

Foliar moisture content input in the Canadian Forest Fire Behavior Prediction System for areas outside of Canada

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Abstract

The foliar moisture content (FMC) of coniferous trees is estimated within the context of the Canadian Forest Fire Behavior Prediction System on the basis of an empirical method that is limited to the forest regions of Canada and immediately adjacent areas of the United States. This paper offers both a review and simple recommendations for obtaining the FMC input in cases where the system is applied outside of Canada in both the northern and southern hemispheres.

Keywords: Canadian Forest Fire Danger Rating System; Crown fire initiation; Fire behavior; Live fuel moisture.

1. Introduction

The foliar moisture content (FMC) of coniferous trees is both an output and input of the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). More specifically, the FMC is one of the factors influencing the onset or initiation of crowning (Van Wagner 1977) in coniferous and mixedwood fuel types that are susceptible to crown fire activity. FMC is also an input in determining the crown fire rate of spread in the conifer plantation (C-6) fuel type of the FBP System. Van Wagner (1989) devised a simple, empirical method for estimating FMC for use within the FBP System. Thus, by its very nature this intermediate output from the FBP System would in the strictness sense be considered as only applicable to Canadian forests. The question naturally arises as to how estimation of the FMC should be handled for areas far outside of Canada (Tymstra *et al.* 2010) where the FBP System might be implemented.

This paper provides brief overviews on the nature of FMC variation in Canadian conifer forests and the general manner in which FMC is estimated within the context of the FBP System. Recommendations for obtaining the FMC input for applications outside of Canada are made on the basis of a review of pertinent literature.

2. Seasonal Trends in Coniferous Foliar Moisture Content in Canada

Repeated FMC sampling of coniferous tree foliage at several locations across Canada has revealed a common pattern or cycle during the fire season (Figure 1) in needles ≥ 1 -year old, namely a period of relatively low values in the spring and early summer before the emergence of new needles (e.g., Van Wagner 1967, 1974; Linzon 1969; Little 1970; Fuglem and Murphy 1980; Springer and Van Wagner 1984; Chrosiewicz 1986). This phenomenon is commonly referred to as the “spring dip” (Van Wagner 1974; Archibald *et al.* 1994). This decrease or minimum occurrence in the FMC is judged to be not so much a

weather-dependent effect but as largely physiological in nature (USDA Forest Service 1960; Little 1970; Van Wagner 1974; Turner and Lawson 1978; Nelson 2001).

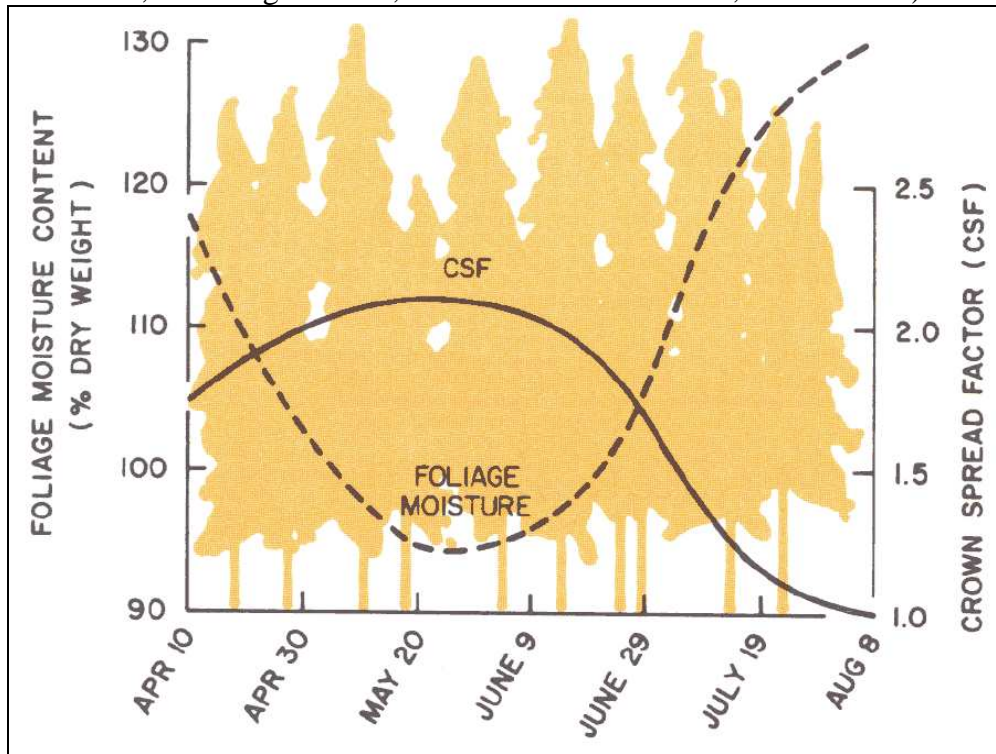


Figure 1. Seasonal trend in coniferous foliar moisture content (FMC) and resultant Crown Spread Factor (CSF) for the Petawawa Forest Experiment Station, Ontario, Canada, as derived by Van Wagner (1974), illustrating the reduced FMC or “spring dip” in late May – early June (from Turner and Lawson 1978). The Crown Spread Index (CSI) developed by Van Wagner (1974) is obtained by multiplying the CSF times the Initial Spread Index (ISI) component of the Canadian Forest Fire Weather Index System (Van Wagner 1987). Crown fires should be expected in pine stands when the CSI exceeds a value of 30.

3. The FBP System Method of Estimating Coniferous Foliar Moisture Content

In the FBP System, the FMC is calculated or estimated from the geographical location (i.e., latitude and longitude), elevation, and Julian date, thereby avoiding the necessity for users to directly supply this input on a daily basis. The FMC within the context of the FBP System represents the moisture content of conifer needles that are at least one-year old which typically constitutes the bulk of the needle biomass (Van Wagner 1974). The seasonal trend in coniferous FMC estimated by the FBP System varies between 120 and 85% (i.e., a 35% range) over the course of the fire season and also includes the “spring dip” which generally occurs between mid-May and late June and (Figure 2).

The equations comprising the model for estimating FMC in the FBP System are based on data collected for a total of eight coniferous tree species and nine different sampling locations across Canada (Figure 3). The general northwest to southeast climatic patterns that occur in Canada (Environment Canada 1984) were taken into account as well. The FMC model also assumes, as illustrated in Figure 4, that the “spring dip” or date of minimum FMC will occur at later dates in the fire season at higher elevations (Fingland

1987). Maps of FMC for Canada are generated on a daily basis throughout the course of the fire season (Figure 5) by the Canadian Wildland Fire Information System (Lee *et al.* 2002).

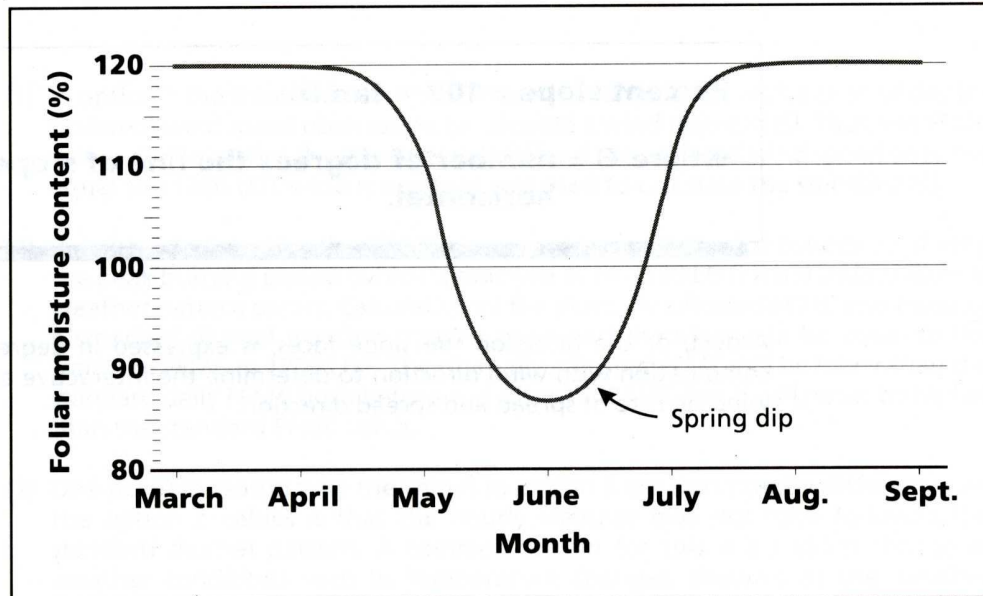


Figure 2. Generalized example of the seasonal trend in coniferous foliar moisture content as estimated by the Canadian Forest Fire Behavior Prediction System (from Hirsch 1996).

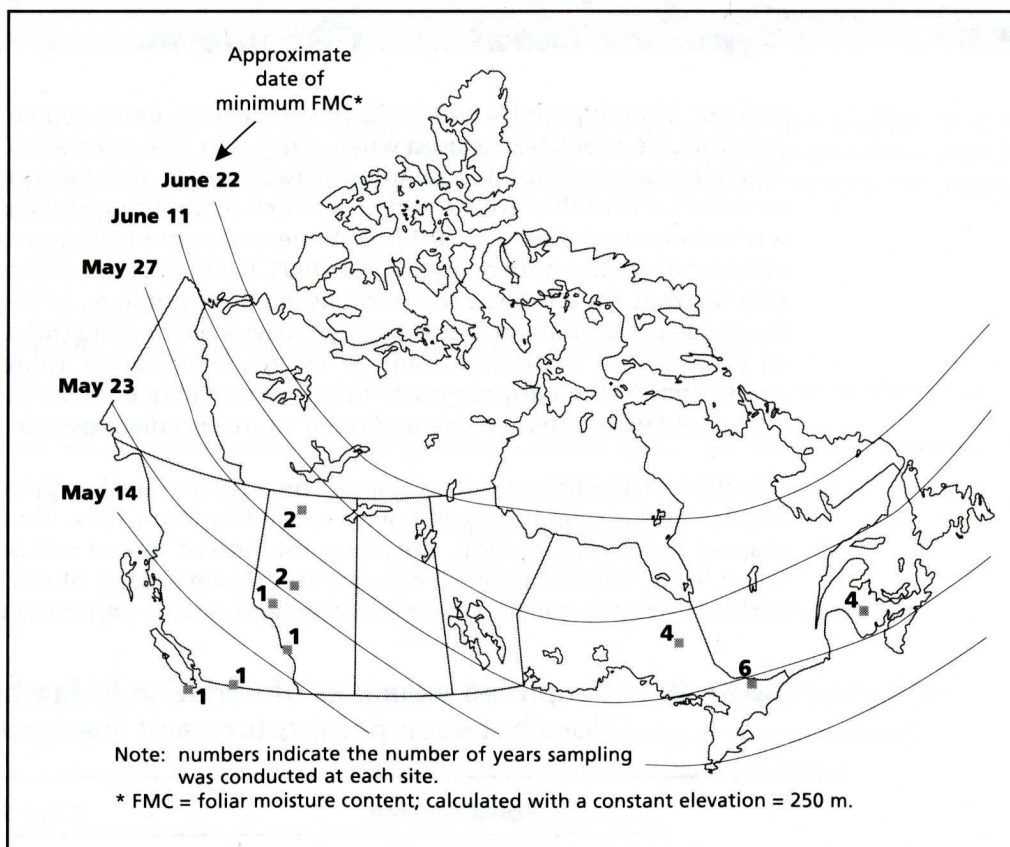


Figure 3. Location of sampling sites used in the developed of the empirical method for estimating coniferous foliar moisture (FMC) content in the Canadian Forest Fire Behavior

Prediction System along with the approximate dates of the “spring dip” or minimum value in coniferous FMC estimated by the system (from Hirsch 1996)

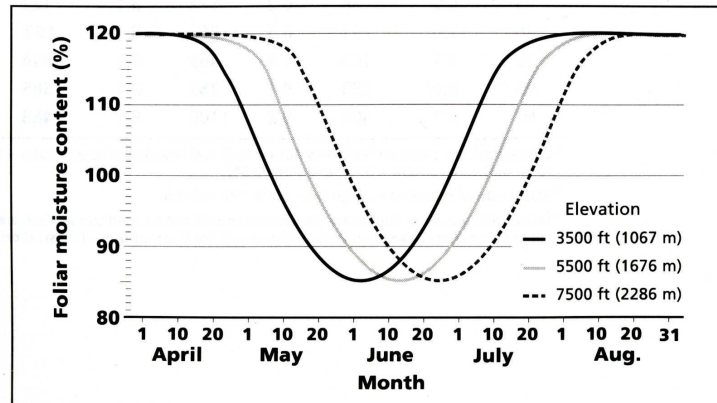


Figure 4. Seasonal trend in coniferous foliar moisture content with elevation for Jasper, Alberta, Canada (52°53'N latitude; 118°04'W longitude), as estimated by the Canadian Forest Fire Behavior Prediction System (from Hirsch 1996).

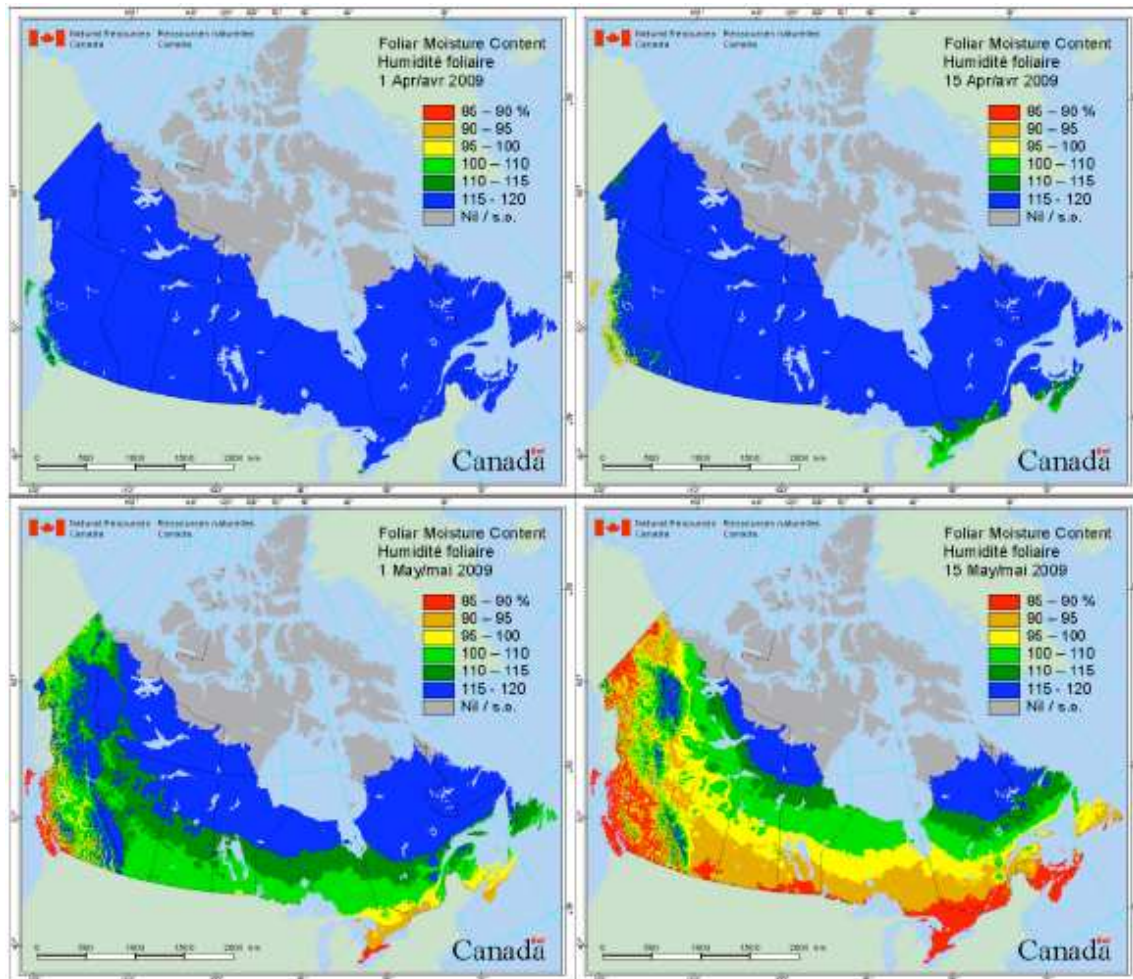


Figure 5. Maps illustrating the spatial and seasonal variation in coniferous foliar moisture content (FMC) throughout the fire season across Canada as generated by the Canadian Wildland Fire Information System (http://cwfis.cfs.nrcan.gc.ca/en_CA/fbmaps/fmc/) based

on the model for estimating the coniferous FMC embedded in the Canadian Forest Fire Behavior Prediction System. (continued)

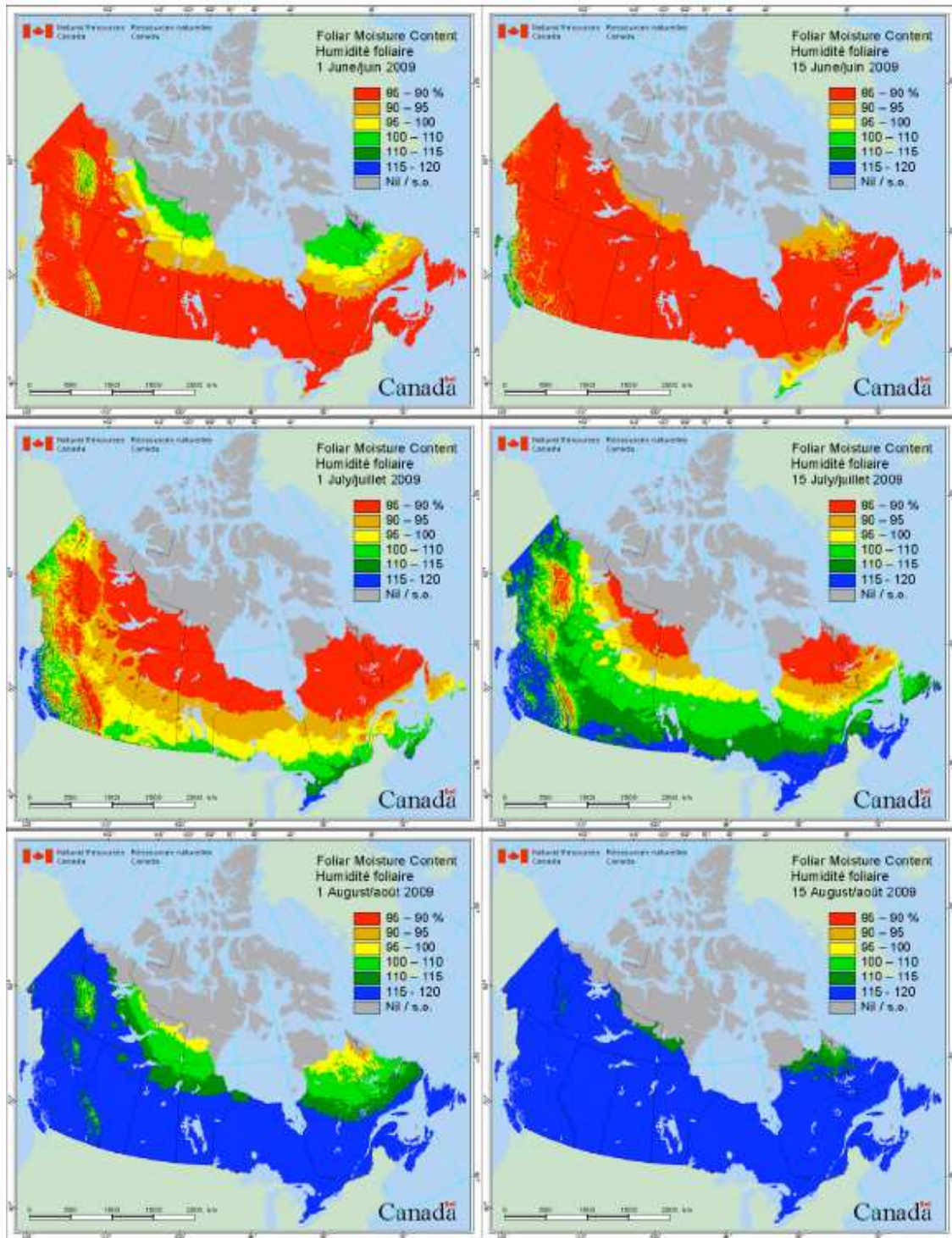


Figure 5. (concluded)

It is worth noting that the FBP System estimates of FMC are not tree species specific but rather a generic value for all conifers, although it is recognized that differences do exist. Furthermore, the system does not presently allow for any year-to-year

variability in FMC, although it is also recognized that such variation does occur. Ongoing research into the estimation of FMC may lead to a more robust model that could account for such refinements (Taylor 2009). However, it is worth bearing in mind that according to the crown fire initiation model of Van Wagner (1977), which is used in the FBP System, the natural variation in canopy base height would allow for a much greater effect on the flammability of coniferous tree foliage that would the observed variation in FMC (Alexander 1988).

4. Findings from Coniferous Foliar Moisture Content Studies Outside of Canada

Drawing in part upon a bibliography originally compiled by Alexander (1988) as well as two subsequent studies (Hartford and Rothermel 1991; Agee *et al.* 2002), Keyes (2006a, 2006b) produced a useful summary of FMC studies carried out on coniferous tree species found in Canada and the USA. Not surprisingly, the seasonal trends in coniferous FMC observed in Canada, including the “spring dip” phenomenon although not as pronounced in some cases, also appears to occur in adjacent regions of the U.S. (Simard *et al.* 1983; Miller 1994; Maguire 1995; Faiella and Bailey 2007; Grima 2009), as illustrated in Figure 6. Schroeder and Buck (1970), however, made no mention of a springtime minimum in FMC within the section on fuel moistures in their monograph.

Ranges in sampled coniferous FMC levels in the west, north-central, and northeastern regions of the U.S., including Alaska, were generally comparable to Canadian conditions. However, coniferous FMC values in the southeastern U.S. were considerably higher. Hough (1973), for example, found that the FMC in sand pine (*Pinus clausa*) in Florida ranged from 120 to 150%. Similarly, the FMC of slash pine (*Pinus elliottii*) in the lower coastal plains of Georgia was found to average 175% (USDA Forest Service 1960).

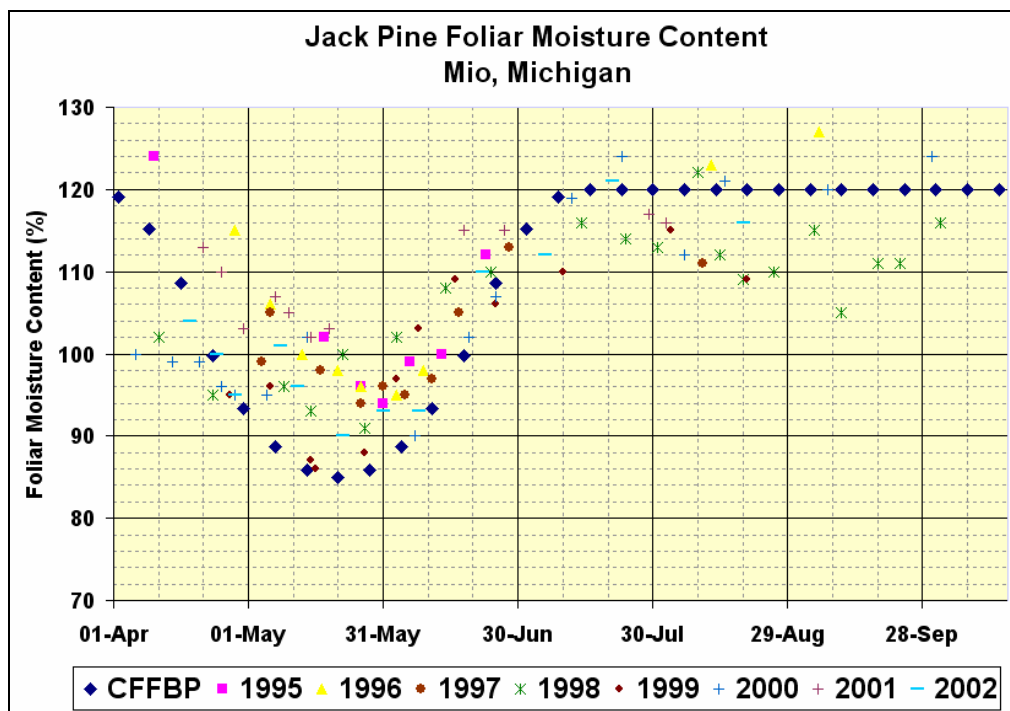


Figure 6. Sampled trends in moisture content detected in jack pine (*Pinus banksiana*) needle foliage over an 8-year period in relation to the estimated output from the Canadian

Forest Fire Behavior Prediction System, denoted by “CFFBP”, for a site in the north-central region of Lower Michigan, USA (from National Wildfire Coordinating Group 2008).

Unfortunately, a FMC summary similar to that of Keyes (2006a, 2006b) has yet to be completed for areas outside of Canada and the USA. Nevertheless, the seasonal cycle in coniferous FMC identified in Canada with its associated “spring dip” has also been found to occur in Russia (Molchanov 1957; Kurbatskii 1972) and England (Hatcher 1990). However, such patterns in coniferous FMC have not been detected at more southerly latitudes outside of Canada such as Australasia (Pook and Gill 1993; Waterloo 1994; Alexander 1998, 2008a) and Brazil (Fernandes and Soares 1981) nor in Portugal (Viegas *et al.* 1992, 2001). Dimitrakopoulos *et al.* (2003) found that minimums in coniferous FMC in Greece tended to occur in late summer (i.e., July and August). Furthermore, coniferous FMC levels for year old and older needles are typically much higher (~120 to 160%) in these mid and southern latitudes as well (Figure 7).

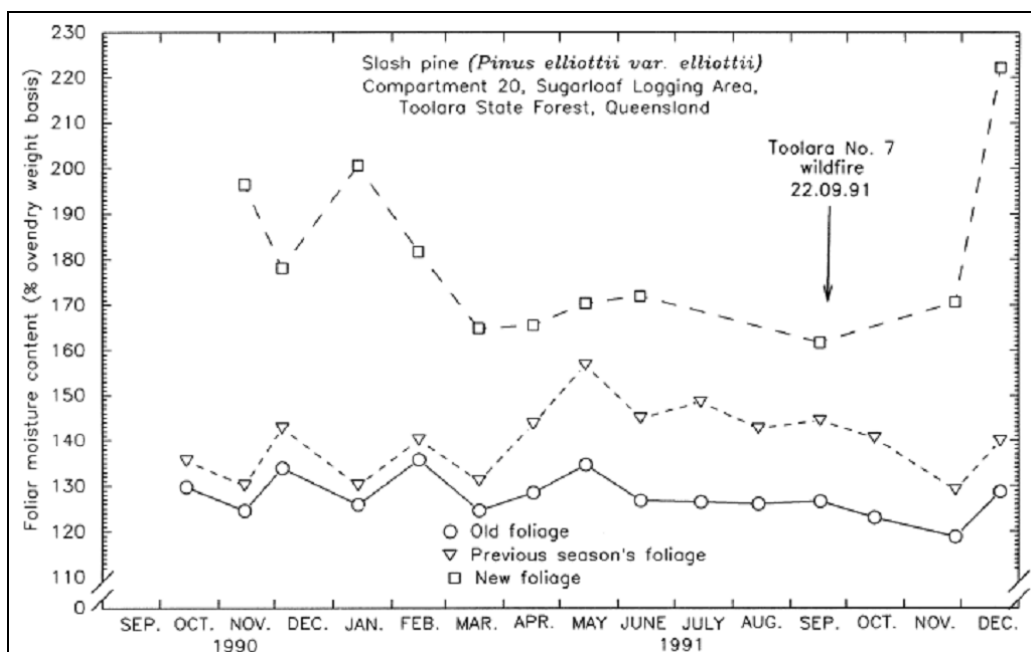


Figure 7. Seasonal trends in the foliar moisture content of a slash pine (*Pinus elliottii* var. *elliottii*) plantation in southeastern Queensland, Australia (from Alexander 1998).

5. Obtaining the FBP System Foliar Moisture Content Input for Locations Outside of Canada

Widespread, global application of the FBP System model for estimating coniferous FMC is clearly not appropriate, although there are certainly some regions of the U.S. that represent notable exceptions. However, on the basis of Figure 6, it is acknowledged that a model similar in form to the FBP System FMC model but based on locally collected data would be a more accurate means of estimating coniferous FMC. It is worth noting that Grima (2009) has, for example, developed an empirical method, including software, for estimating the FMC of pitch pine (*Pinus rigida*) in Massachusetts, USA that relies on either the mean daily temperature or the average of maximum and minimum daily temperatures.

The “Pitch Pine Foliar Moisture Content (FMC) Spreadsheet Calculator” is available for downloading at: <http://www.umass.edu/nebarrensfuels/methods/index.html>

Many questions remain about the seasonal dynamics in coniferous FMC for regions outside of Canada with respect to geographic, site, and climatic characteristics. A comprehensive review and analysis of the literature and data on coniferous FMC studies undertaken outside of Canada and the USA is sorely needed. Such an undertaking would constitute a worthy contribution to the field of wildland fire science and management.

In the interim and in the absence of any definitive research, it is recommended that overseas users of the FBP System either: (i) select a nominal FMC level for use during the entire fire season or (ii) adopt a particular seasonal trend in FMC. In either case, the FMC data would be acquired from the existing literature, unpublished data and/or by direct field sampling using established methods (e.g., Norum and Miller 1984). Dimitrakopoulos (2008), for example, has indicated that he has collected data on coniferous FMC in Greece that has yet to be published as has Mitsopoulos (2008) for Aleppo pine (*Pinus halepensis*) (Mitsopoulos 2005).

The first option mentioned above was used for example in the application of the FBP System in developing forest fire danger class criteria for exotic pine plantations in New Zealand (Alexander 2008a); it was also adopted by Pearce and Anderson (2008) in their manual for predicting fire behavior in New Zealand exotic pine plantations.. On the basis of coniferous FMC samplings undertaken in New Zealand in 1990-1993, a nominal value of 145% was selected. This is similar to the selection of an FMC of 97% for use in construction of the rate of fire/fire intensity class/type of fire tables contained in the FBP System field guide (Taylor *et al.* 1997). This represented the average value associated with the crown fire rates of spread found in the database used in the development of the FBP System (Forestry Canada Fire Danger Group 1992).

6. Concluding Remarks

Adoption of the Canadian Forest Fire Danger Rating System by foreign countries occasionally calls for modifications to existing practices (e.g., Alexander 2008b). The present paper represents a digest of currently available thoughts on the topic of estimating coniferous FMC for areas outside of Canada where the FBP System might be applied in whole or in part. Hopefully it will inspire others to publish existing datasets, carry out new field work, and/or summarize the existing volume of literature, all which would no doubt lead to improvements in our understanding on the subject.

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