Estimation of fire precaution periods using forest fire statistics in South Korea[1]

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Abstract

For forest fire management, special precautions are required in dry and strong-wind seasons vulnerable to severe forest fires. In order to determine the fire precaution periods in South Korea, the records of daily forest fires over the past 16 years, 1991 through 2005, were analyzed. The fire records include information on the number and fire-damaged area of daily fire occurrences all over the country. The daily fire patterns as well as the risk of daily fire were investigated using principal component analysis and cluster analysis. The risk probability function of fire was inferred using an ordered logit model. As a result, it was found that daily fire patterns can be classified into 5 clusters of well-characterized groups and, as a comprehensive indicator for fire risk, the scores of the first principal component of cluster 1 through cluster 5 showed a tendency of increase in an order. By calculating the probability of fire risk and detecting the threshold for the variables of the risk probability model, the period of October 21 through May 17 was recognized as of high-risk fire. Special precautions during the period for forest fire would be recommended in South Korea.

Introduction

The national statistics of forest fire is useful in understanding forest fires in Korea. According to this statistics, the majority of forest fires occur during the dry season and this seasonality can be used in establishing forest fire prevention and suppression plans.

Considering the seasonality of forest fire, forest fire precaution periods in spring and autumn have been designated by Korea Forest Service. However, the fire precaution periods were determined instinctively rather than cautiously based on results of scientific investigations.

The objective of this study is to determine the precaution periods by investigating the patterns of daily fire occurrences as well as the probability of daily fire risk using forest fire statistics.

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Methods

Forest Fire Data

The daily records of forest fire over the past 16 years, 1991 through 2005, were analyzed (Korea Forest Service 2004). The records include information of the number of fire occurrences, daily total area burned and average area burned per fire. The number of fire occurrences and total area burned are effective variables to reflect forest fire characteristics (Barney and stock 1983; Wagner 1988) and average area burned per fire can be used in detecting large forest fires which cause not only huge human and economic losses but also ecological changes dramatically (Kalabokidis et al. 2002). All of the variables were logarithm-transformed to overcome instability of the variance and differences between measurement units.

Statistical Analysis

Multivariate statistical analysis was applied to extracting forest fire characteristics. K-means clustering, the most common non-hierarchical clustering method, grouped the daily fire records with certain types of fire patterns. After clustering analysis, ANOVA and post hoc test (Duncan's multi-range test) were conducted to test significance among the clusters. In addition, principal component analysis provided useful indices in understanding forest fire characteristics.

The fire risk model using the ordered logit model predicted the daily fire risk probability and provided the basis for assessing the adequacy of the existing fire precaution periods.

Results

Characteristics of Forest Fire

As shown in *Table 1*, the daily fire patterns were classified into 5 clusters of well-characterized groups. Cluster 1 has the lowest mean value for the number of fire occurrences, daily total area burned and average area burned per fire representing the day group of less frequent and small size fire. Meanwhile, cluster 5 shows the highest mean value for all variables representing the day group of high frequent and large size fire. Cluster 2, cluster3 and cluster 4 have the middle values between cluster 1 and 5. Moreover, ANOVA and post hoc test (Duncan's multi-range test) was helpful to specify the prior results. Very strong significance is found among clusters for all variables. Especially post hoc test showed that cluster 4 and 5 had no significant difference in number of fire occurrences but in total area burned. It means cluster5 (April 7, April 12 and April 14) gets more damages from large size fires. Contrarily, cluster 2 and 3 has no significant difference in average area burned per fire but in number of fire occurrences and total area burned. It means cluster 3 gets more damages from frequent fires.

Table 1—*Cluster mean for each variable and results for post hoc test.*

Cluster	No. of days	Mean for number of fire occurrences	Mean for total burned area	Mean for burned area per fire
1	113	0.27 [d]	0.14 [e]	0.09 [d]
2	144	0.92 [c]	0.88 [d]	0.31 [c]
3	72	1.54 [b]	1.71 [c]	0.41 [c]
4	33	1.83 [a]	2.45 [b]	0.73 [b]
5	3	1.86 [a]	3.84 [a]	1.99 [a]

a-e means that the same letter is not significantly different at the 0.05 level by Duncan's multi range test.

Principal component analysis also provided useful information on forest fire characteristics**.** *Table 2* shows the main results of the analysis. The 1st principal component (PC1) explaining most of the original variance has almost same positive weight for variables. In other words, it could be considered as a general index of forest fire risk. Meanwhile, the 2nd principal component (PC2) had negative weight for number of fire occurrences and high positive weight for average area burned per fire turning out to be a large-sized fire index.

Table 2—*Eigen vector for each variable and variance proportion for PC1 and PC2*

Principal component	Eigen vector of number of fire occurrences	Eigen vector of total area burned	Eigen vector of average area burned per fire	Cumulative proportion of variance
PC1	0.57	0.62	0.54	85.5 pct
PC2	-0.65	-0.07	0.76	99.3 pct

The clusters and the scores of PC1 show a certain relationship that could help us to understand forest fire characteristics more comprehensively**.** The scores of PC1 had a tendency to increase gradually from cluster 1 to cluster 5 (*Fig. 1*). Based on these results, 5 ordinal risk classes were formed as the dependent variables in the ordered logit model for predicting daily fire risk probability.

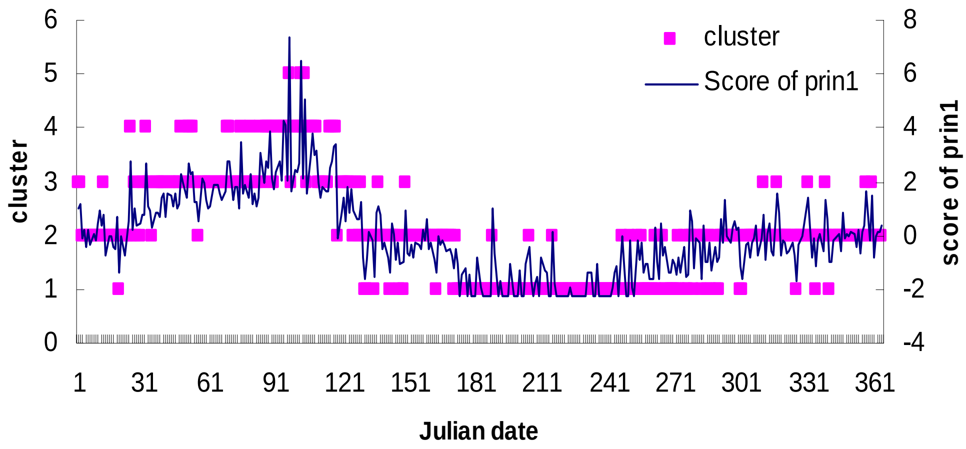

Figure 1—The score of the 1st principal component and the type of cluster for 365 days represented as Julian date.

Fire Risk Model & Its Application

The fire risk model using the ordered logit model was developed for predicting the probability of daily fire risk. From stepwise selection procedure, all of 3 variables showed significance (Likelihood ratio, pr>Chisq =< 0.0001) and were included in fire risk model. The estimates for number of fire occurrences, total area burned and average area burned per fire were -53.3, -40.1 and -40.2, respectively. In other words, larger value of variables, lower probability we have for low-rank fire risk class.

As another key issue, establishing threshold to judge whether to be risky or not with the amount of variables is very important, but somehow tricky. To solve this problem, we combined the results of multivariate statistical analysis with fire risk model again.

Firstly, we found an interesting tendency between the clusters and the scores of PC1. The mean score of PC1 for cluster 1 and 2 has negative values (-1.72 and -0.10, respectively), while cluster 3, 4 and 5 has positive mean score of PC1 (1.34, 2.80 and 6.38, respectively). Thus it could be possible to consider cluster 3 as a critical borderline group for sorting fire risky days. In the fire risk model, p3 meant the probability to be cluster 3. Then, p3=1.0 was established as the threshold and the borderline values for each variable were derived at the threshold point. The borderline values for number of fire occurrences, total area burned and average area burned per fire at the threshold point are 1.0, 1.36, and 0.23, respectively.

Fig. 2 shows the process of extracting risky days for forest fire by applying the borderline values for each variable. It was assumed that the intersection of extracted days from each variable was comprehensively high risk days and, thus, was appropriate to be the precautious period. Conclusively, the precautious period derived from statistical analysis is October 21 through May 17.

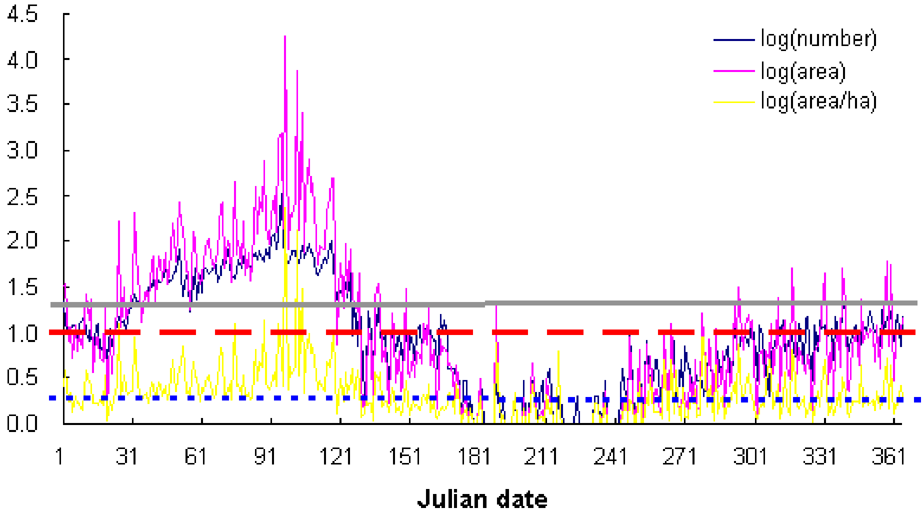

Figure 2—The high risk days above borderline values for each variable (Red dashed line, grey solid line, blue dashed line represent the borderlines for number of fire occurrences, total area burned, and average area burned per fire, respectively).

Discussion

Compared with the existing precaution period, the period estimated by statistical methods is about 60days longer. Because the latter started 10 days earlier in autumn (October 21) and also included middle winter (December 12 through January 1). In fact, middle winter is excluded in the existing precaution period under the assumption of a lot of snow. However, the statistical values such as number of fire occurrences, total area burned, and average area burned per fire showed no big difference with those of the precaution period in autumn. In other words, there is still high risk during middle winter.

In case of autumn, the estimated precaution period suggests earlier preparation for fire occurrences. This is a meaningful result under the circumstances of getting drier autumn weather condition in association with climate change.

In conclusion, establishing 60days longer period may seem to be hard in terms of limitation of labors and resources. However, we'll be able to have more effective strategies for fire prevention and suppression by reflecting those analytic results.

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