THE METHOD FOR CALCULATING FOREST FIRE BEHAVIOR INDEX

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ABSTRACT

The method for calculating forest fire behavior index is studied through the practises in DaXing AnLing during 1984 to 1988. It is proved that the method is suited to the forest regions of our country. According to fuel type and four meteorological factors (temperature, relative humidity, wind speed, rainfall), the method can calculate the fire behavior indices of different topography and fuel type condition, such as rate of spread, flame height, fire perimeter, fire area and fire danger class etc. It is not only suited to single station (small region), but also is suited to more stations (large range). So the method can provide the dependable basis for fire agencies for predicting fire danger and fire behavior and making a decision.

INTRODUCTION

The method for calculating forest fire behavior index is developed on the basis of the application of the Canadian Forest Fire Weather Index System, which is made to suit the forest areas of our country. The method will explain three problems in relation to the specific situation of the time: (1) How is probability of ignition in certain weather condition? (2) How is rate of spread after catching fire? (3) How difficult is it to control a spread fire? Relying on the calculated results, the headquarters of forest fire may issue the various information and data, such as fire danger class, rate of spread, fire area and fire perimeter, etc. So the method will provide dependable basis for analysing the trend of fire and making a decision.

THE STRUCTURE OF FOREST FIRE BEHAVIOR INDEX

In the forest fire behavior index system, weather is considered a basic factor which effects combustibility of forest fuel and fire behavior. But fire behavior is also greatly influenced by the topography and fuel type. In order to calculate the influencing degree of weather on the condition of fire, it is essential to assume that the fuel type and the change in topography are constant. On relatively flat topographical condition, there are four weather factors which are involved in the calculation of forest fire behavior indices. They are temperature (T), relative humidity (H), wind speed (W) and rainfall (R). Normally, the weather readings at solar noon 14 : 00 are applied. For at that time, T is the highest, W is the largest and H is the lowest of the day. Thus the forest fire behavior indices represent really fire danger peak of the day.

Each of forest fire behavior indices is derived from the calculation of the three moisture codes, which are Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and Drought Code (DC) respectively. Each of these moisture codes is expressed in terms of digital data based on the moistthe moisture codes of the day is obtained from adding the adjusted moistening or drying digital information to that of yesterday.

1. The Fine Fuel Moisture Code (FFMC)

The FFMC represents the moisture content of litter and cured fine fuel which layer is about 1cm to 4cm in thickness. The weather factors involved in calculating FFMC are T, H, W and R, and the value of lastday's FFMC is also needed in calculation. As fine fuel is all exposed, it is prone to the weather condition change. Fine fuel only intercepts a portion of rainfall equal to a few mm and it is easiest to get saturated and also to get evaporated. Therefore the value of FFMC represents the moisture condition of the fuel layer, and as most fires are caused by fine fuel, the value of FFMC is most likely to be taken as the indices of the flammability.

2.The Duff Moisture Code (DMC)

The DMC represents the moisture content of loosely compacted, decomposing organic matter 5cm to 10cm in deepth. It is easily influenced by T, H and R. To use the several weather factors with lastday's DMC, the DMC of the day may be calculated. The value of DMC represents the moisture condition of fuel layer which decides the intensity of forese fire in great degree.

3. The Drought Code (DC)

The DC represents the moisture content of the deeper organic layers commonly about 10cm to 20cm in deepth. It is influenced mainly by T and R. So the readings of temperature and rainfall are involved in calculating the value of DC. Timelag of DC may be as long as 52 days and that shows the fuel of deeper layer duff has a greater absorbing ability, which is abont the same as 200 mm rainfall. Since the value of DC is sensitive to seasonal drought, it becomes an important index which can predict an underground fire.

4. The Fire Behavior Index

(1) The Initial Spread Index (ISI)

The ISI is the index which relate itself with spreading rate after a fire is caught. It is influenced by dried degree of fine fuel and wind speed. The value is calculated through the conbination of wind speed with the FFMC. It represents the rate of spread, but doesn't submit to amount of fuel.

(2) The Buildup Index (BUI)

The BUI is a assessment of amount of availble fuel involved in fire.It is obtained from the combination of DMC with DC, among which, the DMC make a largest contribution to BUI.

(3) The Fire Weather Index (FWI)

The FWI is a compound of the three moisture codes, ISI and BUI. It is the intensity index of the spreading fire, as energy output rate per unit of fire front.

Now we list the table 1 about the relation of FWI with fire intensity and with possible fire behavior in a standard forest (Larch forest).

As in the calculating formulas of fire behavior index, the 29 formulas of Canadian Forest Fire Behavior Index System have been taken and repeated outdoor tests have been applied to, on the where they are suitable to the actual situations of forest regions in our country. Thus we have studied the problems as follows:

A. The effect of weather condition of water capacity of forest fuel.

B. The effect of wind and fuel on rate of spread of forest fire.

C. The effect of amount of fuel on fire intensity.

Therefore, it has explained the interrdationship of weather condition with the moisture of fuel and the moisture of fuel with fire behavior.

The calculating program is designed in modular structure on the pc–1500 computer and IBM microcomputer. The program includes multifunction as follows: (a) Calculate everyday's forest fire behavior index. (b) Calculate historic forest fire behavior index. (c) Culculate everyhour's forest fire behavior index. (d) Calculate large areas forest fire behavior index. After inputting four weather factors (T, H, W, R) and lastday's FFMC, DMC, DC, then by the fuel type, the fire behavior indices in different topography and time, such as rate of spread, fire area, fire danger class etc, may be calculated.

Table 1 Relation of FWI with firer intensity and with fire behavior

FWI	fire intensity in fire line	possible fire behovior
0–4	0–26	self–extinction
5–9	26–87	smothering
10–14	87–260	slight surface fire
15–21	260–870	middle surface fire
22–31	870–2600	strong surface fire
32–47	2600–8700	occur spotfire (individul crown fire)
48–66	8700–26000	crown fire
>67	>26000	buidlup (fire storm, whirl–wind of fire)

The noticeable points in the process of calculation are as follows:

(a) To determine the initical date and the initical value of FFMC, DMC, DC.

If the normal layer of snow exists in winter, the third–day after the dissolution of the snow layer in this region is the initical date. In this case, the value concerning the moisture codes of the previous day should be taken in the following way through practicing: FFMC = 85, DMC = 6, DC = 15. If there isn't a obvious layer of snow in winter, the third–day in which the temperature at 14 : 00 has continusely been over 12℃ in this region is the initical date. In this case, the initical value will be: FFMC = 85, DMC = 2α, DC = 2α (α–the number of day after measured oneself rainfall). "The measureable rainfall" must be over 1.5mm in relation the value of DMC and over 2.9mm in relation the value of DC.

(b) To decide the forest fire danger class.

After the calculation of the fire behavior indices, the fire behavior indices, in general, may be divided into five danger classes according to the actual condition of every region. Based on the materials obtained of the value of fire behavior indices in spring form JiaGe DaQi of DaXing AnLing area from 1981 to 1983, the fire danger classes are divided as follows:

Table 2 Fire danger class

Danger class	the value of FWI
I	0–4
II	5–9
III	10–22
IV	23–36
V	>37

THE APPLICATION OF THE METHOD FOR CALCULATING FOREST FIRE BEHAVIOR INDEX

1. In spring 1985, 42 fires occurred in the patroling areas of JiaGeDaQi aviation station. Table 3 and table 4 are made to explain the relation of the number of fire with fire danger class, the number of fire with FFMC.

Table 3 Relation of the mumber of fire with fire danger class

FWI	0–4	5–9	10–22	23–36	37⁺
danger class	I	II	III	IV	V
number of fire	0	1	5	6	30
percentage	0	2.4%	11.9%	14.3%	71.4%

Table 4 Relation of the number of fire with FFMC

FFMC	0–62	63–80	81–86	87–90	90⁺
number of fire	0	0	3	2	37
percentage	0	0	7.1%	4.8%	88.1%

The analyses show that forest fire behavior index is a relative measurement of the fire intensity in fact. It synthesizes three factors such as probability of ignition, the initial rate of spread, fire energy. The value of FWI may be used to predict fire danger class. It can indicate the actual situation through comparing with the number of fire. For example, while class IV and class V, the total rate of fire is 85.7%. Futhermore, the value of FFMC can also be used to divide the class of probability of ignition. For instance, when fire rate is 88.1%, all values of FFMC are over 90. So the value of FFMC can reflect the probability of ignition. Because it is related directly to the water capacity of fine fuel which is easiest to catch fire.

2. The analysis of various indices of extra–large fire taken place in working region of MuNan.

It was in 1985, An extra–large fire was taken place in working region of MuNan from May 11 to 14. It covered as large as 7680 ha (hectare). With the weather information offered by DaXing AnLing meteorological station, the daily FFMC, ISI, FWI and FFMC, ISI, which are calculated one time per three hours, have been worked out, and based on that, the rate of spread is obtained, as is showed in table 5 and figure1:

Table 5 Daily fire behavior indices of the extra–large fire in MuNan.

date	time	FFMC	ISI	FWI	rate of spread (m / min)
May 11	14 : 00	94	39	55	46.6
May 12	14 : 00	97	46	62	53.3
May 13	14 : 00	96	38	38	31.7
May 14	14 : 00	96	44	44	35.0

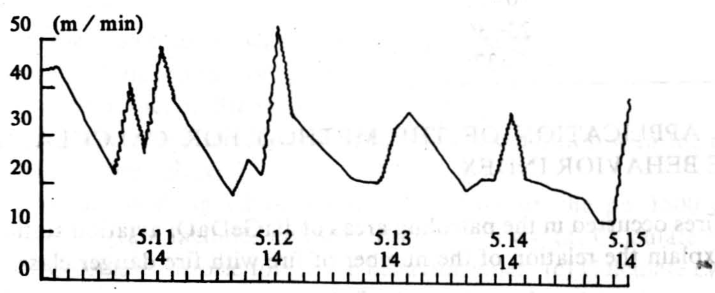

Fig.1 The location chart of rate of spread during the 5 days and nights of the extra–large fire in MuNan

During that period, the FFMC was of large scale. Namely, water capacity was very low. So probability of ignition was high. In May 11, the wind speed was 9m / s. The ISI was 39. The rate of spread was 2.8 km / hr or nearly 50m / min. The rate of spread was too fast. The fire behavior index expresented fire intensity was 55, which was the equivalent to that of 1500 kw / m energy. Before a fire such a high intensity, it was difficul for the fire crew to get near to the firing areas. It is the most dengerous time at 14 : 00–17 : 00 pm. If it had occurred in the morning, the situation would have been better.

3. The analysis of various indices in "5.6" extra–large forest fire

An extra–large forest fire had be taken place in north forest region of DaXing AnLing Since May 6 to June 2 in 1987. It covered as large as 1140 thousand ha. According to the weather information offered by AMuEr meteorological station, DaXingAnLing area, the various indices in different times from May 6 to 8 have been calculated, as is shown below:

Table 6 The fire behavior indices and the rate of spread in different times

date	time	windspeed (m / s)	FFMC	ISI	FWI	rate of spread in different slope (m / min) 0 °	15 °
May 6	14 : 00	6.0	96.9	33.1	25.2	41.1	85.1
May 7	14 : 00	6.0	98.1	38.5	31.6	49.8	103.1
May 7	20 : 00	8.0	98.1	55.7	43.5	73.3	151.7
May 7	21 : 00	10.7	98.2	91.5	63.1	94.1	194.8
May 7	22 : 00	13.0	91.0	139.9	85.8	99.5	206.0
May 7	23 : 00	20.8	98.3	579.7	197.8		
May 8	02 : 00	9.0	93.6	25.1	31.8	24.6	51.1
May 8	14 : 00	6.0	98.3	21.1	29.6	19.5	40.4

It is indicated that all values of FFMC are over 90. The water capacity of fine fuel is extremely low. Probability of ignition was as high as class V. On the other hand, it would be easily on fire once there was any source of fire. So several spots were on fire at 14 : 00 May 6. At that time, the wind speed was 6m / s. The ISI was 33.1. The rate of spread was 85.1m / min or 5.1km / hr (Because the average slope in the forest regions of MoHe and AMuEr is about 15 ° , the rate of spread on 15 ° is used). On May 7. because of the larger frontal fire, had greatly reinforced the fire. In the various indices calculated, the rate of spread was 49.8m / min at 14 : 00 in AMuEr. At 20 : 00, the ISI was added to 55.7. The rate of spread was 151.7m / min. The large fire in TuQiang marched toward AMuEr at 19 : 50 and reached at 23 : 10. The total distance was 30 km. The average rate of spread was over 150m / min. And the whirl–wind of the fire had been formed. At 22 : 00 the wind speed was even higher. The ISI reached 139. The rate of spread was 206m / min or 12.4km / hr. It was so fast that the fire crew couldn't catch up with the fire spread. The FWI, which shows the fire intensity, was 85.8. Its energy was the same as that of 26000 kw / m or more. Before the extra–large fire such a high intensity, it was very difficul to put out the fire. When the whirl–wind of the fire was passing the AMuEr at 23 : 00, the instantaneous wind speed was 20.8m / s, and over 9th class. The ISI was more than tens times higher than the ordinary. The actual rate of spread then was equivalent to that of the wind speed, nearly 60km / hr. This kind of fierce fire went forward while houling and caused the long distance spotfire which was averagely 400m or 500m, and sometimes as far as 2000m or 3000m. At the same time, it was occurred that there were pillars of convection, which were as high as handreds m, even over 1000m. This kind of fire can only be watched rather than put out. The fire crew could do nothing but waiting for a chance to take any measures.

Through the calculation of the fire behavior parameters, fire area, fire perimeter, fire width, and rate of spread in different time and slope may be obtained. For instance, we list the calculating datas at 14 : 00 May 6 in table 7 and table 8.

Table 7 The various indices of fire behavior

spread hour	fire area (ha)	fire perimeter (m)	fire width (m)	rate of spread (m / min)	ISI
1	249.5	6241	1288	41.1	29.5
2	1104.9	13134	2711	45.4	31.5
3	2742.9	20693	4272	49.8	33.7
4	4874.5	27586	5695	45.4	31.5
5	7329.5	33827	6983	41.4	29.5
6	9660.1	38835	8017	33.0	25.7
7	11190.5	41798	8629	19.5	19.5
8	12833.5	44761	9240	19.5	19.5

Table 8 The rate of spread in different time and slope (m / min)

Slope	12 : 00	13 : 00	14 : 00	15 : 00	16 : 00	17 : 00	18 : 00	19 : 00	20 : 00
0	33.0	37.0	41.1	45.4	49.8	45.4	41.1	33.0	19.5
5	39.9	44.7	49.7	54.9	60.2	54.9	49.7	39.9	23.6
10	51.2	54.7	63.8	70.5	77.3	70.5	63.8	51.2	30.3
15	68.3	76.5	85.1	94.0	103.1	94.0	85.1	68.3	40.4
20	94.3	105.7	117.5	129.8	142.4	129.8	117.5	94.3	55.8
25	135.7	152.0	169.1	186.8	204.8	186.8	169.1	135.7	80.3

It is showed in the applications that the Method For Calculating Forest Fire Behavior Index is very useful for making the correct decision, decreasing the loss of resource, and lowering the extinguishing expenses. This method may be applied to different level of fire agencies, and thereby improve the policy–making ability in forest fire management. Therefore, it has a wide prospect in applications.

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