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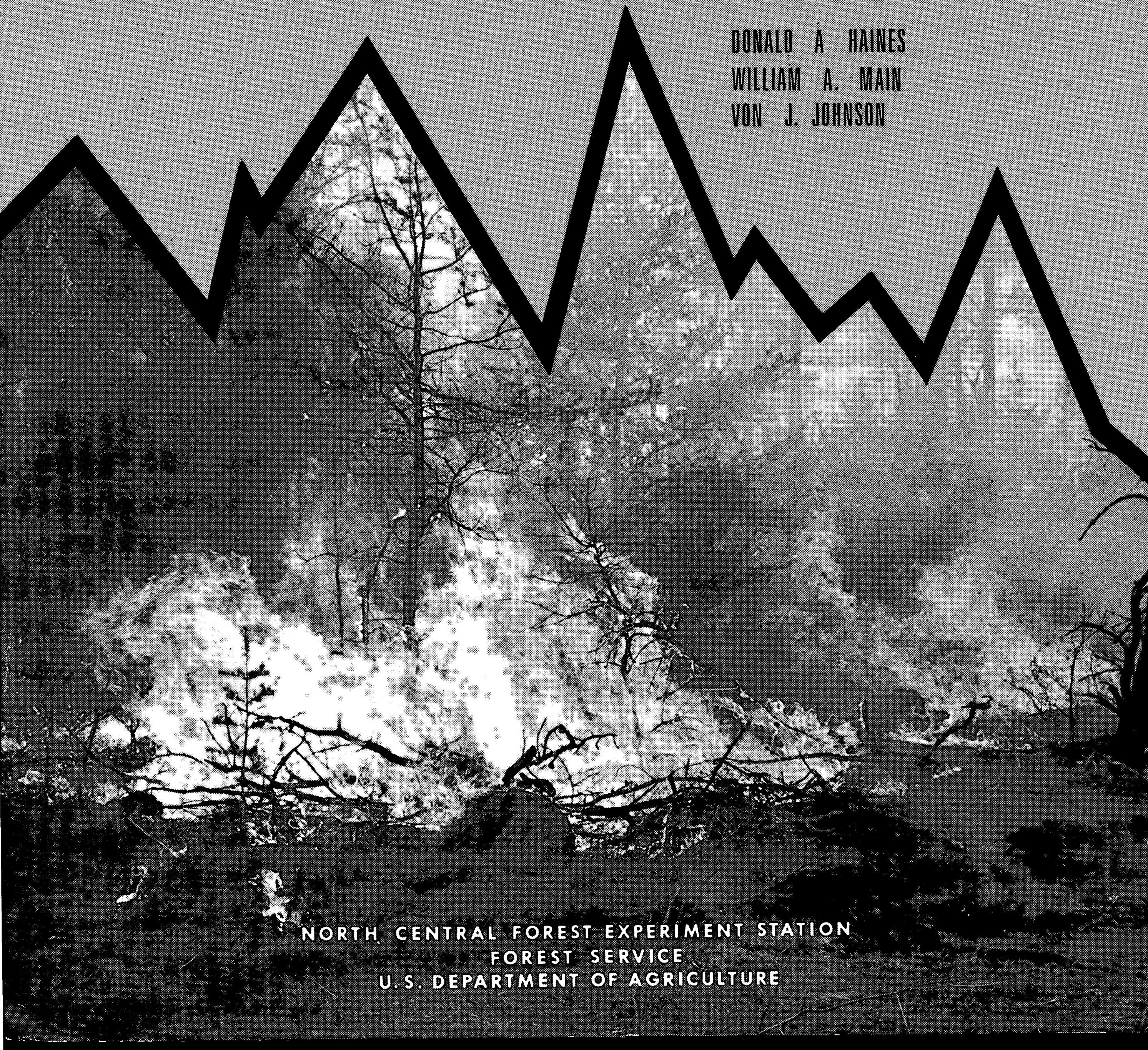

NORTH CENTRAL FOREST EXPERIMENT STATION
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Relation Between The National Fire Danger Spread Component And Fire Activity In The Lake States

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The National Fire Danger Rating System consists of four descriptive components: risk, ignition, spread, and energy release. Each component is intended to provide useful information for judging a potential fire situation. Risk indicates the probable number of firebrands landing on receptive fuels. The ignition component indicates the probability of ignition if a firebrand lands on receptive fuels. The spread component indicates the forward movement of surface fires. The energy release component indicates the driving energy from the combustion process that maintains the fire.

Until recently, only the preliminary indices of the spread component had been applied operationally (USDA Forest Service 1964). Because it was the only developed portion of the total system, the spread component was used (or perhaps abused) not only as an indicator of fire spread but also as an indicator of fire occurrence and burning severity. However, there has been only a limited effort to determine the statistical relationships between it and fire activity.

With the exception of risk, conceptual models for the other components of the System are now developed. Although these components are based on physical laws governing fire behavior, it is necessary to show how well and in what form they serve the purpose for which they were designed. Empirical relationships between various indices or index combinations and fire activity provide such a test and are also a basis for developing operational guides for fire control. Because preliminary indices of spread are familiar, they are used here to develop a flexible system of translating fire danger rating into commonly used measures of fire activity.

Other investigations have tried to determine such things as "normal" class frequency of the spread component. For example, Barney (1967, 1968) graphed the normals and frequency distribution of the buildup index and fine fuel spread index in Alaska, and the Minnesota Department of Conservation (1965, 1966) compiled class frequencies for that State. Nelson (1964) compared cumulated days, fires, and C, D, and E fires by spread indices and the 8 and 8-100 burning index (previously used in some regions). He concluded the timber spread index was superior to the 8 and 8-100 burning index as both an indicator of the probability of fire occurrence and rate of spread.

Little study of the spread component has been made beyond the development of frequency classifications. Since 1964 the Georgia Forest Research Council has published yearly information categorizing Georgia fire activity by spread component classes. Fairly close relationships were found between acres per fire and timber spread index (Ryan and Pachence 1965). Bruce[1] attempted to identify parameters that seemed most useful in accounting for variation in number of fires, and examined spread component indices as input.

No one has attempted to establish the many possible relationships between the National Fire Danger spread component and fire activity. A number of questions about spread component have been asked: Does its reliability as an indicator of fire activity vary during the year? How important is it to include a vegetative stage? Does the system show more meaningful fire activity relationships in conifers than in hardwoods or grasslands? We will give objective answers to some of these questions by presenting various empirical relationships between indices of the spread component and fire activity records in the Lake States. These relationships may also form a base from which comparisons may be made between National Fire Danger Rating System components recently developed and undergoing refinement.

The use of historical fire records in this type of study presents problems. When indices are high, fire protection units try to caution the public, alert fire crews, and maximize suppression ability. Although these factors tend to bias evaluation, they should not affect such things as seasonal variation in fire activity or the relationship between spread indices and conifer versus hardwood fires. Hopefully, sufficient data will reduce the influence of other variables, or at least show systematic bias. Therefore, if treated cautiously, fire activity records can be a valuable tool.

THE DATA BASE AND COMPUTATIONAL PROCEDURE

Daily weather records and fire reports for April 1 to October 31 were collected from nine areas over the Michigan, Minnesota, and Wisconsin region (fig. 1) for the years 1957 to 1962. Each of these nine areas contains a reliable weather observation station near its center. Fire information was included in the data only when the occurrence was within a 35-mile radius of one of these weather sites. Pertinent data were taken from fire and weather forms, tabulated, and placed on punched cards. The data record contains a total of 11,324 observation days, of which 1,958 days had at least one fire. A total of 4,288 fires burned 126,095 acres in the nine selected areas during this period.

The various indices of the spread component were calculated by a computer program developed at the North Central

[1]*Bruce, D. Development of man-caused fire occurrence index. USDA Forest Serv., Pac. Northwest Forest and Range Exp. Sta. Unpublished manuscript. 1965.*

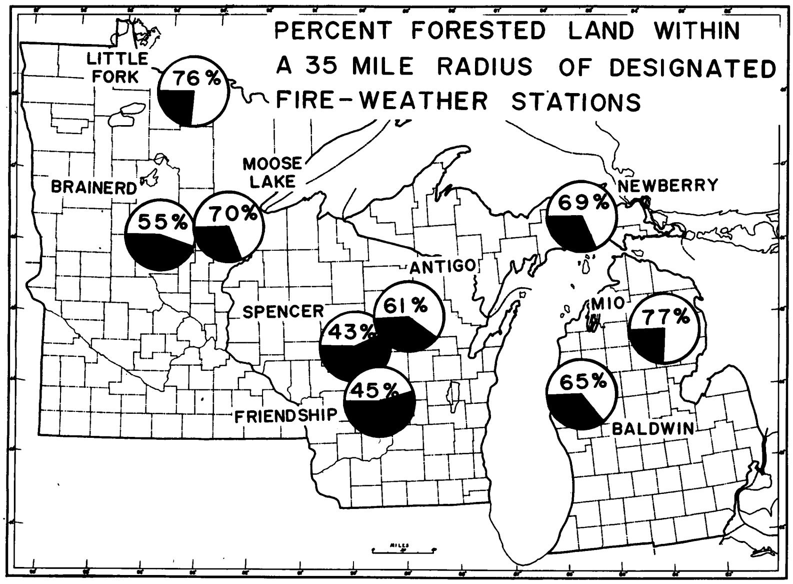

Figure 1.—The nine areas from which fire and weather data were gathered for the years 1957 to 1962.

Forest Experiment Station (Main 1969). The program computes the Buildup Index (BUI), the Fine Fuel Spread Index (FFSI), the Timber Spread Index (TSI), and the Fire Load Index (FLI)[2] (fig. 2). The BUI gives a measure of the progressive drying of fuels (excluding fast-drying fine fuels) and is related to the moisture content of standardized 10-day timelag fuels. FFSI is based on the moisture content of fast-drying fuels coupled with windspeed. TSI is based on the same factors as the FFSI, but the BUI is also included. FLI was developed to indicate the number of man-hours necessary to control an average surface fire in litter-type fuels. It is a composite of the TSI and the BUI. These indices are calculated on a daily basis for vegetative conditions (always green, always transitional, always cured, or chosen). Vegetative stage refers to the physiological

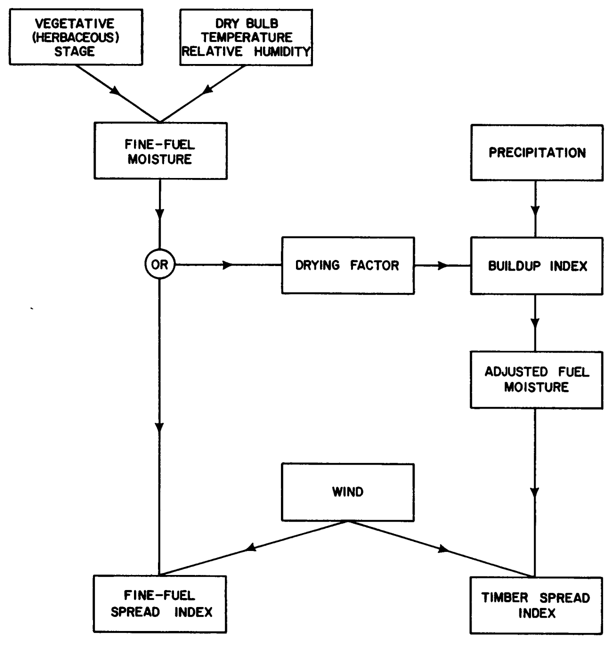

Figure 2.—Indices and input factors of the spread component.

condition of the lesser vegetation and not to deciduous trees and shrubs. Chosen vegetative stage was determined by the observer at an individual station and

[2]*Keetch (1967). (Fire Load = 1.75 log TSI + 0.32 log BUI − 1.640)*

entered each day on the station form. If chosen, the cured stage prevails when vegetation is 75 percent or more dead or dormant, transition when 25 to 75 percent is dead or dormant, and green when less than 25 percent is dead or dormant.

The program also breaks the information into season (spring, summer, fall, and all seasons) and cover type (grass, hardwood, conifer, other, and any). The program then takes the various indices of the spread component and compares them with fire data by regression analysis. This is done on a linear basis as well as with logarithmic transformations. The calculated spread-component values can be compared with such measures of fire activity as fires per fire-day, fires burning more than 10 acres, probability of a fire-day, and others. Computation was done by using mean values over two-unit index-increments and was restricted to a scale range from 0 to 65. The 0 to 65 restriction was imposed because only a few cases occur at the higher end of the scale. Also, we suspect that control action is more intense when the indices are in the upper ranges.

THE SPREAD COMPONENT OVER THE TOTAL FIRE SEASON

The spread component was developed as an indicator of the forward movement of surface fires; therefore, increasing component values should indicate an increasing number of acres burned per fire. Control action along with natural factors would certainly bias this relationship, but the trend should still be apparent. Table 1 gives the coefficients of determination (R^2), using various vegetative-stage values of the indices as predictors of four measures of fire activity, for the entire fire season. The highest R^2 obtained by linear analysis or after transformations is listed. It appears that an R^2 value below about 0.2 is not worth considering.

Table 1.—Coefficient of determination (R^2) values of index by vegetative conditions versus four fire activity measures (the data include the entire fire season for any cover type)

Index, by vegetative condition	Probability of a fire-day	Probability of a C, D, or E fire-day	Number of fires per fire-day	Acres burned per fire
Fine Fuel Spread				
Cured	0.94	0.89	0.64	0.40
Transitional	.93	.93	.42	.26
Green	.91	.94	.72	.42
Chosen	.97	.91	.74	.61
Timber Spread				
Cured	.86	.82	.33	.44
Transitional	.89	.55	.20	.25
Green	.92	.91	.28	.54
Chosen	.95	.57	.59	.36
Buildup	.92	.65	.13	.10
Fire Load	.68	.44	.21	.11

The R^2 values for acres per fire, although meaningful, are still relatively low for all possible vegetative conditions (table 1). Generally, the amount of variation explained with the BUI is low, as is also the case with the FLI. Burned-area criteria do not produce exceptionally high R^2 values, and this is also often the case with another measure of activity — fires per fire-day (table 1). The R^2 values for fires per fire-day are low for the TSI, BUI, and FLI. They are, however, much higher when the FFSI is used. Also, the scatter along the regression line is acceptable (fig. 3).

The FFSI appears to be a fair predictor of fires per fire-day for any vegetative condition except transitional (table 1). However, it does a better job as a measure

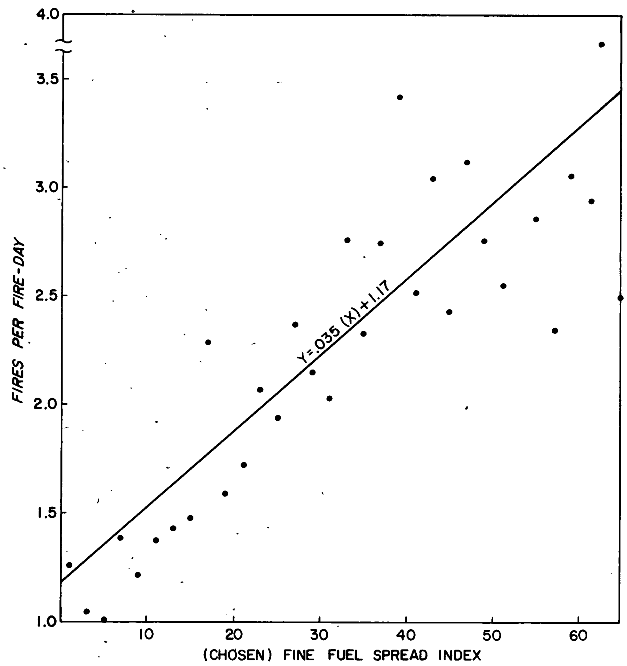

Figure 3.—The relation between the chosen FFSI and expected fires per fire-day.

of the probability of a fire-day. The total-season R^2 value produced by the FFSI for chosen vegetative stage is almost unbelievably high — 0.97. As pointed out by Fahnestock (1965) and others, fire occurrence is largely influenced by the same weather factors as fire size, although the relationships are somewhat different. Therefore, one might expect significant relationships between indices of spread component and fire occurrence. Crosby (1954) and Bruce (1963) also recognized that basically almost all fire-danger meters sort days into classes with general levels of fuel moisture. Both devised methods, with good results, that could employ other fire danger meters as predictors of the probability of fire occurence or the number of fires that might be expected in sections of the central United States. Consequently, it should not be surprising that these data produce the same close relationships.

Probability of fire-day tabulations shows that scatter is at a minimum along the regression line (fig. 4). Here, for instance, one might expect a fire on 1 day out of 10 when the value of the FFSI is 10. On the other hand, that fire will probably be class A or B as the C, D, E fire regression line intersects the x-axis at a FFSI value of 10. When the FFSI reaches 50, there is a 60-percent chance of a fire, and a 40-percent chance of a large fire (class C, D, or E).

The probable number of fires can be determined from the data in figure 3. As an example, on any given fire-day, if the fine fuel spread index is near 25, an area averages two fires. If the same index is at 50, an average of three fires occurs.

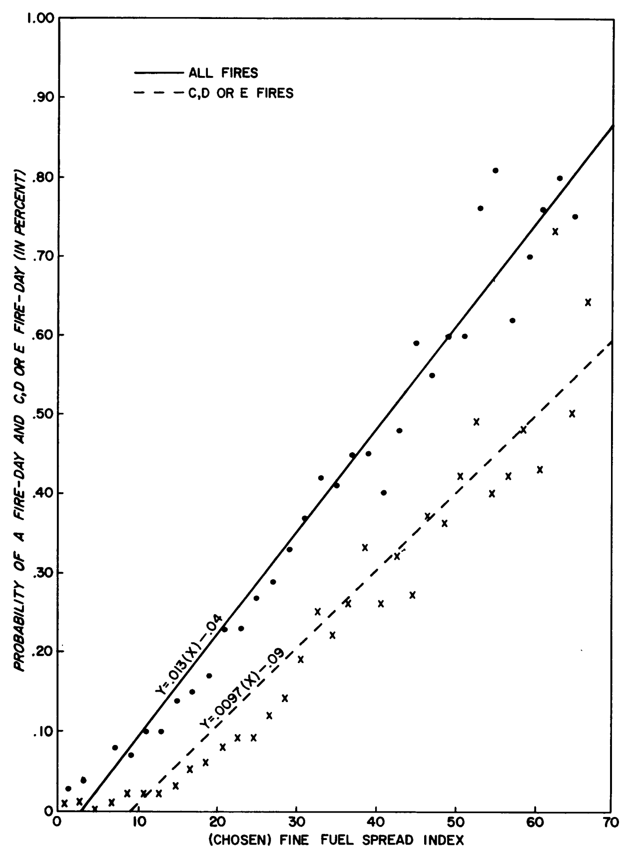

Figure 4.—The relation between the chosen FFSI and both the probability of a fire-day and the probability of a C, D, or E fire-day.

COVER AND SEASONAL CONSIDERATIONS

Thus far we have not considered seasonal and cover-type differences. Of the 4,288 fires used in this sample, 3,075 were spring fires, 948 were summer fires, and only 265 were fall fires. The fact that almost half were grass fires would tend to negate the usefulness of such things as the BUI. The BUI is built upon 10-day drying lag characteristics, and grasses may have a drying factor of a few hours.

Precipitation fits into the TSI scheme through the BUI. Obviously, precipitation influences fire spread in heavier fuels, but this fact isn't readily apparent when the measure is acres per fire (table 2), as R^2 values for the BUI are very lcw. Also, FFSI gives better acres-per-fire R^2 values than TSI (table 2) for hardwood, grass, and shrub cover, while the TSI gives the highest R^2 for conifer. But the FFSI does not use precipitation amount or frequency directly in its computation, while the TSI does. This result then would be expected for conifer cover, but would seem to be the reverse of the expected for hardwood cover.

The probability of a fire-day is in close agreement with the chosen FFSI in the spring (table 3), and additional computations showed that this applies in the spring for all cover types. During summer the relationship is poor, but it is somewhat better in the fall, with further computations showing this was especially true for hardwood cover. In the summer the R^2 value increases dramatically if we assume the cover is always in cured stage instead of choosing the stage. The same general comments hold with the probability of C, D, or E fire-day. When we consider the fire activity to be number of fires per fire-day at each danger level instead of the probability of a fire-day, we find the R^2 for FFSI

Table 2.—*Coefficient of determination (R^2) values of index by cover type versus four fire activity measures (the data include various cover types over the entire fire season using chosen vegetative stage)*

Index, by cover type	Probability of a fire-day	Probability of a C, D, or E fire-day	Number of fires per fire-day	Acres burned per fire
Fine Fuel Spread				
Grass	0.82	0.87	0.54	0.45
Hardwood	.89	.88	.47	.37
Conifer	.84	.83	.22	.23
Other	.87	.88	.22	.32
Timber Spread				
Grass	.53	.19	.10	.03
Hardwood	.61	.47	.28	.16
Conifer	.36	.50	.08	.38
Other	.28	.15	.11	.06
Buildup				
Grass	.82	.17	.27	.03
Hardwood	.84	.55	.10	.06
Conifer	.83	.49	.00	.10
Other	.79	.27	.00	.05
Fire Load				
Grass	.10	.12	.04	.04
Hardwood	.86	.40	.10	.11
Conifer	.09	.16	.07	.05
Other	.37	.34	.01	.09

Table 3.—Coefficient of determination (R^2) values of index by season versus four fire activity measures (the data include three seasons, any cover type, using chosen vegetative stage)

Index, by season	Probability of a fire-day	Probability of a C, D, or E fire-day	Number of fires per fire-day	Acres burned per fire
Fine Fuel Spread				
Spring	0.95	0.91	0.53	0.15
Summer	.32	.06	.22	.18
Fall	.57	.60	.26	.33
All season	.97	.91	.74	.61
Timber Spread				
Spring	.87	.80	.32	.27
Summer	.46	.14	.13	.21
Fall	.44	.32	.22	.31
All season	.95	.57	.59	.36
Buildup				
Spring	.89	.73	.08	.15
Summer	.91	.47	.45	.42
Fall	.54	.26	.06	.04
All season	.92	.65	.13	.10
Fire Load				
Spring	.54	.26	.04	.33
Summer	.46	.09	.04	.32
Fall	.23	.22	.08	.09
All season	.68	.44	.22	.35

chosen vegetative stage is highest in the spring and much lower in the summer.

There is a problem in interpreting the importance of the varying R^2 values in the tables. Are we justified in assuming, for example, that a superior-inferior relationship holds between the probability of a fire-day and the FFSI in grass as against hardwood (R^2 = 0.82 and 0.89 respectively) (table 2)? Fisher's z' transformations method (Brooks and Carruthers 1953) yields confidence limits (at the 0.05 level) for correlation coefficients and may help solve the problem.

Results of the transformation of correlation coefficient for the regression data show that if one of the corresponding R^2 values is in the 80's, there would have to be a difference of roughly 0.15 between R^2's before the larger R^2 yields a superior relationship. When the R^2's are lower, the difference between values that indicate a superior-inferior relationship would have to be even greater. If we apply these methods to the stated problem example, we see that the FFSI apparently does not give differing results in differing cover types for the criterion, probability of a fire-day.

During the summer a special problem develops with all fire activity measures. The data tend to group at the lower end of the spread index range unless the vegetative stage is considered to be always cured. Cured choice will cause the data to spread over the scale in a better distribution.

SUMMARY AND CONCLUSIONS

The various indices did not produce exceptionally high R^2 values when compared with the activity measure, acres per fire, although the coefficient of determination values are statistically important in many cases. This may be the result of field methods employed in measuring acres burned, or because burned acreage is not a good way to judge spread, or because of omission of important variables that result from control action. As Countryman (1966) states, no danger rating system tries to make a complete evaluation of fire danger, and all, therefore, are partial, not total, systems. There are just too many factors that affect fire danger to include all in an operational system. No usable rating method, consequently, explains total variation. Also, the present design of the spread index may not adequately predict fire spread; however, because the criterion used here was burned acreage and not rate of spread measurement, no firm conclusion can be drawn.

On the other hand, when we use the spread component to measure another form of fire activity – probability of a fire-day – we find excellent associations on a total-season basis and good relationships for many seasons and cover types. What this implies is that spread component indices are a good approximation of ignition.

The inclusion of vegetative stage in the indices does not always appear to produce significantly better relationships. If a single vegetative condition is used, the cured stage is probably best for various forms of spread. This stage produces a more normal distribution over the scale range. A continuous choice of green vegetative condition is especially poor because it gives low-scale, skewed distributions.

The various forms of the spread component consistently show the best results during the spring season in Michigan, Minnesota, and Wisconsin. The FFSI and TSI produce the poorest results during the summer. The R^2 values for the BUI are lowest in the fall.

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