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Changes of Landscape Pattern and Vegetation Structure in Rural Area Disturbed by Fire

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산불지역에서 경관유형과 식생구조의 변화

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ABSTRACT

This study was focused on the effects of fire on spatial change of vegetation landscape in rural region. Fire types recognized as crown fire, severe surface fire and light surface fire in order of increasing intensity were described in a fire map. GIS was introduced to understand the relationship between fire types and topographic conditions or vegetation types. We also investigated land-use type and regeneration strategies after burning. Fire intensity depended on topographic conditions and vegetation types. Special land-use type in this area was collection of edible mushroom (*Tricholoma matsutake*). Mushrooms had been obtained from *Pinus densiflora* forests existing as edaphic climax or managed artificially. Regeneration strategy in burned areas was to make sprouts from burned oak stumps. A higher density and growth rate of sprouts, as compared to those on unburned areas, facilitated vegetation succession from *P. densiflora* forest to oak forest and consequently led to change of landscape pattern.

Key words: Landscape change, Fire types, GIS, Regeneration strategy, *Pinus densiflora*.

INTRODUCTION

Changes of landscape pattern are significantly affiliated to the type of artificially or naturally induced disturbances and related to intensity, probability and frequency of the disturbance (Franklin and Forman 1987, Turner and Bratton 1987, Hong 1998). Human activity is one of the important factors among causal factors of disturbance (Holzner *et al.* 1983, Zonneveld 1989, McDonnell and Pickett 1990, Hong *et al.* 1995). Fire has been considered as the most important natural and human-induced disturbance inducing ecosystem and landscape heterogeneity because of its intensity and high frequency (Romme 1982, Pickett and White 1985, Turner and Bratton 1987, Trabaud and Galti 1996).

Ignition sources of forest fires in Korea are generally artificial ones, such as misuse of fire for agricultural and forest management, burning of rubbish, and accidental fire from glowing cigarette butts (Forest Research Institute 1996). Propagation of forest fires is

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largely influenced by weather and forest conditions (Whelan 1995). The resistance of trees to fire depends on plant species. For example, broad-leaved trees composing of climax forests are not burned easily. However, most post-fire invaders of secondary forest tend to burn easily (Nakagoshi 1984, Nakagoshi *et al.* 1987). The regeneration sources of plant species in burned stands are sprouts from burned stumps, subterranean organs, buried seeds, and newly invading seedlings (Nakagoshi *et al.* 1987). Regeneration strategies by those sources are influenced by fire intensity, burned season, and fire interval (Malanson 1987). Therefore, it is necessary to understand the effect of fire as one of the disturbance factors on changes in landscape pattern and landscape structure to establish the ecological framework for restoration of fire-disturbed vegetation (Hong and Lee 1997).

The first purpose of this study is to map the fire types through defining the landscape patch identified according to fire intensity by field survey. Secondly, through geographic information system (GIS, Bridgewater 1996), we tried to clarify the relationships between pattern and structure of fire-disturbed landscape and landscape attributes such as elevation, aspect, and slope. Thirdly, we evaluated the regeneration strategies to understand the successional trend of vegetation after this fire.

STUDY AREA

The largest forest fire in modern history of Korea occurred in 1996 in Kosung-Gun, eastern Korea (Fig. 1). Forest of about 5,000 ha was burned by this fire. Kosung-Gun is located on the east of the Taeback Mountains, which divide Kangwon Province as Youngdong region and Youngseo region, eastern part and western part of that, respectively. Climate of this area is relatively warm and humid comparing with the west of Taeback Mountains on the same latitude. Annual mean temperature and precipitation are 11.9℃ and 1,128mm, respectively (Korea Meteorological Administration 1990). Warmth Index (WI, ℃), Coldness Index (CI, ℃), and Index of Moisture (IM) are

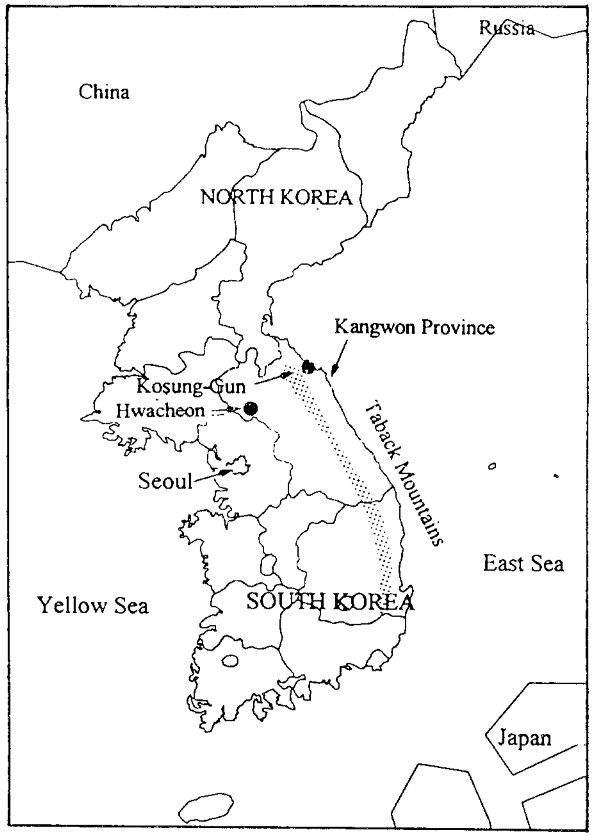

Fig. 1. The location of study area, Kosung-gun.

94.6, −19.3 and 61.7 (Yim and Kira 1975), respectively. Climatic characteristics in this area is similar to those of wet coastal region rather than those in Youngseo regions on the same latitude (e.g. 102.9, −28.2 and 41.1 at Hwacheon, see Fig. 1). Red and yellow forest soil is partly distributed in coastal area, and brown and reddish brown forest soil is distributed in the mountainous area. Parent rock of this region is generally composed of granite (Forest Research Institute 1996).

Total area of Kosung-Gun is 62,138 ha, vegetation area is 46,920 ha (75.5%), and burned area by this fire is about 5,000 ha (8.0%). Previous vegetation to fire in this area had been mainly composed of *Pinus densiflora* forest and pine-oak mixed forest (approx. 64% of total vegetation cover). According to Hong *et al.* (1993, 1995), pine forest in rural region had been dominated by traditional landscape management regimes such as slash and burning agriculture, making graveyard and harvesting plant fuel. Additionally, edible mushroom (*Tricholoma matsutake*) is the remarkable economic product from pine forest in this area. Many people periodically have been managed the vegetation structure of pine forest for more production of the mushroom. About 400 ha of pine forest had been used for collection of mushroom (Forest Research Institute 1996).

A fire occurred on April 23, 1996 and it was the biggest one among fires have been occurred during last 20 years in Korea (Forest Research Institute 1996). This fire was ignited by misuse of fire, as it was, human activities. Most burnt areas were covered with flammable vegetation type mainly composed of pine forest of dry condition (Table 1). Dry Föhn (Foehn) blowing from the Taeback mountains located on the west and the unexpected fluctuation of air pressure had, moreover, accelerated the spreading of fire (Forest Research Institute 1996).

The effect of fire on change of vegetation landscape are divided into several types according to the intensity and frequency of fire (Whelan 1995). Whole parts of the tree including crown and branch were burnt in pine forest of dry soil condition and induced crown fire. Only the lower part of stem and litters on forest floor were, however, burnt in pine forest of relatively moist condition below mid-slope and brought out surface fire. In this study, surface fire was divided into light and severe surface fires by its intensity. The intensity of fire was relatively mild in broad-leaved forest maintaining moist condition comparing with pine forest. Moreover, broad-leaved trees were resistant to fire, so most trees among them were alive after fire.

Table 1. The climatic condition of Kosung-Gun in the period of outbreak of fire

Date	Maximum velocity of wind (m/sec)	The direction of wind	Air humidity (%)
April 22 '96	9.3	W	35
April 23	17~27	NW	27
April 24	17~27	SW	26

This data was refered from the report of Forest Research Institute, 1996.

METHODS

This study was focused on changes of landscape structure and pattern by disturbance of fire. Fire intensity types and previous vegetation distribution pattern to fire were investigated. Fire types were classified into 3 types according to the intensity of fire disturbance. When whole parts of tree including crown and stem as well as litters on the forest floor were burnt, it was classified into crown fire. When all the part below crown was burnt, it was classified into severe surface fire. On the other hand, when only

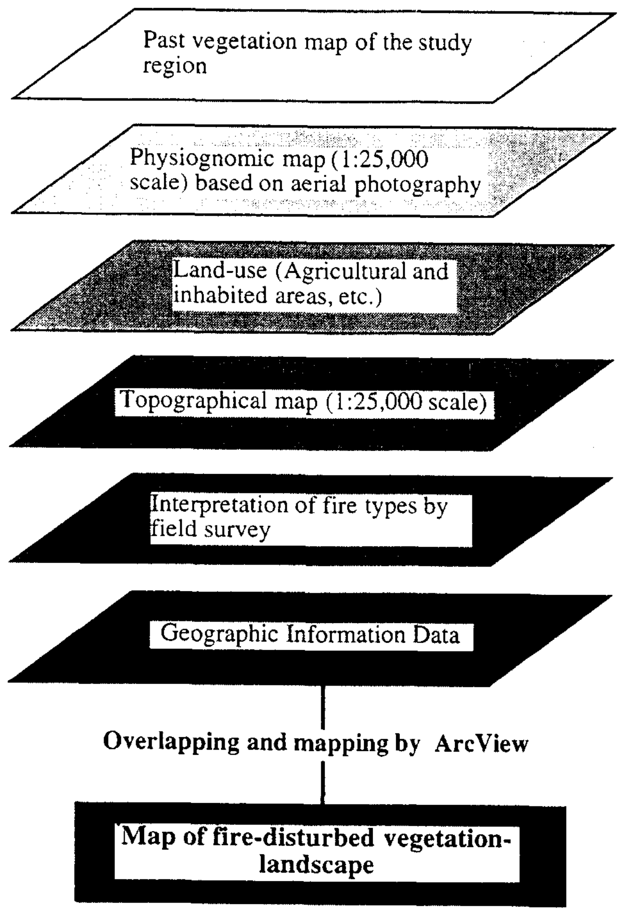

Fig. 2. Mapping processes of fire-disturbed vegetation landscape using GIS technique.

the lowest part of tree was burnt and the cambium beneath the bark was not burnt, so most needle leaves were remained alive, it was classified into light surface fire. Severe surface fire, viz, is more intensive disturbance than light surface fire. Fire types divided like this were described on topographic map of 1:25, 000 scale.

Fig. 2 shows the flowchart for mapping of actual vegetation and fire-disturbed types. The smallest size of patch was 625 m^2 (25 m × 25 m). The patch smaller than this size was neglected and involved to near landscape element. LANDCADD (LANDCADD International 1992) as one of GIS (geographic information system) supported by AutoCAD was introduced for making maps of vegetation and fire types and to evaluate relationships between fire types and vegetation types and / or geographical attributes such as elevation, aspect, and slope. On the other hand, we set up permanent quadrats (each 100 m^2 sized) at each site of different fire types for long-term studies on forest succession to explain landscape change since fire break from such a result. Location of all woody plants within each permanent quadrat was plotted. Successional tendency was interpreted by analyzing diameter (mature tree: diameter at breast height, seedling and sapling: diameter at ground surface) class distribution of dominant woody species.

RESULTS AND DISCUSSION

Previous vegetation to fire

Map of previous vegetation was shown in Fig. 3. Previous vegetation to fire tended to be distributed in the following order of pine forest, mixed forest of pine and oaks, and oak forests from coastal area to inland area. Pine forest was mainly dominated by Korean red pine, *Pinus densiflora*. Pine-oak mixed forest and oak forest were dominated by *P. densiflora* and *Quercus mongolica*, respectively. Alien pine species such as *Pinus rigida* were introduced in some places for plantation and erosion control. Deciduous broad-leaved forests such as *Q. acutissima, Castanea crenata*, and *Robinia pseudoacasia* were covered surrounding hamlets as a patch of small size. Agricultural land and inhabited area were restricted in lowland near the coast and stream side. Dimensions of landscape elements of pine forest, mixed forest, oak forest, plantation, agricultural area, aquatic area, and human settlements were 3,134 ha (45.6%), 1,304 ha (19.0%), 407 ha (5.9%), 24 ha (0.3%), 1,543 ha (22.8%), 108 ha (1.6%), and 350 ha (5.1%).

P. densiflora forest, especially in rural regions, is a secondary forest, and it has been periodically maintained by people for production of edible mushroom (*Tricholoma matsutaka*). In addition, periodical forest-use such as cutting and thinning to get wood, fuel, feed for livestock, and organic fertilizer also have played an important role in maintaining this forest type (Nakagoshi *et al.* 1987, Hong and Nakagoshi 1996). The effects of human disturbance on the landscape system were identified through exploring an actual vegetation map. Pine forest favorable to human impact commonly changes to oak forest as a disturbance decreased (Lee 1995a, b, Hong *et al.* 1995). In this area, a large patch of pine forest often occurring at the early successional stage was found at the lowland where human interference frequently occurring. On the other hand, oak forest (*i.e. Quercus mongolica*) in mid- to late successional stages was identified in the place remote from the village.

Fire-disturbed types

Fire-disturbed types classified by the intensity of fire were described in a map (Fig. 4). In a fire map, crown fire of the highest intensity was mainly distributed in eastern part of the study area, while light and severe surface fires of low intensity were in western part. Such a difference would be caused by topographic condition (Table 2) and vegetation type (Table 3). Analyses of relationships between fire types and topographic condition were shown in Fig. 5. In a distribution of fire types according to elevation, the ratio of light surface fire tended to increase as elevation becomes higher, while that of severe surface fire

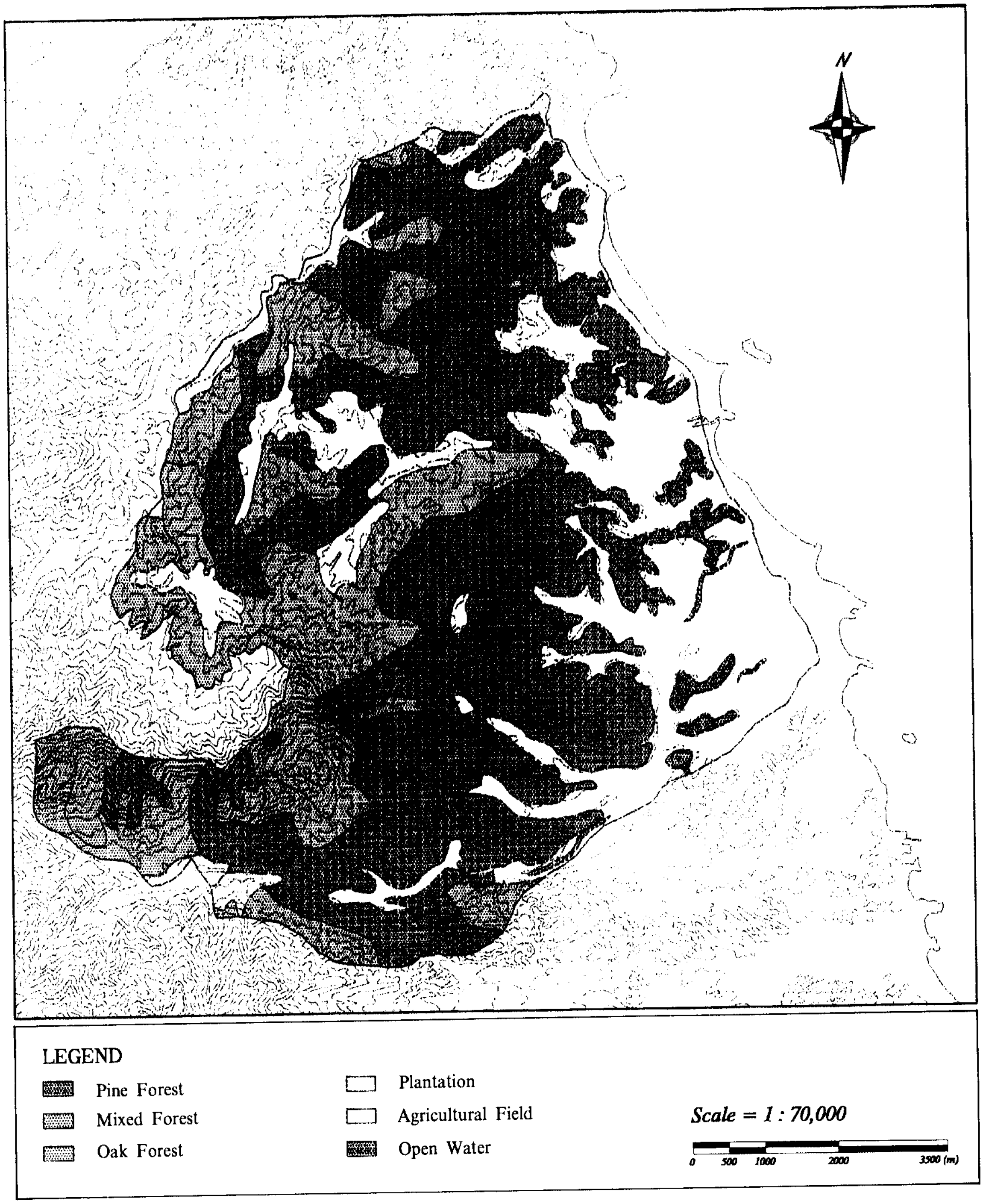

Fig. 3. A map showing the vegetation landscape before fire, 1996 by LANDCADD. This map was redrawn from the vegetation map (Environment Admimistration 1990) and the physiognomic map (Forestry Research Institute 1996).

decreased as the elevation increased. That of crown fire, on the other hand, showed an opposite tendency to that of light surface fire even though the ratio was fluctacted. In a result according to the degree of slope, ratio of light surface fire increased as the degree of slope increase. Severe surface fire, however,

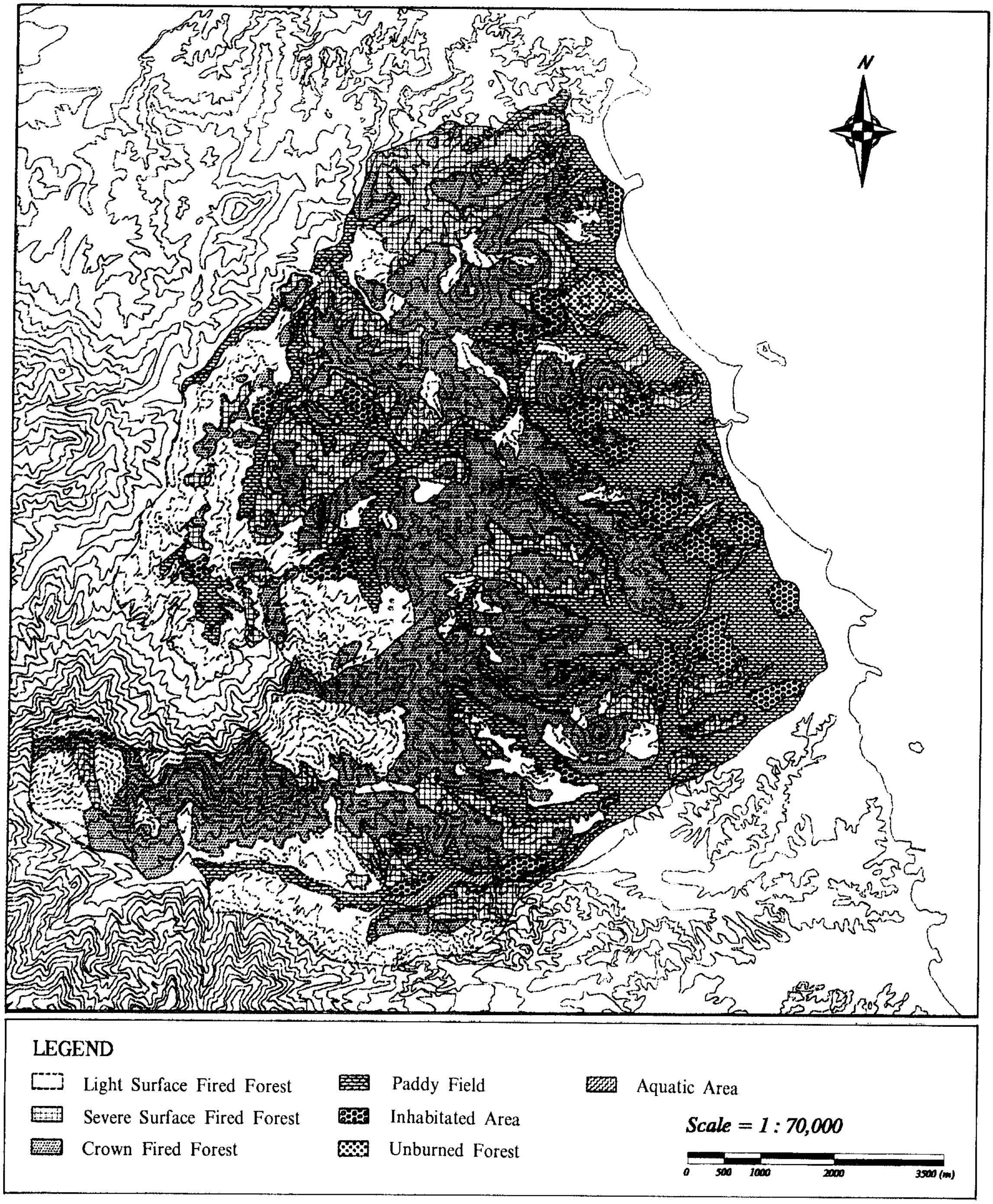

Fig. 4. A map showing the fire types after fire, 1996 and landscape elements.

showed an opposite tendency to that of light surface fire. On the other hand, the ratio of crown fire did not show any remarkable change with the degree of slope. In the case of aspect, ratios of light and severe surface fires and crown fire were higher in northern aspect, flat area, and southern aspect, respectively. Such a difference in fire type according to the aspect would be related to the amount of radiation and the

Table 2. Size (ha) of burnt vegetation and landscape elements analyzed by LANDCADD in fire disturbed area of Kosung-Gun

Landscape attribute		Burnt vegetation* Light surface fire 1693	Severe surface fire 1115	Crown fire 2410	Agricultural field 1543	Inhabited area 350	Unburned forest 53	Aquatic area 108
Elevation(%)	0−100	299.2 (17.67)	633.8 (56.84)	891.7 (37.00)	1319.4 (85.51)	304.8 (87.09)	53 (100)	– –
	~200	613.4 (36.23)	388.7 (34.86)	948.2 (39.34)	183.2 (11.87)	34.5 (9.85)	– –	– –
	~300	44.6 (26.26)	69.1 (6.20)	309.2 (12.83)	40.4 (2.62)	10.7 (3.66)	– –	– –
	~400	161.3 (9.53)	10.9 (0.98)	93.7 (3.89)	– –	– –	– –	– –
	~500	76.0 (4.49)	7.2 (0.64)	75.4 (3.13)	– –	– –	– –	– –
	~600	67.6 (3.99)	5.4 (0.48)	49.9 (2.07)	– –	– –	– –	– –
	~700	10.3 (0.61)	– –	36.4 (1.51)	– –	– –	– –	– –
	~800	16.9 (1.00)	– –	5.5 (0.23)	– –	– –	– –	– –
	~900	3.7 (0.22)	– –	– –	– –	– –	– –	– –
Slope(%)	0~5	226.0 (13.35)	294.5 (26.41)	440.1 (18.26)	1030.9 (66.82)	213.5 (61.00)	18.9 (35.60)	
	~10	84.3 (4.98)	65.6 (5.88)	132.8 (5.51)	120.4 (7.80)	23.4 (6.68)	1.9 (1.69)	– –
	~15	106.0 (6.26)	126.6 (11.35)	209.9 (8.71)	89.2 (5.78)	35.1 (10.03)	5.4 (10.17)	– –
	~30	600.4 (35.46)	434.5 (38.97)	825.4 (34.25)	243.2 (15.76)	77.0 (22.01)	22.4 (42.37)	– –
	~45	433.4 (25.60)	155.3 (13.93)	500.8 (20.78)	42.3 (2.74)	1.0 (0.28)	5.4 (10.17)	– –
	~60	151.0 (8.92)	31.4 (2.82)	181.0 (7.51)	8.5 (0.55)	– –	– –	– –
	>60~	91.9 (5.43)	7.1 (0.64)	120.0 (4.98)	8.5 (0.55)	– –	– –	– –
Aspect (%)	East	22.3 (13.19)	100.6 (9.02)	306.3 (12.71)	217.9 (14.12)	64.3 (18.38)	8.1 (15.25)	– –
	Flat	107.8 (6.37)	157.1 (14.09)	233.5 (9.69)	595.3 (38.59)	132.7 (37.88)	5.4 (10.17)	– –
	N.E	348.2 (20.56)	175.0 (15.70)	361.0 (14.98)	269.6 (17.47)	45.8 (13.09)	7.2 (13.56)	– –
	North	201.6 (11.91)	157.1 (14.09)	193.5 (8.03)	94.0 (6.09)	6.8 (1.95)	4.5 (8.47)	– –
	N.W	182.8 (10.80)	141.8 (12.72)	177.4 (7.36)	99.5 (6.45)	10.7 (3.06)	4.5 (8.47)	– –
	S.E	236.3 (13.96)	144.6 (12.97)	454.6 (18.86)	145.5 (9.43)	41.9 (11.98)	10.7 (20.34)	– –
	South	166.9 (9.86)	88.9 (7.97)	305.3 (12.67)	48.8 (3.16)	19.5 (5.57)	2.7 (5.09)	– –
	S.W	123.8 (7.31)	75.4 (6.76)	241.0 (5.70)	50.8 (3.29)	24.4 (6.96)	7.2 (13.56)	– –
	West	102.3 (6.04)	74.5 (6.68)	137.4 (5.70)	21.6 (1.40)	3.9 (1.11)	2.7 (5.09)	– –

* Burnt vegetation includes the element of meadow and orchard.

Table 3. Size (ha) and ratio (%) of fire types according to the landscape element

Landscape element	Light surface fire	Severe surface fire	Crown fire
Agricultural field*	115(6.8)	129(11.6)	105(4.4)
Broad-leaved forest	206(12.2)	23(2.1)	178(7.4)
Coniferous forest	722(42.7)	700(62.8)	1712(71.0)
Mixed forest	626(36.9)	263(23.5)	415(17.2)
Plantation	24(1.4)	–	–
Total	1693(100)	1115(100)	2410(100)

* Orchard and meadow belong to this element.

difference of soil moisture in each aspect.

As was mentioned above, fire types depended on topographic condition (Whelan 1995). The reason is that topographic condition ultimately determines the vegetation patchiness (*viz* heterogeneity) such as the biomass accumulation, distribution of undergrowth and litter that can play a role of fuel during fire. In our study, fire was mild in high elevation and steep slope with sparse undergrowth, and it became stronger in the low elevation and smooth slope with dense undergrowth. In the smooth slope, moreover, wind accelerates the wind-driven fire and thus is responsible for the spreading of fire (Johnson 1995). But phenomenon that the ratio of crown fire decreased and that of light surface fire increased in high elevation above 600 m can be interpreted in a different viewpoint. That is, the reason can be found in vegetation type as is mentioned afterward considering that inland area with higher elevation is covered with oak forest differently from coastal area with

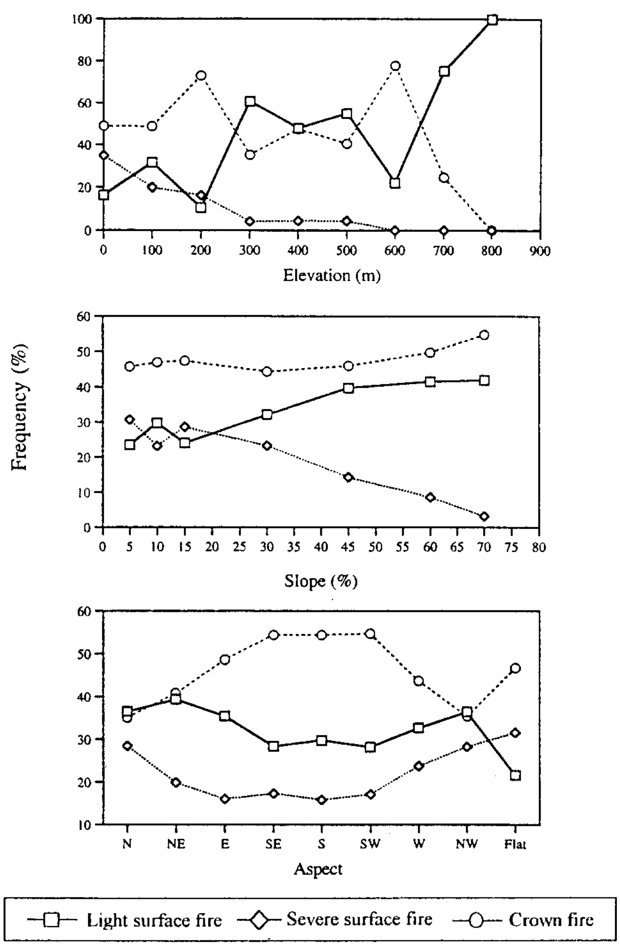

Fig. 5. Distribution analysis of fire types related to geographical attribute data which based on GIS-aid analysis.

pine forest.

Fire types were also different according to vegetation type (*i.e.* Johnson 1995, Whelan 1995). The reason is that the fuel condition governing the spread and intensity of fire are determined by vegetation type. Consequently, the spreading of fire was determined by the synergism of the pine-dominated vegetation type and habitat condition (*e.g.* wind, soil moisture). Most oak forests were disturbed by light surface fire, while the ratio of crown fire was the highest in the pine forest. We deduced that such a difference might be related to characteristics of bark of pine and oak with different content of flammable resin. Moreover, considering the fact that tolerance of pine to water deficit was higher than that of oak, cause of such a difference can be also found in moisture conditions in habitat of pine and oak (Lee 1997).

Fire as a cause of landscape changes

Land-use pattern of Kosung-Gun is mainly divided into agriculture and forestry. Major agricultural land-use is for production of rice. Cropland producing corn and potato also occurred near paddy field. Wood production from pine forest is the main forestry in this region. However, special forest land-use in this region is to collect edible mushroom (*Tricholoma matsutake*). People periodically had harvested the mushroom in the pine forests that had been maintaining as edaphic climax on mountain ridge or peak and managing artificially for production of that. However, most pine forest were burnt and mycellia of the mushroom were injured by heat of fire. Consequently, area producing mushroom was destroyed and mushroom is no longer got in this area. In this way, outbreak of fire might be an important causative factor inducing drastic change of total landscape system (Turner and Bratton 1987, Trabaud and Galti 1996). Many people who had been depended on the production of mushroom lost their valuable merchandise as the pine forest is destroyed. Thus, land-use pattern in pine forest of this area will be changed for substitute rural economy.

Fire as a cause changing vegetation structure

Size distribution of major populations in plant community reflects the tendency of vegetation succession (Barbour *et al.* 1987). Fig. 6 shows the size distribution of major woody species in the pine forest before (A) and after (B) fire. *P. densiflora* population is composed of two groups: mature trees more than 18.0 cm and young trees less than 18.0 cm of diameter at breast height (DBH) (Lee and Kim 1989). From the size distribution, we could know that seedlings and saplings of pine had been recruited ac-

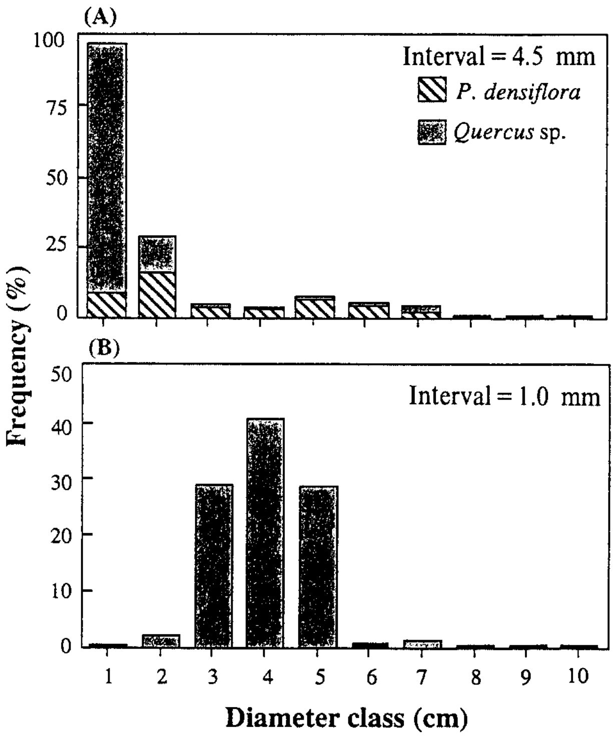

Fig. 6. Size distribution of *P. densiflora* and *Quercus* spp.

tively before fire. This active recruitment of pine seedlings might be originated from artificial interference considering that *P. densiflora* is shade intolerant species. Other indication of artificial interference in the pine forest can be found in oak stumps with sprouts.

In a diagram of oaks on the forest floor, they were composed of young trees less than 10 cm in diameter (Fig. 6A). Their diameter was smaller than young trees of the pine but their density (7,100/ha) was higher than that of young pine (2,300/ha). Such diagram shows successional tendency that pine population is replaced by oak populations. On the other hand, most oaks were sprouts originated from cut stump. From this fact we could know that succession had been retarded by excessive artificial interference to maintain continuously the pine forest.

Most pine trees were died by this fire excepting those in light surface fired area. But in cases of young oaks under the pine canopy, only their aerial parts were died and subterranean part with latent bud was alive. In general, plants have special life forms and survival strategies under the disturbance regime (Trabaud 1987). After the disturbance, many oak sprouts were originated from subterranean regenerative bud. Regeneration sources in those burnt pine forests were sprouts occurred from burnt oak stumps and thereby formed young oak stand (Fig. 6B). Their density (77,000/ha) was higher and their growth was more rapid comparing with those under unburned pine forest (Lee and Hong 1998). From those results, we estimated that fire facilitated succession from pine forest to oak forests and consequently induced change of landscape pattern.

CONCLUSION

Fire types recognized as crown fire, severe surface fire, and light surface fire in order of increasing intensity were described in a fire map. As the results of analyses by using GIS, fire intensity depended on topographic conditions and vegetation types.

Special land-use type in this area was collection of edible mushroom (*Tricholoma matsutake*). Mushrooms had been obtained from *Pinus densiflora* forests existing as edaphic climax or managed artificially. However, most pine forest were burnt and mycellia of the mushroom were injured by heat of fire. Consequently, area producing mushroom was destroyed and mushroom is no longer got in this area. In this way, outbreak of fire might be an important causative factor inducing drastic change of total landscape system. Many people who had been depended on the collection of mushroom lost their valuable merchandise as the pine forest is destroyed by fire. Thus, land-use pattern in pine forest of this area will be changed for substitute rural economy.

Regeneration strategy in burned areas was sprouts from burned oak stumps. Density and growth rate of oak sprouts increased in burned area, those results might be contributed to vegetation succession from *P. densiflora* forest to oak forest.

In conclusion, change of land-use pattern and facilitated succession would be factors changing landscape pattern in this burned area.

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적 요

본 연구에서는 식생경관에 미치는 산불의 영향을 밝혔다. 산불의 종류는 그 강도에 따라 수관화, 심한 지표화 및 약한 지표화로 구분하였고, 각 종류를 지도로 나타내었다. 산불의 종류와 지형요인 또는 식생유형 사이의 관계는 GIS를 이용하여 분석하였다. 그밖에 토지이용 유형 및 산불지역에서 식생의 재생전략도 조사하였다.

산불의 강도는 지형요인 및 식생유형에 따라 달랐다. 이 지역에서 특이한 토지이용유형은 송이버섯 생산이었다. 송이버섯은 토지극상으로 존재하거나 인위적으로 관리되는 소나무림으로부터 얻었었다. 산불지역의 재생전략은 불에 탄 참나무류 그루터기로부터 맹아를 발생시키는 것이었다. 불이 나지 않은 지역과 비교하여 불이 난 지역에서 맹아의 높은 밀도와 빠른 생장속도는 소나무림으로부터 참나무림으로의 천이를 촉진시켰고, 결과적으로 경관유형의 변화를 가져왔다.

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