PRELIMINARY ASSESSMENT OF THE APPLICATION OF THE CANADIAN FOREST FIRE DANGER RATING SYSTEM (CFFDRS) TO ALASKAN ECOSYSTEMS

An evaluation of the 'state of knowledge' prepared for the Alaska Interagency Fire Community

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Introduction

The Canadian Forest Fire Danger Rating System (CFFDRS) has been under development by the Canadian Forest Service since 1968, and comprises two major subsystems: the Canadian Forest Fire Weather Index (FWI) and the Canadian Forest Fire Behavior Prediction (FBP) Systems **(Stocks et al. 1989, Taylor and Alexander 2006)**. In Canada the FWI System has been used since 1970; this empirical system is comprised of six standard components **(Van Wagner 1987)** that provide numerical ratings of relative fire potential for a standard fuel type on level terrain that are derived from weather observations **(Van Nest and Alexander 1999)**. The first three components of the FWI System are fuel moisture codes that track changes in the daily moisture content of three classes of fuel (Fine Fuel Moisture Code=FFMC, Duff Moisture Code =DMC, and Drought Code=DC), each with different rates of drying **(Van Wagner 1987)**. The remaining three components of the FWI System are indices of fire behavior that represent the rate of spread (Initial Spread Index=ISI), amount of fuel weight (Buildup Index=BUI), and fire intensity (Fire Weather Index=FWI) **(Van Wagner 1987, Stocks et al. 1989)**.

The first complete edition of the FBP System was completed in 1992 **(Forestry Canada Fire Danger Group 1992, Van Nest and Alexander 1999)**, and provides actual quantitative estimates of aspects of fire behavior for specific weather conditions, fuel types and topographic conditions **(Hirsh 1993, Hirsh 1996, Van Nest and Alexander 1999)**. Actual fire behavior is incorporated into the FBP System, and includes data from 495 fires, of which 409 are experimental fires and 86 are documented wildfires **(Hirsch 1996)**. The FBP System utilizes the FFMC, ISI and BUI components from the FWI System as inputs (**Hirsch 1993, Alexander and Cole 1995)**. Operationally, the FBP System is used by fire management agencies for the quantitative prediction of fire behavior and for preparedness planning **(Hirsch 1993)**.

The Alaska Interagency Fire Community adopted the CFFDRS in July 1992 in place of the U.S. National Fire Danger Rating System **(Alexander and Cole 1995, Cole and Alexander 1995, Alexander and Cole 2001)**, as it was believed that the CFFDRS was more applicable to Alaskan ecosystems, which are primarily boreal and tundra. However, since its adoption in Alaska, very little ground-truthing of the CFFDRS has been performed, and as a result there has been inconsistent use of the system within and among fire management agencies **(Wilmore 2000)**. As of 2014 there are several unresolved issues associated with the application of an empirically derived fire danger rating system that is not specifically calibrated for the environment of Alaska. For example: although black spruce (*Picea mariana*) is the dominant forest type in Alaska, the fuel moisture models in the FWI System were calibrated largely for Jack pine (*Pinus banksiana*) and lodgepole pine (*Pinus contorta*); the seasonal pattern of evapotranspiration in northern latitudes is not accounted for by the fixed day length factors in the equations of the fuel moisture codes; and drainage restrictions resulting from permafrost are not accounted for in the fuel moisture code equations **(Wilmore 2001)**. In an effort to compile the available information addressing issues over the use of the CFFDRS, its relation to Alaskan fuels, and the resultant impact on fire behavior predictions, the Alaska Interagency Fire Community developed the following list of topics for which they wished to evaluate the '*state of knowledge*':

1) ***Overwintering stations: pros and cons***
2) ***Fuel moisture measurements and comparisons***
3) ***Adjustment of mid- season indices based on fuel moisture measurements***

4) ***Whether data trends or raw values are more important for fire behavior prediction***
5) ***Impacts of using solar noon vs. non-solar noon observations***
6) ***Effects of errors in precipitation reporting***
7) ***Analysis of any Alaskan data***
8) ***Justification for thresholds in fire danger rating charts***

Although more than 60 documents were reviewed, this report provides a preliminary summary of the most relevant resources (e.g., peer-reviewed journal publications, government technical reports, conference proceedings, results from workshop/conference presentations, and personal communications from individuals in the local and international wildfire community) available that address each of the above listed topics of interest. Many of these documents are available online (www.frames.gov/cffdrs). The '*state of knowledge*' on each of the topics outlined by the Alaska Interagency Fire Community is addressed in bullet form below under separate headings. The evaluation of the *'state of knowledge'* regarding concerns over the use of the CFFDRS in Alaska is intended to assist the Alaska Interagency Fire Community with identifying *knowledge gaps* that could be addressed through ongoing and/or novel research efforts, and developing strategies to assist wildfire managers with the use and adaptation of the CFFDRS in Alaska.

State of Knowledge

1) Overwintering stations: pros and cons

- **Marty Alexander (*Personal Communication, 2014*)**
  - Using the default spring DC startup value of 15 assumes that the DC fuel layer is completely recharged or saturated
  - The methodology for undertaking adjustments to the spring DC starting values as a result of very high fall ending values and/or below normal overwinter precipitation is clearly documented (see **Turner and Lawson 1978** and **Lawson and Armitage 2008**)
  - There are implications for extrapolating fire danger indexes between two fire weather stations that are following different operational practices regarding the spring DC startup value
  - To validate a decision to either use the default value or adjust the spring DC each year, fuel moisture should be sampled at each fire weather station three days after snow free cover occurs. Then one of the relationships outlined by **Lawson and Dalrymple (1996)** can be applied to evaluate how much agreement there is between the spring DC starting value based on sampled moisture contents and the value derived using the overwinter procedures

- **Alden (2013a)**
  - Differences in the overwintered and non-overwintered CFFDRS indices decreased throughout the season, particularly when there was ample rainfall
  - The differences in the BUI are greatest with a high DMC and a low non-overwintered DC
  - The differences in the FWI indices become irrelevant as the differences between the DC values decrease and as the DC continues to increase throughout the fire season

- **Alden (2013b)**
  - In the early 1990s the overwintering procedure was applied to all fire weather stations across Alaska
  - Around 1996, this practice was not consistently implemented, as it was believed that permafrost resulted in the spring soil moisture being sufficient to make a DC of 15 appropriate. This reasoning was predominately applied by the Alaska Fire Service, while the state of Alaska Division of Forestry continued to analyze the overwinter precipitation along with the fall DC to adjust the starting spring DC value
  - The following recommendations are made:
    1) Use the overwintering tables across Alaska in order to implement a statewide consistent fire danger rating system
    2) Use the existing CFFDRS histories and fire behavior information from well documented fires to validate the CFFDRS indices to improve the understanding and use of the CFFDRS indices. The data exists, but needs to be compiled and analyzed.

- **Lawson and Armitage (2008)**
  - The DC is the only moisture code that must be overwintered
  - "As **Van Wagner (1985)** explained, any moisture index can be overwintered, but whether the effect of doing so projects far enough into the new season for it to be worthwhile depends on the time lag. This principle is governed by the time lag theory for negative exponential systems, whereby the proportion of any effect remaining after one time lag period is 36.8%, after two periods is 13.5%, after three periods is 5.0%, and after 4 periods is 1.8%. Taking 5% as the practical point of no further concern, time lags between 32 and 64 days were shown to cover the range of effects between disappearing during the current season and extending into the next fire season. Thus, with a time lag of 53 days in standard weather, DC may carry forward the effect of winter precipitation into the new fire season's starting value."
  - Overwintering the DC tends to be unnecessary in regions where winter precipitation normally exceeds 200 mm

- **Bourgeau-Chavez et al. (2007)**
  - The default DC value of 15 does not work well in Interior Alaska, where the average precipitation per year is 300 mm, with only half of that occurring in the form of snow
  - SAR (synthetic aperture radar) data may be used to improve the application of the current weather-based fire danger rating of the CFFDRS in Interior Alaska "by initializing the spring values of DC, calibrating the fuel moisture codes throughout the season and providing additional point-source data"
  - In this study, an algorithm was developed that related radar backscatter values to DC for several recently burned boreal forests
    - The use of burned test sites is a useful method of determining moisture changes in forest fuels, since the FWI moisture codes are designed to provide a general overview of fuel moisture conditions and how they change over time
  - The methods presented here were evaluated based on *in situ* moisture and precipitation measurements and are consistent across the test sites and years of data

- **Wilmore (2001) –** *(refer to 2)*

- **Lawson and Dalrymple (1996)**
  - The authors present the non-linear regression equations that predict forest floor moisture content at specified depths from calculated DC values of three detailed studies in Coastal and Interior British Columbia, and Southern Yukon
  - The Whitehorse regression equation for northern white spruce (*Picea glauca*) duff may account for higher saturated moisture contents at low DC values on sites with and without permafrost where restricted drainage resulting from frozen ground persists into June north of 60˚latitude. This equation crosses the CWH curve at a DC of approximately 300, which may indicate that longer summer day lengths in the north produce lower moisture content in the forest floor than in southern British Columbia
  - The results of wide-ranging empirical field studies support the theoretical need (based on timelag) to overwinter the DC

- **Turner and Lawson (1978)**
  - In regions where winter precipitation is insufficient to saturate the deep, heavy duff fuels the "DC can be adjusted upward in the spring when daily calculations begin after snowmelt is complete"
  - "Persons responsible for operating fire weather stations which are not part of a provincial or regional network would be advised to contact the Regional Fire Weather Authority for starting code values to ensure that non-network stations receive the same treatment as network stations."
  - To determine spring DC starting values, two values must be obtained from the appropriate sources of records for FWI data and year-round weather data:
    1) The DC value reached on the last day of index calculations from the previous autumn--ideally this date should be November 1 or date of continuous snow cover or ground freeze-up, whichever comes first.
    2) Total precipitation amount in mm water equivalents for the period between the date of last calculation in autumn to the date of spring start up of calculations
  - Refer to Appendix I (Page 31) for a detailed description of the methods required for the overwinter adjustment of the Drought Code starting values

2) *Fuel moisture measurements and comparisons (also included in this topic area are references that describe the algorithms used to relate measured fuel moisture contents to the fuel moisture codes in the FWI System)*

- **Marty Alexander (*Personal Communication, 2014*)**
  - When developing empirical relationships between moisture content measurements and fuel moisture codes you need to sample a range of moisture contents
    - Destructive soil sampling procedures can include rain exclusion areas (**Otway et al. 2007**) that induce low moisture levels with correspondingly high DMC and DC codes to ensure that dry fuel moisture conditions are represented in the empirical relationships

- **Eric Miller (*Personal Communication, 2014*)**
  - None of the DC calibration equations really works well for Alaska. The Whitehorse equation **(Lawson and Dalrymple 1996)** just fits the data the least poorly
  - Preliminary data indicates that the DC should be zero at approximately 550%, which is equivalent to the field capacity of the upper duff. However, the duff moisture could be higher than this if the mineral soil layer is frozen and water is ponding.
  - To develop a calibration equation specific to Alaska you would have to evaluate historical data to see what the highest DC value you would ever probabilistically see in the field and set that value to zero percent moisture. This process would allow you to define the top and bottom ends of the DC scale
  - Ideally, a calibration equation should include data from several fire seasons

- **Brenda Wilmore (*Personal Communication, 2014*)**
  - The fuel moisture of feathermoss sites need to be studied in more detail under laboratory conditions to gain a greater understanding of the moisture dynamics, as the bulk density of feathermoss changes throughout the season. Similar studies have been done for Sphagnum moss sites
  - The data used to develop the equation in **Wilmore (2001)** was collected during two very wet years; therefore, this data needs to be combined with other fuel moisture data in Alaska that includes both wet and dry years to develop an equation that is more representative of fuel moisture conditions in Alaskan boreal forest ecosystems.

- **Lawson and Armitage (2008)**
  - "FBP System applications are more site specific and time sensitive than FWI applications. Therefore, as noted by the **Forestry Canada Fire Danger Group (1992)**, the hourly FFMC computational method is preferable for the prediction of fire behavior to both the standard daily FFMC, which has a standard diurnal curve embedded in it, and the single diurnal curve in the table presented by **Van Wagner (1972)**. In this way, hourly weather variations, rather than average diurnal weather trends, can be reflected in the fire behavior predictions." (Page 4)
  - "Users should be aware of a problem with the hourly FFMC algorithm that occurs in the absence of rain. In this situation, the diurnal amplitude of the hourly FFMC curve is unrealistically restricted during the nighttime hours. The consequence of using hourly FFMC during extended dry periods is that predictions of fire spread generated through the FBP System (or simulations of fire growth generated by a fire growth model such as Prometheus) will predict fire growth at night in excess of what would be expected in nature. In such excessively dry situations, the diurnal FFMC provides a more realistic indication of the diurnal variation in FFMC between daytime and nighttime (Fig. A2.2)." (Page 61)
  - "The diurnal FFMC model has certain limitations related to where and how it was developed. The algorithm was derived from mid-latitude field experiments, so it is not recommended for use north of 60° latitude." (Page 62)

- **Jandt et al. (2005)**
  - Duff moisture contents were determined on upland and lowland sites in Alaska with feathermoss (*Hylocomium splendens* or *Pleurozium schreberi*) using destructive sampling methods that generally follow those described by **Wilmore (2000, 2001)**:
    - Standardized squares of duff were cut (4" square on top) from live moss down to mineral soil or ice
    - 2 to 4 duff core samples having 4 layers each were collected each sampling day
    - Extracted plugs were divided into fuel layer types as follows: live moss (compared to the FFMC), dead moss (used to calculate DMC), upper duff (used to calculate DC) and lower duff
    - In the lab, the samples were weighed wet and dried at 100˚C for 24 hours or until a constant weight was attained
    - Gravimetric moisture contents were calculated for each sample layer using the equation: MC%=[(wet weight – dry weight)/dry weight – bottle weight)] × 100
  - Most weather stations were started in the spring with <u>default FWI values</u> (FFMC 85, DMC 6 and DC 15); however, the Anchorage station was started with a DC value of 50 based on low snow and over-wintered drought conditions in 2003
  - Several equations have been developed to convert duff moisture contents to DMC and DC values for varying forest and forest floor types
    - In 2000-2001, the Whitehorse white spruce/feathermoss model (**Lawson and Dalrymple 1996, Lawson et al. 1997**) worked best for the DMC, while the black spruce/feathermoss model developed locally by **Wilmore (2001)** best fit the DC observations
  - <u>Standardized collection methods</u> for destructive sampling of moss and duff moisture are required to allow comparison of data gathered cooperatively among different investigators and agencies, and data collected from different areas and times
  - Although comparison of measured duff moisture contents with the FWI values generally agreed, there were some consistent patterns of deviation
    - <u>In the spring, feathermoss may dry at a faster rate than that predicted by the FWI equations, which may result in duff conditions being drier than predicted by the DMC and DC equations in the early summer</u>

- **Beck and Armitage (2004)**
  - The FFMC tracks the moisture content of fine, dead forest fuels and may be calculated using one of three methods: 1) the standard daily FFMC which is calculated using the FWI System; 2) the application of diurnal weather trends may be used to adjust the standard daily FFMC for time of day; or 3) the hourly FFMC developed by **Van Wagner (1977)** can be applied given hourly weather inputs and an hourly FFMC program
  - On dry days, the diurnal model best tracked the amplitude of the moisture content of feathermoss fuels throughout the day
  - Both the hourly and diurnal models overestimated the minimum moisture content of feathermoss on dry days, and underestimated feathermoss moisture content following a rain event

- **Wilmore (2001)**
  - Stratification by fuel layer is more desirable than stratification by soil depth in 5-cm increments, as there is a tendency for the 5-cm depth increments to incorporate more than one fuel layer, which results in a smaller range of bulk density measurements between layers stratified by depth
  - The Douglas-fir duff used to calibrate the DC in the FWI System is much denser than feathermoss duff; therefore, the DC predicts higher moisture contents and less variability than were observed in the upper duff fuels
  - The standard DMC moisture equivalent equation under predicted the moisture contents observed in the dead moss in the spring and fall; however, it closely matched the moisture contents observed throughout the peak fire season in Interior Alaska (mid-May through mid-July)
  - Although the empirical DC moisture equivalent equation developed by Wilmore does not produce a stronger statistical relationship, it does model the steep drying phase in the spring starting values of the DC from a saturated condition, which captures the suspected drainage that occurs in permafrost soils as the active layer recedes
    - "Restricted drainage rather than overwinter precipitation seems to be the factor determining spring moisture contents in the O-horizon"
  - The **Lawson and Dalrymple (1996)** procedures do not contain all of the processes that impact initial spring moisture contents in boreal forest feathermoss sites. Results suggest that fall moisture contents in conjunction with snowpack insulation effectiveness may provide more accurate indicators of spring soil moisture recharge in permafrost sites
  - "Although the new DC moisture equivalent equation was derived from and tested on more data points than other eco-region specific equations (**Lawson and Dalrymple 1996**), fire personnel should still exercise caution when applying this formula as it does not address the actual processes affecting moisture movement in the feathermoss fuel layers"

- **Wilmore (2000)**
  - The sampling methods presented here for determining fuel moisture content are designed for repeated on-site validation/calibration of the FWI System of the CFFDRS and include:
    - Destructive sampling techniques to determine the actual moisture content of the organic soil
    - Time domain reflectometry (TDR) probe sampling procedures
  - These sampling procedures are specific to the C-2 FBP System fuel type model, which is generally accepted as the primary wildfire fuel type in Interior Alaska

- **Lawson et al. (1997)**
  - The flammability of the duff layer is important since duff consumption is the primary energy source produced by forest fire
  - This document presents the DMC equations available to convert DMC values into predicted moisture content values for duff layers in several regions

  - Knowledge of duff moisture content is required to: start a weather station late in the fire season; predict smoldering ignition for forest duff types; and compare the prediction systems for forest floor consumption with those in other regions, countries, etc.
  - Calibration equations for the National Standard and Best-fit non-linear regression equations linking DMC to forest floor moisture content in Coastal B.C. CWH, Southern Interior B.C., and Southern Yukon (Equations for: Pine/White Spruce Feather moss; Sphagnum and Undifferentiated duff; Pine/White Spruce Reindeer lichen, and White spruce/feather moss forest types) are listed in Table 1
  - The moisture contents of the southern Yukon duff types exceed those of the National Standard until the DMC increases beyond values of 35-50. These higher moisture contents may be attributed to frozen ground restricting drainage in the spring and higher moisture holding capacity of the Yukon duff (moss and lichen) relative to the national standard (needle litter).

- **Lawson et al. (1996)**
  - The FFMC tracks the moisture content of fine, dead forest fuels from day to day, and is computed each day from daily weather readings measured at noon LST
  - Although this once-per-day estimation of fine fuel moisture is useful for daily fire prevention and preparedness planning, higher resolution throughout the diurnal cycle may be required for quantitative prediction of fire behavior
  - Within the FBP System there are three available options to calculate the FFMC:
    1) Standard daily FFMC from the FWI System;
    2) FFMC at desired time *t* (between 1200 and 2000h LST), from **Van Wagner's (1972)** diurnal FFMC table; and
    3) Hourly FFMC, using hourly weather and **Van Wagner's (1977)** hourly FFMC program
  - This report presents computer code and look-up tables for a diurnal FFMC that is calculated for each hour without the need for hourly weather data. This diurnal FFMC replaces the equation in **Van Wagner (1972)**.
  - The program presented here may not be appropriate for regions north of 60˚ latitude, since the predicted trend of increasing fine fuel moisture content in late afternoon and evening represents trends in mid-latitude regions
    - During the summer at latitudes north of 60˚, litter moisture may stay near mid afternoon levels into the early evening

- **Norum and Miller (1984)**
  - This report describes in detail the methods involved in fuel moisture sampling prior to the adoption of the CFFDRS in Alaska
  - Accurately determining the duff moisture content is very important, given the way that it influences the impacts and final results of a fire
  - The feathermosses and lichens that are commonly found in the understory of black spruce forests in Interior Alaska dry and wet rapidly, and thus when these live fuels become dry they can support fuel similar to the way fine dead fuels do
  - The collection of proper material must be standardized if accurate estimates are to be achieved, and data from several locations compared

- "For information to be used as input to the NFDRS, fuels must be sampled throughout the fire season, beginning as soon as snow melts in spring and ending late in summer when no possibility of fire remains. The standard time for NFDRS weather observations is at 1400 hours, usually the warmest part of the day."
- Fuel sampling of down and dead woody fuels, litter and mosses and lichens should be sampled daily because of their quick response to changes in weather, whereas, biweekly sampling is sufficient for shrubs, grasses, herbaceous plants, duff, and conifer foliage, as moisture changes in these fuels are slower
- "The number of samples collected is less important than their quality and how well they represent the sampled area…they should span the range of conditions, elevations, positions, and situations each fuel experiences on the area expected to burn."

3) Adjustment of mid- season indices based on fuel moisture measurements

- **Lawson and Armitage (2008)**
  - In addition to over-wintering the DC *(refer to 1)*, ground-truth sampling of duff moisture content is a necessary procedure "when fire weather stations are established later in the season for some special purpose, such as servicing a campaign wildfire or prescribed burn"
    - Normally the fuel moisture codes from the nearest representative weather station are used as starting values for a weather station initiated mid-season. "However, in critical situations, ground-truth sampling results can be compared with the predicted results" for one of the calibration equations (**Lawson and Dalrymple 1996**), "and the DC from the nearest weather station can be adjusted up or down, as appropriate"

- **Jandt et al. (2005)**
  - Determining the duff moisture content at a site is useful in determining if a weather station should begin with indices set at default (saturated) conditions or some other level

- **Lawson and Dalrymple (1996)**
  - Procedures for field verification and calibration equations are not only applicable to determining the DC startup value in early spring, but also any time that a weather station is started up throughout the fire season

4) Whether data trends or raw values are more important for fire behavior prediction

- **Marty Alexander (*Personal Communication, 2014*)**
  - This topic is not specific to the CFFDRS

- **Brenda Wilmore (*Personal Communication, 2014*)**
  - Since sampling, data ranges and standard errors are so large, data trends are probably more important than raw values for fire behavior prediction

5) Impacts of using solar noon vs. non-solar noon observations

- **Ziel (2014)**
  - "…all daily Fire Weather Index values in the state are calculated from observations established as 1400 Alaska Daylight Savings Time (AKDT)…the FWI System is based on standard observations collected at 'solar' noon, when the sun is directly overhead."
  - "…because the time of maximum temperature and minimum relative humidity in high summer is progressively later as latitude increases," Van Wagner "suggested that daily observations could be delayed in the far north to eliminate much of the difference that occurs."

- **Lawson and Armitage (2008)**
  - "Deviations from the basic observation time of 1200 LST may be specified at the regional level for stations that are close to time zone boundaries, are at high latitudes, or both" (Page 11)
  - Van Wagner suggested that the observation time could be progressively delayed from noon at lower latitudes to 1400 at higher latitudes to more accurately account for daily peak fire danger conditions at higher latitudes

- **Hirsch (1996)**
  - At high latitudes the peak burning conditions may occur later in the day and last longer due to the amount of summer time daylight than at lower latitudes, where the peak burning period is assumed to be 1700 LDT, if a standard diurnal weather pattern occurs

6) Effects of errors in precipitation reporting

- **Sharon Alden (*Personal Communication, 2014*)**
  - When precipitation errors are detected for specific fire weather stations, they are either corrected using the average value of the closest weather stations, or in some instances the station is deleted to prevent the over/under prediction of the moisture codes

- **Lawson and Armitage (2008)**
  - The FWI System requires an uninterrupted daily weather record
  - The best possible estimate of the missing weather observation is necessary to maintain the continuity of the moisture codes
  - This publication provides detailed instructions on how to estimate missing weather observations that result from equipment malfunction, etc. (Page 15)
  - "Estimated values for wind and distribution of rain are usually adequate for the bookkeeping required to keep track of the moisture codes. However, the values of ISI and FWI components calculated for those days may be subject to large errors and should be treated with caution." (Page 16)

7) Analysis of any Alaskan data

- **Ziel (2014) -** *(refer to 8)*

- **Alden (2013a, 2013b) -** *(refer to 1)*

- **Barnes and Miller (2012)**
  - The FBP System uses foliar moisture content to evaluate crown fire potential
  - Even in very wet years black spruce foliage moisture content is around 100%; therefore, there is great crown fire potential throughout the fire season, as crown fire risk is high for foliar moisture contents in the range of 100-120%
  - There is very little known in Alaska about live fuel moistures; therefore, sampling efforts need to be repeated over multiple years
  - Efforts to evaluate the fit of the CFFDRS to Alaska forest ecosystems have been haphazard
  - The RAWS stations need to be calibrated with field measurements

- **Cole (2009)**
  - The report contains a detailed description of fire behavior characteristics and management strategies employed at Dune Lake and Totek Lake, Alaska
  - The FBP System was used to determine the intensity and rates of spread for the FBP System fuel types 0-1a (matted grass) and 0-1b (standing grass), C-2 (boreal spruce), and M-2 (boreal mixedwood-green)
  - July 27th 2009
    - Between 2030 to 2130 several portions of the east perimeter displayed continuous crown fire in the C-2 (boreal spruce) FBP System fuel type
    - Using the FBP System, an intensity ranking class of 5/6 was assigned, indicating extreme fire behavior and burning conditions
    - There were several days where the FFMC value was greater than 90 and the BUI was greater than 150; at a BUI=150 fuels are at their most cured state and anything above this value has little effect on fire intensity
    - Comparison of the observed fire behavior observations to the Head Fire Intensity Class Graph for the CFFDRS FBP System C-2 Boreal Spruce fuel type indicated that the fire behavior closely matched the predictions given in the CFFDRS interpretive materials prepared for Alaska (e.g., **Alexander and Cole 1995**)
  - July 30th 2009
    - Fire management efforts continued on Dune Lake where fuels "were so dry there was nearly complete consumption of the ground fuels"

- **Cronan and Jandt (2008)**
  - This report summarizes research that assessed the relationship between stand age and fire behavior in the black spruce forest type of Interior Alaska
  - Fuels data were collected from 21 sites ranging in age from two to 227 years old
  - Fuels data, seasonal weather averages and fuel moistures were used to evaluate fire behavior in each stand using existing models

- To assess the accuracy of the models, the predicted fire behavior was then tested against the actual fire behavior observations in eight of the 21 stands that were burned following the collection of the fuels data
- Results of a regression analysis suggest that predicted fire behavior reflects actual fire behavior, as there was a high degree of correlation between predicted and observed rates of spread
- "No single modeling system met all of the requirements of this project. Requirements included: the capacity to calculate rate of spread (ROS) and fire-line intensity (FLI), the flexibility to predict fire behavior over multiple fire types, and the ability to predict fire behavior over a continuous range of fuels. To meet these requirements, components of several modeling systems including BehavePlus3 and the Canadian FBP System, as well as separate crown fire behavior models were linked."

➢ **Jandt et al. (2005) -** *(refer to **2**)*

➢ **Ferguson et al. (2003)**

- Moisture sensing devices were placed at different horizons within moss and upper duff layers at sites within the boreal forest of Alaska
- *In situ* measurements were made using Campbell Scientific CS-615 time-domain reflectometers (TDRs) and supplemented with traditional sampling measurements that were collected using a standard procedure described by **Wilmore (2000, 2001)**
- *In situ* moisture sensors are useful for monitoring moisture dynamics at time scales critical for prescribed fire planning and wildfire management
- Although it is difficult to calibrate the TDR sensors, as a result of the heterogeneity of the soil matrix, which contains roots, grass, etc., TDR sensors can detect subtle changes in moisture that are not detectable from sample data. Thus, TDR sensors may be used to increase understanding of the spatial and temporal variations in fuel condition and potential flammability
- Results indicated that drying rates tend to be greater in *Hylocomium* moss than in *Pleurozium* or mixed-moss types
- "Better understanding of the quantifiable features that influence moisture flux will improve our ability to model the spatial and temporal variation in fuel moisture across the landscape and understanding of related patterns in fire spread and subsequent severity"

➢ **Rorig et al. (2003)**

- Neither the NFRDS nor the CFFDRS were developed and tested in the boreal forests of Alaska; therefore, uncertainty exists in the estimates of the actual fuel moistures from the indexes of these two fire danger rating systems
- The FFMC, DMC and DC components of the CFFDRS, and the 1-hour, 10-hour, 100-hour, and 1000-hour fuel moisture indexes of the NFDRS were computed and compared with moss and fuel stick moistures that were collected in and near the watershed of the FrostFire experimental burn
- In this study, the starting value of the DC was not adjusted *(refer to **1**)* because the moisture content of the duff layer early in the season was sufficiently high

  - **Van Wagner (1970)** found that the effect of longer daylength is offset by the lower sun angle at high latitudes, and negates any significant increase in the amount of energy available for drying the deeper organic layers that comprise the DC
  - "Unlike the deeper organic layers, the moisture content of fine fuels may be significantly affected by longer daylight hours occurring at higher latitudes," thus, litter moisture may be underestimated by the FFMC north of 60˚ latitude
  - Despite the fact that both the NFDRS and CFFDRS "were developed in different ecosystems and geographic regions, both showed value in tracking fuel moistures in Alaska"
  - Results indicate that the DMC identified the two episodes during the summer when fires actually occurred, and when moss moisture measurements were driest throughout the summer

- **Wilmore (2001) -** *(refer to 2)*

- **Alexander (1995)-Postscript September 3, 2012 -** *(refer to **8**)*

- **Cole and Alexander (1995)**
  - This report presents a fire intensity class graph for the boreal spruce forest type that was prepared using the mathematical relationships and criteria as given by the CFFDRS
  - Data from the 1983 Rosie Creek Fire near Fairbanks, Alaska is used as an example to demonstrate how to determine the fire intensity class from the ISI and BUI indices of the FWI System
    - In addition to weather observations, the BUI was required to evaluate the cumulative drying that occurred in the forest fuels

- **Norum and Miller (1984) -** *(refer to 2)*

- **Norum (1982)**
  - This report describes the prediction of wildfire behavior in black spruce forests in Alaska prior to the adoption of the CFFDRS in Alaska
  - The results indicate that fire behavior fuel model 9 accurately predicts the rate of spread of fire in black spruce forests of Alaska when the model result is multiplied by 1.2
  - Fuel model 5 is recommended for determining reaction intensity
  - The procedures outlined in this report yield accurate predictions of fire behavior in black spruce fires in Alaska, provided good quality weather forecast data is used

8) Justification for thresholds in fire danger rating charts

- **Sharon Alden (*Personal Communication, 2014*)**
  - Original threshold values used in Alaska were taken from **Alexander and Cole (2001)**; however, over the years the breakpoints have been modified

- **Marty Alexander (*Personal Communication, 2014*)**
  - No one can tell you the basis for the Alaska fire danger rating thresholds printed in various editions of the 'Alaska Handy Dandy Field Guide'

- The thresholds need to be formally peer-reviewed and published
- To develop fire danger rating thresholds, the fire climatology of Alaska needs to be determined. The fire climatology can be determined by back-calculating the fuel moisture codes and fire behavior indexes of the FWI System from historical weather records for longer term fire weather stations. The fire activity in Alaska can then be related to the six standard components of the FWI System to gain an understanding of the significance of the values.

➢ **Ziel, R. 2014.**
- Page 8 contains a table listing the current Alaska Interagency FWI interpretation thresholds

➢ **Alexander (1995)-Postscript September 3, 2012**
- A table is presented based on the Head Fire Intensity Class Graph (**Alexander and Cole 1995, Cole and Alexander 1995**) that provides an example of how one might derive fire danger rating class criteria for Alaska using the FWI component of the FWI System
    - Alternatively, there is the method described in Van Wagner (1987) used by all the Canadian provinces and territories, except British Columbia which uses a FWI/BUI matrix for broad fire danger class ratings
- FWI component values are presented for the Washington Creek Fire of June 21, 2004, and provide an example of an Extreme fire danger rating

➢ **Alexander and Cole (2001)**
- Actual fire behavior can be expected to vary from one fuel type to another at the same moisture code or index value, since the FWI System is dependent solely on weather observations
- This summary provides general interpretations of threshold values of fire danger rating based on fire research and operational experience from several years in conifer stands in the boreal forest, including Alaska

➢ **Taylor and Lawson (1996)**
- The FWI System alone or in association with the BUI is generally the most effective way to describe classes of fire danger
- Fire danger classes are based on the relationship between past fire activity and the FWI System components

Knowledge Gaps

From the above summary of the *'state of knowledge'* concerning the use of the CFFDRS in Alaska the following *knowledge gaps* were identified. This list is only intended to initiate discussion amongst the Alaska Interagency Fire Community, and is by no means complete:

1) Overwintering procedures do not contain all of the processes that impact initial spring moisture contents in boreal forest feathermoss sites in permafrost *(refer to **1, 2**)*;
2) The scale of the DMC and DC fuel moisture codes needs to be defined for Alaska fuels *(refer to **2**)*; and

3) The fire climatology in relation to the FWI System fuel moisture codes and fire behavior indexes has not been clearly defined for Alaska *(refer to **1**, 2, **8**)*

Strategies to Address Knowledge Gaps

Strategies to address the *knowledge gaps* listed above include but are by no means limited to the following:

1) Increasing communication between wildfire management agencies, especially in regards to procedures regarding the spring start up values of the DC;
2) Compiling datasets collected over several years from across Alaska to develop an Alaska specific calibration equation relating sampled fuel moisture contents to the FFMC, DMC and DC;
3) Developing innovative, cost-effective methods to estimate fuel moisture on a larger scale (e.g., *refer to **1***-relating SAR data to the FWI System fuel moisture codes);
4) Initiating research partnerships both within and between the Alaska Interagency Fire Community and potential collaborators at research institutes (e.g., University of Alaska);
5) Developing a research plan that prioritizes the information needs of the Alaska Interagency Fire Community in regards to its application of the CFFDRS to Alaska; and
6) Comparing the fit of the CFFDRS and the NFDRS to Alaskan forests. The Alaska Interagency Fire Community currently implements aspects of both the CFFDRS and the NFDRS.

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