Jour. Korean For. Soc. Vol. 95, No. 2, pp. 160~167 (2006)

JOURNAL OF KOREAN FOREST SOCIETY

Predicting on Human-caused Forest Fire Occurrence in South Korea

Hee Mun Chae[1]* and Chan yong Lee[2]

[1]The Institute of Forest Science, Kangwon National University, Chuncheon 200-701, Korea
[2]Department of Forest Resources Protection, Forest Resources Faculty, College of Forest Science, Kangwon National University, Chunceon 200-701, Korea

Abstract : Most of the forest fires that occur in South Korea are caused by human. We partitioned South Korea into nine districts and used observed weather data and daily fire occurrence records for the 1994 to 2003 period to develop a human-caused fire occurrence model of South Korea. Logistic regression analysis techniques were used to relate the probability of a fire day to Fine Fuel Moisture Code (FFMC) component of the Canadian Forest Fire Danger Rating System. The probability of the number of fire day was increased as FFMC increased in the nine districts of South Korea.

Key words **:** *human-caused fire occurrence, logistic regression analysis, Fine Fuel Moisture Code*

Introduction

Korea is located at the heart of the Western North Pacific region and lies alongside of China and Russia and is close to the Japan. Korea encompasses 221,000 km^2, of which 45% (99,600 km^2) makes up the Republic of Korea. Sixty percents of Korea are mountainous and it is highly indented coastline and surrounding seas. The geographical characteristic of the Korea lies in the east part of the continent and has seasonally distinct rainfall and temperature distribution.

Korea has four seasons. Spring and fall are relatively short compare to summer and winter. Summer is hot, humid. About 60% of the annual rainfall occurs between June and September. Winter is dry and very cold due to northwesterly Siberian air masses that sweep down from the north. The average temperature is between 10 and 16°C. Annual mean rainfall ranges from 1,000 mm to 1,800 mm and its seasonal distribution is irregular. The rainy season usually begins in late June and lasts approximately 30 days and two or three typhoons strike between June and October in every year (Korea Meteorological Administration 2003).

The forested area of Korea is 6.4 million ha which covers about 60% of total land area in 2003. The total growing stock in that year were 468 million m^3 with stock volume per ha estimating to be 73 m^3. Almost 76% of all trees were less than 30 years of age (Korea National Statistics, 2003). Forest of South Korea is comprised of Conifer fo rest (42%), Hardwood forest (26%) and Mixed forest (30%). Fires in pine or shrub forests are more intensive. Korea is susceptible to forest fire because many forests of Korea are occupied by conifer tree.

Most forest fires occur during dry and windy spring and fall seasons. More than 60% of the fires occur from March to May. During this period, the air is comparatively dry and many people enter the forests for recreational purposes. Major causes for forest fires in Korea are human activities: accidental fires in mountains (42%) and agricultural burns (18%). Total number of 5,070 fires occurred during 1994-2003. There were 729 fires in 2000 and 786 fires in 2001 which were two particularly bad years. Forest fire in South Korea occurred mainly because of human (e.g; visiting mountain for recreations, farmer activity for agriculture, smoking). Forest fires occur mainly on March and April of every year (Korea Forest Service 2003). (Table 1 and Figure 1).

We used the Canadian Forest Fire Danger Rating System (CFFDRS) to predicts fire danger rating in South Korea. CFFDES is a process of systematically evaluating and integrating the individual and combined factors influencing danger of fire (Stocks *et al.* 1987). Fire Danger Rating System uses daily weather observations to calculate index for predicting fire occurrence. Canadian Forest Fire Weather Index System (FWI) of Canadian Forest Fire Danger Rating System (CFFDRS) uses tem-

*Corresponding author
E-mail: cheemun6606@hotmail.com

Table 1. Number of forest fires in South Korea by month and cause during 1994 to 2003.

Month	Number of fire	Visiting mountain	Farmer	Refuse	Smoking	Tomb visits	Children	Other
Total	5,079	2,194	895	309	399	369	169	744
Jan.	226	121	15	7	6	16	14	47
Feb.	723	278	141	47	50	42	40	125
Mar.	1,314	449	329	123	107	59	57	190
Apr.	1,781	763	307	99	144	210	49	209
May.	310	178	30	7	42	6	2	45
Jun.	110	50	24	4	4	6	0	22
Jul.	13	7	3	0	0	0	0	3
Aug.	5	3	0	0	0	0	0	2
Sep.	75	33	10	1	4	21	0	6
Oct.	112	66	14	4	7	3	0	18
Nov.	166	99	9	7	12	5	3	31
Dec.	244	147	13	10	23	1	4	46

*This data was collected from Korea Forest Service (http:// www. foa. go. Kr, cited May 2003). There were relatively more forest fire on April when many people visit their ancestor's site.

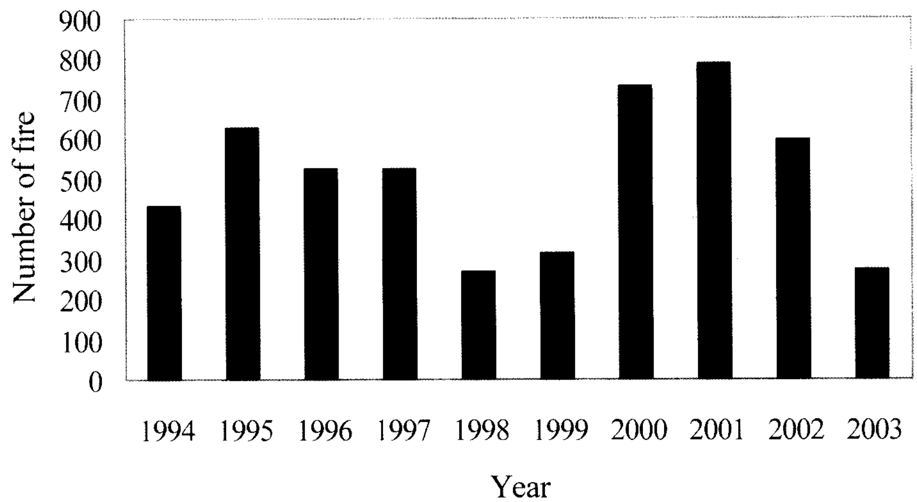

Figure 1. Number of forest fires in South Korea from 1994 through 2003.

perature (daily measurement of air temperature), relative humidity, rainfall (24 hour accumulated rainfall), average wind speed to predict daily fire occurrence (Van Wagner 1987). FWI system has six standard components and provides numerical rate of relative wildland fire potential. The first three components are fuel moisture code which is flows of daily change in the moisture contents of forest fuel : Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and Drought Code (DC). The other three Components are Fire Behavior Index : Initial Spread Index (ISI), Buildup Index (BUI) and Fire Weather Index (FWI).

Forest fires are caused by lighting or human and most of them are caused by people in South Korea. Human-caused fires are results of various human activities such as recreation (e.g; camping) or industrial activity (e.g; timber production or railway transportation). Human-caused fires can occur the fine fuel on the surface of the forest floor land on fuel and a fire brand (e.g; a cigarette). Fine fuels are needles and twigs and small diameter woody or grassy on the forest fuel. These types of materials play very important role in determine of ignition. The fine fuel moisture code (FFMC) is a good indicator of potential occurrence of fires caused by human (Van Wagner 1970) and it is reasonable to assume the probability distribution of number of human-caused fires that the Sioux Lookout area of Northwestern Ontario each day is Poisson with excepted number of fire day dependent upon Fine Fuel Moisture Code (FFMC) of the Canadian Forest Danger Rating System (CFFDRS) (Cunningham and Martell 1973). Logistic regression analysis techniques to predict the probability of a fire

Table 2. Human-caused fire occurrence during 1994 to 2003 in districted study area.

Province		Size (km^2)	Number of days	Number of fires	Number of fire days
Chungcheongbuk-Do		7,431	2,879	282	176
Chungcheongnam-Do		12,585	2,907	429	223
Gangwon-Do	Chuncheon	12.584	2,289	313	203
	Gangneung	4,028	2,838	199	149
Gyeonggi-Do		11,723	2,848	719	320
JeollaBuk-Do		8,050	2,923	271	170
JeollaNam-Do		12,547	2,920	320	191
Kungsanbuk-Do		20,967	2,981	678	344
Kungsannam-Do		11.281	2,992	459	297
Total			25,577	3,670	2,073

day as assume the FFMC (Martell *et al* 1987). Other related studies were described by Crosby (1954), Cunningham and Martell (1973), Martell *et al.*(1987, 1989), Todd and Kourtz (1992), Vega Garica *et al.* (1995), Pew and Larsen (2001), Wotton *et al.* (2003), Preisler *et al.* (2003).

In the case of South Korea, most forest fires result from human activity (Table 1). We used the FFMC to model daily human-caused fire occurrence in South Korea. This study was conducted to predict daily human-caused fire occurrence by using logistic model.

Material and Methods

Our study data is based on 10 years (1994 to 2003) of historical forest fire occurrence data of Korea Forest Service (2003). The weather data (temperature, relative humidity, wind speed and rainfall) collected by Korea Meteorological Administration (2003). Weather data used for this study was daily noon temperature (°C), daily average wind speed (m/sec), 24 hour accumulated rainfall (mm) and a daily relative humidity (%).

Our study area was divided into nine districts (Chungcheongbuk-Do, Chungcheongnam-Do, Gangwon-Do (Chuncheon, Gangneung), Gyeonggi-Do, JeollaBuk-Do, JeollaNam-Do, Kungsanbuk-Do and Kungsannam-Do). These study area boundaries corresponded with the provincial boundary of South Korea. In case of Gangwon-Do, we partition two areas (Chuncheon, Gangneung) because of the spatial variables of weather that is a result of mountain ridge that ranges from the north-to-South and divides Gangwon-Do. Gangneung is an oceanic climatic area and Chuncheon is a continental climatic area. Average temperature is between 12 and 14°C in Gangneung and 10°C in Chuncheon. Gangneung area had occurred big fires in 1995 and 2000.

In the number of fire day, Kungsanbuk-Do (344 day/10 year) has more than that of other study areas. In total number of forest fires, Gyeonggi-Do (719 fires/10year) has more than that of other study areas (Table 2).

Weather data was collected at the following weather station areas : Chungju weather station in Chungcheongbuk-Do, Daejeion in Chungcheongnam-Do, Chuncheon and, Gangneung in Gangwon-Do, Seoul in Gyeonggi-Do, Jeonju in JeollaBuk-Do, Kwangju in JeollaNam-Do, Daegue in Kungsanbuk-Do and Busan in Kungsannam-Do.

We computed Fire weather Index using to selected weather data by the FWI calculation program (stocks *et al.* 1987) It is made daily noon temperature (°C), daily average wind speed (m/sec), 24 hour accumulated rainfall (mm) and daily relative humidity (%) as input data and output values are FFMC, DMC, DC, BUI, ISI and FWI.

Starting calculations for FWI system analysis in this study start at daily noon temperature of 12°C at each year. In this case, starting values are FFMC 85, DMC 6 and DC 15 (Stocks *et al.* 1987). The FFMC is numerical rating of moisture contents of litter are other cured fine fuel.

We use the logistic regression analysis that Martell *et al.* (1989) used in the province of Ontario to develop fire occurrence model for each province in South Korea. Martell *et al.* (1987) found that of the six components of CFFDRS, the Fine Fuel Moisture Code (FFMC) and Build Up Index (BUI) were the most significant independent variable in most of the logistic regression equations the considered. This analysis was developed by Loftsgaarden and Andrews (1992), Chou *et al.* (1993) and Vega Garcia *et al.* (1995).

The form of the logistic model is

$$P = \exp(\beta_0 + \beta_1 FFMC)/1+\exp(\beta_0 + \beta_1 FFMC) \quad (1)$$

Where P is the probability of the fire day and β_0 and β_1 are model parameters. We used SPSS Program(SPSS 12.0 for windows) to estimate of our model parameters.

Results and Discussion

Our results are shown in Tables 2 and 3. Number of fire in South Korea occurred about 5,079 fires during ten years (1994-2003). This study used 3,670 fires, 2,073 fire days and 25,577 observed days for analysis (Table 2). Number of fires, fire days and observed days were 282, 176 and 2,879 in Chungcheongbuk-Do, 429, 223 and 2,907 in Chungcheongnam-Do, 313, 203 and 2,829 in Chuncheon, 199, 149 and 2,838 in Gangneung of Gangwon-Do, 719, 323 and 2,848 in Gyeonggi-Do, 271, 170, 2,923 in JeollaBuk-Do, 320, 190 and 2,920 in JeollaNam-Do, 678, 344 and 2,981 in Kungsanbuk-Do, 459, 297 and 2,992 in Kungsannam-Do. Table 3 shows the results of the logistic regression analysis of the relationship between human-caused fire occurrence and the FFMC on each nine study area. FFMC was statistically significant in the nine study areas. P value is significant in the each nine study area ($p<0.05$).

FFMC was the best fire weather variable for predicting human-caused fire Occurrence in fire seasons (Martell *et al.* 1987). We considered only the FFMC Index for modeling daily fire occurrence in this study. The relationship between daily fire occurrence and the FFMC is shown in figure 2 (A, B, C, D, E, F, G, H, I). In the case of low FFMC, no fire occurred in a day. In the case of high FFMC, one ore more fire occurred in a day. Some fire days (especially 5th on April in every year) have one or multiple fire number in a day during 1994 to 2003 (figure 2. B, C, D, I).

Theses come from Korean traditional culture that many Koreans visit their ancestor's grave. Sometimes, they cook and burn grave to control weed. In Gyeonggi-Do (Figure 2, D), fire occurred 16 times in 1994, 13 times in 2000 and 16 times in 2003 on this day.

Relationship between the probability of fire day and the FFMC is shown in Figure 2 (A-1, B-1, C-1, D-1, E-1, F-1, G-1, H-1, I-1). The Probability of fire day increases as FFMC increases. Moisture contents of fine fuel decreases as FFMC increases. Ease of ignition might best be indicated by FFMC(Van Wagner 1970). FFMC reflects the fuel moisture conditions of the litter and fine fuel. As fuel moisture decreased in this fine fuel, FFMC index was increased and ignition became easily.

We tested our probability model. This model was tested on the fire occurrence data from nine district of South Korea 2004 spring fire season (Table 4). We are predicted daily fire occurrence by previously studied equation of Martell *et al.* (1987). It was 57.9%-73.3% for predicted daily fire occurrence. Our probability model's prediction is similar to the results of previous study (Chou *et al.* 1993, Vega Gracia *et al.* 1995 and pew *et al.* 2001).

Daily fire occurrence in South Korea is influenced by weather conditions. Choi and Han (1996) were studied to develop forest fire occurrence model by using weather data (relative humidity, temperature, wind speed, longitude of sunshine, rainfall and duration of rainfall) in Taegue, Andong, Pohang area of South Korea and they found that fire occurrence was effected by relative humidity, longitude of sunshine, duration of rainfall. Our

Table 3. The results of logistic regression analysis in each district of South Korea.

Province			Estimate parameters	Standard error	Wald	P
Chungcheongbuk-Do		FFMC	0.401	0.041	96.234	0.000
		Constant	-37.661	3.641	106.960	0.000
Chungcheongnam-Do		FFMC	0.377	0.033	106.327	0.000
		Constant	-31.581	2.894	119.072	0.000
Gangwon-Do	Chuncheon	FFMC	0.190	0.022	74.987	0.000
		Constant	-18.502	1.909	93.962	0.000
	Gangneung	FFMC	0.350	0.035	97.385	0.000
		Constant	-33.685	3.203	110.573	0.000
Gyeonggi-Do		FFMC	0.180	0.018	100.123	0.000
		Constant	-17.341	1.578	120.719	0.000
JeollaBuk-Do		FFMC	0.204	0.026	61.322	0.000
		Constant	-20.051	2.280	77.310	0.000
JeollaNam-Do		FFMC	0.217	0.027	62.478	0.000
		Constant	-21.168	2.413	76.972	0.000
Kungsanbuk-Do		FFMC	0.404	0.031	168.319	0.000
		Constant	-37.631	2.794	181.428	0.000
Kungsannam-Do		FFMC	0.360	0.035	103.574	0.000
		Constant	-33.485	3.136	113.985	0.000

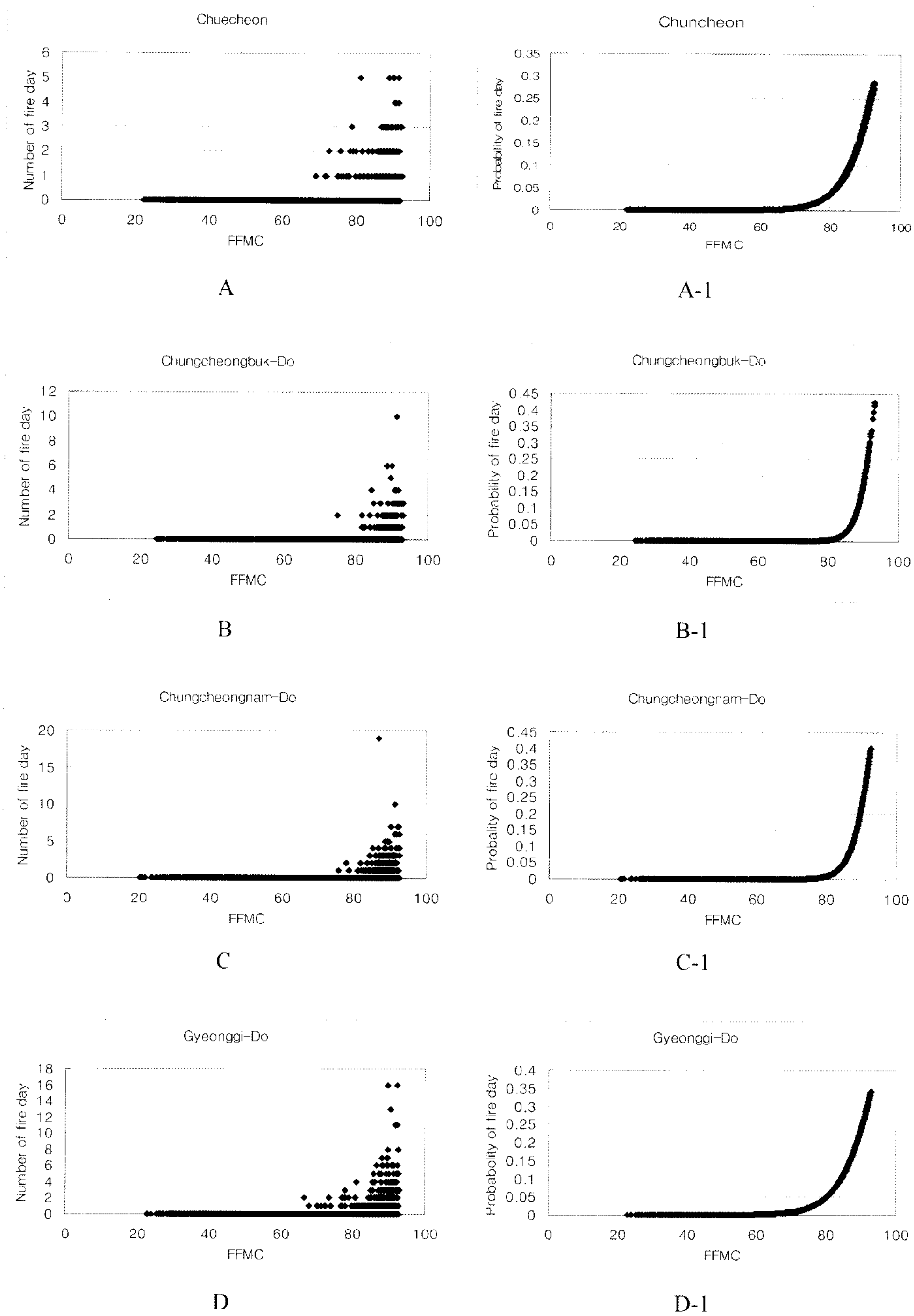

Figure 2. Relationship between the observed number of fires and probability of fire by FFMC to the nine districts of our study area in South Korea.

model is designed to predict fire occurrence based on the weather data. Our study use daily noon temperature (°C), daily average wind speed (m/sec), 24 hour accumulated rainfall (mm) and daily average relative humidity (%).

Fire season in South Korea begins on February 1st. However, our study did not start on this day because the starting date was not appreciated for the CFFDRS. This problem brought the inaccurate results when using weather data and fuel condition as the model to predict of daily fire occurrence. So, our calculation in this study for more accurate prediction of daily fire occurrence started at daily noon temperature of 12°C everyday (Stocks *et al.* 1987).

Our logistic model equations are based on 10-year of historical data. However, we tested prediction model with only one year (spring fire season in 2004) (Table 4). For more accurate prediction model program, we need to test more in the future study. Fire occurrence

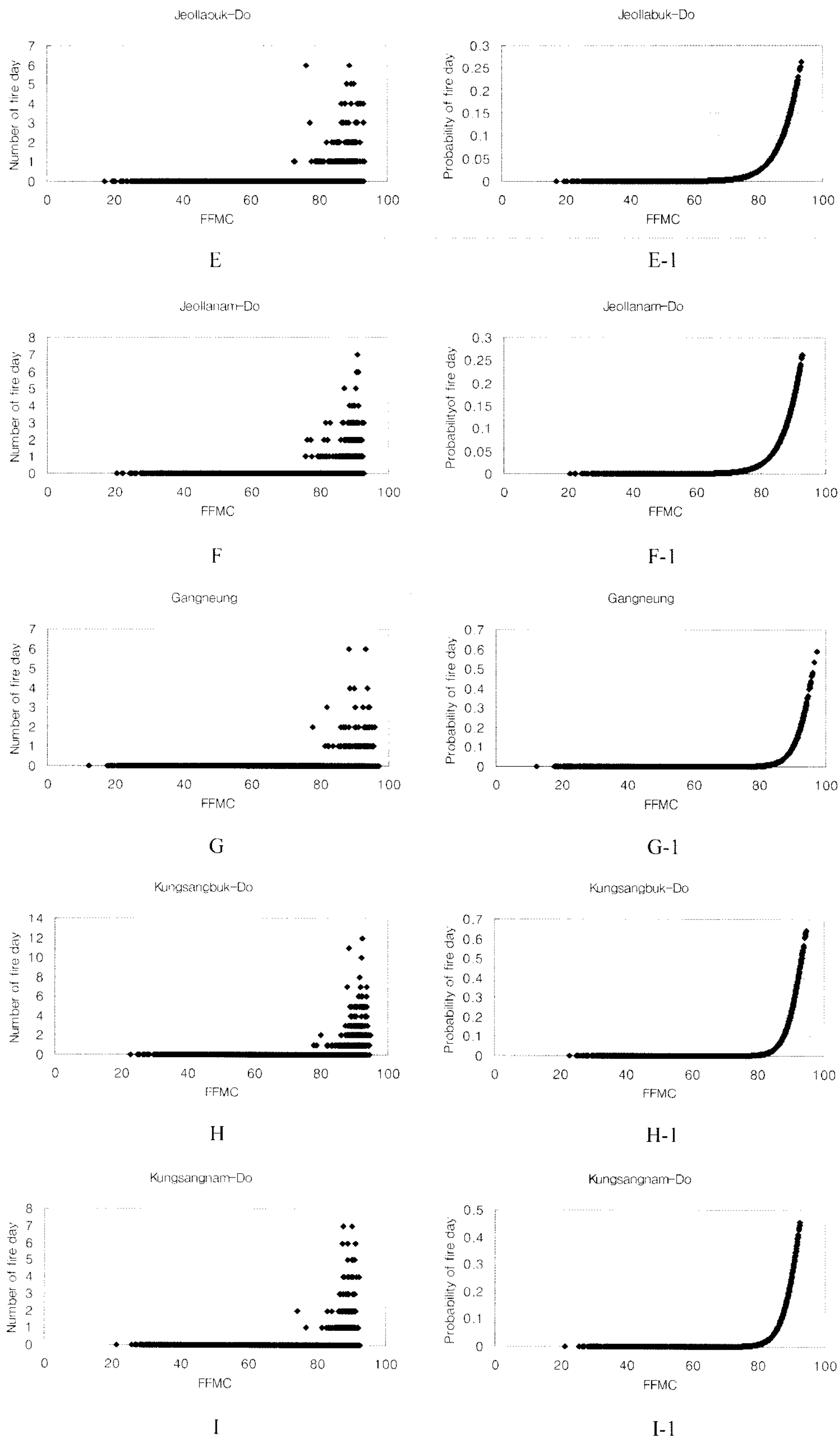

Figure 2. Continued.

predictions are used for fire prevention and detection, and initial attack purpose for forest fire control. We must develop fire prevention system and more accurate fire forecast system through this study.

Table 4. Predicted daily fire occurrence by logistic equation in each district area in the 2004 spring fire season of South Korea.

Chungcheongbuk-Do		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire day	11	2	13
	Non fire day	7	66	73
	Total	18 (61.1%)	68	86
Chungcheongnam-Do		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	10	7	17
	Non fire day	5	63	68
	Total	15 (66.7%)	7	85
Chuncheon(Gangwon-Do)		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	10	5	15
	Non fire days	6	45	51
	Total	16 (62.5%)	50	66
Gangneung(Gangwon-Do)		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	9	4	13
	Non fire days	6	62	68
	Total	15 (60.0%)	66	81
Gyeonggi-Do		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	14	9	23
	Non fire days	10	54	64
	Total	24 (58.3%)	63	87
Jeollabuk-Do		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	6	7	13
	Non fire days	4	70	74
	Total	10 (60.0%)	77	87
Jeollanam-Do		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	11	9	20
	Non fire days	4	64	68
	Total	15 (73.3%)	73	88
Kungsanbuk-Do		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	20	13	33
	Non fire days	9	44	55
	Total	29 (68.9%)	57	88
Kungsannam-Do		Predicted day		
		Fire days	Non fire days	Total
Observed day	Fire days	11	7	18
	Non fire days	8	61	69
	Total	19 (57.9%)	68	87

Acknowledgments

This work was supported by the Post-doctoral Fellowship program of Korea Science and Engineering Foundation (KOSEF) and we thank to Professor David L Martell at University of Toronto for his advice to the Canadian Fire Danger Rating System.

Reference

1. Choi, K. and Han, S.Y. 1996. Developing Forest Fire Occurrence Probability Model Using Meteorological Characteristics. Journal of Korean Forest society 85(1): 15-23.
2. Chou, Y.H., Minnich, R.A., and Chase, R.A. 1993. Mapping probability of fire occurrence in San Jacinto Mountains, California, USA. Environmental Management 17: 129-140.
3. Crosby, J.S. 1954. Probability of fire occurrence can be predicted. Northern Ozark Forest Research Center. October, 1954.
4. Cunningham, A.A. and Martell. D.L. 1973. A stochastic model for the occurrence of man-caused forest fires. Canadian Journal of Forest Research 3: 282-287.
5. Korea Forest Service. 2003. Available from http:// www. foa. go. Kr.
6. Korea Meteorological Administration. 2003. Available from http://www. Kma. go.kr.
7. Korean national statistic office. 2003. Available from http://www. Nso.go.kr.
8. Loftsgaarden, D.O., and Andrews, P.L. 1992. Constructing and testing logistic regression model for binary data; Applications to the National Fire Danger Rating System. United States Department of Agriculture. Forest Service. Intermountain Research Station. General Technical Report INT-286. 36pp.
9. Martell, D.L., Bevilacqua, E. and Stocks, B.J. 1989. Modeling seasonal variation in daily human-caused forest fire Occurrence. Canadian Journal of Forest Research. 19(10): 1555-1563.
10. Martell, D.L., Otukol, S. and Stocks, B.J. 1987. A logistic model for predicting daily human-caused forest fire occurrence in Ontario. Canadian Journal of Forest Research 17(5): 394-401.
11. Pew, K.L. and Larsen, C.P.S. 2001. GIS Analysis of Spatial and Temporal Pattern of human-caused wildfires in the temperature rain forest of Vancouver Island, Canada. Forest Ecology and Management 140 : 1-18.
12. Preisler, H.K., Brillinger, D.R., Burgan, R.E. and Benoit, J.W. 2003. Probability based models for estimation of wildfire risk. International Journal of wildland fire 13(2): 133-142
13. Stocks, B.J., Alexander, M.E., Mcalpine, R.S., Lawson, B.O. and Van Wanger, C.E. 1987. Canadian Forest Fire Danger Rating System. Users' Guide. Canadian Forest Service Fire Danger group.
14. Todd, B. and Kourtz, P.H. 1992. Predicting the daily occurrence of human-caused Forest Fire. Petawawa National Forestry Institute. Information Report PI-X-103. 16pp.
15. Van Wagner, C.E. 1970. New development in forest fire danger rating. Canadian Forest Service Report. Environment Information Report Ps-X-19.
16. Van Wagner, C.E. 1987. The development and structure of the Canadian forest fire weather index system. Canadian Forest Service. Petawawa National Forestry Institute. Forest Technical Report ETR-35. Chalk River. Ontario. 36pp
17. Vega Garcia, C., Woodard, P.M., Titus, S.J., Adamowicz, W.L. and Lee, B.S. 1995. A logit Model for predicting the Daily Occurrence of human caused forest fires. International Journal of wildland fire 5(2): 101-111.
18. Wotton, B.M., Martell, D.L. and Logan, K.A. 2003. Climate change and human-caused forest fire occurrence in Ontario. Climatic change 60: 275-295.

(Received October 4 2005; Accepted November 14, 2005)