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Study of the Recovery Characteristics of Vegetation and the Effects of Topographical and Soil Factors in Devastated Forest Land

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The recovery characteristics of vegetation and the effects of topographical and soil factors were analyzed, targeting Mt. Tateishi, which is mostly covered with granite and located on the Itoshima peninsula in Fukuoka Prefecture.

The results are summarized as follows.

The vegetation of this area can be divided into 4 vegetation groups, nominated as group 1, group 2, group 3 and group 4 according to crown closure and the volume of woody plants.

The volume of both herbs and woody plants increased gradually from group 1 to group 3. The volume ratio of herbs to woody plants reached a maximum in group 2. The volume ratio of herbs to woody plants was at a minimum in group 4.

Of the topographical factors, the aspect of slope was a significant factor affecting vegetation volume but the shape of slope did have a great effect. In areas where vegetation volume was greater, the total soil layer was deeper.

The volume ratio of broad-leaved trees to conifers increased markedly from groups 1 through 4. Conifers covered an overwhelming area in group 1. Evergreen broad-leaved trees covered the largest area in group 4.

The succession depended on the site conditions. Group 2 was an edaphic climax having developed under harsh conditions. Some group 3 areas in favorable conditions were able to develop into group 4 type areas.

INTRODUCTION

To clarify the effects of topography and soil on the recovery of vegetation in devastated forest land, a definitive case study was carried out targeting Mt. Tateishi, which is located on the western tip of Itoshima peninsula in Fukuoka Prefecture.

This study also aims to produce a model that can be applied to forecasting and subsequent action to facilitate vegetation recovery in similar forest land devastated by erosion, hillside collapse or destructive logging etc.

AREA UNDER STUDY

Mt. Tateishi, as shown in Fig. 1 and Fig. 2, has a maximum height of 209m above sea level. The basic rock is granite. Mean annual rainfall is about 1,700mm. A strong north-western wind blows in winter.

There are large granite rocks on this mountain. In particular one of the largest rocks on the north side of the mountain top probably gave the mountain its name, ' Tateishi', which literally means "Standing stone" in Japanese (Yui, 1990).

In illustrations from early texts (Kaibara, 1703; Okumura, 1821), published 300 years ago, there were large rocks and no vegetation. Elsewhere (Toumura, 1989), there is a description of Mt. Tateishi at an unspecified date as white and bare.

The forest stand map (Fig. 3) (made from an aerial photograph taked in 1961) shows that there are conifer stands on both northern and southern slopes. Now, as shown in Fig. 4, there are comparatively superior stands composed mainly of evergreen broad-leaved trees on the northern slopes and large rocks mentioned above are hidden by these stands. These stands are considered to be stable flora.

However, evergreen broad-leaved trees which have coexisted with the *Pinus* spp. still remain on the southern slopes. The areas were invaded by *Dicranopteris pedata* (Koshida) and *Gleichenia japonica* (Urajiro) after *Pinus* spp. had died out.

Red pine stumps over 40cm in diameter exist in the foliage areas of *Dicranopteris pedata* (Koshida) and *Gleichenia japonica* (Urajiro). Although extensive erosion occurred mainly in rock covered areas where red pine had died out on the southern slopes, there are some spots in which vegetation has recovered considerably and various kinds of plants are in evidence.

A panoramic view from the east is shown in Fig. 5. The 3 peaks are standing in a gently undulating row from east to west. The central peak (ie. the top of Mt. Tateishi) has a gentler slope compared with the eastern peak. In general, the southern and northern slopes are nearly symmetrical and there are few ravines on these slopes.

Figure 6 shows the relief energy in every 50m x 50m square area of Mt. Tateishi. In Fig. 6, the northern slopes have a greater total relief energy compared with the southern slopes.

The target area under study is a elliptical area including the top of Mt. Tateishi and comprises 130ha of national forest.

Field investigation was carried out in the period from Dec. 1989 to May 1991.

PARTITION OF FLORA AND CHARACTERISTICS OF VEGETATION STRUCTURE

1. Method of investigation

1. 1. Vegetation investigation

31 circular plots (each 100m² in area) were set up randomly in the target area. The location of the plots is shown in Fig. 2. Aspects of woody plants and herbs studied in the plots are listed below.

Woody plants: tree species, tree height, crown diameter, clear-length

Herbs: herb species, herb height, level surface area

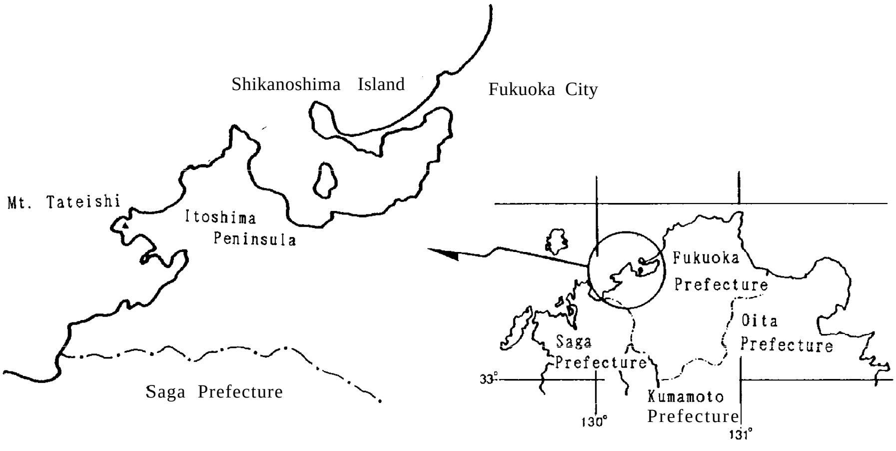

Fig.1 Location of Mt. Tateishi, the target area.

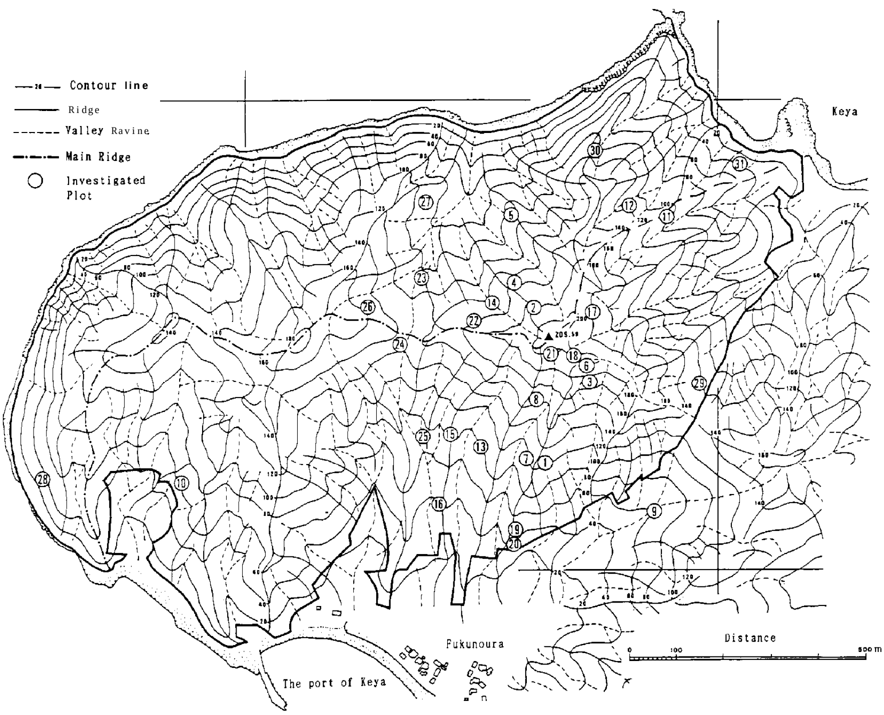

Fig.2 Location of investigated plots.

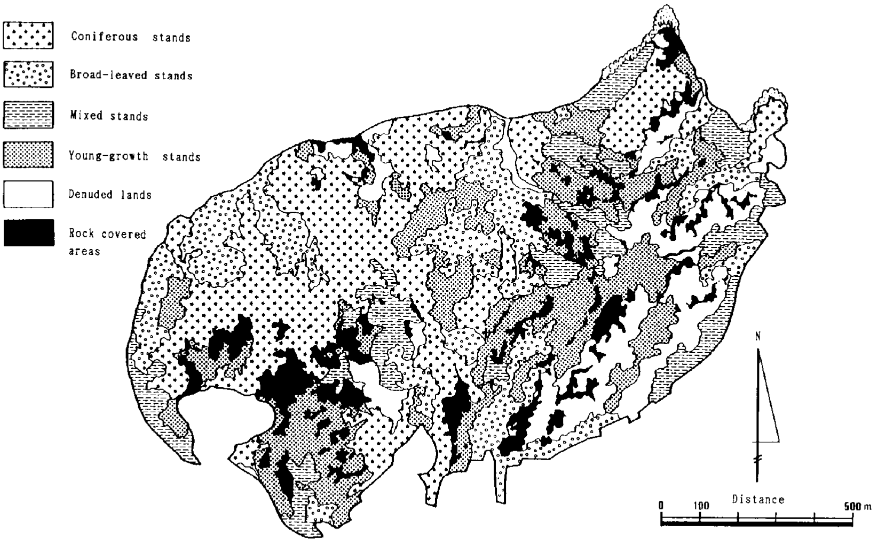

Fig.3 Forest type map of the target area.

Moreover, crown closure, percentage of area covered by herbs, erosion area rate and percentage of area covered by rock were measured visually. Erosion area rate is the ratio of the area where the FH layer had been washed away (even though the litter layer may still remain) to the total area of the plot.

Shape of crown closely resembled a cone. Crown volume is expressed as the volume of the cone and is calculated using crown diameter and crown height. Total crown volume in a plot is defined as the volume of woody plants.

Volume of herbs is derived by multiplying the height by the level surface area, by one third. The sum of the volume of woody plants and herbs is defined as the vegetation volume.

Volume of woody plants, herbs and vegetation in each plot is listed in Table 1.

1. 2. **Analysis of topography**

The target area was divided into 65 slope units on a map of scale 1:5000. The slope of each unit had only one aspect.

In addition, lattices (50m in actual length on each side) were set up on the target area. An area surrounded by lattice lines was designated an inspection area. Elevation, aspect of slope, slope angle and shape of slope (ie. convex, concave and plain) were measured at every inspection area (491 areas).

The distance from each intersection of lattice lines to the nearest ridge was measured in the direction of the water-flow. In addition the length of each slope unit was measured.

Table 2 shows the maximum, minimum and mean values of elevation, slope angle, slope length and the distance from a ridge as indicated above.

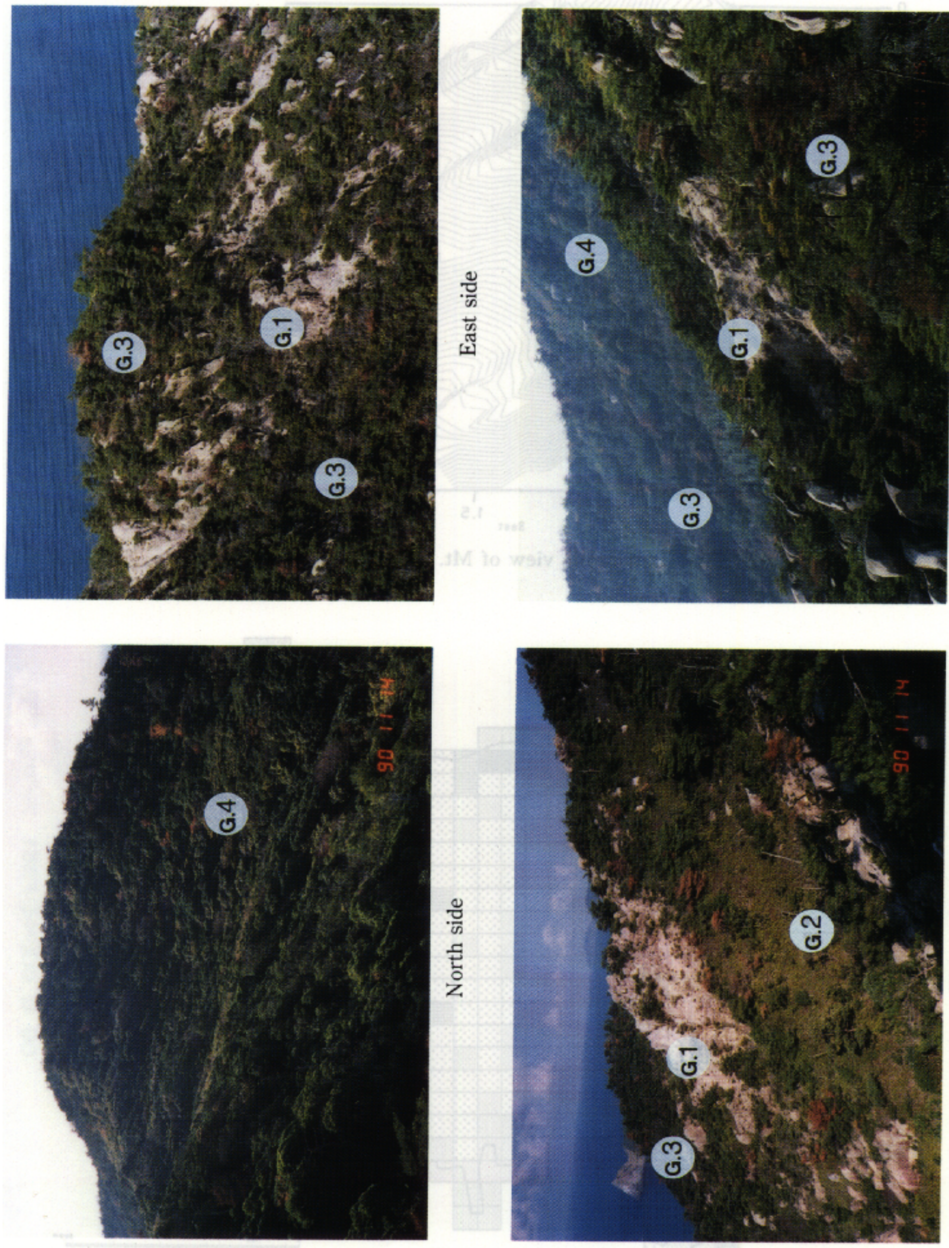

Fig.4 Views of Mt. Tateishi.

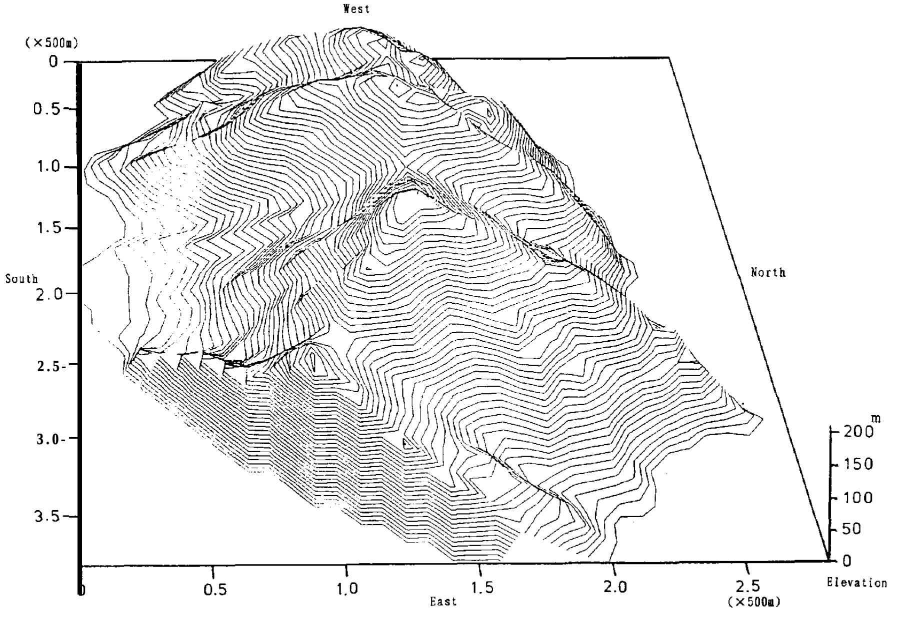

Fig.5 Panoramic view of Mt. Tateishi.

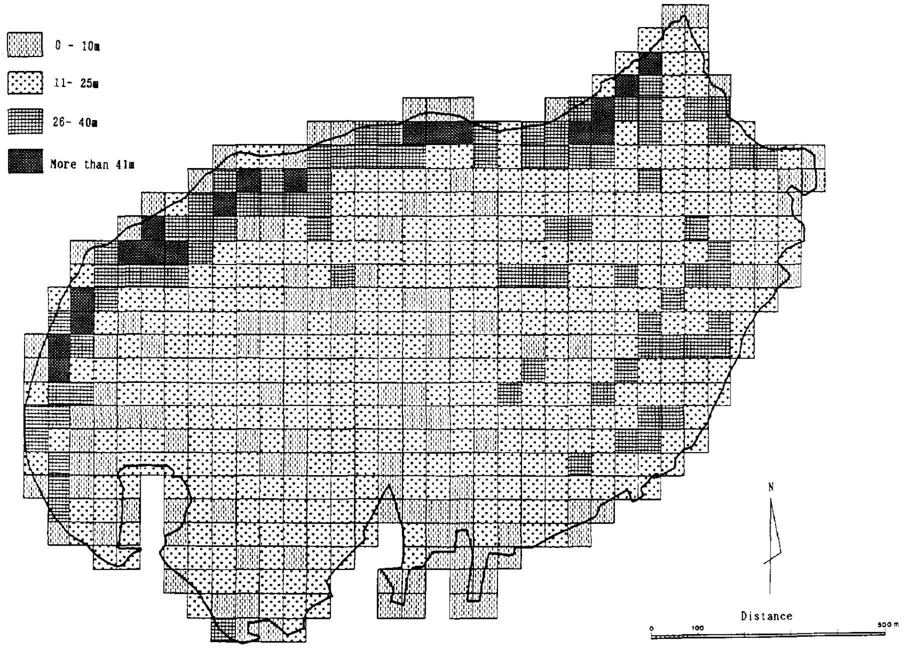

Fig.6 Distribution of relief energy in the target area.

Table 1. Volume of herbs and woody plants in the plots of each vegetation group. Unit : $m^3/100m^2$

Group 1				Group 2				Group 3				Group 4			
Plot No.	Woody plants	Herbs	Total	Plot No.	Woody plants	Herbs	Total	Plot No.	Woody plants	Herbs	Total	Plot No.	Woody plants	Herbs	Total
1	2.01	0.63	2.64	7	39.78	75.90	115.68	13	189.15	15.00	204.15	18	244.20	59.63	303.83
2	1.02	0.01	1.03	8	52.74	35.75	88.49	14	131.33	165.00	296.33	19	389.55	15.00	404.55
3	11.25	0.66	11.91	9	10.66	57.00	67.66	15	189.52	27.00	216.52	21	335.78	42.25	378.03
4	12.94	2.45	15.39	10	10.16	116.00	126.16	16	139.70	123.00	262.70	22	263.69	4.50	258.19
5	4.91	0.05	4.96	11	47.62	80.00	127.62	17	97.04	120.00	217.04	23	1171.76	1.25	1173.01
				12	18.39	54.00	72.39					24	380.47	4.38	384.85
												25	1172.71	18.00	1190.71
												26	190.55	9.00	199.55
												27	1969.64	0.01	1969.65
												28	317.77	0.60	318.37
												29	251.77	2.80	254.57
												30	645.32	0.02	645.34
												31	573.15	2.00	575.15
Mean	6.43	0.76	7.19	Mean	29.89	69.78	99.67	Mean	149.35	90.00	239.35	Mean	608.18	12.26	620.44

Table 2. Values **for** the topographical factors.

	Elevation	Relief* energy	Slope length	Distance from a ridge
Max.	203.0^m	75.0^m	265.0^m	185.0^m
Min.	5.0	5.0	10.0	0.0
Mean	96.3	26.2	82.6	38.3

*Relief energy in 50m × 50m square area

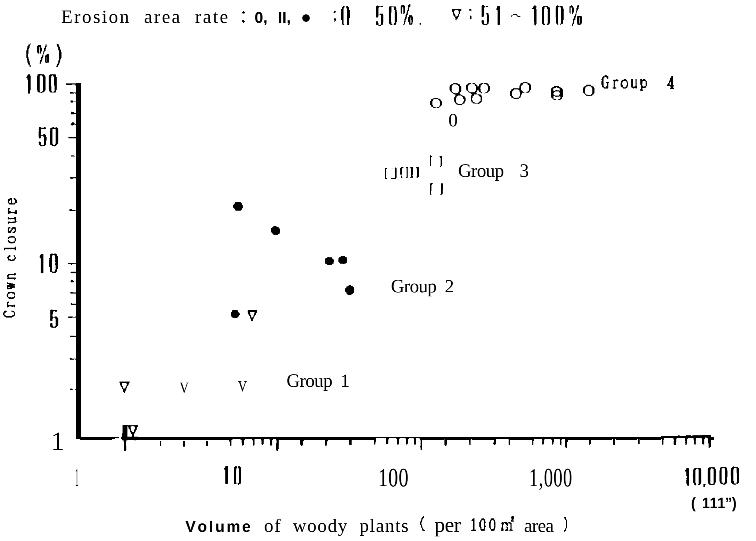

Fig.7 Division of vegetation group based on crown closure and volume of woody plants.

2. Division of flora

Figure 7 shows the relationship between the volume of woody plants and crown closure.

Both variables display a linear relation on a logarithmic scale. In cases where the volume of woody plants is greater, crown closure is greater.

In Fig. 7, the plotted values can be used to identify some groups according to crown closure. In addition, according to whether the erosion area rate exceeded 50% or not, 4 groups were identified. These groups were designated as group 1, group 2, group 3 and group 4, as indicated in Fig. 7. The means of crown closure of groups 1, 2, 3 and 4 were 3%, 12%, 30% and 83%, respectively.

Typical sites of these groups are indicated in Fig. 4.

3. Volume structure of each group of woody plants and herbs

Figure 8 shows the volume conformation of woody plants and herbs in each group. Total volume increases from group 1 to group 4 clearly. In both woody plants and herbs, the total volume increases in the order of group 1, group 2 and group 3.

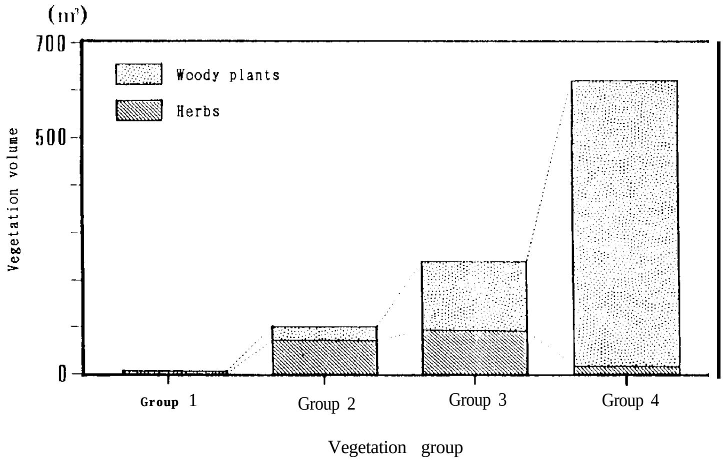

Fig.8 The volume composition of herbs and woody plants in each vegetation group.

However, the volume of herbs does not increase significantly. In group 4, though the volume of woody plants is greatest, the volume of herbs is less than in group 2 and group 3.

Volume ratio of herbs to the total is highest (ie. 70%) in group 2 and lowest (ie. 2%) in group 4. These results indicate that crown closure has developed to near its maximum in group 4.

4. **Distribution of Flora in each group**

The flora map in Fig. 9 was derived from aerial photographs of crown closure and erosion area rate was derived from on site investigation.

As indicated in Fig. 9, a salient difference in flora between the southern slope and northern slope is apparent. The border was the main ridge passing across the top of the mountain from east to west.

In particular, this difference is more apparent in the western half of the target area closer to the sea.

Group 4, ie. the area covered by a stable upper layer, is widely spread on the north side of the mountain. However, group 1, (ie. denuded land or eroded areas) and groups 2 and 3, (ie. the area covered by a layer of sub-trees) occupy many areas on the south side.

Table 3 indicates the ratio of the area (area ratio) of each group to the total area of each slope unit according to the aspect of slope and slope position (ie. higher, middle and lower).

The area covered with vegetation was greatest in the middle positions followed in order by the lower and higher positions for all groups. The total vegetation volume in the higher position was 1/3 of that in the middle position.

The area ratio of each group to the total of all groups is shown in Fig.10 with values from Table 3. In Fig. 10, group 4 occupies an overwhelmingly large area and groups 1, 2 and 3 occupy only a small area on the northern slopes. Group 4 is distributed

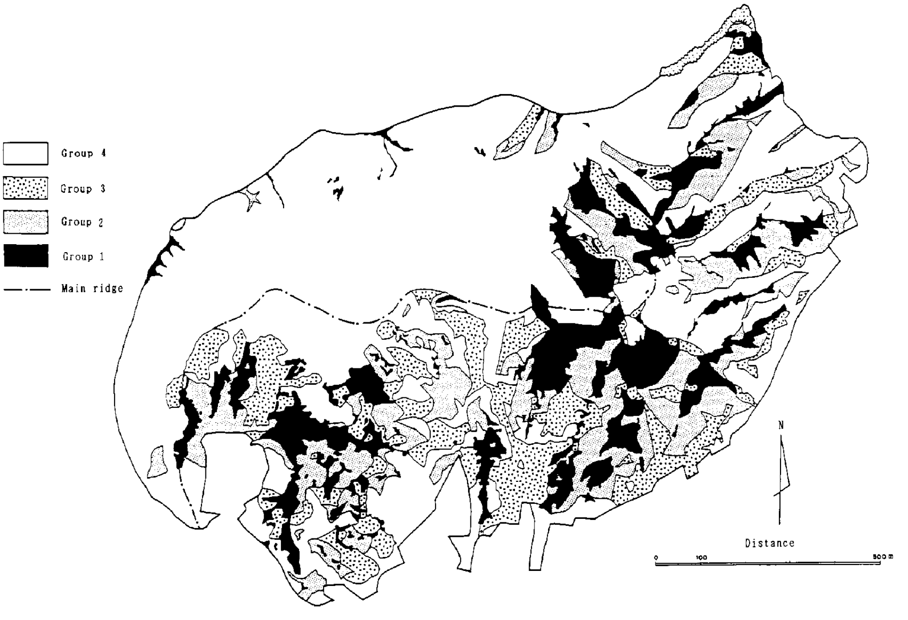

Fig.9 Distribution of vegetation groups in target area.

Table 3. Areas of each vegetation group according to the position and aspect of the slope. Unit : ha

		Total	Group 1	Group 2	Group 3	Group 4
	Total	130.09	14.13	24.60	17.62	73.74
Higher position (over an elevation of 141m)	North	7.35	0.28	0.41	0.34	6.32
	West	3.51	0.99	1.22	0.31	0.99
	South	6.04	0.94	2.21	0.57	2.32
	East	4.35	0.68	1.51	0.13	2.03
	Subtotal	21.25	2.89	5.35	1.35	11.66
Middle position (an elevation of 71-140m)	North	20.00	0.43	0.24	0.71	18.62
	West	11.16	1.80	2.11	1.66	5.59
	South	15.52	2.45	4.67	4.12	4.28
	East	14.02	1.30	5.38	2.24	5.10
	Subtotal	60.70	5.98	12.40	8.73	33.59
Lower position (an elevation of O-70m)	North	14.06	0.48	0.28	0.06	13.24
	West	10.84	1.30	1.06	1.42	7.06
	South	11.77	1.24	2.68	3.33	4.52
	East	11.47	2.24	2.83	2.73	3.67
	Subtotal	48.14	5.26	6.85	7.54	28.49

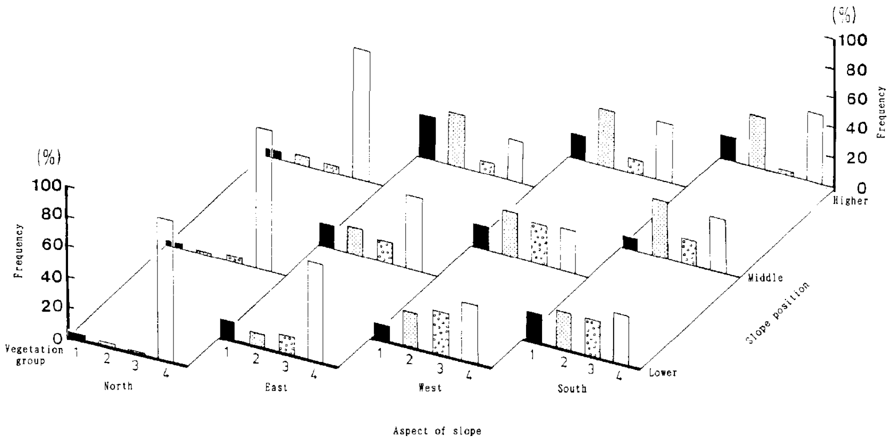

Fig.10 Frequency distributions of vegetation groups for each position and aspect of slope.

widely and the recovery of vegetation is considered to be advanced in lower positions.

As slope position moves higher on the western slopes, the area covered by group 4 becomes smaller and that by groups 1 and 2 larger. This observation indicates that the recovery of vegetation has yet to advance in higher positions.

On the southern slopes, no vegetation group occupies a majority of the area, and the area covered by vegetation increases gradually in order from group 1 to group 4 in lower positions. In middle positions, the area covered with vegetation is distributed uniformly, and groups 2 and 4 occupy a larger area in higher positions.

On the eastern slopes, each group is distributed uniformly in lower positions. However, groups 2 and 4 occupy a large area and groups 1 and 3 are small.

On the whole, group 3 is comparatively small in higher positions. Group 3, considered to have low resistance to adverse climatic conditions, does not grow well in higher positions where conditions are harsh.

These tendency will be analyzed in a later section in detail.

5. **Distribution of vegetation and the effect of topographical factors**

Distribution of vegetation in each group and their relation to the topographical factors of slope are examined as follows.

Vegetation volume in each group represent the stage of vegetation recovery and is defined as an objective variable. Topographical factors, (ie. explanatory variables), used here are aspect of slope, shape of slope, elevation, slope length, relief energy and distance from a ridge. Analysis of the relationship between these variables were carried out using the *Quantification 1 method' (Suhryouka-ichi-rui).*

Results from the analysis are shown in Table 4. In Table 4, absolute values of category weight of both northern and southern slopes are nearly the same and are very large, though their effects can be either positive or negative. Vegetation volume is larger on the northern slopes and smaller on the southern slopes. Aspect of slope is a significant factor influencing vegetation volume.

Regarding category weight of slope shape, convex shape has a very negative effect on vegetation volume. Concave shape and plain shape have a positive effect on volume.

Table 4. The analysis of the relation between topographical factors and vegetation volume (using '*Quantification 1 method*').

Factor	Category	Weight
		342.2
	North	140.8
Aspect	West	2.9
of slope	South	-131.3
	East	-12.9
	Convex	-61.7
Shape	Plain	14.1
of slope	Concave	16.1
Explanatory variable		Regression coef.
Elevation		-0.10
Relief energy		-1.96
Slope length		0.77
Slope position		0.35
Mul. cor. coef.		0.42

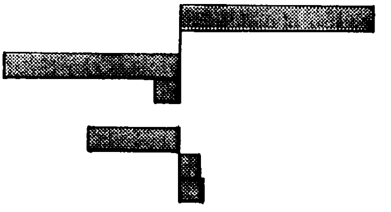

Table 5. The analysis of the relation between topographical factors and vegetation volume on the southern and northern slopes (using multiple regression analysis).

Topographical factors	Southern slopes	Northern slopes
Elevation	0.09	~0.002
Relief energy	-0.35	0.03
Slope length	0.08	0.14
Distance from a ridge	0.10	0.15
Mul. cor. coef.	0.35	0.26

This is considered to be related to the fact that water-flow spreads wider and that water cannot be kept longer on convex slopes than on concave or plain slopes.

Other topographical factors are numerable variables and the following were identified according to their regression coefficients. The larger the slope length and distance from a ridge, and the smaller the elevation and relief energy, the greater the vegetation volume became. This is probably because water can be retained longer without surface soil erosion.

The multiple correlation coefficient was 0.42 which was significant at a 0.1% level of significance, Vegetation volume can be satisfactorily explained by these variables.

To clarify the effects of numerable variables quantitatively on each aspect of slope, multiple regression analysis on the vegetation volume and topographical factors was carried out. The results are shown in Table 5. The following were defined using the values of the standard correlation coefficient.

Slope length and the distance from a ridge have a very positive effect on vegetation volume on the northern slopes. Relief energy has a minor effect and elevation has

Table 6. Values of soil factors and vegetation volume in each investigated plot.

Plot. No	Aspect*[1] of slope	Slope angle (°)	Elevation (m)	A_0 Layer: Area rate covered by A_0 layer (%)	A_0 Layer: Volume ($m^3/100m^2$) L Layer	A_0 Layer: Volume ($m^3/100m^2$) FH Layer	Soil: Erosion area rate (%)	Soil: Depth(cm) A Layer	Soil: Depth(cm) B Layer	Soil: Depth(cm) Total	Soil: Hardness(mm)*[2] Surface soil	Soil: Hardness(mm)*[2] A Layer	Soil: Hardness(mm)*[2] B Layer	Vegetation volume*[3] ($m^3/100m^2$) Total	Vegetation volume*[3] ($m^3/100m^2$) Woody plants	Vegetation volume*[3] ($m^3/100m^2$) Herbs
1	2	34	105	2	0.040	0.001	98	1.5	33.0	36	12	10	13	2.64	2.01	0.63
2	1	30	185	3	0.009	0.002	98	0.1	36.0	38	10	7	10	1.03	1.02	0.01
3	3	28	170	2	0.070	0.001	99	0.1	29.0	29	7	8	8	11.91	11.25	0.66
4	4	23	155	3	0.060	0.002	98	0.1	24.0	24	7	8	8	15.39	12.94	2.45
5	2	22	110	3	0.090	0.002	99	0.1	7.0	7	7	8	8	4.96	4.91	0.05
7	2	35	95	80	1.000	0.040	20	9.5	18.0	36	9	13	14	115.68	39.78	75.90
8	3	25	145	70	1.400	0.010	40	17.5	11.0	29	9	14	13	88.49	52.74	35.75
9	2	23	65	80	3.200	0.008	0	29.0	95.0	130	13	15	20	67.66	10.66	57.00
10	2	24	60	100	8.000	7.000	0	13.5	56.5	110	7	10	15	126.16	10.16	116.00
11	4	28	105	100	2.000	2.500	0	15.0	9.5	30	6	9	13	127.62	47.62	80.00
12	1	26	135	90	1.800	1.350	15	3.0	6.5	13	10	10	10	72.39	18.39	54.00
13	2	31	80	85	4.250	0.430	0	14.5	34.0	51	9	9	17	204.15	189.15	15.00
14	4	24	145	100	6.000	5.000	0	17.5	85.5	150	4	7	10	296.33	131.33	165.00
15	2	16	85	90	2.700	0.630	5	10.0	21.0	56	6	8	22	216.52	189.52	27.00
16	2	18	40	100	2.500	5.000	0	19.5	54.0	80	7	9	24	262.70	139.70	123.00
17	4	22	180	100	8.000	3.500	0	5.5	20.5	65	6	6	22	217.04	97.04	120.00
18	3	17	200	90	3.000	3.000	0	6.0	8.5	16	12	15	32	303.83	244.20	59.63
19	3	32	50	100	4.000	2.000	0	25.0	17.0	60	6	12	23	404.55	389.55	15.00
20	3	32	35	100	4.000	2.000	0	48.5	26.0	78	5	10	22	404.55	389 55	15.00
21	2	26	195	100	3.000	0.700	0	28.0	13.5	58	8	10	13	378.03	335.78	42.25
22	1	12	160	100	2.500	1.000	0	31.0	16.5	55	8	8	16	268.19	263.69	4.50
23	1	22	110	100	6.000	0.500	0	35.0	69.5	120	8	17	23	1173.01	1171.76	1.25
24	3	25	125	100	5.000	0.500	0	25.0	87.0	123	9	19	18	384.85	380.47	4.38
25	2	24	70	100	3.000	2.000	0	37.0	106.5	163	5	10	18	1190.71	1172.71	18.00
26	4	24	155	100	2.000	0.500	0	42.0	46.0	95	10	18	23	199.55	190.55	9.00
27	4	32	90	90	4.500	0.270	0	40.5	67.0	116	5	9	15	1969.65	1969.64	0.01
28	2	20	30	100	8.000	1.750	0	17.0	53.0	105	5	8	19	318.37	317.77	0.60
29	4	26	120	100	6.000	1.000	0	22.5	134.5	157	10	12	13	254.57	251.77	2.80
30	4	17	110	100	7.000	1.000	0	36.0	107.0	162	6	10	18	645.34	645.32	0.02
31	1	36	40	100	6.500	1.250	0	36.0	30.5	76	7	10	13	575.15	573.15	2.00

*[1]—1:North 2:West 3:South 4:East

*[2]— Measured by Yamanaka's soil hardness meter

*[3]— • Woody plants: {(Mean radius of crown)^2 $\times \pi \times$ (Tree height − Clear-length)} /3

• Herbs: Herb height X Level surface area

Table 7. Correlation coefficients of soil factors and vegetation volume.

	Slope angle	Elevation	Volume of L layer	Volume of FH layer	A layer depth	B layer depth	Total layer depth
Slope angle	1.00						
Elevation	-0.19	1.00					
Volume of L layer	-0.15	-0.40*	1.00				
Volume of FH layer	-0.23	-0.22	0.50**	1.00			
A layer depth	0.31	-0.31	0.13	-0.23	1.00		
B layer depth	-0.12	-0.25	0.47**	0.10	-0.13	1.00	
Total layer depth,	-0.15	-0.35	0.66**	0.25	-0.08	0.93**	1.00
Hardness of surface soil	0.06	0.26	-0.37*	-0.36	-0.12	-0.05	-0.26
Hardness of A layer	0.02	-0.01	0.02	-0.22	-0.15	0.24	0.22
Hardness of B layer	-0.35	-0.27	0.34	0.27	-0.13	0.07	0.21
Area rate covered by A, layer	-0.20	-0.43*	0.69”	0.45**	0.15	0.28	0.53**
Erosion area rate	0.20	0.44*	-0.69**	-0.42*	-0.17	-0.31	-0.54**
Volume of woody plants	0.09	-0.20	0.33	-0.11	0.35	0.39’	0.50**
Volume of Herbs	-0.15	0.03	0.23	0.78**	-0.15	-0.04	0.06
Vegetation volume	0.07	-0.20	0.36*	-0.03	0.34	0.40*	0.52**

※ Level of significance *: 5%
**: 1%

very little.

Each kind of flora exists on the southern slopes and the effects of topographical factors can probably be observed more clearly. The multiple correlation coefficient was 0.35 which was significant at a 0.1% level of significance. Vegetation volume can therefore be calculated very accurately. In this regression analysis, relief energy had a very negative effect on vegetation volume. The effects of slope length, distance from a ridge and elevation were comparatively great.

There is a great difference between the northern and southern slopes. Factors relating to the uninterrupted spread of small scale slopes (ie. slope length and distance from a ridge) are dominant on the northern slopes. Factors relating to changeability and varying according to the location of the slope unit (ie. relief energy) are dominant on the southern slopes.

THE CORRELATION OF FLORA CHARACTERISTICS WITH DEVELOPMENT OF THE SOIL LAYER.

1. Method of investigation

Investigation of soil profile was carried out at the center of each plot. After removing the top soil layers until bedrock was reached, an identification of the soil layer, ie. L, FH, A, B and C layer, was carried out in addition to the recording of soil color, soil structure, soil hardness, content ratio of gravel and soil humidity by observation and measurement. The results are summarized in Table 6.

(Table 7. contnnued)

Hardness of surface soil	Hardness of A layer	Hardness of B layer	Area rate covered by A layer	Erosion area rate	Volume of woody plants	Volume of Herbs	Vegetation volume
1.00							
0.52**	1.00						
0.09	0.43’	1.00					
-0.26	0.28	0.56**	1.00				
0.21	-0.29	-0.60**	-0.99**	1.00			
-0.37*	0.13	0.22	0.34	-0.36	1.00		
-0.15	-0.18	0.11	0.33	-0.32	-0.32	1.00	
-0.40”	0.11	0.24	0.39*	-0.41*	0.99**	-0.22	1.00

2. The correlation of flora characteristics with soil factors

As shown in Table 6, values varied widely in general except for soil hardness. Moreover, there were too many factors for the number of investigated sites. Therefore, only essential factors were selected by correlation analysis.

Table 7 shows the results of correlation analysis on soil factors based on Table 6. In Table 7, L layer depth closely correlated to the layer depth of FH, B and the total layer. B layer depth correlated to total layer depth. Therefore, no part of the soil layer have developed in isolation, but rather in conjunction with all other layers.

The area ratio of the Ao layer correlated to L and total layer depth, soil hardness of B layer and erosion area rate. Erosion area rate correlated to L and total layer depth. The volume of woody plants correlated to the volume of herbs.

Based on these correlations, representative factors were selected. Consequently, depth of A layer, B layer and the total layer and soil hardness of A and B layers were selected. Subsequently, multiple regression analysis was carried out on vegetation volume using those factors. The results are shown in Table 8. The multiple correlation coefficient was 0.68, significant at a 0.1% level. According to the values of the standard correlation coefficient, the greater the depth of the total layer and A layer, the greater the volume of vegetation became. Although the effect of soil hardness was small, the lower the hardness of surface soil, the greater the vegetation volume became. This is considered to be reflected by the observation that the more mollified the surface soil became, the more water infiltrated and the more vegetation grew. Through plant growth, accompanied by root growth, the soil became deeper and more mollified. A tendency for the soil layer to become deeper with plant growth can be observed.

TREE SPECIES AND THE FORECAST OF PLANT SUCCESSION

1. Method of investigation

The tree species and the volume of woody plants were determined in each plot. Based on the volume of woody plants, composed of evergreen and deciduous broad-

Table 8. The relation between soil factors and vegetation volume(using multiple regression analysis)

	Regression coef.
A layer depth	0.35
Total layer depth	0.49
Hardness of surface soil	-0.23
Multiple cor. coef.	0.68

Table 9. Species and volume of woody plants of major trees in each tree category.

Broad-leaved trees — Evergreen

Species		Yabu-nikkei	Hime-yuzuriha	Shii spp.	Yama-momo	Hama-biwa	Kakure-mino	Shiro-damo	Tabu-noki	Kashi spp.
Group	4	1210.69	1182.57	237.80	147.58	76.67	46.22	29.93	17.77	15.50
	3	0.00	90.46	1.02	38.82	0.00	16.38	0.05	5.42	11.62
	2	11.83	11.83	0.00	4.52	0.00	0.00	0.00	0.00	0.00
	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Broad-leaved trees — Deciduous

Species		Konara	Shide spp.	Yama-zakura	Nogu-rumi	Yama-haze	Ryoubu	Ooba-yashabushi
Group	4	753.83	49.79	35.38	27.24	0.39	0.17	0.00
	3	36.21	0.00	25.50	1.00	0.64	0.00	36.22
	2	0.00	0.00	0.00	0.00	0.00	0.00	3.35
	1	0.00	0.00	0.00	0.00	0.00	0.00	0.32

Coniferous trees

Species		Akamatsu	Kuromatsu
Group	4	249.02	0.00
	3	82.46	53.05
	2	96.34	1.56
	1	18.04	10.41

Trees:
- Yabunikkei : *Cinnamomum japonicum*
- Himeyuzuriha : *Daphniphyllum teijsmannii*
- Shii spp. : *Castanopsis spp.*
- Yamamomo : *Myrica rubura*
- Hamabiwa : *Litsea japonica*
- Kakuremino : *Dendropanax trifidus*
- Shirodamo : *Neolitsea sericea*
- Tabunoki : *Machis thunbergii*
- Kashi spp. : *Quercus spp.*
- Konara *Quercus serrata*
- Shide spp. *Carpinus spp.*
- Yamazakura *Prunus jamasakura*
- Nogurumi *Platycarya strobilacea*
- Yamahaze *Rhus sylvestris*
- Ryoubu *Clethra barbinervis*
- Oobayashabushi *Alnus sieboldiana*
- Akamatsu *Pinus densiflora*
- Kuromatsu *Pinus thunbergii*

leaved trees and coniferous trees, a survey was carried out of the number of plants in each vegetation group as shown in Table 9.

2. **Major tree species in each vegetation group**

The following can be deduced from Table 9.

1) Evergreen broad-leaved trees: *Euonymus japonica* (Masaki) and *Eurya japonica* (Hisakaki), shrubs, occupy a large area in groups 1 and 2. Sub-trees and trees appear in groups 2 and 3 despite their volumes being minor. The trees, *Cinnamomum japonicum* (Yabunikkei) and *Daphniphyllum teijsmannii* (Himeyuzuriha) etc, overhang shrubs and sub-trees. They have reached a stable flora stage (Numata, 1988).

The number of tree species is 6 in group 1, and is 10, 15 and 19 in group 2, 3 and 4, respectively. The number increases markedly from groups 1 through 4.

2) Deciduous broad-leaved trees: In group 1, *Alnus sieboldiana* (Obayashabushi) appears infrequently. In group 2, *Euscaphis japonica* (Gonzui) begins to appear. In groups 3 and 4, *Quercus serrata* (Konara), *Platycarya strobilacea* (Nogurumi) and *Rhus sylvestris* (Yamahaze) etc. appear and the number of species becomes great. The

(Table 9. contnued〉

Sub-trees									Shrubs	
Yabu-tsubaki	Hisa-kaki	Nezumi-mochi	Kuroki	Tobera	Haku-sanboku	Shashanbo	Masaki	Aoki	Inutsuge	Yama-tsutsuji
620.78	611.82	575.67	202.43	42.13	24.16	13.06	1.34	1.03	0.17	0.00
1.59	132.82	108.93	44.53	29.57	0.00	7.66	6.39	0.00	0.00	0.08
0.00	21.12	2.96	9.55	5.95	0.00	5.98	12.98	0.00	0.07	0.18
0.00	1.92	0.00	0.00	0.00	0.00	0.27	0.68	0.01	0.01	0.47

Gonzui	Hamakusagi
15.41	12.20
5.27	0.00
0.87	0.00
0.00	0.00

Sub-trees: Yabutsubaki : *Camellia japonica*
Hisakaki : *Eurya japonica*
Nezumimochi : *Ligustrum japonium*
Kuroki : *Symplocos lucida*
Tobera : *Pittosporum tobira*
Gonzui : *Euscaphis japonica*
Hamakusagi : *Premna japonica*

Shrubs: Hakusanboku : *Viburnum dilatatum*
Shashanbo : *Vaccininum bracteatum*
Masaki : *Euonymus japonica*
Aoki : *Aucuba japonica*
Inutsuge : *Ilex crenata*
Yamatsutsuji : *Rhododendron obtusum*

number of species is smaller than for evergreen broad-leaved trees in general. The number is 1, 2, 6 and 8 in groups 1, 2, 3 and 4 respectively and increases from groups 1 to 4 in the same way as in case 1. In group 4, *Alnus sieboldiana* (Oobayashabushi), which appeared frequently in many areas in group 3, does not appear at all.

3) Coniferous trees: Red pine occupies the majority of area in all groups. Black pine, which appeares in groups 1, 2 and 3, does not appear in group 4. The number of tree species is very small ie. 2, 2, 2 and 1 in groups 1, 2, 3 and 4, respectively.

3. Ratio of broad-leaved trees and of coniferous trees to all trees in each vegetation group

Table 10 shows the volume of evergreen and deciduous broad-leaved trees and coniferous trees in each vegetation group. The volume increases from groups 1 to 4 in every tree category (ie. evergreen and deciduous broad-leaved trees and coniferous trees). However, the volume of broad-leaved trees in group 4 increased by a factor of 1,000 compared with the volume in group 1. The volume of coniferous trees increased by a factor of 10. This is quite a significant difference.

Figure 11 indicates the volume ratio of each tree category. The coniferous tree category is overwhelmingly large in group 1, and is still large in group 2, followed by the evergreen broad-leaved category. The evergreen broad-leaved category increases rapidly and becomes the largest, and the deciduous broad-leaved category increases considerably, though its volume is smaller than that of coniferous category in group 3. The evergreen broad-leaved category becomes overwhelmingly large in group 4, followed by the deciduous broad-leaved and coniferous categories.

4. Forecast of plant succession

In an aerial photograph taken 30 years ago, there were coniferous stands all over the mountain slopes. These coniferous trees are considered to have died off due to a noxious insect, *Bursaphelenchus xylophilus* or Pine wood nematode. Subsequently, broad-leaved stands with high crown closure belonging to group 4 appeared as part of the flora succession on the northern slopes. This is probably because strong young evergreen growth already existed under coniferous trees and a deep soil layer had been formed. On the other hand, the southern slopes became denuded, or developed into groups 1 or 2 consisting of only *Dicranopteris pedata* (Koshida) and *Gleichenia japonica* (Urajiro), or into group 3, if a considerable amount of low vegetation was already present.

This flora succession is thought to depend on site conditions. This can be deduced from tree species and volume.

In group 1 areas, vegetation invades areas where soil has been deposited in gullies. Consequently the area becomes stable. On surrounding slopes, soil deposition progresses slowly with the progress of vegetation invasion. Therefore, dominant occupation by *Dicranopteris pedata* (Koshida) and *Gleichenia japonica* (Urajiro) becomes imposssible. Initially group 1 is formed and then broad-leaved trees invade and occupy the most of the area. They develop into group 3 bypassing the group 2 stage.

In group 2, which is composed of *Dicranopteris pedata* (Koshida) and *Gleichenia japonica* (Urajiro), the height of vegetation exceeds 2 meters. Especially in cases where coverage rate increases, vegetation cannot invade from outside and the situation

Table 10. Volume of woody plants in vegetation group in the target area

Unit: $10^3 m^3$

Vegetation group	Tree category	Total	Tree	Sub-tree	Shrub
Group 4	Evergreen broad-leaved trees	5057.32	2964.73	2052.83	39.76
	Deciduous broad-leaved trees	894.41	866.80	27.61	
	Coniferous trees	249.02	249.02		
Group 3	Evergreen broad-leaved trees	495.34	163.77	317.44	14.13
	Deciduous broad-leaved trees	104.84	99.57	5.27	
	Coniferous trees	135.51	135.51		
Group 2	Evergreen broad-leaved trees	72.14	16.35	39.58	16.21
	Deciduous broad-leaved trees	4.22	3.35	0.87	
	Coniferous trees	97.90	97.90		
Group 1	Evergreen broad-leaved trees	3.36		1.92	1.44
	Deciduous broad-leaved trees	0.32	0.32		
	Coniferous trees	28.45	28.45		

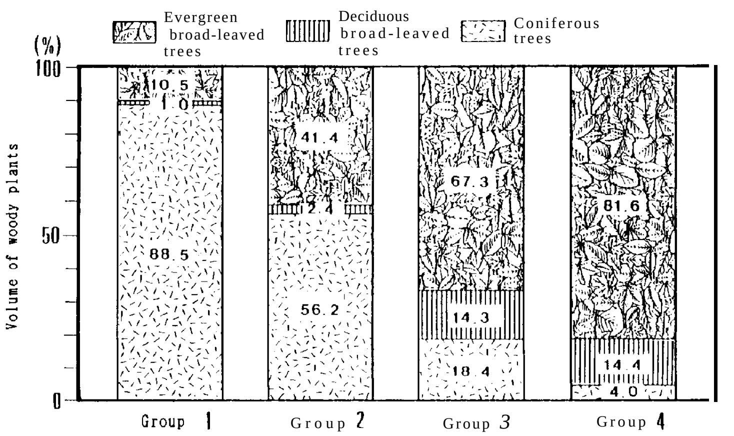

Fig.11 The volume ratio of broad-leaved trees and coniferous in each vegetation group.

remains unchanged. This situation is thought to be an edaphic climax. However, when organic soil is exposed by collapse or by other causes, red pine, *Quercus spp.* (Kashi), *Alnus sieboldiana* (Oobayashabushi) and *Miscanthus sinensis* (Susuki) in addition to *Dicranopteris pedata* (Koshida) and *Gleichenia japonica* (Urajiro) invade and the group retrogresses to group 1. If trees have already invaded the area and are growing vigorously, the group can possibly move to group 3 with the development of shade.

Group 3, which has few red pines or advanced evergreen trees, moves to group 4 with the dying off of low vegetation such as *Dicranopteris pedata* (Koshida) and *Gleichenia japonica* (Urajiro) and the stabilization of upper trees.

On the other hand, group 3 with a high content of red pines, sometimes retrogres-

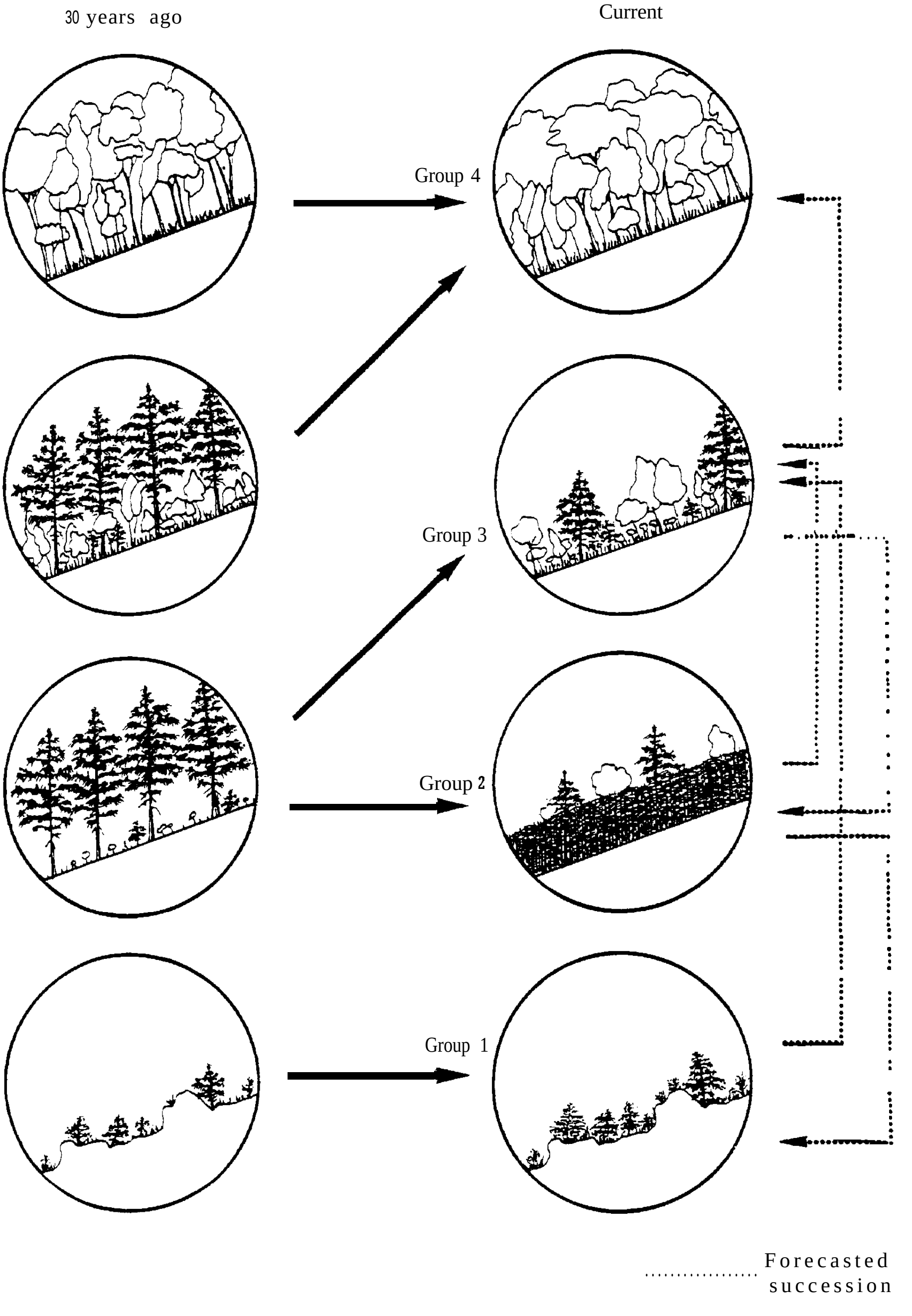

Fig.12 Model of the plant succession in the target area.

ses to group 2 with the dying off of red pines. This dying off is due to conditions of low vegetation and poor soil.

The species present in group 4 are generally regarded to represent examples of climax flora. Group 4 can be observed to develop into comparatively stable flora. (Kimmins, 1987; Numata, 1988)

These transitions are illustrated in Fig. 12.

CONCLUSIONS

The conclusions are listed below.

1) The vegetation of this area can be divided into 4 vegetation groups based upon crown closure and the volume of woody plants. These groups are designated group 1, group 2, group 3, and group 4 according to the growth stage of crown closure and the volume of woody plants.

2) Each group displayed specific characteristics in terms of the volume composition of herbs and woody plants. The volume of both herbs and woody plants increased gradually from group 1 to group 2 to group 3. However, the volume ratio of herbs to woody plants reached a maximum in group 2. The volume of herbs and the volume ratio of herbs to woody plants was at a minimum in group 4. In group 4 crown closure had reached a near maximum stage of growth.

3) On the northern slopes of the mountain, group 4 occupied the greatest area irrespective of the position on the slope, (ie. higher, middle or lower). Therefore, the recovery of vegetation was found to be considerably advanced there. On the other hand, all groups were present on the southern slopes, each group occupying almost the same total area.

4) The relationship between vegetation volume (ie. total volume of herbs and woody plants) and topographical factors was analyzed using the '*Quantification 1* method'. Vegetation volume was found to be correlated closely to the stage of vegetation recovery. As a result, the aspect of slope, north and south, was found to be a significant factor affecting vegetation volume. However the shape of slope, (concave, convex or plain), did not greatly effect vegetation volume, though vegetation volume did become smaller on convex slopes.

In areas where vegetation volume was greater (ie. vegetation had recovered well), the soil layer was considerably deeper.

5) Concerning evergreen broad-leaved trees species, shrubs were common in group 1. Sub-trees and trees were mainly evident in groups 2 and 3, and trees, indicating stable vegetation conditions, formed a dense canopy above the shrubsand sub-trees. The number of these species increased clearly from groups 1 to 4.

Deciduous broad-leaved tree species were generally less common than evergreen species, increasing gradually from groups 1 to 4. In regard to conifers, red pine and black pine were present.

6) The volume ratio of broad-leaved trees to conifers increased rapidly from groups 1 to 4. Conifers covered an overwhelming area in group 1. However broad-leaved trees, especially evergreen, increased greatly in groups 2 and 3, while conifers declined. Evergreen broad-leaved trees covered the largest area in group 4. Therefore, group 4 is thought to have reached a stable flora condition.

7) The succession, estimated by the number of species and volume of vegetation in each group, was thought to depend on the conditions existing at the sites. Group 2 was thought to be an edaphic climax having developed under harsh conditions. Some group 2 areas would remain unchanged if there were no hillside collapses or any deterioration in vegetation caused by shade from upper layer vegetation. Some group 3 areas under favorable conditions were able to develop into group 4 type areas.

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