larger model with forest type, season and stand density. The full form of the model tested was then,

$$\begin{aligned} \ln(mc(obs)) = \; & \beta_0 + \beta_1 \cdot \ln(mc(FFMC)) + \\ & \beta_2 \cdot FOREST + \beta_3 \cdot DENSITY + \beta_4 \cdot SEASON \\ & + \beta_5 \cdot FOREST \times \ln(mc(FFMC)) \\ & + \beta_6 \cdot DENSITY \times \ln(mc(FFMC)) \\ & + \beta_7 \cdot SEASON \times \ln(mc(FFMC)) \\ & + \beta_8 \cdot mc(DMC). \quad [5] \end{aligned}$$

3. RESULTS AND DISCUSSION

There were 11871 paired observations of mc(obs) and mc(FFMC) in the test fire dataset. Table 1 summarizes these numbers in terms of the break down by each of forest type, season and density.

The log transformed plot of mc(obs) and mc(FFMC) in Figure 1 shows that there is a strong general relationship between observed moisture content and moisture content as estimated by the FFMC model. The analysis of variance confirms this with R^2 value of 48% and an F-value=10869 (p<0.0001).

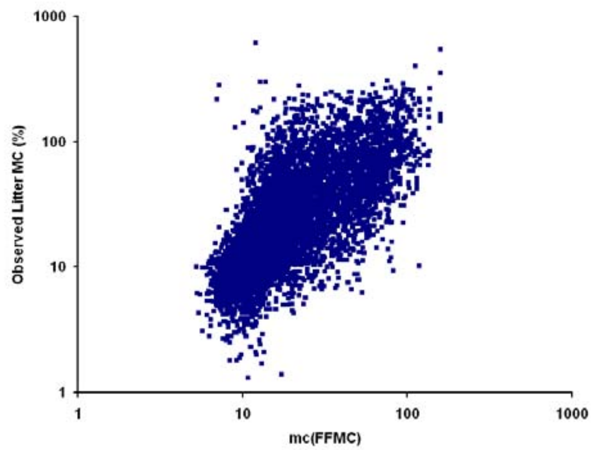

Figure 1: Log transformed plot of observed moisture vs. modelled moisture from FFMC. A log tranform was used to eliminate increasing variability with moisture content.

Table 1: Frequencies for litter moisture observations in each of the categories of the main variables tested in the analysis of variance.

FOREST	Frequency	SEASON	Frequency	DENSITY	Frequency
Deciduous	2859	Spring	1253	Light	579
Fir	243	Summer	9993	Moderate	1793
Mixedwood	2253	Fall	625	Dense	9499
Pine	6084				
Spruce	432				

The analysis of the individual influence of each term on the relationship between mc(obs) and mc(FFMC) showed each of FOREST, SEASON and DENSITY were significant effects. Interaction terms for each variable with mc(FFMC) were also significant indicating the slope of relationship between ln(mc(FFMC)) and ln(mc(obs)) varied with each factor as well as the intercept.

That forest type has a significant influence on the relationship between observed vs. modelled litter moisture content is not surprising. Forest type influences the type of litter on the forest floor (long needle, short needle, leaf, mixed leaf and needle, etc.) and different canopy structures can lead to differences in solar radiation, rainfall and wind penetration into a stand, all influences that would affect moisture of material on the forest floor.

The sign of the coefficient on the density term implied that as stands of the same forest type become denser, observed litter moisture increases for a given FFMC. That is, given a constant value of FFMC from a nearby weather station, a denser canopy would have a wetter litter layer than a lower density stand. This is most likely a function of the reduced solar radiation incident on fuels (and to a lesser extent the reduced wind flowing over the surface of the forest floor) as stand density increases.

The influence of season in the deciduous and mixedwood types was not surprising as leaf flush and fall would modify the surface microclimate in these stands (changing solar radiation and amount of rainfall penetrating through to the forest floor). Currently the FBP System modifies expected fire behaviour in mixedwood stands corresponding to a change brought on by leaf flush in summer.

When examining the strength of the seasonal effect for each forest type individually it was found that the same significant seasonal signal existed for the Pine type as well. The strong seasonal effect in the pine forest type is unexpected, given that there is no major change in the canopy of a pine forest with the seasons. It was hypothesized that the seasonality effect in pine stands might be due to the influences of moisture content of the organic layer that are not accounted for by the FFMC: in the spring the organic layer would be, in general, wetter than later in the summer. However analysis of the significance of season in the pine type with a duff moisture content term included showed that the seasonality remained a significant factor in the relationship between mc(obs) and mc(FFMC) after adjusting for the influence of organic moisture.

Analysis carried out to examine for the influence of organic moisture, on the relationship between observed and modelled moisture was carried out using the form given in Eq. 3. This showed that moisture in the upper portions of the organic layer did have a significant influence the relationship between mc(obs) and mc(FFMC). This relationships had an R^2=52% and a model F-Value of 6318 (p>0.0001). A summary of the regression coefficients is presented in

Table 2. The sign of the coefficient indicates that, for a constant FFMC, a wetter upper organic layer leads to wetter litter on the surface. Plots of this relationship for a moderately dense pine forest type in the summer are shown for several DMC values in Figure 2.

Table 2: Coefficients from the ANOVA examining the effect of duff moisture on the observed and modelled moisture content relationship (model form is given in Eq. 3).

Model Variable	coefficient	Standard error	Student-t value	p
Intercept β_0	0.186	0.026	7.39	<0.0001
ln(mc(FFMC)) β_1	0.794	0.011	73.72	<0.0001
mc(DMC) β_2	0.0032	0.0001	30.39	<0.0001

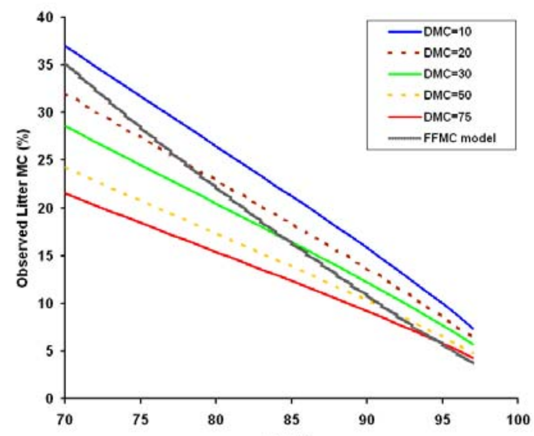

Figure 2: The impact of changing duff moisture content on the litter moisture and FFMC relationship. This example is a moderate density pine forest in the summer.

Table 3 presents the basic ANOVA summaries for each variable and Table 4 lists the model coefficients for the full model form given in Eq 6. The final model has an R^2 of 62% and a model F-value=1074 ($p<0.0001$). It is important to note that the litter moisture observations from the small scale test fire database are an estimate based on one or, on some occasions two, samples taken from the forest floor. As such these estimates have a sizeable standard error associated with them, and no doubt contribute somewhat to the unexplained variability in these results.

Table 3: Analysis of variance summary for the full model of litter moisture given in Eq. 6. (all effects included).

Variable	df	F-value	P
ln(mc(FFMC))	1	749.9	<0.0001
FOREST	4	3.51	0.0071
FOREST×ln(mc(FFMC))	4	14.3	<0.0001
SEASON	2	23.3	<0.0001
SEASON×ln(mc(FFMC))	2	42.8	<0.0001
DENSITY×ln(mc(FFMC))	2	254.0	<0.0001
mc(DMC)	1	1077.2	<0.0001

Using Table 4, specific equations relating FFMC value to actual litter moisture content in a stand can be developed for each forest type, stand density, or season, and adjustments to litter moisture can be made to account for the moisture content of the duff. For example, for a pine forest with moderate closure in summer, the resultant model is,

$$mc = EXP\{0.2811 + 0.7211\times\ln(mc(FFMC)) + 0.003138\times mc(DMC)\},$$

while the same pine forest, with light canopy closure, in summer gives the following model,

$$mc = EXP\{0.2811 + 0.6404\times\ln(mc(FFMC)) + 0.003138\times mc(DMC)\}.$$

For a deciduous forest, moderate canopy closure in the summer, surface litter moisture can be predicted with the model

$$mc = EXP\{0.1326 + 0.8514\times\ln(mc(FFMC)) + 0.003138\times mc(DMC)\}.$$

The relationship between actual litter moisture and FFMC in these examples is shown in the plots in Figure 3. A list of equations for each of the forest type, stand density and season categories can be found in Table A-1 in the Appendix.

Figure 3 compares the relationship between FFMC and actual surface litter moisture for the pine and deciduous forest types for different stand densities. These relationships are for the summer period and for a DMC value of 25 (178 %mc) which is the average DMC in the dataset used to derive these equations. As one would suspect, litter in the deciduous stands are wetter than the pine stands for each density category for any given value of FFMC. As surface fuels become very dry differences between stand types (between deciduous and pine) and with stand closure tend to disappear.

Table 4: Coefficient values for model based on Eq. 6

Variable [value in Eq. 6]	Cate-gory	Co-efficient	Std err.
Intercept [β_0]	-	0.7303	0.1413
Ln(mc(FFMC)) [β_1]	-	0.4672	0.0473
FOREST [β_2]	Decid.	-0.2194	0.1321
FOREST [β_2]	Fir	-0.5952	0.2236
FOREST [β_2]	Mixed	-0.0897	0.1340
FOREST [β_2]	Pine	-0.0709	0.1270
FOREST [β_2]	Spruce	0.0	-
FOREST×ln(mc(FFMC)) [β_5]	Decid.	0.1350	0.0432
FOREST×ln(mc(FFMC)) [β_5]	Fir	0.1468	0.0830
FOREST×ln(mc(FFMC)) [β_5]	Mixed	0.1181	0.0435
FOREST×ln(mc(FFMC)) [β_5]	Pine	0.0047	0.0411
FOREST×ln(mc(FFMC)) [β_5]	Spruce	0.0	-
SEASON [β_4]	Spring	0.0	-
SEASON[β_4]	Sum.	-0.3783	0.0764
SEASON[β_4]	Fall	0.3306	0.1578
SEASON×ln(mc(FFMC)) [β_7]	Spring	0.0	-
SEASON×ln(mc(FFMC)) [β_7]	Sum.	0.2492	0.0278
SEASON×ln(mc(FFMC)) [β_7]	Fall	0.1121	0.0558
DENSITY [β_3]*	ALL	0.0	-
DENSITY×ln(mc(FFMC)) [β_6]	Light	-0.0807	0.0080
DENSITY×ln(mc(FFMC)) [β_6]	Mod.	0.0	-
DENSITY×ln(mc(FFMC)) [β_6]	Dense	0.1208	0.0060
Mc(DMC) [β_8]	-	0.00313	0.0001

* Note that the DENSITY term β_3 was found to be not significant when the DENSITY interaction terms was included so it was eliminated from the final ANOVA; therefore β_3=0.

Figure 4 shows a similar comparison but with stand density held constant at moderate and season varying. Here again for each season litter in the deciduous stands is wetter for any given level of FFMC, until very dry conditions are reached.

Figure 5 contrasts litter moisture in the mixedwood forest type with the deciduous, holding stand density constant at moderate. This comparison shows that, within each season, litter on the surface of the mixedwood forest is drier than that in the deciduous forest at a given value of FFMC.

Also of note in Figure 3 to Figure 5 is the similarity of some curves to the standard curve for the FFMC and moisture content relationship given by Eq 1. The summer models of moderate density pine and spruce types most closely track the standard FFMC/MC relationship. This agreement is not surprising as the FFMC model was developed in a moderate closure Pine stand, with the summer period making up the bulk of the observations.

4. SUMMARY

The analysis presented has shown that, while FFMC is correlated with actual litter moisture content in a range of stands, the relationship between actual litter moisture and FFMC varies with forest type, stand density, season and with the moisture of the upper levels of the organic layer. Models explicitly laying out these relationships were developed and can be used in these types of stands when actual litter moisture estimates are required.

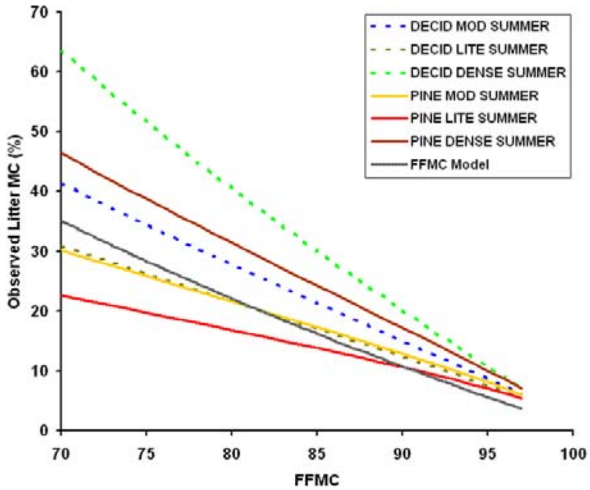

Figure 3: A comparison of the impact of stand density on litter moisture content FFMC relationship for the pine and deciduous forest type. The summer class and a DMC value of 25 have been used for all models.

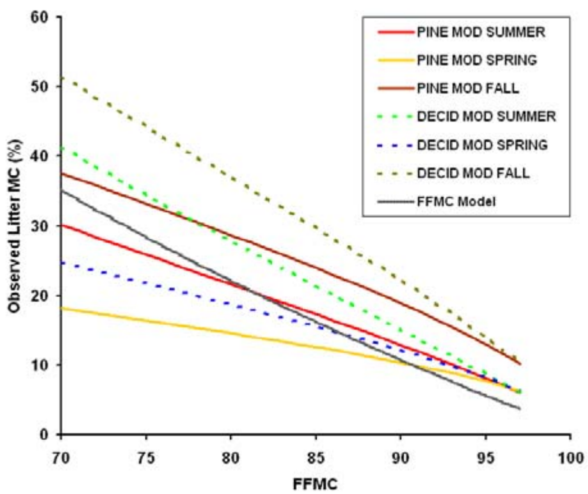

Figure 4: A comparison of the impact of season on the litter moisture and FFMC relationship for the pine and deciduous forest type. A moderate density stand and a DMC value of 25 have been used for all models.

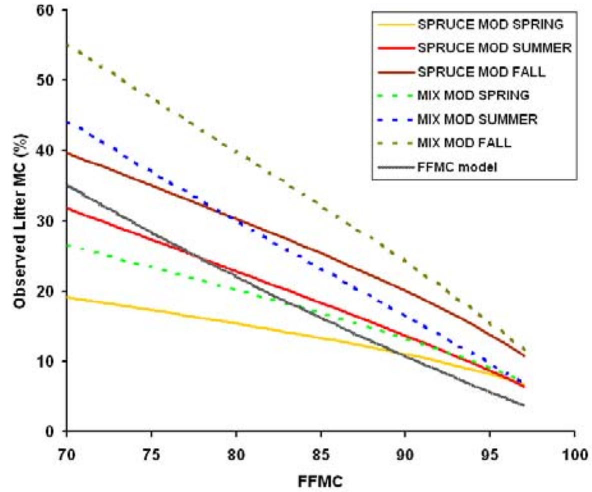

Figure 5: A comparison of the effect of season on the litter moisture and FFMC relationship for the mixedwood and pure spruce forest types. A moderate stand density and a DMC value of 25 have been used for all models.

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Appendix

Table A-1: Models of actual litter moisture content based FFMC, forest type, season, stand density and DMC.

Model Variable			Model
FOREST	DENSITY	SEASON	
Deciduous	Light	Spring	mc = EXP{0.5109 + 0.5215×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Light	Spring	mc = EXP{0.1351 + 0.5333×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Light	Spring	mc = EXP{0.6406 + 0.5046×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Light	Spring	mc = EXP{0.6594 + 0.3912×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Light	Spring	mc = EXP{0.7303 + 0.3865×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Moderate	Spring	mc = EXP{0.5109 + 0.6022×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Moderate	Spring	mc = EXP{0.1351 + 0.6140×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Moderate	Spring	mc = EXP{0.6406 + 0.5853×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Moderate	Spring	mc = EXP{0.6594 + 0.4719×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Moderate	Spring	mc = EXP{0.7303 + 0.4672×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Dense	Spring	mc = EXP{0.5109 + 0.7230×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Dense	Spring	mc = EXP{0.1351 + 0.7348×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Dense	Spring	mc = EXP{0.6406 + 0.7061×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Dense	Spring	mc = EXP{0.6594 + 0.5927×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Dense	Spring	mc = EXP{0.7303 + 0.5880×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Light	Summer	mc = EXP{0.1326 + 0.7707×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Light	Summer	mc = EXP{-0.2432 + 0.7825×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Light	Summer	mc = EXP{0.2623 + 0.7538×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Light	Summer	mc = EXP{0.2811 + 0.6404×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Light	Summer	mc = EXP{0.3520 + 0.6357×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Moderate	Summer	mc = EXP{0.1326 + 0.8514×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Moderate	Summer	mc = EXP{-0.2432 + 0.8632×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Moderate	Summer	mc = EXP{0.2623 + 0.8345×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Moderate	Summer	mc = EXP{0.2811 + 0.7211×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Moderate	Summer	mc = EXP{0.3520 + 0.7164×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Dense	Summer	mc = EXP{0.1326 + 0.9722×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Dense	Summer	mc = EXP{-0.2432 + 0.9840×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Dense	Summer	mc = EXP{0.2623 + 0.9553×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Dense	Summer	mc = EXP{0.2811 + 0.8419×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Dense	Summer	mc = EXP{0.3520 + 0.8372×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Light	Fall	mc = EXP{0.8415 + 0.6336×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Light	Fall	mc = EXP{0.4657 + 0.6454×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Light	Fall	mc = EXP{0.9712 + 0.6167×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Light	Fall	mc = EXP{0.9900 + 0.5033×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Light	Fall	mc = EXP{1.0609 + 0.4986×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Moderate	Fall	mc = EXP{0.8415 + 0.7143×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Moderate	Fall	mc = EXP{0.4657 + 0.7261×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Moderate	Fall	mc = EXP{0.9712 + 0.6974×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Moderate	Fall	mc = EXP{0.9900 + 0.5840×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Moderate	Fall	mc = EXP{1.0609 + 0.5793×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Deciduous	Dense	Fall	mc = EXP{0.8415 + 0.8351×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Fir	Dense	Fall	mc = EXP{0.4657 + 0.8469×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Mixed	Dense	Fall	mc = EXP{0.9712 + 0.8182×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Pine	Dense	Fall	mc = EXP{0.9900 + 0.7048×ln(mc(FFMC)) + 0.003138×mc(DMC) }
Spruce	Dense	Fall	mc = EXP{1.0609 + 0.7001×ln(mc(FFMC)) + 0.003138×mc(DMC) }

Note: Values for mc(FFMC) and mc(DMC) are calculated from FFMC and DMC using the FWI System relations given here in Eq. 1 and Eq. 4 respectively.