LANDFORM EFFECTS ON TREE SIZE IN REESTABLISHED FORESTS AFTER FIRES

Sadao TAKAOKA and Kaichiro SASA*

Abstract The spatial heterogeneity of tree size in stands recovered after fires was examined in a 5 m × 110 m belt transect and 150 plots in the Teshio Experiment Forest situated in northern Japan. Tree growth in the reestablished stands was affected by topographic conditions. Canopy height and maximum DBH varied with slope aspect, topographic position, and elevation as well as stand age. They were found to be small 1) on southeast-, south-, southwest-, and west-facing slopes, 2) on ridges, upper parts of slopes, and terrace surfaces, and 3) within high-elevation zones. The effects of ultramafic soil from serpentinized rock on tree size were smaller than those of the topographic conditions. It follows from these findings on reestablished communities that prevailing southwesterly winds are importantly involved in regeneration.

Key words: post-fire regeneration, landform effect, tree size, stand-origin map, northern Japan

1. Introduction

The stand-origin map, a designation made by Heinselman (1973), is necessary when fire behavior and other ecological phenomena are analyzed at a landscape level. Such a map is usually made by mapping and dating past forest fires. Fire boundaries are determined by aerial photo interpretation, and stand ages are estimated from fire scars, maximum ages of canopy trees, and growth release in trees that survive past fires (Hemstrom and Franklin, 1982; Romme, 1982; Foster, 1983; Johnson and Fryer, 1986; Masters, 1990; Johnson and Larsen, 1991).

Fire boundaries can be determined from changes in tree height, crown dimensions, and species composition of a canopy layer. These features of a stand, however, may not always change consistently with the passage of time since the last fire because microsite conditions as well as stand age may affect tree growth and cover type in reestablished stands. Landform is an important factor of change in vegetation caused by fire. Fire behavior is controlled by landform, and post fire regeneration is affected by landform which in turn determines microsite conditions (Fig. 1).

---

* College Experiment Forests, Hokkaido University

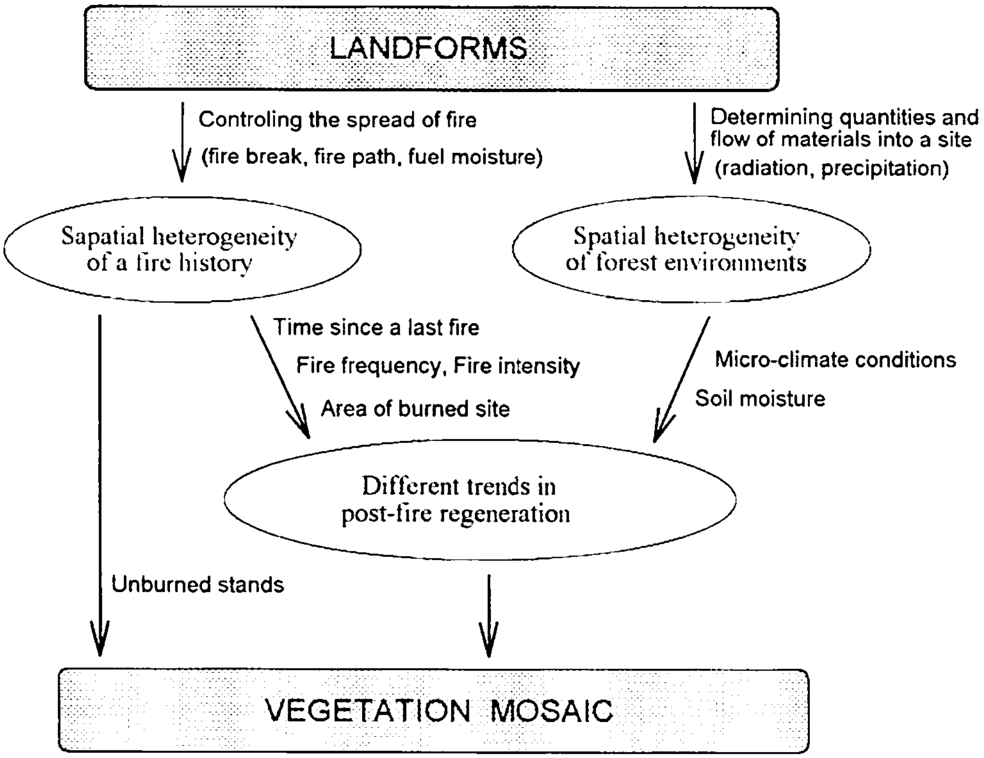

Fig. 1 Schema showing landform effects on vegetation change caused by fires, based on data from studies by Wright and Bailey (1982), Johnson (1992), and Agee (1993)

The present study was conducted to assess the spatial heterogeneity of tree size of post-fire stands with special reference to landform effects and determine factors that control the size of reestablished trees.

Examination was also made of long-term effects of fire on vegetation at a landscape level. Post-fire succession in a stand at an early stage has been extensively studied in Japan (*e.g.* Nakagoshi *et al.* (1981) for western Honshu and Iizumi (1987) for northern Honshu). Little attention, however, has been directed to the effects of fire on broad-scale vegetation for long periods, although broad-scale but short-term observation (Iizumi *et al.*, 1987) or long-term but small-scale observation (Tsuda, 1987; Kushima, 1989) has been made.

2. Study Area

The site of this study was the Teshio Experiment Forest (22,576 ha) of the Faculty of Agriculture, Hokkaido University, located in northern Hokkaido, Japan (Fig. 2). Mean annual temperature observed in the forest is 5.7°C, and mean annual precipitation is approximately 1,400 mm.

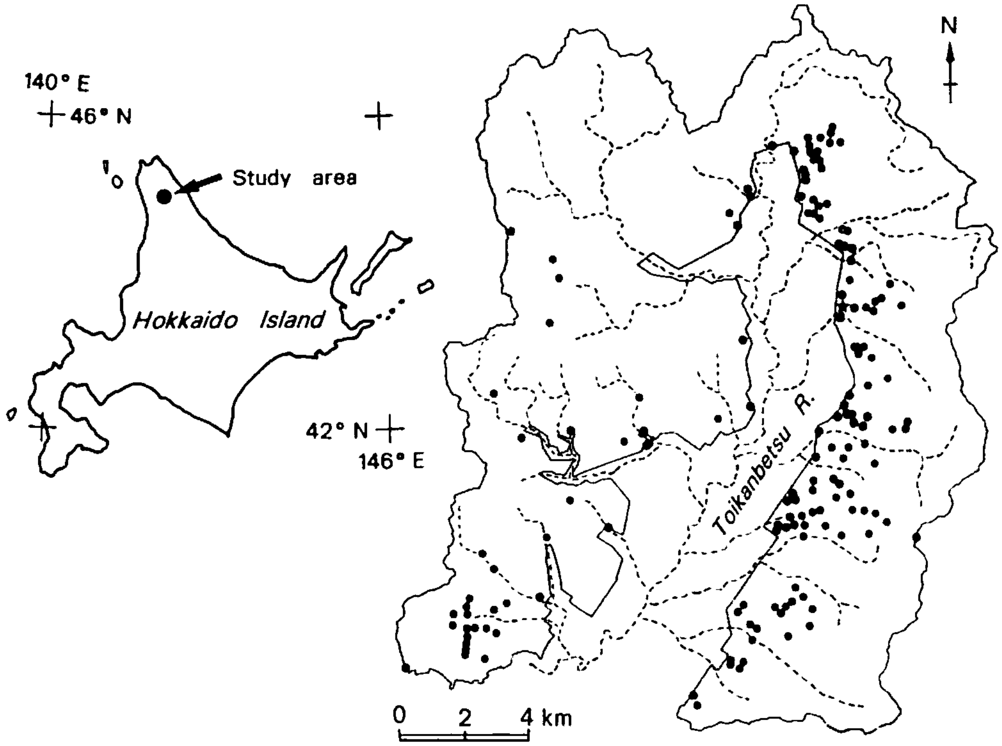

Fig. 2 Locations of the belt transect (star) and study plots (solid circles)

This area is located in a transitional zone between cool-temperate and subarctic zones. The dominant climax species of the forest include *Abies sachalinensis*, *Picea jezoensis*, *Quercus mongolica* var. *crispula*, *Tilia japonica*, *Kalopanax pictus* and *Acer mono*, except the area with serpentine rock where *Picea glehnii* is dominant (Tatewaki and Igarashi, 1971). Most of the area is covered by secondary forests and *Sasa* grasslands which formed following to fires or logging. After fires, few forest stands formed on south-, southwest-, and west-facing slopes, where *Sasa* grasslands and open shrublands are dominant (Fig. 3). Most of the understory of the primeval and secondary forests are dominated by *Sasa senanensis* and *S. kurilensis*.

There are wind-shaped trees within *Sasa* grasslands (Fig. 4-a), indicating southwesterly winds to prevail throughout this area. According to wind observation data from the nearest four AMeDAS stations during 1978-1991, winds from SSW, SW, and WSW are the most frequent in spring and summer. Thus wind-shaped trees are considered to be formed in these seasons.

Fig. 3 Asymmetrical vegetation in the Teshio Experiment Forest
Sasa grasslands or open shrublands developed on south-facing slopes and secondary forests on north-facing slopes.

Fig. 4 Wind-shaped trees on a south-facing slope (a) and even-aged forest dominated by *Betula ermanii* on a north-facing slope (b)

3. Methods

The spatial heterogeneity of tree size in reestablished stands was assessed on two different spatial scales. First, changes in height and diameter at breast height (DBH) were examined along topographic profile in a belt transect (5 m x 110 m) established perpendicularly to a ridge line running west to east. Height and DBH of all trees more than 1.5 m tall and *Sasa*-community height were measured in the transect. Increment cores from 20 cm above ground were taken from three canopy trees on the north-facing slope and from two invading trees in a *Sasa* grassland on the south-facing slope, with a Swedish increment borer.

Secondly, canopy height and maximum DBH of secondary forests were measured in 150 plots. Some cores were taken from canopy trees at a height of 20 cm above ground in each plot. Emergent and old trees growing within secondary stands were not measured or cored, since they appeared to have survived past fires. In the plots within *Sasa* grasslands, invading trees were measured and cored. The effects of environmental factors such as slope aspect, topographic position, elevation, and geology on size were determined using Hayashi's quantification theory-I, a multivariate statistical system of analysis devised by Hayashi (1950, 1952).

4. Results

Changes in tree size within the transect

A secondary forest dominated by *Betula ermanii, Alnus hirsuta*, and *Phellodendron amurense* was observed on the north-facing slope (Fig. 5). Canopy height was about 14 m at the middle and lower parts of the slope. Height decreased with approach to the ridge. On the ridge and south-facing slope, no continuous canopy layer was present; shrubs about 2 m in height grew in the *Sasa* grassland. Some shrubs higher than 3 m were wind-shaped owing to contact with southwesterly winds. DBH also decreased with proceeding toward the ridge. Height of the *Sasa* community of the understory in the secondary forest ranged from 1.4 to 1.6 m on the north-facing slope and 0.4-1.0 m on the ridge and south-facing slope. Although *Sasa* coverage was 90-100 % on the upper part of the south-facing slope, it had decreased on the ridge and south-facing slope, where *Miscanthus sinensis* dominated.

Cores from *B. ermanii* trees comprising the canopy layer had 43-46 rings on the north-facing slope. The cores from two trees, possessing no pith, had at least 33 rings on the south-facing slope.

Changes in tree size throughout the study area

Figure 6 shows the relationship between age and size (height and DBH) for 366 *B. ermanii* trees from which complete cores with a pith or almost complete cores with one or two years lacking were taken. Size was not in direct proportion to age. For example, the height of 50 year-old trees ranged from 4 to 18 m, and DBH from 5 to

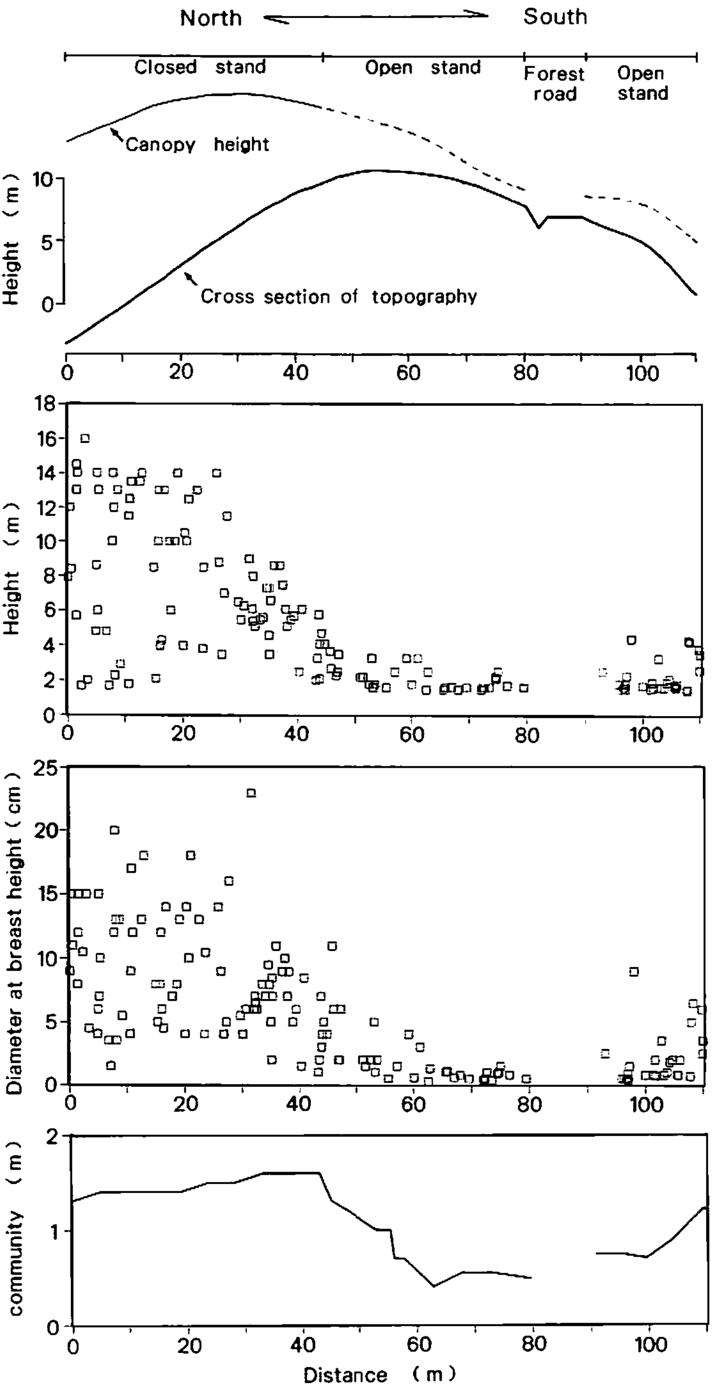

Fig. 5 Changes in height and diameter at breast height of trees and height of the *Sasa* community, as a function of topography along the transect

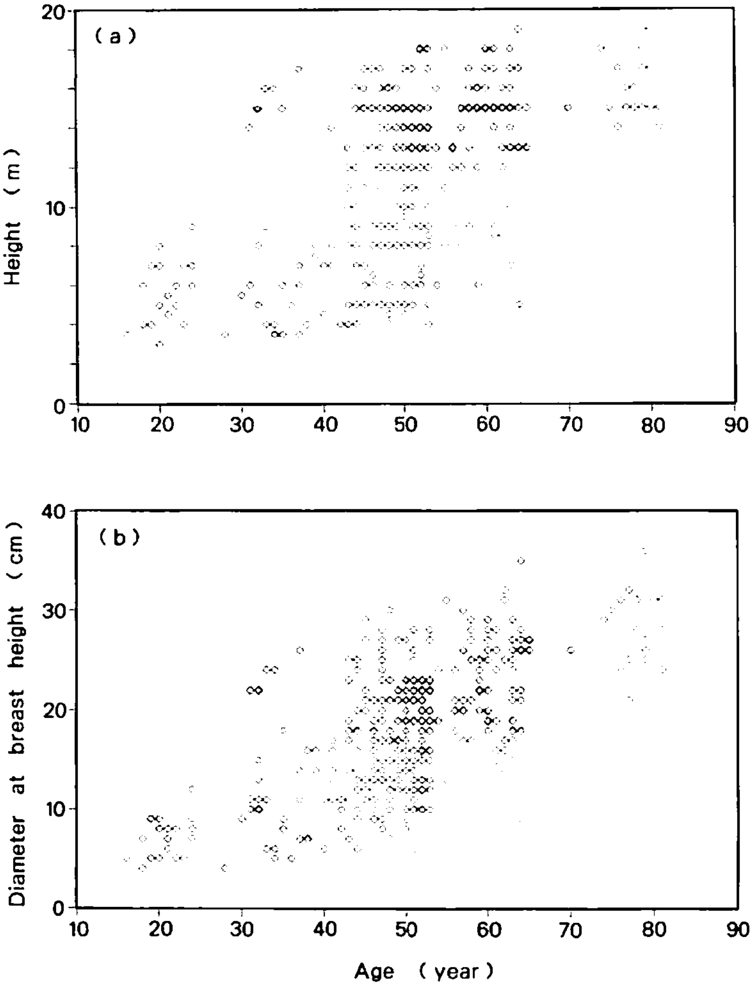

Fig. 6 Height (a) and diameter at breast height (b) of 366 cored trees of *Betula ermanii* in relation to ages

30 cm.

The results of multivariate statistical analysis are shown in Table 1. Multiple correlation coefficients (MC) for height and DBH were high (MCs: 0.675 and 0.626 respectively), suggesting that about 40% of variation in tree size can be explained by the studied four factors (MC^2s: 0.456 and 0.392 respectively). The range of category score for topographic position is the largest of those of the four factors. The other three factors for tree height are arranged in order of increasing score as follows: slope aspect, elevation, and geology. The factors for DBH in the order of increasing dominance were found to be elevation, slope aspect, and geology. Variation in scores of height and DBH according to topographic position, slope aspect, and elevation indicated the following: 1) the scores for the topographic position has small values on ridges, upper parts of slopes, and terrace surfaces 2) the scores for the slope aspect exhibits small values on southeast-, south-, southwest-, and west-facing slopes 3) the scores decrease with increasing elevation. The range of category score for geology is the smallest. The scores of height and DBH in serpentinite areas are less than that in other geological areas.

5. Discussion

North- and south-facing slopes in the studied transect were of the same fire origin. These slopes had apparently burned in 1947, in consideration of the number of rings of cored trees and documented evidence by the forest office of the Teshio Experiment Forest. Vegetation type and tree size on the south-facing slope differed from those on the north-facing slope, this difference possibly becoming evident initially during post-fire regeneration. Logs and snags beneath litter layer suggest that before the fire, trees had been distributed evenly on the ridge and the south-facing slope as well as on the north-facing slope.

Ridges and upper parts of slopes were generally well-drained sites. Soil dryness due to landform control of water flow may thus possibly have hindered the development of secondary forests at certain points in the transect. However, prevailing southwesterly winds apparently had greater effect on post-fire regeneration in consideration of the followings: 1) reestablished communities on the upper parts of the north- and the south-facing slopes varied in type and structure although they originated in the same fire, and 2) in some cases, tree shape was affected by prevailing southwesterly winds.

The effects of the southwesterly winds on tree size could be seen not only in the transect but throughout the study area. The results of a multivariate statistical analysis indicate slope aspect, topographic position, and elevation to affect tree growth. Both height and DBH were small in plots at certain topographic positions and particular slope aspects exposed to the southwesterly winds. The main reason for smaller tree size with increasing elevation is considered not a decrease of approximately 2°C in temperature for a 400 m rise in elevation but greater wind speed due to reduced friction with the ground surface.

Forests usually do not develop well on soil derived from serpentinized ultramafic rock (Roberts and Proctor, 1991). Few secondary forests developed well in serpentinite areas also in the present study site, possibly due to the distinctive chemical and physical properties of soil from weathered serpentinized rock (Nakata, 1986; Nakata and Kojima, 1987). However, this would not be a major adverse factor for forest establishment. The results of the present study indicate serpentine soil to probably be less important than others for development of *Sasa* grasslands and open shrublands. Serpentinite had limited effect on tree growth as shown in Table 1.

Table 1 Effects of environmental factors on tree growth as determined by Hayashi's Quantification Theory-I

Item	Category	Frequency	Height (apical growth: m/yr)			Diameter (radial growth: cm/yr)		
			Category score	Range	Partial correlation	Category score	Range	Partial correlation
Topographic position	Ridge	36	0.007	0.087	0.293	- 0.004	0.141	0.262
	Upper part of slope	57	- 0.024			- 0.025		
	Lower part of slope	41	0.019			0.034		
	Terrace surface	14	0.014			- 0.005		
	Valley bottom plain	2	0.063			0.116		
Slope aspect	N	17	0.053	0.077	0.406	0.048	0.096	0.338
	NE	4	0.040			0.026		
	E	9	0.007			0.020		
	SE	8	- 0.018			- 0.039		
	S	22	- 0.024			- 0.049		
	SW	20	- 0.007			- 0.030		
	W	18	- 0.008			- 0.014		
	NW	15	0.022			0.027		
	- (Flat surface)	37	- 0.014			0.020		
Elevation	0 - 100 m	77	0.023	0.058	0.309	0.029	0.133	0.334
	101 - 200 m	35	- 0.016			0.004		
	201 - 300 m	29	- 0.029			- 0.050		
	301 - 405 m	9	- 0.036			- 0.104		
Geology	Serpentinite	50	- 0.018	0.026	0.192	- 0.014	0.020	0.092
	Others	100	0.009			0.007		

Apical and radial growth rates were calculated by dividing canopy height and maximum DBH in each plot by stand age.

6. Conclusions

Canopy height and maximum DBH in reestablished stands were not always in direct proportion to stand ages since tree growth was affected by microsite conditions. Tree size varied with slope aspect, topographic position, and elevation. The effects of ultramafic soil derived from serpentinized rock on tree size were smaller than those of topographic conditions. Prevailing southwesterly winds should be considered essential for heterogeneous formation.

When identifying past fire boundaries for drawing a stand-origin map, not only aerial photo interpretation but also observation and sampling in the field are indispensable.

Acknowledgments

This paper is dedicated to Professor Hiroshi Kadomura in commemoration of his retirement from Tokyo Metropolitan University, who gave the first author a opportunity to study vegetation geography.

The authors are grateful to Professors Hiroshi Machida, Makoto Kimura, Nobuyuki Hori, and Dr. Shuichi Oka of Tokyo Metropolitan University for their many valuable comments. They also thank the staff of the Teshio Experiment Forest of Hokkaido University and Ms. Mio Kasai of Kyushu University for supports in conducting the field work. This research was funded in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science, and Culture, Japan relating to JSPS Fellowships for Japanese Junior Scientists.

References Cited

Agee, J. K. (1993): *Fire ecology of Pacific Northwest forests*. Island Press, 493p.

Foster, D. R. (1983): The history and pattern of fire in the boreal forest of southeastern Labrador. *Can. J. Bot.*, **61**, 2459-2471.

Hayashi, C. (1950): On the quantification of qualitative data from the mathematico-statistical point of view. *Ann. Inst. Statist. Math.*, **2**, 35-47.

—— (1952): On the prediction of phenomena from qualitative data on the quantification of qualitative data from the mathematico-statistical point of view. *Ann. Inst. Statist. Math.*, **3**, 69-98.

Heinselman, M. L. (1973): Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. *Quat. Res.*, **3**, 320-382.

Hemstrom, M. A. and Franklin, J. F. (1982): Fire and other disturbances of the forests in Mount Rainier National Park. *Quat. Res.*, **18**, 32-51.

Iizumi, S. (ed.) (1987): *Ecology of forest fire: fire behavior in forest area and fire effects on ecosystem*. Rinya-kasai-kenkyu Group, Tohoku University, Sendai, 340p.**

——, Shitara, H., and Kikuchi, T. (1987): Mechanism of forest fire spreading in northern suburbs of Sendai. In Iizumi, S.(ed.) "*Ecology of forest fire: fire behavior in forest area and fire effects on ecosystem.*" Rinya-kasai-kenkyu Group, Tohoku University, Sendai, 11-18.**

Johnson, E. A. (1992): *Fire and vegetation dynamics: Studies from the North American boreal forest.* Cambridge University Press, New York, 125p.

—— and Fryer, G. I. (1986): Historical vegetation change in the Kananaskis Valley, Canadian Rockies. *Can. J. Bot.*, **65**, 853-858.

—— and Larsen, C. P. S. (1991): Climatically induced change in fire frequency in the southern Canadian Rockies. *Ecology*, **72**, 194-201.

Kushima, H. (1989): A fire history of secondary forest stands in Tokyo University Forest in Hokkaido. *Abstracts of symposium papers and posters presented at the 36 th Mtg. Ecol. Soc. Jpn.*, p.129.*

Masters, A. M. (1990): Changes in forest fire frequency in Kootenay National Park, Canadian Rockies. *Can. J. Bot.*, **68**, 1763-1767.

Nakagoshi, N., Nakane, K., Imaide, H., and Nehira, K. (1981): Regeneration of vegetation in the burned pine forest in southern Hiroshima Prefecture, Japan. I: Floristic composition, vegetation structure and biomass in the early stage of regeneration. *Mem. Fac. Integrated Arts and Sci., Hiroshima Univ.*, Ser. IV, **6**, 69-113.**

Nakata, M. (1986): Changes of vegetation and soils caused by forest fire in the serpentine area. *Jpn. J. For. Environ.*, **28**, 37-45*

—— and Kojima, S. (1987): Effects of serpentine substrate on vegetation and soil development with special reference of *Picea glehnii* forest in Teshio District, Hokkaido, Japan. *Forest Ecology and Management*, **20**, 265-290.

Roberts, B. A. and Proctor, J. (1991): *The ecology of areas with serpentinized rocks: A world review*. Kluwer Academic, Dordrecht, 427p.

Romme, W. H. (1982): Fire and landscape diversity in subalpine forests of Yellowstone National Park. *Ecol. Monogr.*, **52**, 199-221.

Tatewaki, M. and Igarashi, T. (1971): Forest vegetation in the Teshio and Nakagawa District Experiment forests of Hokkaido University, Prov. Teshio, N. Hokkaido, Japan. *Res. Bull. Coll. Exp. For. Fac. Agric. Hokkaido Univ.*, **28**, 1-192.**

Tsuda, S. (1987): Vegetation affected by forest fires in Teshio, Hokkaido. In Iizumi, S.(ed.) "*Ecology of forest fire: fire behavior in forest area and fire effects on ecosystem.*" Rinya-kasai-kenkyu Group, Tohoku University, Sendai, 173-179.**

Wright, H. A. and Bailey, A. W. (1982): *Fire ecology, United States and southern Canada.* John Wiley and Sons, New York, 501p.

(*: in Japanese, **: in Japanese with English abstract)