Analysis of the American National Fire Danger Rating System (NFDRS) vs. the Canadian Fire Weather Index System (FWI) for the Superior National Forest.

Technical Fire Management-17

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TABLE OF CONTENTS

Executive Summary

This technical Fire Management Project is a comparison of the American system of fire danger rating (NFDRS) and the Canadian system of fire danger rating (FWI). The scope of the analysis area was the east zone of the Superior National Forest in northeastern Minnesota. The forests fuel types, topography, climate, weather, fire behavior, and the overall environment are more similar to Canada than any other forests in the lower 48. The fire danger indices from both systems were paired up and analyzed for accuracy and success. Each system has three fuel moisture indices and four fire behavior indices that were paired up with each systems closely related descriptor. Historical weather and fire occurrence data was used in three statistical analysis methods.

A perception exists that the Canadian system is more accurate, easier to understand a gives a better indication of fire danger than the American system. Many management decisions are made from outputs and predictions of the fire danger rating systems. As professionals in fire management strive to increase trustworthiness, precision, efficiency, and effectiveness of our decisions we should use the best science for our local environment. A system that is easy to use and is understandable to our public and fellow employees should also be a consideration.

Introduction:

This project describes the collection and analysis of historical fire weather and fire history data with the objective of making an objective assessment of the performance of both the Canadian (CFFDRS) and the United States (NFDRS) fire danger rating systems on the Superior National Forest.

The Superior National Forest in the far northeastern corner of Minnesota borders Ontario, Canada for 150 miles of its northern boundary. The 3 million acre National Forest contains 440,000 acres of lakes and 2,300 miles of streams. The 1.1 million acre Boundary Waters Canoe Area Wilderness is located within the National Forest.

It is the perception of some local fire management officers, fuels specialists and others, that the Forest should use the Canadian Forest Fire Danger Rating System (CFFDRS) instead of the National Fire Danger Rating System (NFDRS). Specifically, there is the opinion that the NFDRS over predicts fire danger. As a result, more fire management and suppression resources are used than if the Forest was using the Canadian system. An additional consideration is the simplicity in the application of the Canadian system in comparison to the NFDRS.

Background:

The perception that the Canadian system is better may be due to the close similarities in plant species, fuel types, climate, topography, land type between southern Ontario and northeastern Minnesota, which is the southern extent of the Canadian Shield. It is characterized by glacially scoured bedrock with thin deposits of course loamy till and numerous lakes. This part of the state has relatively high relief and rugged topography and contains several small mountain ranges. The region has the most snowfall and shortest growing season in the state. It contains plant and tree species, topography, and weather more like that found in Ontario, Canada than other forests in the lower 48 states.

The project area is the far northeast part of the Superior National Forest. The Superior National Forest contains boreal type forest of Jack Pine, Black Spruce and Balsam Fir along with the upper Great Lakes Pine types of Red Pine and Eastern White Pine. It also contains Birch, Maple, and Aspen with other associated hardwoods. The Superior National Forest, and the East Zone in particular, is unique in that it is the southern tip of the Boreal Forest type. Administratively, it is the East Zone of the forest and contains portions of the Gunflint Ranger District as shown in figure 1. On July 4th 1999 a microburst from a squall line created a massive “blowdown” of timber over 400,000 acres of the Superior National Forest. Much of the blowdown occurred within the Boundary Waters Canoe Area Wilderness. The existence of these heavy and continuous fuels on the Forest has added concern to fire managers about all aspects of the fire management program, particularly prevention and prescribed fire programs for the next 10 years.

The completion of this project required the accessing databases of historical fire weather and fire occurrence data in order to perform the danger rating system comparisons. Fire weather observations for 1977 through 2003 were obtained from the National Interagency Fire Integrated Database (NIFMID) for the Gunflint Ranger District Seagull Guard stations' Remote Automatic Weather Station (RAWS). Fire occurrence data for the Gunflint District for the same period were also obtained from the NIFMID.

Fuel model G was used for all of the fire analysis runs in Firefamily Plus. Fuel Model G is used for dense conifer stands where there is heavy accumulation of litter and down woody material. Such stands are typically overmature and may also be suffering insect, disease, and wind damage. The 1999 blowdown event heavily occurred within this project area. The duff and litter are deep and much of the material is greater than three inches in diameter.

Problem Statement:

The Superior National Forest uses the National Fire Danger Rating System to make operational fire management decisions, produce staffing requirement guidelines, engage fire restrictions, and provide fire prevention information to the public. The Forest Fire Management Officer(s) and Fuels Specialist(s) are uncertain whether the Canadian Forest Fire Danger Rating Systems-Fire Weather Index or the National Fire Danger Rating System gives them the most appropriate information to help them make more prudent, efficient management decisions. No comprehensive analysis has been done on the Superior Forest to provide guidance for resolving this question.

Goal:

Guiding principles number 5 and 6 in chapter 3 of the 2001 Federal Wildland Fire Management Policy promotes economic viability and using the best available science.

The Forest Supervisor, Forest Fire Management Officer, and Forest Fuels Specialist are looking to use the fire danger rating system that allows them to make the best fire management decisions they can, accurately reflect actual conditions, and is efficient and easy to use.

Objectives:

Determine which system, NFDRS or CFFDRS most accurately models fuel moisture and fire behavior descriptors for the area.

Determine which system is most accurate in predicting actual fire activity.

General Descriptions

NFDRS: National Fire Danger Rating System

In 1968, work began on a fire danger rating system that would be designed around science and engineering principles rather than local observations (Bradshaw et. al., 1983). Basic laws of physics of moisture gain and loss, as driven by local weather conditions, were used to make the fire danger rating system applicable anywhere in the country. In 1972 the development of the deterministic fire behavior model (Rothermel 1972) allowed for significant advances in the fire behavior modeling aspect of fire danger rating. The first national version, operated manually using tables and nomograms, was released in 1972. In contained nine fuel models that covered grasses, shrub, timber, and slash fuel type. In 1978 what is essentially the current NFDRS was released (Deeming and others, 1977). It is based on mathematic and physics models that systematically integrate the physics of combustion between 20 fuel models, weather, topography, and risk. NFDRS tracks the effect of previous weather events on live and dead fuels and estimates future effects based on predicted weather conditions. It had supporting computer programs such as AFFIRMS (Helman et. al. 1987) to produce daily indexes and archive fire weather observations. And there were computer programs to access the archived data (Furman and Brink, 1975) and run fire weather climate analysis (Main et. al. 1982). In 1988 a minor update was released to better tune the system to users in the southeastern United States. Currently the NFDRS is supported by various computer systems including the US Department of Interior, Bureau of Land Management's ASCADS program that delivers hourly weather observations from RAWS stations to the USDA Forest Service's Weather Information Management System (WIMS) where NFDRS calculations are performed and fire weather observations continue to be archived. Application of the NFDRS is supported by Firefamily Plus (Bradshaw and McCormick, 2001) which continued the tradition of fire weather climate analysis started with the original FireFamily computer programs in the early 1980s.

Defining Fire Danger Rating

"The resultant descriptor of the combination of both constant and variable factors which affect the initiation, spread and difficulty of control of wildfires on an area" (Deeming et al., 1972). The various factors of fuels, weather, topography and risk are combined to access the daily fire potential on an area. Since many of the factors (fuels, weather, topography) and terminology (spread and intensity) that are a part of NFDRS are those that also affect fire behavior predictions, fire danger and fire behavior are often confused and misused. The main difference is that fire danger is a broad scale assessment, while fire behavior is site specific. Fire danger ratings describe conditions that reflect the potential, over a large area, for a fire to ignite, spread and require suppression actions. And, based on the location of the weather station and time of observation, the NFDRS fire danger rating is designed as a 'worst case' estimate.

Fire behavior deals with an existing fire in a given time and space by describing the movement, intensity and combustion of that fire. This definition or differences between fire danger and fire behavior were difficult for me to separate or conceptualize during my analysis and early stages of this project. As I discovered during my research, this is one of the major differences of the Canadian system and NFDRS.

The Structure of NFDRS

There are three major components in the structure of NFDRS: *Scientific basis*, *User controlled site descriptors*, and *weather/non weather data inputs*. The *scientific basis* uses mathematical models to calculate fire danger. These models represent basic principles of combustion physics. Fuel characteristics such as ignition temperature, rates of combustion, moisture of extinction, chemical properties and heat energy were laboratory determined (Schlobohm and Brain, 2002).

The other 2 components of NFDRS:

<u>User controlled site descriptors</u>	<u>Data Inputs</u>
-Fire danger rating area	-weather data
-Fuel Models	-state of herbaceous vegetation
-Slope class	-measured woody fuel moisture
-Live fuel type	-season codes
-Climate class	-greenness factors (green up date)
-Annual precipitation	-season codes, and KBDI initiation

The selection of a fuel model, or fuel models is a big part of the application of the NFDRS. There are 20 fuel models in the current NFDRS, but the 1988 update actually updated the existing 20 fuel models such that the user has two fuel models systems (1978 or 1988) each with 20 fuel types to choose from when using NFDRS. The details between the model systems and fuel types is beyond the scope of this project but is a principal reason that the NFDRS is more cumbersome to use than the CFFDRS.

<u>Definitions of fuel moisture descriptors</u>:

1 hr. timelag fuels: Dead fuels consisting of herbaceous plants or roundwood less than ¼ inch in diameter. Also included is the uppermost layer of litter on the forest floor.

10 hr. timelag fuels: Dead fuels consisting of roundwood in the size range of one quarter to one inch in diameter and, very roughly, the layer of litter extending from just below the surface to three-quarters of an inch below the surface.

100 hr. timelag fuels: Dead fuels consisting of roundwood in the size range of 1 to 3 inches in diameter and, very roughly, the forest floor from three quarters of an inch to four inches below the surface.

1000 hr. timelag fuels: Dead fuels consisting of roundwood 3 to 8 inches in diameter or the layer of the forest floor more than 4 inches below the surface.

Live Woody Fuels: Naturally occurring fuels whose moisture content is controlled by the physiological processes within the plant. The NFDRS system considers only material small enough to be consumed in the flaming front *(leaves, needles, and twigs).*

Live Herbaceous Fuels: A plant that does not develop woody, persistent tissue but is soft and sprouts from its base (perennials) or develops from seed (annuals) each year. Included are grasses, forbs and ferns.

Definitions of Fire Danger descriptors:

Ignition Component (IC): A rating of the probability that a firebrand will cause a fire requiring suppression action. It ranges on a scale of 0 to 100.

Spread Component (SC): A rating of the forward rate of spread of a headfire. Wind speed, slope and fine fuel moisture are the key inputs into calculating SC. The SC has an open ended scale, thus with no upper limit.

Energy Release Component (ERC): A number related to the available energy (BTU) per unit area (square foot) within the flaming front at the head of a fire. It is a reflection of all the available live and dead fuels have to potential fire intensity. The scale is open ended and is relative.

Burning Index (BI): A number related to the contribution of fire behavior to the effort of containing a fire. The BI is an indicator of difficulty of control and is a combination of spread component and energy release component.

NFDRS Structure

(taken from 2002 NWCG publication PMS-932 "Gaining an understanding of the National Fire Danger Rating System")

Application of NFDRS

During the development of the NFDRS it was designed that it be a relative, not absolute system and that the application of the information would essentially be "climatology" based. That is, given a history of weather at a location, the fire danger climatology of the area would be the basis for establishing certain fire management activities. It was decided that it would be a threshold-exceedence based system. The Forest Service established the values of the 90 and 97 percentile levels for high and extreme levels of fire danger. These values serve as the basis for computing staffing levels for internal affairs and adjective ratings for public information. Using climatological thresholds based on percentiles also was a method where the differences in fire danger indexes caused by differing fuel models could be normalized to compare areas using different fuel models.

FWI: Canadian Fire Weather Index System

Research on forest fire danger and fire behavior rating began in Canada in 1925. In the next several decades four different fire danger rating systems were developed. Although somewhat different and improved, each version was one of evolution from the previous version, not a complete change. Certain information and features were retained from system to system. The original version of the Fire Weather Index system was issued in 1970. Simplification increased with respect to weather measurements and methods of calculation. There was a philosophy to base danger ratings on field experiments analyzed by empirical mathematics. Physical theory, although used qualitatively to good advantage in the design of the experiments, was not used directly in the analysis leading to the final results (Van Wagner, 1987). As a result of this philosophy, there exists a great body of field data of three kinds: weather readings, fuel moisture contents, and small test-fire ratings all linked together. It is also worth mentioning, the Canadian Fire Behavior Prediction System (FBP) also uses many decades of observation data on wildfires and prescribed burns as its basis.

The Canadian philosophy of using field-based measurements (statistics based) versus the United States philosophy of using deterministic models (physics-based) for the drying and wetting of fuels is the major difference between the two systems.

Defining Fire Danger (Merrill and Alexander 1987)
"A general term used to express an assessment of both fixed and variable factors of the fire environment which determines the ease of ignition, rate of spread, difficulty of control and fire impact."

FWI: The Structure of the Canadian Fire Weather Index System

The Canadian Forest Fire Danger Rating System (CFFDRS) is the national system for rating fire danger in Canada. The Canadian Forest Fire Weather Index (FWI) System is a sub-system of the CFFDRS. The purpose of the FWI System is to account for the effects of weather on forest fuels and forest fires (Alexander and Van Nest, 2003). The FWI System is comprised of six components; three fuel moisture codes and three fire behavior indexes. The FWI System uses temperature, relative humidity, wind speed, and 24-hr precipitation measurements made at noon local time. These values are used to predict the peak burning conditions that will occur during the heat of the day usually around 1600 hrs. ((1)) The fuel moisture codes describe the different depth and size of fuel and water holding capacity and drying time. The Fine Fuel Moisture Code (FFMC) represents the daily affect of rainfall and relative humidity on fire potential. The larger and deeper fuels, represented by Duff Moisture and Drought Codes (DMC and DC), represent drying day length and seasonal progression (Van Wagner, 1987).

The three moisture codes plus wind are linked in pairs to form two intermediate indexes that are in turn combined to yield the final index of FWI. The FWI system uses a single generalized fuel type of a pine forest. Fuel moisture data from Jack/Lodgepole pine and Red/White pine stands were used in the development of the system.

The three moisture codes and corresponding fuels are:

1. *Fine Fuel Moisture Code* (FFMC), which represents the moisture content of litter and other fine fuels in a forest stand less than 1 cm in diameter. The FFMC is the top layer 1-2 cm deep. This code indicates the relative ease of ignition and flammability of fine fuel.
2. *Duff Moisture Code* (DMC), represents the moisture content of loosely compacted, decomposing organic matter. This duff layer is 5-10 cm deep. This code indicates fuel consumption in moderate duff layers and medium sized woody material.
3. *Drought Code* (DC), represents a deep layer of compact organic matter approximately 10-20 cm deep. This code indicates seasonal drought effects on forest fuels, and the amount of smoldering in deep duff layers and large logs.

The three fire behavior indices:

1. *Initial Spread Index* (ISI), a numerical rating of the combination of wind and the FFMC that represents the expected rate of spread.

2. *Buildup Index* (BUI), a numerical rating of the total amount of fuel available for combustion that combines DMC and DC.

3. *Fire Weather Index* (FWI), a numerical rating that combines ISI and BUI. This indicates the fire intensity by combining the rate of spread with the amount of fuel being consumed. This is suitable as a general index of fire danger.
   (De Groot, 1987).

Structure of the Canadian Forest Fire Weather Index (FWI) System

(taken from the Canadian Forestry Service technical report #35 “Development and structure of the Canadian Forest Fire Weather Index System”, 1987)

Application of CFFDRS – FWI)

Since the Canadian FWI system is based on fuel moistures from similar forest types and only one type of fuel is used the fire danger codes, the FWI does not have the problems of comparing outputs from different fuel model.

For the comparison of the National Fire Danger Rating System and the Canadian Fire Weather Index System I used the index pairs listed below. The pairs indicate the indices that are most similar in each system's model structure.

American NFDRS		Canadian FWI
10 hr. fuel moisture	vs.	Fine Fuel Moisture Code (FFMC)
100 hr. fuel moisture	vs.	Duff Moisture Code (DMC)
1000 hr. fuel moisture	vs.	Drought Code (DC)
Ignition Component (IC)	vs.	Fine Fuel Moisture Code (FFMC)
Spread Component (SC)	vs.	Initial Spread Index (ISI)
Energy Release Component (ERC)	vs.	Buildup Index (BUI)
Burning Index (BI)	vs.	Fire Weather Index (FWI)

Analysis Methods and Data

Fire danger rating systems are basically climatology based systems and indexes are most meaningful when compared with historical values. Associating historical fire activity with indexes provides information to assess the effectiveness of an index. (Andrews et. al. 2003). The USDA Forest Service, Fire and Aviation Management maintains the Weather Information Management System (WIMS) where NFDRS indices are computed, and the National Interagency Wildland Fire Integrated Database (NIFMID) where historical fire weather observations and fire occurrence records are stored. Public access to the historical data is via website (http://famweb.nwcg.gov/weatherfirecd/.)

Andrews and Bradshaw (1997) describe a method and computer program (FIRES) designed to assist in analysis of fire danger rating systems. The function of the FIRES program is included in the newer FireFamily Plus (Bradshaw and McCormick, 2001) program. The program has the capability of producing both Canadian FWI and NFDR rating indexes from a daily weather stream.

As noted in the Background section, fire weather observations for 1977 through 2003 were obtained from the NIFMID for the Gunflint Ranger District Seagull Guard Station along with fire occurrence data for the Superior National Forest, Gunflint District for the same period. These data files were loaded into FireFamily Plus to perform the analysis. As also noted in the background, the NFDRS requires selection of a fuel model to produce fire danger indexes. Fuel model G (Short Needle Pine with heavy dead) was used for all of the fire analysis runs in Firefamily Plus. Model G is used for dense conifer stands where there is a heavy accumulation of litter and down woody material. Such stands are typically overmature and may also be suffering insect, disease, and wind damage. The 1999 blowdown event heavily occurred within this project area. The duff and litter are deep and much of the material is greater than three inches in diameter.

FireFamily Plus provides two standard analysis tools that compare the fire danger indexes and fire occurrence. This is done by associating fires, usually from an administrative unit to weather at a nearby fire weather station. Then, for every day of weather, it is noted whether there was a fire with that discovery date on the unit. If so, the day is called a fire-day. If not, it is called a no fire-day. If the day is a fire-day, the program examines the cause(s), number and size of fires discovered that day. Based on user defined thresholds, the fire-day is further classified as a large-fire day (yes or no) and a multiple fire-day (yes or no). Once these classifications are made, one can look at the statistical attributes of fire danger indexes for different fire-day types.

The first statistical tool in FireFamily Plus is logistic regression. Logistic regression is useful for analyzing relationships between scalar independent variables and binary outcome variables. A binary variable is one that can be only two values, such as yes/no or on/off. Because of the fire-day/no-fire day classification fire-day is a binary variable.

Logistic Regression Analysis

I used Firefamily Plus to run logistic regression analysis on fire activity associated with the Gunflint ranger Districts Seagull RAWS weather station. The analysis covered the years 1977 through 2003 because the Seagull weather station has no data prior to 1977. As described above, the fire danger index is the independent variable and the binary response variables are fire-day, multiple fire-day and large fire-day   And I used Fuel Model G for all the NFDRS analysis runs while the FWI does not require a fuel model designation. The analysis was split into spring (April 1st – May 31st) and summer (June 1st-October 31st) fire seasons. These are the typical fire seasons in this region of NE Minnesota and South Central Ontario.

I used the chi-square statistical tables produced by FireFamily Plus to quantify how the various indexes compared to each other. The chi-square test is useful for testing categorized variables and is a way to quantify the FireFamily Plus graphs with the model and goodness of fit data points. The smaller the chi-square statistic the better the index fits the data. A large chi-square means that the model does not do to well at predicting (expected) compared to the observed. A small chi-square value means a close agreement between the expected and the observed fire occurrence. A null hypothesis may be that a model has no more "skill" than picking using a random number. I can reject the null hypothesis when the probability of obtaining a larger chi-square is greater than a threshold value, depending on the degrees of freedom (DF) in the table. This regression model always has 8 degrees of freedom because it has 10 rows (categories). The limiting values of chi-square at 4 confidence levels for 8 degrees of freedom are:

P-Value, 8 DF	10% (0.10)	5% (0.05)	1% (0.01)	.1% (0.001)
Limiting chi-square	13.36	15.51	20.09	26.12

The next page is an example of two fire statistical analysis runs I used comparing FFMC and FM10. After those two examples a summary table and graph are shown. The remaining runs are located in the appendix.

Percentile Analysis

The second statistical tool in FireFamily Plus is called percentile, or cumulative distribution analysis. Here, FireFamily Plus separates out the fire danger index into four distributions based on all-days, only fire-days, only large fire-days, and only multiple fire-days. By visually observing the curves, one can more easily compare the distributions of all days, fire days, large fire days, and multiple fire days. The shifting, or separation of the curves to the right (or left in some cases) shows the effectiveness of a particular index in discriminating fire-days from non-fire days. In order to quantify the distribution shift of the curves I measured the differences in the percentiles and the sum of the differences as a single number to quantify the shifts and documented in Andrews 2004. A higher sum of the differences, at the pre determined index values, indicates a greater shift thus a better index than its corresponding index. In this case NFDRS versus corresponding Canadian FWI indexes.

Using Firefamily Plus I ran the cumulative analysis and printed out the cumulative distribution curves (percentiles). Again Fuel Model G was used for the NFDRS analysis using the Seagull RAWS station weather data from 1977-2003 and fire occurrence data from the Gunflint Ranger District. The table below and the two percentile graphs, on the following two pages, are how I measured and quantified the distribution shifts for the FWI and BI indexes. The remaining tables and graphs are located in the appendix.

Success Ratio Analysis

I developed a third analysis method that is not in FireFamily Plus that I call the Success Ratio. The ratio analysis is a comparison of predicted days at the high, very high, and extreme fire danger levels and actual fire activity on these days. It is the success of the various predicted indices and actual fire activity. The larger the ratio value the better that index is compared with its corresponding index. A ratio of one would mean a perfectly successful index for that fire season year. I converted the decimal ratio to a percentage to perhaps more easily visualize the results. The percent of predicted days at index values of high, very high, or extreme, matching up with actual fire days is the percent success of that index at predicting fires.

For this analysis I only used the two indices of Burning Index (BI) and Energy Release Component (ERC) along with their associated Canadian Indices of Fire Weather Index (FWI) and Buildup Index (BUI). The reason being these indexes are what we presently use here to set the staffing guidelines. Again I split the fire season into spring and summer seasons.

Below is an example of fire occurrence data and the season severity output for the days above the high fire danger. I manually associated all fire activity with those days above high fire danger.

Alternatives

1. Continue using the present American System of Fire Danger Rating to set staffing guidelines, fire danger ratings, and make fire management decisions.

2. Use the Canadian Fire Weather Index system to set staffing guidelines, fire danger ratings, and help make fire management decisions.

Recommendation:

The recommended alternative is number 2.

Please reference Table 13 on the next page.

The results of the statistical analysis for chi-square goodness of fit were split between the two systems in the indices model performance. The NFDRS index models performed better during the summer fire season. The FWI system performed slightly better during the spring season.

The results of the percentile analysis were clearer in the results. The Canadian system showed a much higher sum of the differences. The Canadian index descriptors showed a greater curve shift, thus a better index in this analysis method.

The results of the success ratio analysis for the four indexes that were analyzed showed the Canadian system performed better at predicting wildfire occurrences at all levels above high fire danger.

Conclusion:

After performing the analysis of the two systems at this location, the Canadian system performed better than the American NFDRS system. The FWI system performed better in two of the three analysis methods. After reading various literature, history, and structure pertaining to both systems, I found the Canadian system to be less cumbersome, easier to understand, and easier to interpret. The development of the FWI system was one of evolution of many decades of weather observations, fuel moisture contents, test fires and wildfire observations. The Canadians have been observing fire weather and fire occurrences and related field data into the development. With this development philosophy, I think the system has been simplified and is easier to understand and calculate. The similarities in weather, fuels, and terrain of Ontario Canada with northeastern Minnesota should be a consideration in deciding which system to use.

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