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Article

Analyzing the Effects of Environmental Factors on the Site Indexes of Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) Manmade Coniferous Forest Stands in the Shikoku National Forest Using GIS

Eiji Kodani [*1, 2], Naoto Matsumura [*3] and Aki Tarumi [*1]

ABSTRACT

The effects of environmental factors on the site indexes of Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) manmade coniferous forest stands were analyzed in the Shikoku National Forest using GIS. Rock type had a significant relationship with the site index, while soil type did not. Temperature had a positive relationship and radiation had a negative relationship with the site index data of Sugi and Hinoki. On the other hand, precipitation had a positive relationship with the site index of Sugi, but no significant relationship with the site index of Hinoki. Snow depth had a negative relationship with the site index of Hinoki, while it had no significant relationship with the site index Sugi. These results correspond well with the species' characteristics.

Keywords: site index, Hinoki, Sugi, environmental factors, Shikoku Island

INTRODUCTION

The development of practical methods for measuring forest carbon stock, absorption, and emission in large areas has become increasingly important for forestry under the Kyoto Protocol. Forest carbon stock and absorption in forests depend on site quality, even if species, stand age and operation are the same. The site index, which is defined as the dominant stand height at a specific age, is used for assessing site quality in forest management. The site index is important for estimating forest carbon stock and absorption, especially in large areas.

The site index is calculated using a guide curve (Eq. 1) and a site index curve (Eq. 2; Avery and Burkhart, 1988; Nishizawa, 1972; Parde and Bouchon, 1988). The specific age is 40 years in Japan, as usual.

Log $Hd = b_0 + b_1 / t$ (Hd: stand height, t: age) (1)

Log S = Log $Hd + b_1\ (1 / t - 1/40)$ (2)

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Historically, the site index was used mainly as a forest productivity index in Japan, because it is used in empirical yield tables. Yield tables for national forests were developed in each region and each Japanese climatic division from 1940 to the 1970s. Yield tables for private forests were developed in each prefecture in the same period. The yield tables are separated into three to five classes, and the site index is used for more precise predictions (Fig. 1).

From 1950 to the 1960s, manmade forests were planted extensively in Japan, and a large demand emerged for research to more precisely predict yield from planted areas (Watanabe *et al.*, 1965). Kobayashi (1963) and Nishizawa *et al.* (1965) developed a method for predicting the site index by using mathematical quantification theory class II, and Mashimo (1960) developed a standard soil-surveying method

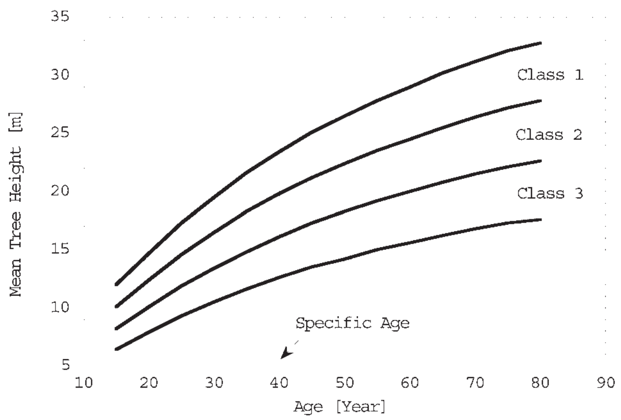

Fig. 1 Site index curve of Sugi in the Shikoku National Forest

for the site index. Using these results, many studies and surveys of site index were conducted by the government and prefectural governments from 1960 to the 1970s. Score tables for site index predictions were developed in each region, climatic zone, and prefecture within the scope of the developed yield tables (MASHIMO, 1983).

In many previous studies, researchers surveyed the site index and site-environmental factors (e.g., forest soil type, soil depth, micro-topography, slope direction, rock type, elevation, annual temperature, annual precipitation, etc.) in local or smaller areas (MASHIMO, 1983; YOSHIDA, 1985). When analyzing the site index at a local scale, environmental variations would be expected to be smaller than those at a larger scale. When analyzing the effects of environmental factors at a larger scale, it is necessary to analyze site index throughout the extent of the yield tables or the prefecture's boundaries. However, there has been little research on the site index at large scales.

Shikoku Island has large variation of climatic conditions. The average temperature in lowland areas near the coast is higher, while the temperature in mountainous areas is lower, depending on the elevation. The southern part of Shikoku Island has more total annual precipitation, while the northern part of the island has less precipitation. The Shikoku Island is suitable for the effect of the environmental factors on the site index.

The objective of this study was to analyze the effects of site and site-environmental factors (temperature, precipitation, radiation, snow depth, catchment area, soil type, and rock type) on the site index of Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) manmade coniferous forest stands in the Shikoku National Forest using GIS.

METHODS

The site index curves for Sugi and Hinoki were calculated for the empirical yield tables of the Shikoku Regional Forest Office (FORESTRY AGENCY, 1953; FORESTRY RESEARCH INSTITUTE OF THE FORESTRY AGENCY, 1957). We used these curves for calculating the site index (Sugi b_1 = 15.7, Hinoki b_1 = 19.0). In addition, stand height in the site index is the average of dominant trees. In the yield tables, the trees are classified as thinned and non-thinned with the selection criteria for thinning from below. The dominant trees are defined as those that are non-thinned and the site index is calculated. However, in our regression analysis between the average of dominant trees

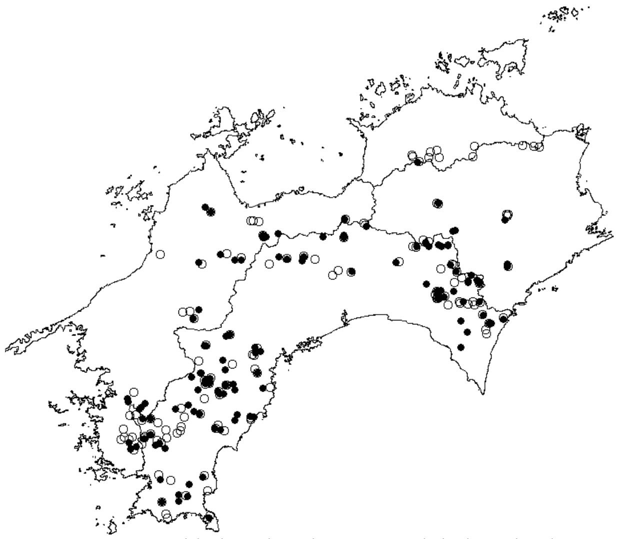

Fig. 2 Field plots distribution on Shikoku Island
Note: Black circles: Sugi, white circles: Hinoki)

and the average of total trees, the gains were approximately 1 and the offsets were approximately 0 in Sugi and Hinoki. Therefore, we used the average of total trees for calculating the site index.

The Shikoku Regional Forest Office set 400 permanent sample plots for developing a more precise yield table and surveyed them at 5-year intervals from 1982 to 2005. Field plots data for Hinoki and Sugi in the Shikoku National Forest were selected. Site index data for each plot were calculated using the guide curve. The specific age of the site index is 40 years in Japan and the site index data were extracted from the range of 25 to 64 years, around the specific age of 40 years. When plots had repeated measurement data, the data corresponding to the age closest to the specific age were selected. The number of extracted plots was 126 for Sugi, and 135 for Hinoki. The distribution of plots spreads out over the entire Shikoku Island, corresponding to the distribution of national forest (Fig. 2).

The Geographical Survey Institute of Japan provided 1-km_2 mesh data or third mesh data, which covers the entire land area of Japan and includes various types of digital cartographic information (JAPAN MAP CENTER, 1994). Third mesh data on soil type and rock types were used for the environmental factors. Mesh Climatic Data 2000 by the Japan Meteorological Agency (JMA), was used for climatic data (monthly mean temperature, total precipitation, radiation with shading, and snow depth; JAPAN METEOROLOGICAL AGENCY, 2002). Catchment area was calculated using 50-m mesh DEM

Table 1 Summary of the climatic data in the field plots of Sugi and Hinoki

		Annual mean temparature (℃)	Annual total precipitation (mm)	Annual mean radiation (MJ m^{-2})	Maximum snow depth (cm)	Elevation (m)
	Average	11.9	2833	13.8	7.4	644
Sugi	Maximum	16.9	3920	15.0	19	1400
(*n*=126)	Minimum	7.2	1353	12.9	0	97
	Average	12.3	2575	13.7	6.8	559
Hinoki	Maximum	17.3	3879	14.9	19	1286
(*n*=135)	Minimum	7.7	1306	12.9	1	34

data (Mitsuda *et al.*, 2001). The range of climatic data in the field plots of Sugi and Hinoki were summarized in table 1.

The positions of the plot data were surveyed, using the marks on the 1/5000 forest base map or 1/20000 forest operation map and national forest GIS. The latitude and longitude coordinates of the field plots were converted into third mesh code, and third mesh data on plot position were extracted.

Regression analysis was used to assess the effects of continuous data such as temperature and precipitation on the site index, while one-way ANOVA and multiple comparisons were used to assess the effects of categorical data such as soil and rock type. For one-way ANOVA, first, when calculating the histogram of groups, those with little data were eliminated or integrated into similar groups. Second, Levene's test for homogeneity of variance was used. When there was no significant difference in variance across groups, the F-test was used. When there was a significant difference, we used Welch's ANOVA for the means. Finally, when there was a difference between the mean group scores, Tukey-Kramer's HSD (honestly significant difference) test for multiple comparisons was used, with $\alpha = 0.05$.

JMP (SAS, Inc.) and STATISTICA (Statsoft, Inc.) software were used for statistical analysis, and TNTmips (MicroImages, Inc.) and IDRISI32 (Clark University) were used for GIS analysis.

Multiple regression analysis was performed to estimate the site index by environmental factors. Stepwise regression was used to select the best independent variables from the site-environmental factors.

In previous site index studies in Japan, mathematical quantification theory class II has been used to estimate the site index using environmental and site factors, and the quantitative data for the independent variables were converted to categorical data (Kobayashi, 1963; Nishizawa *et al.*, 1965; Mashimo, 1983). JMP includes a general linear model, which we used to create a multivariate regression model. Quantitative and categorical data were calculated using the general linear model, and categorical data were calculated as dummy variables.

RESULTS AND DISCUSSIONS

In some cases, the effects of environmental factors showed the same trend in the site indexes for both Sugi and Hinoki plots, while in other cases, the effects differed between the respective species.

With regard to the effect of soil type on the site index of Sugi, there was no significant difference in variance across all groups (p = 0.56, Fig. 3a), and the F-test indicated no significant difference among means (p = 0.37, Fig. 3b). Using multiple comparisons, the groups could not be separated. Similarly, for the site index of Hinoki, there was no significant difference in variance across all groups (p = 0.084) and F-test indicated that there was no significant difference among means (p = 0.12).

With regard to the effect of rock type on the site index of Sugi, there was no significant difference in variance across all groups (p = 0.38, Fig. 4a), and the F-test indicated there was a

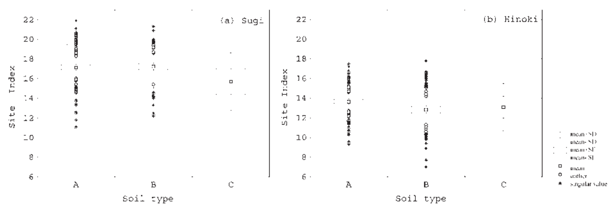

Fig. 3 Box plots of the site index on soil type (A: brown forest soil (BFS), B: dry BFS, C: wet BFS)

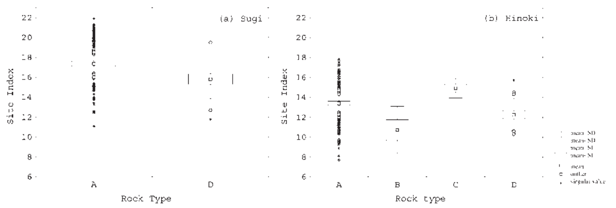

Fig.4 Box plots of the site index on rock type (A: Sedimentary rock-alternating strata, B: Sedimentary rock-sandstone, C: Sedimentary rock-mudstone, D: Metamorphic rock-black or green schist)

significant difference among means (p = 0.016). Using multiple comparisons, the groups were separated into two classes. The site index in sedimentary rock-alternating strata was significantly larger than the site index in green or black schist. In the site index of Hinoki as well, there was no significant difference in variance across all groups (p = 0.13), and the F-test indicated that there was a significant difference among means (p = 0.0031, Fig. 4b). Using multiple comparisons, the groups were separated into two classes. One class included sedimentary rock-alternating strata, mud stone, green or black schist, and the other included green or black schist, and sandstone. The site index of mudstone and sedimentary rock-alternating strata were significantly larger than the site index of sandstone.

Monthly mean temperature had a positive relationship with the site index data on Sugi and Hinoki (Table 1). Annual total precipitation and monthly total precipitation from March to June had a positive relationship with the site index of Sugi, while the parameters for precipitation, had no effect on the site index of Hinoki. Monthly radiation during the growing season from April to August had a negative relationship with the site index data on Sugi and Hinoki.

Catchment area had no significant relationship with the site index data of Sugi and Hinoki. Elevation had a negative relationship with the site index data of Sugi and Hinoki. Snow depth had a negative relationship with the site index of Hinoki, while it had no significant relationship with the site index of Sugi. These results are summarized in Fig. 5.

Gross potential photosynthesis (GPP) or Net Primary Product (NPP) are functions of temperature, radiation and water stress (Eq. 3; Waring and Running 1998; Uchijima and Seino 1985). The site index is affected by GPP or NPP.

$$GPP = \alpha \sum APAR \cdot f(H_2O) \cdot f(D) \cdot f(T) \qquad (3)$$

(α: maximum quantum efficiency, $APAR$: absorbed photosynthetically active radiation, f (H_2O): soil water deficit, f (D): vapor pressure deficit, f (T): temperature modifier)

Table 2 Correlation coefficients of between the site - environmental factors and the site indexes of Sugi and Hinoki

(a) Sugi *n*=126

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.	
Monthly mean temperature	0.22	0.23	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.20	0.23	
	p=.012*	*p*=.009*	*p*=.004*	*p*=.005*	*p*=.006*	*p*=.007*	*p*=.010*	*p*=.011*	*p*=.008*	*p*=.012*	*p*=.014*	*p*=.022*	*p*=.009*	
Monthly total precipitation	0.04	0.13	0.19	0.20	0.18	0.20	0.09	0.12	0.08	0.12	0.14	0.02	0.15	(Annual total)
	p=.628	*p*=.133	*p*=.036*	*p*=.022*	*p*=.047*	*p*=.024*	*p*=.341	*p*=.198	*p*=.400	*p*=.198	*p*=.110	*p*=.848	*p*=.091	
Radiation with shading	0.08	0.08	-0.04	-0.26	-0.30	-0.31	-0.20	-0.18	-0.02	-0.01	0.05	0.08	-0.11	
	p=.359	*p*=.352	*p*=.672	*p*=.004*	*p*=.001*	*p*=.000*	*p*=.024*	*p*=.049*	*p*=.805	*p*=.890	*p*=.549	*p*=.358	*p*=.216	

	Jan	Feb	Mar	Dec	MAX	**Elevation**	**Catchment area**	**Rock type**	**Soil Type**
Snow depth	-0.01	-0.07	-0.09	0.09	0.00	-0.24	0.15	0.21	0.01
	p=.954	*p*=.436	*p*=.309	*p*=.295	*p*=.959	*p*=.007*	*p*=.089	*p*=.016*	*p*=.3671

(*: p<0.05)

(b) Hinoki *n*=135

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.	
Monthly mean temperature	0.11	0.12	0.13	0.14	0.16	0.18	0.19	0.17	0.14	0.10	0.09	0.09	0.14	
	p=.191	*p*=.176	*p*=.145	*p*=.114	*p*=.060	*p*=.036*	*p*=.027*	*p*=.045*	*p*=.098	*p*=.234	*p*=.280	*p*=.301	*p*=.117	
Monthly total precipitation	-0.11	-0.03	0.07	0.09	0.03	0.05	0.02	0.02	-0.09	-0.08	0.02	-0.05	0.01	(Annual total)
	p=.191	*p*=.729	*p*=.442	*p*=.301	*p*=.697	*p*=.567	*p*=.787	*p*=.848	*p*=.284	*p*=.374	*p*=.827	*p*=.543	*p*=.938	
Radiation with shading	0.01	-0.03	-0.14	-0.22	-0.19	-0.28	-0.25	-0.24	-0.19	-0.17	-0.06	-0.03	-0.21	
	p=.896	*p*=.722	*p*=.118	*p*=.009*	*p*=.025*	*p*=.001*	*p*=.004*	*p*=.005*	*p*=.026*	*p*=.050*	*p*=.521	*p*=.771	*p*=.015*	

	Jan	Feb	Mar	Dec	MAX	**Elevation**	**Catchment area**	**Rock type**	**Soil Type**
Snow depth	-0.08	-0.18	-0.16	-0.02	-0.12	-0.20	0.06	0.29	0.13
	p=.342	*p*=.037*	*p*=.066	*p*=.846	*p*=.162	*p*=.018*	*p*=.475	*p*=.003*	*p*=.122

(*: p<0.05)

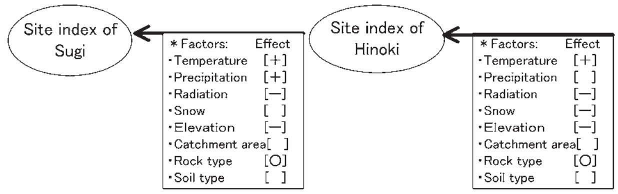

Fig. 5 Summary of the effects of environmental factors on the site index of Sugi and Hinoki

A rise in temperature increased the site index due to the activation of photosynthesis. A rise in radiation decreased the site index due to the increase in evapotranspiration and resultant water deficit. The site index is higher on the northern side of the terrain due to lower radiation (Mashimo, 1983) and this corresponded to the trend in radiation. In general, Sugi grows better in areas of greater moisture, while Hinoki grows well in areas that are dry (Mashimo, 1983). These site index results correspond well to the characteristics of the species.

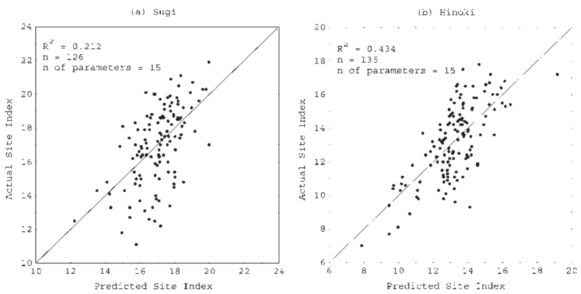

Fig. 6 Scatter diagram of actual site indexes and predicted site indexes from multiple regression models using the environmental factors

Stepwise multiple regression analysis was performed between the site index data of Sugi and Hinoki, and the environmental factors. The regression model for the site indexes of Sugi or Hinoki included 15 parameters (Fig. 6(a), (b)). The coefficients of determination in the site index models were not strong. Although the effects of environmental factors on the site indexes could be analyzed, it was difficult to precisely estimate the site indexes.

In the previous studies, soil and terrain factors were important and were surveyed precisely in the field. Survey items for forest soil productivity on Shikoku Island included soil type, rock type, elevation, slope direction, micro-topography, and others (Mashimo, 1983; Shikoku Regional Forest Office, 1967, 1968a, b, 1970). Soil type has the strongest relationship with the site indexes of Sugi and Hinoki throughout Shikoku Island. However, soil type had no significant relationship with the site indexes (Fig. 3) because of the coarse resolution of the soil map used in this study and the absence of detailed micro-topography and moisture profiles in the classification of soil type. A detailed soil map for all of Shikoku Island has not been compiled, and creation of such a map will be necessary for accurate estimation of site index.

In the previous studies, few climatic environmental factors were examined. For example, studies included a warmth index from monthly temperatures, but did not include precipitation data (Shikoku Regional Forest Office, 1967, 1968a, b, 1970) because the mesh climate data set was developed after the previous studies were executed. On the other hand, although few soil map and terrain factors were included in the present study, we were able to use Mesh Climatic Data 2000 (Japan Meteorological Agency, 2002), which included many climatic environmental factors. We analyzed site index across two climatic regions using yield tables and over the scope of four site index studies. We found an effect of climatic environmental factors on site index on Shikoku Island, which experiences wide climatic variation, especially in temperature and precipitation.

The data on each item is well laid out in the surveys on forest soil productivity on Shikoku Island (Shikoku Regional Forest Office, 1967, 1968a, b, 1970). On the other hand, the data from this study were arranged to create a more precise yield table and to identify standard forest stands, rather than to assess the best or worst cases selected in each region by local foresters.

Coefficients of determination in previous studies were higher than we found in this study for predicting site indexes of Sugi and Hinoki using site-environmental factors (Shikoku Regional Forest Office, 1967, 1968a, b, 1970), but it is difficult to produce a detailed soil map across the whole of Shikoku Island, within both national and private forests, and in four prefectures. We used GIS data to make the dataset more accessible, and we consider this method to be a useful and practical approach for estimating site index throughout Shikoku Island or in other large-scale programs.

CONCLUSION

The effects of environmental factors on the site indexes of Sugi and Hinoki manmade coniferous forest stands were analyzed in the Shikoku National Forest using GIS. In some cases, the effects of environmental factors showed the same trend in the site indexes of both Sugi and Hinoki plots, while in other cases, the effects differed between the respective species. Rock type had a significant relationship with the site indexes of Sugi and Hinoki, while soil type did not. Temperature had a positive relationship and radiation had a negative relationship with the site indexes of Sugi and Hinoki. On the other hand, precipitation had a positive relationship with the site index of Sugi, but had no significant relationship with the site index of Hinoki. Snow depth had a negative relationship with the site index of Hinoki, while it had no significant relationship with the site index of Sugi.

We showed the effects of environmental factors on the site indexes of Sugi and Hinoki. However, the coefficients of determination were not strong in the regression models used to estimate the site index by site-environmental factors, suggesting that it is difficult to estimate the site index. In future, we would like to analyze more detailed site-environmental factors, such as by detailed soil map, micro-topography and survey of plots in the worst and best areas for growth, and develop a more precise site index map using GIS.

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Article

Change of Spatial Structure Characteristics of the Forest in Oshiba Forest Park in 10 years

Songqiu Deng [*1] and Masato Katoh [*1]

ABSTRACT

Traditional parameters of forest structure could not meet the need of modern forest management completely. In order to know change law of forest structure in a given period, based on the survey on forest status, spatial structure characteristics of the forest dominated by *Pinus densiflora* and *Chamaecyparis obtusa* in 1999 and 2009 were studied by four spatial structure indices of mingling, angle index, neighborhood comparison and opening degree. The results indicated that: Species richness increased somewhat with seven species in 2009 while four species in 1999. The diameter class of *Pinus densiflora* was not continuous due to lack of small trees, whereas other species were small trees except for *Chamaecyparis obtusa*. The average mingling was 0.316 and 0.567 respectively in 1999 and 2009, indicating that mixed degree between species from middle-mixed developed into high-mixed level. The distribution pattern of all trees from regular became random. However, neighborhood comparison was 0.456 and 0.474 respectively in the two periods, showing the ratio of the trees whose growth was in oppressed status increased somewhat. And the average opening degree decreased from 0.393 to 0.304, indicated that growth space of most trees were in inadequate condition in 2009. From succession, *Pinus densiflora* will disappear from the stand finally, while *Chamaecyparis obtusa* will continue to be in dominance in competition between species. Most of broad-leaved species are in disadvantage at present, and effective measures need to take to protect successful growth of them. Finally, possible operation plan for the forest was discussed.

Keywords: spatial structure, mingling, angle index, neighborhood comparison, opening degree

INTRODUCTION

Some parameters, such as species composition, density, diameter and height structure, basal area and volume, were always adopted to describe forest structure in traditional forestry science (Davis and Johnson, 1987; Mushove, 1997; Hitimana *et al.*, 2004; Takiya *et al.*, 2010), and they were classical and essential in forest research. But these indices lacked detailed spatial information (Aguirre *et al.*, 2003), which led to that we did not know how to choose the objective trees in selection cutting and were difficult to evaluate the effect of management. Now stand spatial structure defined to analyze spatial relationships between individual trees has gradually become the focus in forest structure research (Moeur, 1993; Gadow, 1997; Zenner and Hibbs, 2000; Hui *et al.*, 2004). And it might be described from three aspects as follows: the degree of mutual isolation between species, distribution pattern of trees on ground and the differentiation and growth status of individual trees (Gadow and Füldner, 1992; Füldner, 1995a; Aguirre *et al.*, 2003).

In the past, isolation degree between species was described by mixed ratio defined as the proportion of different species in the forest (Gadow and Füldner, 1992; Hui and Hu, 2001). Diversity index and species richness were always used to measure the rich degree of species (MacArthur and MacArthur, 1961; Pielou, 1977; Niese and Strong,1992; Lahde *et al.*, 1999). However, all of them lacked spatial distribution information of every species in the stand. Then segregation index was presented to reflect the isolation level of two species (Pielou, 1961). But it was merely fit for the forest in which the distribution of tree species followed to random state (Füldner, 1995b). In view of the above, mingling was presented to measure isolation degree of species (Gadow and Füldner, 1992).

The distribution pattern of trees might be divided into three manners: clumped, random and regular (Pielou, 1959; Ripley, 1977; Gadow *et al.*, 1998). In all of parameters used to measure distribution pattern, aggregation index presented by Clark and Evans (1954) was used widely until now. But it only considered the distance between the target tree and the nearest neighboring tree, which led to its application being limited to the small-scale (Ripley, 1977; Gadow *et al.*, 1998). This problem was solved by the K function and pair

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correlation function, where the distances between all trees were considered (DIGGLE, 1983; GADOW and FÜLDNER, 1992; AGUIRRE *et al*., 2003). However, it could only provide unique value for judgment of pattern and needed too much cost to measure the distance of every two trees. Based on these, angle index was developed (GADOW *et al*., 1998; CORRAL-RIVAS *et al*., 2010).

Size differentiation expressed by the relative difference between the reference tree and its neighboring trees was used to reflect the variation degree of adjacent individuals (GADOW and FÜLDNER, 1992; GADOW *et al*., 1998). And diameter size differentiation was used for reconstruction of forest structure for the first time (LEWANDOWSKI and GADOW, 1997). But the average value of this index might result in contradictory explanation sometimes and in some extent it is unsure completely when referring the structure characteristic of a special stand to reconstruct forest (FÜLDNER, 1995a). Then neighborhood comparison was presented to quantify dominant relationship between the reference tree and neighboring trees (HUI *et al*., 1998, 1999).

AGUIRRE *et al*. (2003) thought the integrated application of angle index, mingling and neighborhood comparison might describe spatial structure characteristic of forest well. But neighborhood comparison only considered qualitatively the relative difference between the target tree and its neighbors, and it thought there was no disturbance when all neighbors are smaller than the reference tree. In fact, all neighboring trees in some certain range would influence growth of the target tree, and this effect would change with the variation of distance and the size of neighbors. So the method could not express completely growth condition of the trees, however it was essential for forecast of forest development and succession. In this research, an index named as opening degree was introduced as the complement of the above indices.

Analysis on stand structure characteristics with reasonable indices was the basis of forest management. But now it seems that traditional parameters cannot meet completely the need of modern forest with more emphasis on ecological protective function and recreation function. Although there were some researches of evaluation on forest status by spatial structure indices (AGUIRRE *et al*., 2003; HAO *et al*., 2006; DENG *et al*., 2010a), hardly any comparison of structure characteristic in different periods and analysis on causes and effect factors. The objective of this study, based on the survey of the forest status, attempted to firstly develop a quantitative description method for complex spatial structure of forest by the integrated application of some new parameters which can reflect different spatial attributes of stand. And then it was used to analyze the change law of forest spatial structure and development process in a ten years period for the purpose of assessment on effectiveness and appropriateness of management. Finally, with the manner of individual tree selection, for spatial structure optimization, possible operation plan for the forest was discussed. This paper might provide a new theory and approach for choosing objective trees in selection cutting and also offer some recommendation for management of modern forest.

MATERIALS AND METHODS

Study Site and Vegetation

Field survey was conducted in Oshiba Forest Park with an area of about 100 ha in Ina ravine (137°55'~137°57'E, 35°52'~35°53'N, Nagano Prefecture, central Japan), a special terrain, where *Tenryuu* River goes through from north to south, and it was surrounded by Alps mountain range, a most important zone of forest for Japan and there is a special institute named as Education & Research Center of Alpine Field Science (AFC) in Faculty of Agriculture, Shinshu University for the research of this area.

The average altitude, annual average precipitation and annual mean temperature at the nearest meteorological station were about 800 m, 1467.2 mm, and 12.1℃, respectively. The brown soil in survey plots originated from volcanic ash. And the vegetation was mainly composed by man-made pure forests dominated by *Pinus densiflora* and *Chamaecyparis obtusa* with different ages and *Pinus densiflora* - *Chamaecyparis obtusa* mixed forest (KODA *et al*., 2008).

Plot Measurements

Twenty permanent plots with different size (10 × 10 m, 15 × 15 m or 20 × 20 m) were established in 1998 in the park. All the trees whose diameter at breast height (DBH) was larger than 3.5 cm were surveyed, including species, DBH, tree height, crown size, clear bole height and coordinate in 1998 and 2009, respectively. Besides, in 2009 we also surveyed distribution of the trees of DBH $\leq$ 3.5 cm and the trees being cut in the ten years, which might be used to research the relationship between growth of regeneration trees and disturbance. In this research, we only analyzed the change of spatial structure characteristics of the 11^{th} plot with a size of 20 × 20 m. This plot was located in the function zone for walk and it is the most typical stand with the largest area in the park. In addition, it had been managed by the selection cutting in the ten years period. The structure change expressed interactive effect of management and unintentional disturbance.

Analyses

Treatment method of plot edge correction

The results of spatial structure analysis always were influenced by the boundary effect. The treatment methods of edge correction mainly included eight neighborhood translation (NT) (RADTKE and BURKHART, 1998), eight neighborhood reflection (NR) (PRETZSCH, 2002), buffer zone (BZ) (DIGGLE, 2003; GADOW *et al*., 2003), distance comparison of the nearest neighborhood (DC) (POMMERENING and STOYAN, 2006) and distance determinant method of the 4^{th} neighborhood (DD) (ZHOU *et al*., 2009).

Comparison of different methods showed that NT, BZ and DD was more exact than NR in analyzing spatial structure, and DD was much better than NT in applicability of plot shape and more effective than BZ in the ratio of the trees taken part in the calculation (ZHOU *et al*., 2009). But in NT, boundary effect of the plot was corrected by copying eight same ones and moving them to the eight azimuths around it, which might reflect original meaning of sample plot method better, and also was understood and acceptable easily at the same time. So the method of NT was used for the correction of plot edge effect in this research.

Definition of spatial structure unit

All spatial structure indices were based on a unit which was made up by one reference tree and *n* nearest neighboring trees. And the number of units equaled to the number of all the trees in the plot, because every tree of the plot would be a target tree. Now the issue was how to decide the number of neighboring trees. FUELDNER (1995a) using instances showed it would result in confusion easily in description of species isolation degree of mixed forest when selected only a nearest neighboring tree, when selected two, it was difficult to reflect the truth of mixed forest composed by more than four tree species, and when the number of neighbors was more than six, it needed too much cost and time in survey and calculation and lowered sensitivity. Based on these, he recommended the unit by selecting three neighbors, which was adopted by other studies in Europe and named as four group structure method. But it was known easily that there were *n*+1 classes or grades in the relationship between the reference tree and *n* neighboring trees. Four or six (even number) classes or grades might be gotten when selecting three or five neighbors, which lacked middle transition state and would not be in accord with nature. In the unit with a reference tree and four neighbors (Fig. 1), there were five grades, for example: none-mixed, low-mixed, middle-mixed, high-mixed and highest-mixed in description of species isolation degree; dominant, subdominant, intermediate, oppressed and full-oppressed in expression of tree growth status, which could be explained well from biology, and the spatial structure information was complete and interpreted easily. This method had been also proved to be most suitable based on practical considerations in connection with the field assessment methods and was used to analyze forest spatial structure successfully (ALBERT, 1999; HUI and HU, 2001; AGUIRRE *et al.*, 2003).

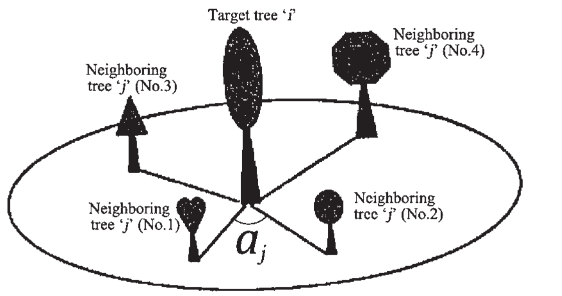

Fig. 1 The unit of spatial structure analysis

Mingling (M_i)

Species diversity has become a very important aspect of forest management and conservation and a number of parameters are available to describe it. Diversity index and species richness were always used to measure the rich degree of species (MACARTHUR and MACARTHUR, 1961; PIELOU, 1977; NIESE and STRONG, 1992; LAHDE *et al.*, 1999). However, they lacked spatial information. Then segregation index was presented to reflect the isolation level of two species (PIELOU, 1961). But it was merely fit for the forest in which the distribution of tree species followed to random state (FÜLDNER, 1995b). In order to resolve the above shortcomings, with combining their advantages at same time, mingling was presented to measure isolation degree between different tree species (GADOW and FÜLDNER, 1992).

Mingling was defined as the proportion of the *n* nearest neighbors that didn't belong to the same species as the reference tree (FÜLDNER, 1995b; HUI and HU, 2001), which might reflect the mixed level of different tree species and express spatial information in the community well. The mingling of every unit might be calculated by the formula as follows:

$$M(o)_i = \frac{1}{n}\sum_{j=1}^{n} V_{ij} \tag{1}$$

where *n* is the number of neighbors, and in this research, *n*=4. When neighbor *j* belongs to the same species as reference tree *i*, V_{ij}=0; otherwise, V_{ij}=1; and $0 \leq M(o)_i \leq 1$.

But this definition only considered the species difference of the reference tree and neighbors, and neglected the difference of species between neighbors, which might get the same result in different stand structure (TANG *et al.*, 2004). Based on this, the above formula was improved as follows:

$$M_i = \frac{n_i}{n^2}\sum_{j=1}^{n} V_{ij} \tag{2}$$

where n_i is the number of species of neighbors, *n*=4 and other parameters as the above formula. The mingling of every unit assumed ten values with a range from 0 to 1 in different situation showed in Fig. 2.

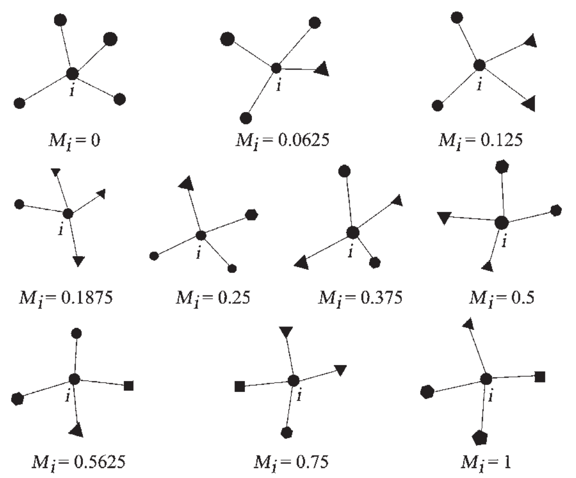

Fig. 2 Ten values of mingling in different situation
Note: Different shape represented different tree species.

Angle Index (W_i)

Population distribution pattern is one of stand spatial attributes, and from the total stand, it might be divided into three manners: clumped, random and regular (PIELOU, 1959; RIPLEY, 1977; GADOW *et al.*, 1998). Some parameters based on plot investigation were used to measure distribution pattern at first, but there were various result for the same stand with different plot size sometimes. Then methods based on distance comparison were developed fast, where aggregation index presented by CLARK and EVANS (1954) was used widely until now. But it only considered the distance between the target tree and the nearest neighboring tree, which led to its application being limited to the small-scale (RIPLEY, 1977; GADOW *et al.*, 1998). This problem was solved by the K function and pair correlation function, where the distances between all trees were considered (DIGGLE, 1983; GADOW and FÜLDNER, 1992; AGUIRRE *et al.*, 2003). However, all of them could only provide unique value for judgment of pattern, which is difficulty to describe more detailed spatial characteristics. In view of these, angle index based on point processes theory was presented (GADOW *et al.*, 1998; CORRAL-RIVAS *et al.*, 2010). This parameter having the same reliability and uniformity as aggregation index and pair correlation function had been proved by HUI *et al.* (1999; 2004) by using computer forest simulation, and it might judge stand spatial pattern easily by sampling survey instead of every tree survey.

Angle index described the regularity degree of spatial distribution of n trees nearest to a reference tree. W_i was based on the classification of the angles a_j, the small angle of two angles composed by the reference tree and every two adjacent trees of the four neighbors (Fig. 3). A reference quantity was the standard angle a_0, which was expected in a regular point distribution, and when there were four neighbor trees, a_0=72° (AN, 2003). The binary random variable Z_{ij} was determined by comparing each a_j with the standard angle a_0. The angle index was then defined as the proportion of angles a_j which were smaller than the standard angle a_0:

$$W_i = \frac{1}{n}\sum_{j=1}^{n} Z_{ij} \tag{3}$$

When $a_j<a_0$, Z_{ij}=1, when $a_j \geq a_0$, Z_{ij}=0, and n=4. With four neighboring trees, there were five possible values that W_i could assume for every unit in different situation showed in Fig. 3.

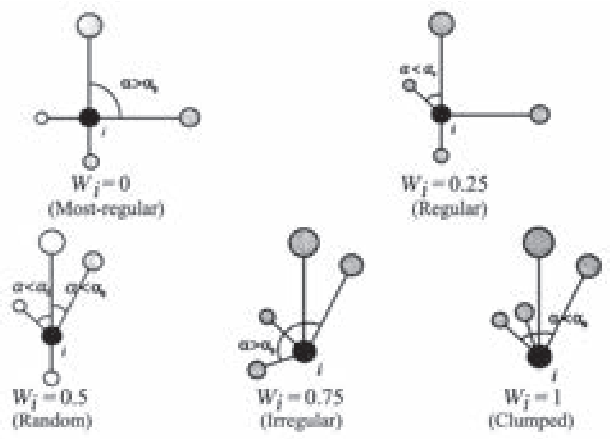

Fig. 3 Five values of angle index in different situation

Neighborhood Comparison (U_i)

In traditional forestry, diameter class structure was always used to describe growth of trees in stand, which was available to analyze the discrepancy between different communities or population. But it was applied difficultly to express the inner differentiation of individual trees in a stand or plot. Then size differentiation expressed by the relative difference between a reference tree and the nearest neighboring tree was used to reflect the variation degree of two adjacent trees (GADOW and FÜLDNER, 1992; GADOW *et al.*, 1998). However, its average value might result in contradictory explanation sometimes in analyses of mixed forest and it was unsure completely when referring the structure characteristic of a special stand to reconstruct forest (FÜLDNER, 1995a). Therefore, neighborhood comparison, developed from the index of size differentiation, was presented to quantify dominant relationship between the reference tree and n nearest neighboring trees (HUI *et al.*, 1998, 1999).

Neighborhood comparison, the expression of relative attribute dominance of a given tree to relate the immediate neighboring trees, was defined as the proportion of the n nearest neighbors whose size were larger than the reference tree i. It could be calculated in the same way as the previous tree-based structural parameters:

$$U_i = \frac{1}{n}\sum_{j=1}^{n} C_{ij} \tag{4}$$

where n=4. When neighbor j is larger than reference tree i, C_{ij}=1; otherwise, C_{ij}=0, and $0 \leq U_i \leq 1$. With four neighbors, U_i for every unit could assume five values, which pointed to dominant, subdominant, intermediate, oppressed and full-oppressed status of the target tree respectively (Fig. 4).

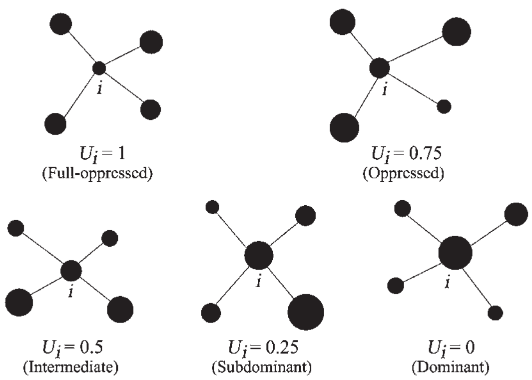

Fig. 4 Five values of neighborhood comparison in different situation

Note: Circle size represented relative DBH of tree.

Opening Degree (K_i)

Tree growth with no management depended mainly upon three factors: gene of itself, natural environment such as illumination, moisture and soil, and competition from other trees. It is difficulty to modify gene of tree species in general management, and for the trees in a special stand with small-scale, there was no significant difference in natural condition. Competition between trees was divided into two aspects: aboveground and underground, which corresponded to illumination and nutrient respectively. Although a number of parameters were available to describe interference between trees, but were unable to express the above two aspects at the same time.

Opening degree, as an indirect index reflecting relative illumination intensity, was presented by LUO *et al.* (1984). It was defined as the sum of ratio of the distance from the location of target tree to all of neighbors in each quadrat to their height. His research suggested that this index had a significant correlation with growth of trees in understorey and regeneration, and the distribution of populations depended on the light levels (LUO *et al.*, 1984). Because of the correlation between tree height and calyptra, it might also reflect growth space of trees (HAO *et al.*, 2006). Here opening degree was introduced as a parameter measuring growth condition of target tree. With some improvement for the uniformity with other spatial structure indices, it was defined as the average value of ratios between distances from every neighbor *j* to the reference *i* and the height of corresponding neighbor *j* in each unit. Opening degree could be calculated by the formula:

$$K_i = \frac{1}{n}\sum_{j=1}^{n} D_{ij}/H_{ij} \tag{5}$$

where D_{ij} is the distance between neighbor *j* and target tree *i*, H_{ij} is the height of corresponding neighbor *j*, and n=4.

RESULTS

Basic Characteristics of the Forest

The species richness of the plot increased somewhat with seven species in 2009 while four species in 1999 and the density raised from 850 trees/ha to 1425 trees/ha (Table 1). According to volume, *Pinus densiflora* was the absolute dominant species in 1999, but with the development in the ten years its dominance decreased somewhat because of cutting. *Chamaecyparis obtusa* was the most species all the time from density, which was also dominant species in the forest with its growth now. From DBH, all of *Pinus densiflora* were large size trees and lacked of regeneration while all of broad-leaved trees were small (Table 1).

Mixed Degree of Different Species

Species diversity has become a very important aspect of forest management and conservation (AGUIRRE *et al.*, 2003). Mingling (M_i) was used to reflect the mixed degree of different species in this research. The mingling value of every reference tree unit could be divided into five values or intervals: 0, (0, 0.25], (0.25, 0.50], (0.50, 0.75] and (0.75, 1], where (0, 0.25] meant $0 < M_i \leq 0.25$ and others were the same, corresponded to the degree of none-mixed, low-mixed, middle-mixed, high-mixed and highest-mixed respectively (Fig. 2). M_i =0 showed that the four neighbors belonged to the same species as the reference tree, while M_i =1 indicated that all of neighbors and reference tree belonged to different species. Then the frequencies of different mixed degree units of the total stand and different species were counted respectively (Fig. 5, Fig. 6).

In 1999 the average mingling of the total stand was 0.316, belonging to middle-mixed degree (Table 2). The ratio of low-mixed, middle-mixed and high-mixed units was up to 97%, and there was no highest-mixed unit (Fig. 5). From different species, the frequency distributions of *Pinus densiflora* and *Chamaecyparis obtusa* were similar to the trend of the total stand, and their average minglings were 0.286 and 0.334 respectively, belonged to middle-mixed. This was because the forest was mainly composed by *Pinus densiflora* and *Chamaecyparis obtusa* and the percentage of them was up to 94.1% (Table 1), presented the mixed degree of the stand depended on these two species.

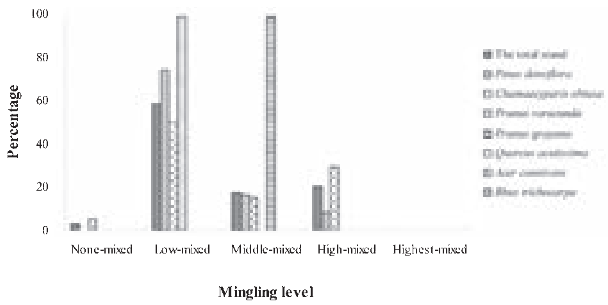

Fig. 5 The frequency distribution of Mingling of the forest in 1999

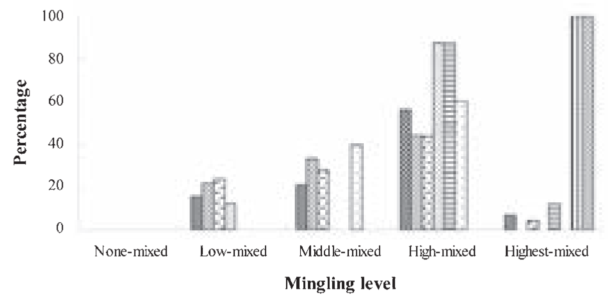

Fig. 6 The frequency distribution of Mingling of the forest in 2009
Legend is same as Fig. 5.

Table 1 The difference of stand status of the forest in Oshiba Forest Park between in 1999 and 2009

Species	Density				DBH/cm						Volume	
	1999		2009		1999			2009			1999	2009
	No.·hm^{-2}	%	No.·hm^{-2}	%	D_{min}	D_{max}	$\overline{D}$	D_{min}	D_{max}	$\overline{D}$	m^3·hm^{-2}	m^3·hm^{-2}
The total stand	850	100	1425	100	3.5	69.0	24.0	3.5	71.0	17.4	622.600	649.950
Pinus densiflora	300	35.29	225	15.79	46.0	69.0	55.2	54.5	71.0	59.8	613.175	601.125
Chamaecyparis obtusa	500	58.82	625	43.86	5.5	18.0	7.2	3.9	24.8	13.1	9.175	43.675
Prunus verecunda	25	2.94	200	14.04	6.0	6.0	6.0	3.8	11.7	6.5	0.200	2.650
Prunus grayana	25	2.94	200	14.04	3.5	3.5	3.5	3.6	7.5	5.3	0.050	1.525
Quercus acutissima	0	0.00	125	8.77	0.0	0.0	0.0	4.2	7.0	5.3	0.000	0.825
Acer connivens	0	0.00	25	1.75	0.0	0.0	0.0	4.1	4.1	4.1	0.000	0.100
Rhus trichocarpa	0	0.00	25	1.75	0.0	0.0	0.0	3.5	3.5	3.5	0.000	0.050

Table 2 The average value of four spatial structure indices of the forest in 1999 and 2009

Species	Year	Mingling $/\overline{M}$	Angle Index $/\overline{W}$	Neighborhood Comparison $/\overline{U}$	Opening Degree $/\overline{K}$
The total stand	1999	0.316	0.456	0.456	0.393
	2009	0.567	0.478	0.474	0.304
Pinus densiflora	1999	0.286	0.521	0.375	0.405
	2009	0.521	0.389	0.028	0.300
Chamaecyparis obtusa	1999	0.334	0.425	0.475	0.397
	2009	0.463	0.460	0.480	0.323
Prunus verecunda	1999	0.250	0.250	0.750	0.195
	2009	0.617	0.531	0.594	0.287
Prunus grayana	1999	0.375	0.500	0.750	0.348
	2009	0.734	0.531	0.688	0.256
Quercus acutissima	1999	-	-	-	-
	2009	0.650	0.600	0.550	0.287
Acer connivens	1999	-	-	-	-
	2009	1.000	0.250	0.750	0.421
Rhus trichocarpa	1999	-	-	-	-
	2009	1.000	0.500	1.000	0.334

Comparing with 1999, the average mingling of the plot increased to high-mixed status with a value of 0.567 in 2009 (Table 2). The mingling of all of species raised with different extent, especially some new species invaded in the plot in 2009 such as *Acer connivens* and *Rhus trichocarpa* were up to 1.000, suggested that their four neighbors attributed absolutely different species. In the frequency graph, there were some highest-mixed units but no none-mixed units in 2009, and most units located in high-mixed degree (Fig. 6), showed that more reference trees were either surrounded by three or even four neighbors that belonged to different species.

Distribution Pattern ofIndividual Trees

Angle index (W_i) was used to measure the distribution pattern of trees on the ground. With four neighbors, there were five possible values: 0, 0.25, 0.50, 0.75 and 1, that W_i could assume for every unit, corresponding to the manners of most-regular, regular, random, irregular and most-irregular status respectively (Fig. 3). W_i =0 indicated that the four trees in the vicinity of the reference tree were positioned in a most-regular manner, whereas W_i =1 pointed to a clumped distribution (Fig. 7, Fig. 8). The average value of angle index of all units in the plot could be used to judge distribution pattern of the total stand, when 0.475 $\leq$avg. W_i $\leq$0.517, belonged to random pattern, and when $<$ 0.475 or $>$ 0.517 was regular pattern or clumped pattern respectively (Hui *et al.*, 2004).

For the total stand, there were no clumped and most-regular units in 1999, and the ratio of irregular units was only less than 10% (Fig. 7). In case of other all concentrated on random and regular pattern, which resulted in the average angle index of 0.456 attributed to regular distribution, the typical model of man-made forest. From different species, the frequencies of *Pinus densiflora* with a clumped pattern in irregular, random and regular presented the characteristic of symmetrical distribution, while the units of other species in 1999 belonged to random and/or regular pattern were up to 90% even to 100%.

The average angle index of the total stand in 2009 was 0.478 (Table 2), belonged to random distribution according to the above standard of judgment. The frequencies in five patterns showed the feature of normal distribution (Fig. 8), the characteristic of climax community, indicated that the arrangement of trees on the ground was more reasonable with the development of ten years. For different species, the units of *Pinus densiflora*, its distribution changed from clumped in 1999 to regular in 2009, located mainly in random and regular manner, while *Chamaecyparis obtusa* with a regular distribution all the time was similar to the total stand. The pattern of *Prunus verecunda* was clumped in 2009 but regular in 1999. And the units of *Prunus grayana* with a change from random to clumped concentrated mainly in irregular and

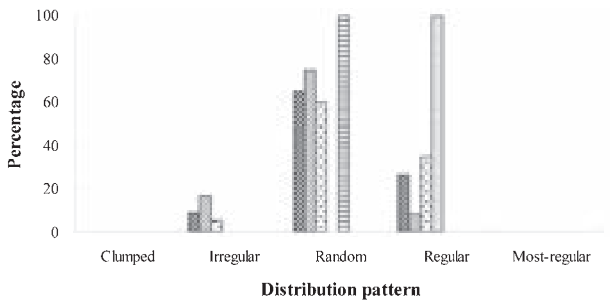

Fig. 7 The frequency distribution of Angle Index of the forest in 1999 Legend is same as Fig. 5.

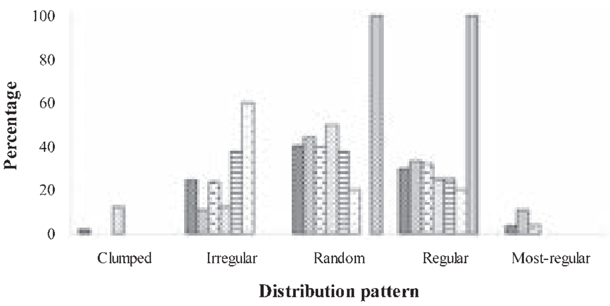

Fig. 8 The frequency distribution of Angle Index of the forest in 2009 Legend is same as Fig. 5.

random model in 2009, whereas *Acer connivens* and *Rhus trichocarpa* with only one tree attributed to regular and random, respectively.

The Size Differentiation of Trees

Neighborhood comparison (U_i) qualitatively described relative dominance of the reference tree and neighbors, and it could be divided into DBH U_i, height U_i and tree-crown U_i and so on, according to different parameters of comparison. In plot survey, the measurement of DBH had higher accuracy than tree height and tree-crown. And for the two latter, it even was contradictory result sometimes, for example, for the same tree, its height and/or tree-crown might be negative growth after a ten years period because of the measurement by different surveyor. In addition, there were significant correlations between DBH and tree height and tree-crown in general stand. In view of the above, we adopted DBH as the comparison variable. With four neighbors, U_i for every target tree could also assume five values: 0, 0.25, 0.50, 0.75 and 1, corresponding to the status of dominant, subdominant, intermediate, oppressed and full-oppressed of it respectively (Fig. 4). U_i =0 presented that no neighbor was bigger than reference tree, while U_i =1 made clear the target tree was smaller than all the four neighbors. Then the frequencies of the total stand and different species were counted in the two periods respectively (Fig. 9, Fig. 10).

About 60% of the trees in the plot located at intermediate and dominant status, the latter was made up of *Pinus densiflora* units, and over 30% trees were oppressed by their neighbors in 1999 (Fig. 9). In spite of all of *Pinus densiflora* were bigger than other species, but only about 40% of them were dominant

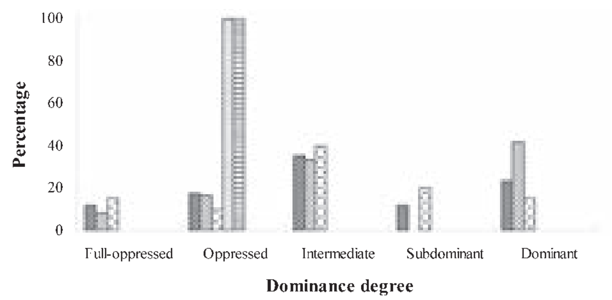

Fig. 9 The frequency distribution of Neighborhood Comparison of the forest in 1999
Legend is same as Fig. 5.

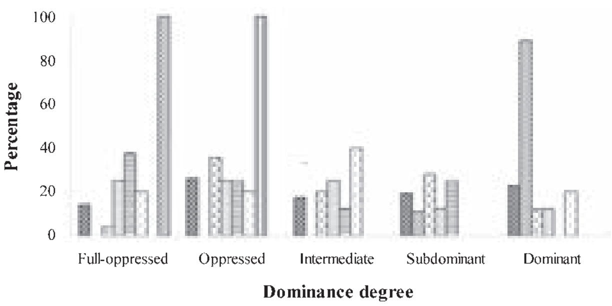

Fig. 10 The frequency distribution of Neighborhood Comparison of the forest in 2009
Legend is same as Fig. 5.

and the oppressed was even up to 25%. This because some individuals of *Pinus densiflora* were either surrounded by three or even four neighbors that belong to the same species, which could also be certified by the result of mingling (Fig. 5). In contrast, the frequency of *Chamaecyparis obtusa* was similar to normal distribution, while *Prunus verecunda* and *Prunus grayana* were all oppressed because of smaller DBH.

In 2009, the intermediate trees were decreased to the half of 1999, whereas oppressed and full-oppressed reference trees increased evidently, because there were more small broad-leaved trees (Fig. 10). At the same time, more *Pinus densiflora*, whose neighborhood comparison reduced from 0.375 to 0.028 (Table 2) and the latter indicated that there were hardly any neighbors bigger than the reference tree in DBH, were dominant in the comparison with their neighbors. Because some individuals of *Pinus densiflora* were cut in the period, which resulted in the change of the units with *Pinus densiflora* as the reference tree and more small trees of other species becoming their neighbors. The change of *Chamaecyparis obtusa* was the same as the total stand and the units in oppressed and full-oppressed were equal to subdominant and dominant, while most of broad-leaved trees were in oppressed or full-oppressed status (Fig. 10).

The Growth Space of Reference Tree

Growth potential of a tree was decided by not only the natural environmental condition but also the competition and interference of its neighboring trees. Neighborhood comparison neglected the effect of distance between reference tree and neighbors on the interference intensity, the opening degree (K_i) was introduced to measure growth space of reference tree, which could reflect the spatial condition around it and interference of neighbors at the same time. In this study, opening degree was defined as the average value of ratios between distances from every neighbor *j* to the reference *i* and the height of corresponding neighbor *j* in each unit. There is an inverse ratio between opening degree and tree height and a direct ratio between opening degree and distance, the shorter distance and/or the higher neighboring tree, the lower value of opening degree. According to our practical survey and analysis for the correlation between opening degree and growth speed of 1200 trees containing over hundred species, we thought it could be divided into five intervals: (0, 0.2), [0.2, 0.3), [0.3, 0.4), [0.4, 0.5) and [0.5, +∞), corresponding to the growth space of most-inadequate, inadequate, adequate, more-adequate and most-adequate respectively (Deng *et al.* 2010a). The value lower than 0.2 suggested the condition of very high density and average height of neighboring trees around the target tree, which resulted in very low growth of it and thus indicated the status of most-inadequate.

The average opening degree of the forest in 1999 was 0.393 belonged to adequate and neared to more-adequate (Table 2), indicating that there was enough space for the growth of most trees. From Table 1 we might know the average area of 11.7 m^2 for every tree, which also could illustrate the above conclusion. But there was a remarkable difference between species with a range from 0.195 of *Prunus verecunda* to 0.405 of *Pinus densiflora*, showing the heterogeneity of growth space assigned the different species and individuals (Table 2).

No units of *Chamaecyparis obtusa* with an opening degree of 0.397 were in most-inadequate and all of them distributed in other four statuses averagely (Fig. 11). *Prunus grayana* was in adequate with only one tree in 1999.

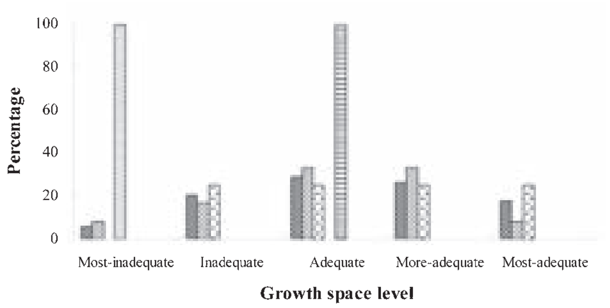

Fig. 11 The frequency distribution of Opening Degree of the forest in 1999
Legend is same as Fig. 5

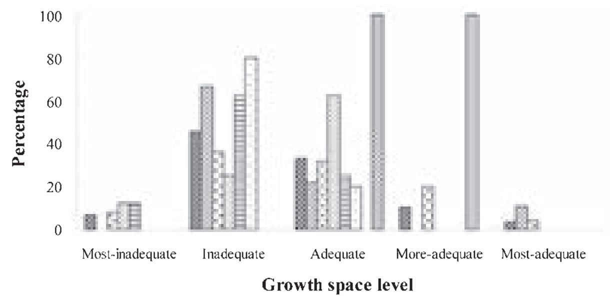

Fig. 12 The frequency distribution of Opening Degree of the forest in 2009
Legend is same as Fig. 5.

The opening degree of the plot in 2009 decreased to 0.304, the critical value of inadequate and adequate, suggested that the use for horizontal space in the plot was in the status of saturation (Table 2). In fact, now some species such as *Prunus verecunda* and *Prunus grayana*, with a value of 0.287 and 0.256 respectively, have been in inadequate even though others were adequate. And from the statistic of frequency, comparing with 1999, the units in inadequate increased while in more-adequate and most-adequate decreased significantly in 2009 (Fig. 12). Therefore, with the time going on, the space will become the main constraint factor of tree growth someday, especial for the broad-leaved trees because they are small and in the underlayer of the stand.

DISCUSSION

In the ten years, the change and development of spatial structure of the forest was mainly influenced by three factors: cutting, invasion of broad-leaved trees and unintentional disturbance of tourists, whereas the last one affected majorly the herb, shrub and small trees in understorey. Five trees, whose DBH was larger than 3.5cm in 1999, with three *Pinus densiflora* and two *Chamaecyparis obtusa* were cut in this period (Fig. 13a, c). In the 10 years, twenty six broad-leaved trees invaded the plot but five of them were cut, and thirteen *Chamaecyparis obtusa* invaded the plot but six of them were cut (Fig. 13a, b). The cutting of *Pinus densiflora* and *Chamaecyparis obtusa*, the two dominant species of the stand, resulted in the reduction of the units composed by same species, while the invasion of broad-leaved trees improved the probability of neighbors belonging to different species as the reference tree. Therefore, we might know the mixed level of all species was raised with different extent and the average mingling of the total stand increased from middle-mixed to high-mixed status (Table 2).

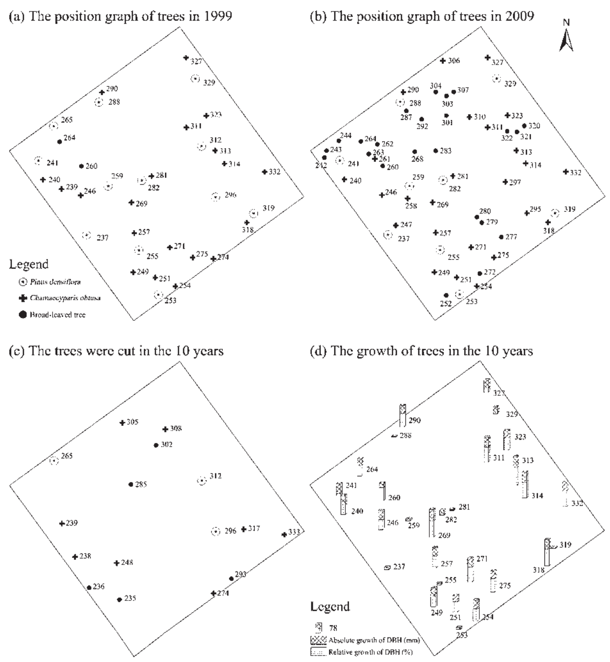

Fig. 13 The development process of the forest in the ten years
Absolute growth of DBH: DBH in 2009 minus DBH in 1999 (unit: millimeter)
Relative growth of DBH: (Absolute growth of DBH / DBH in 1999) * 100 (unit: percentage)
'78': the height of prism represented absolute growth of 78 millimeter or relative growth of 78%

The stand in this research derived from pure forest of *Pinus densiflora* in wasteland after forest fire and grassland with man-made afforestation in 1916 and some *Chamaecyparis obtusa* were replanted around 1980, where almost all trees were planted by regular manner and this feature could be also reflected by the angle index in 1999. Owing to it belonging to protection forest, there were hardly any traces of tree thinning and only invasion of two broad-leaved trees until 1999. Then the regular pattern was changed by random cutting and the regeneration and growth of broad-leaved trees in random positions. So the distribution of the trees in the plot was developed into random pattern in 2009 (Fig. 13b).

On the other hand, because of the cutting of some *Pinus densiflora*, the units with *Pinus densiflora* as reference tree and neighbors at same time were decreased, which resulted in the increment of other units with small tree as reference tree and large trees as neighbors. And comparing with neighbors, the new trees which joined in the plot in the ten years were almost in full-oppressed or oppressed condition. Therefore the neighborhood comparison of the total stand increased from 0.456 to 0.474 (Table 2). At the same time, because new trees were more than cut trees, the density of the forest improved from 850 trees/ha to 1425 trees/ha (Table 1), which made the average distance more shorter between different individuals, and all trees became more higher with the growth, so the average opening degree fell into the critical status of inadequate and adequate.

From the tendency of forest succession, though *Pinus densiflora* is in absolute dominance in basal area and volume (Table 1), but there are not any small trees of complement for its regeneration, so if damaged by natural disaster, disease or insect or when they are aging, this population will disappear from the forest finally. Now the *Chamaecyparis obtusa* is dominant in density and continuous in diameter class (Table 1). Their growth space is adequate and they hold advantageous ecological niche in vertical structure and are growing with a high-speed (Fig. 13d). Therefore, if no high-intensity disturbance, they will continue to be in dominance in competition between species and will be in the highest layer of the stand at the end. Most of broad-leaved species are in disadvantage at present. The number of them is too less, their growth space is not enough and they are interfered by neighboring trees and people at the same time, which will result in the difficulty of growth and regeneration. So we should take effective measures to protect the successful growth of them to ensure the species diversity of the forest and stability of the community.

From the management process of the plot, we might know that cut trees were selected with random and subjective manner by managers because of the lack of uniform standard, only according to some fundamental principles of traditional operation. Sixteen trees were cut in the ten years, including three *Pinus densiflora*, eight *Chamaecyparis obtusa* and five broad-leaved trees with two species (Fig. 13c), which was contradictory evidently with the high biodiversity and the management goal of irregular uneven-aged mixed forest. And from the growth figure (Fig. 13d), we might know that the growth of these trees around on *Pinus densiflora* which were cut in this period was more than other trees, indicated that the interference of *Pinus densiflora* was an important constraint factor for the growth of other species. But from the position graph (Fig. 13a, c), No.241 tree was reserved while the 296 was cut in the operation process, it was clear that the former hindered the growth of more target trees around it, also showed the random and no-criterion in the selection of cut trees.

This research attempted to provide some recommendation for the selection of cut tree by spatial structure theory. The results indicated that the distribution pattern of trees on the ground was reasonable in 2009, because the average value of angle index was 0.478 belonging to random distribution (Table 2), and the frequency of all units was similar to normal distribution (Fig. 8), the feature of climax community. And the mingling of the total stand was up to 0.567, attributing to the high-mixed degree. So now the main problem we faced is how to improve the dominance of small trees and expand the growth space of all trees especial broad-leaved species, which are the important target trees in future and should be paid more attention to cultured.

From the position graph of trees in 2009, *Pinus densiflora* of No.241 and 253 hindered or affected the growth of the trees around them, so they should be cut in the next operation. No.288 and 282 may become the candidates, because if cut, the former can improve the growth environment of many broad-leaved trees near to it and the latter can create larger forest gap, which can provide advantages for the invasion or replant of more other species. Although all of *Pinus densiflora* interfere with other trees in some extent because of their huge crown, DBH and root, but some individuals of them should be retained for the need of diversity of species and landscape, in fact the trees of bigger DBH might improved the scenic beauty value of forest (DENG *et al.*, 2010b). For management of *Chamaecyparis obtusa*, No.318 may be cut, which is too near to the 319, the reserved tree in next operation, and if cut, the population competition for the 295 will be reduced. The 261 with poor growth due to serious species competition might also be cut. If 237, 259, 282 and/or 288 retaining, the *Chamaecyparis obtusa* of 247, 258, 281 and/or 290 should be cut, because they are difficult to growth well in the disturbance of the former. On the other hand, if possible, we may replant some other broad-leaved trees of moderate size in the gap in order to improve the mixed degree further and shorten the invasion time of other species and succession to climax community.

Management target of modern forestry is to reconstruct structure of man-made forests by simulating the structure of natural forests. For this target, the first issue is how to express structure characteristics of forest. But it seems unable to describe forest structure well by using only one parameter because of the complexity. So a system used to evaluate different aspects of stand spatial structure was created by grouping four indices: mingling, angle index, neighborhood comparison and opening degree in this study. A number of studies indicated that they are available and may interpret spatial characteristics of forest with different types effectively. Mingling was proved to be better than traditional mixed ratio in the expression of isolation degree between tree species for mixed forest by HUI and HU (2001) and TANG *et al.* (2004) with some instances. By using computer forest simulation, HUI *et al.* (1999; 2004) suggested that angle index had the same reliability as aggregation index and pair correlation function, but it was easier explained and could provide more results for the judgment of spatial distribution patterns of every unit, different species and the total stand respectively than the two latter with only a result for a stand. Neighborhood comparison quantified dominant relationship between the reference tree and n nearest neighboring trees (HUI *et al.*, 1998, 1999). And opening degree, which had a significant correlation with growth of trees in understorey and regeneration, was introduced as the complement of neighborhood comparison in this study. In addition, some parameters of this system had been successfully used to analyze present status of spatial structure of natural mixed forest (HU *et al.*, 2003), to explain the discrepancy of spatial attributes of different type stands (AGUIRRE *et al.*, 2003), and to predict the change of structure characteristics of man-made pure forests with different management measures such as thinning and selection cutting (HAO *et al.*, 2006; ZHAO *et al.*, 2008).

In this study, although only the 11th plot had been analyzed with the purpose of exploring new approach for description of forest spatial structure, but the results expressed information of structure change of the forest impacted by management and unintentional disturbance very well. Now the next issue is how to get spatial structure characteristics of all units in the park (i.e. the park was been as a large plot), which is the basis for the planning of operation and can be come into true by two steps: firstly the information: species, position and tree height and size of all individual trees, might be interpreted by high resolution satellite or aerial image and LiDAR image by individual tree crown method, then introduce the special program of computing spatial structure indices and all the above information into ArcGIS software and thus realize calculation automatically. Finally, the target trees of reserving or cutting would be selected automatically by the advanced inquiry function of ArcGIS by giving different weighing of key parameters. But there are still a number of key techniques need to resolve and this idea depends upon the development of remote sensing to a great extent.

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Article

Scotland's Forestry Cluster Experience and Relevance to Japanese Prefectural Forestry- A Case Study of Nagano Prefecture

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ABSTRACT

Porter's Industrial Cluster Theory has been applied to Scotland's forestry industries since 2000, and this paper analyses the relevance of this experience for prefectural forestry policies in Japan, based on Nagano Prefecture as a case study. First, the paper discusses the key contributions to industry competitiveness resulting from clusters and their networks. Next, the current situation in Nagano is considered together with emerging prefecture policies to increase timber supply and encourage its forestry industry. Strengths and weaknesses in the prefecture's forestry system are identified and the extent to which Nagano's policies already reflect experience in Scotland is summarised. While many of the overall aims are similar to those of Scotland's forestry cluster, Nagano Prefecture has some weaknesses including the fragmented ownership structure and the multiple stages in the distribution chain. Based on Scotland's experience, potential remains to develop and manage effective cluster networks, and to stimulate cooperation across the supply chain between timber producers and users to improve productivity and develop markets, thereby 'co-creating' value.

Keywords: forestry management, Scotland, forestry cluster, competitive forestry, Nagano forestry, prefectural forestry

INTRODUCTION

Japan is seeking to increase the productive use of its extensive forest cover, as many of the forests planted during the 1950s and 1960s reach maturity. Japan's Forest Agency introduced support for 'New Production Systems' between 2006 and 2011 (Japan Forestry Agency, 2007) to encourage a more efficient supply chain and increased supply for large-scale users, and announced in 2010 a target to raise Japan's self-sufficiency rate in timber to 50% over the next 10 years (Japan Forestry Agency, 2010). A combination of increased domestic production and falling overall demand have caused the self-sufficiency rate to rise to 24.0% in 2008 and subsequently to 27.8% in 2009 from a low of 18.2% in 2000 (Japan Forestry Agency, 2010), but progress towards the long term target remains dependent on improving the international competitiveness of Japanese timber.

The challenge to domestic timber competitiveness due to the availability of cheaper imports is not confined to Japan. European forestry operates in the same international market, and other researchers have examined the lessons which might be learnt from practice overseas (e.g. Owari, 2007; Aikawa, 2010). One particular approach to strengthening competitiveness was deployed in Scotland from 1999 via the 'Scottish Forestry Industries Cluster' (SFIC). This applied the management theories of Harvard Economist Michael Porter to bring a systems approach to improving the efficiency and performance of the forestry supply chain through the mechanism of 'Clusters'. Clusters seek to strengthen the interconnections between cluster members along the supply chain, and with service providers, related industries, and institutions such as universities and standards institutions (Porter, 1990). Clusters can contribute to stimulating productivity improvements and innovation via intensifying both competing and cooperative interactions between cluster members.

Japan's New Production Systems (NPS) initiative mentioned above, though not based on Porter's cluster theories, applies similar thinking through its focus on securing stable supplies of timber, reducing distribution costs, improving the efficiency of the supply chain, and strengthening links between suppliers and markets (Tateiwa, 2007; Japan Forestry Agency, 2007; Inamoto, 2007). The different organisational models deployed in Scotland and Japan towards similar objectives thus provide an opportunity to research their relative effectiveness and consider whether the explicit focus on cluster thinking in the SFIC could be relevant to Japan's own forestry policies (Norton, 2008).

A survey of the role of the SFIC was carried out in 2008

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(NORTON and UEKI, 2009). Over the period studied (1999-2008), timber supply had increased by over 20% to 6,500,000 m^3 annually, and processing capacity had also expanded, so that 84% of timber harvested in Scotland was processed there, making an important contribution to the local economy. Implementation of the SFIC had contributed to greater reliability of supply, better information sharing, improved competitiveness along the supply chain, and stronger links between suppliers and markets. Cluster activities took place mostly between private sector organisations, with the government providing funding for the creation and early operation of the SFIC. The Cluster contributed to industry performance via a number of mechanisms which are summarised in Table 1.

This paper examines in more detail the relevance of the SFIC model to Japan, using Nagano Prefecture as a case study[1]. The current situation in Nagano is described, and similarities and differences between Scotland and Nagano's forestry industry are evaluated. In particular, we consider how far Nagano Prefecture policy is already applying lessons from the SFIC's experience (in particular the factors identified in Table 1 on the operation of cluster networks and collaboration), and whether the experience of the SFIC offers any valuable insights for the future development of Nagano's forestry industry.

METHODS

The analysis of Nagano Prefecture's forestry was based on information from Nagano Prefecture Forestry Division, Chubu Division of the Forestry Agency, the Association of Nagano Forestry Owner Associations, and individual associations. This was supplemented by interviews with these and other organisations (North Shinshu Timber Centre, and 4 private timber processors). Particular focus was placed on forest ownership and management, the potential for a long-term sustainable yield, and the supply chain from timber supply through distribution and processing to markets. We use 2008 as the year for comparison since that was when the Scottish survey was carried out.

According to Porter's theory (PORTER, 1996), clusters involve relationships which are geographical, business-related, and knowledge-related and are seen as encouraging innovation and improved competitiveness through social and business network relationships. Such relationships encourage beneficial links which are vertical (e.g. buying and selling chains) and horizontal (complementary products and services, the ability to share technologies, labour, etc.). Involvement in cluster networks can encourage innovation, arising from direct and indirect interaction between firms and other organisations-including sources of knowledge such as research institutes and universities. In our Nagano survey, we thus also looked for organisational models or activities which shared some of the above features of clusters; one company (Tohsen Group) adjoining Nagano Prefecture which exhibits some cluster characteristics was also interviewed.

Table 1 SFIC contributions to Scottish Forest Industry performance

Action or objective	Example or mechanism
Provision of predictable, reliable and long-term sustainable supply.	Cooperation between FCS and private owners on cutting strategy and planting.
Cooperative measures to improve productivity in the supply chain.	E-commerce for transactions, transport logistics improvement, sharing best practice.
Strengthening personal and organisational networks connecting suppliers and users.	Ensuring secure supplies for major new investments in sawmills and biomass.
Simplifying the supply chain.	Organisations which straddle the supply chain or provide contract services creating economies of scale.
Integration of forestry factors into other separately administered areas of government policy and associated grants.	Leisure, recreation, tourism, economic development and environmental policies (including global warming) take into account forestry interests.
Market diversification.	Imports substitution of sawn woods (especially for construction); large-scale biomass and CHP; domestic heating, fuel stoves and pellets; board manufacture; co-products (paper, garden centres).
Regulations and standards.	Engagement of standards organisation in promoting the role of wooden housing in meeting standards for sustainable housing.
Public purchasing.	Architects and Local Authority specifications to help local timber compete.
Research and development.	New applications for timber.
Training.	Forestry workforce training, architect professional development (training on wooden construction).

Source: NORTON and UEKI (2009).

[1] Nagano Prefecture was selected because of the location of the authors' institution (Shinshu University), the similarity of Nagano's forested area to that of Scotland (10,580 km^2 and 13,300 km^2 respectively), the presence of many important multiple uses (including National Parks) and because analysis of some prefectural forestry policies had already been carried out (UEKI, 2009).

NAGANO FORESTRY

General Characteristics

Nagano, with a forested area of 10,598 km^2, possesses the third largest area of forest among Japanese Prefectures, and its 2008 production was in 16th position (Japan Forestry Agency, 2009). The age distribution of Nagano's forest is shown in Fig. 1 (together with that of Scotland), from which it can be seen that there was a high rate of planting during the 1960s. As a result, the growing stock is expanding (artificial forest volume increased from 68 million m^3 in 2003, to 75 million m^3 in 2008, and to 84 million m^3 in 2010), and will continue to increase as trees mature (Nagano Prefecture, 2009a). A comparison of forest resources and timber production between Nagano and Scotland is in Table 2.

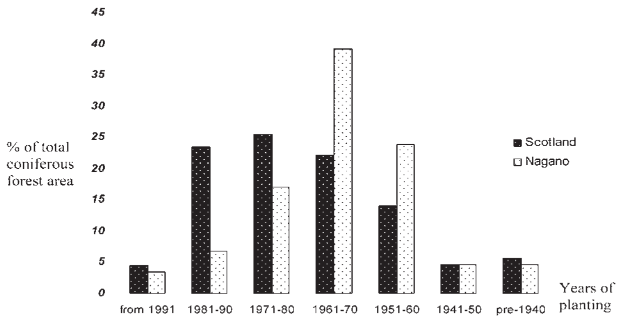

Fig. 1 Years of planting of coniferous forests in Nagano Prefecture and Scotland
Source: Nagano Prefecture (2009a); Forestry Statistics (2009)

Table 2 Forest resources and production (2008)

Aspect	Nagano	Scotland
Forest Area (km^2)	10,598	13,410
Artificial forest (%)	42	70
Private (%)	47.7	60
Local Public owned (%)	16.3	2
National forest (%)	36	38
Overall Production (m^3)	311,000	5,338,000
Clear cut/thinning ratio	20/80	80/20
Private production (m^3)	185,000 (59%)	2,976,000 (56%)
National Forest Production (m^3)	126,000 (41%)	2,362,000 (44%)

Source: Nagano Prefecture (2009a); Forestry STatistics (2009).

Timber Production

Supplies of timber produced within the prefecture, timber entering from adjacent prefectures and imports are shown in Table 3. Timber production (despite slight increases in recent years) is still less than that in 2000, but imports from overseas have declined substantially. Supply within the prefecture is dominated by thinning as the main source of increased supply-the target area for thinning was 18,000 ha/year in 2007, rising to 24,000 ha/year from 2011 onwards (Nagano Prefecture, 2009a).

Table 3 Timber supply and demand in Nagano Prefecture (1,000 m^3)

Year	2000	2004	2005	2006	2007	2008
From National Forest	129	83	97	102	114	126
From Private Forests	196	177	165	165	180	185
Total production in Nagano Prefecture	325	260	262	267	294	311
Demand within Nagano Prefecture	521	374	327	299	286	252
Demand supplied from Nagano timber	225	209	204	201	216	178
Demand supplied from Imports	278	155	115	87	54	56
Demand supplied from other prefectures	18	10	8	11	16	18
Prefecture self-sufficiency rate (%)	43.2	55.9	62.4	67.2	75.5	70.6

Source: Timber Statistics for 2008 (Nagano Prefecture, 2009b).

Forest Ownership and Yield

In common with the rest of Japan, private forest (47.7% of Nagano's forests) is divided among many thousands of individual owners, of which 62% own less than 1 ha, 34% between 1-5 ha, and only 1% own 20 ha or larger (Nagano Prefecture, 2009a). Individual members join Forestry Owner Associations (FOA) to allow collective management of their forest (Fujisawa, 2004); of the over 92,000 private owners in Nagano, 88,064 were FOA members in 2007, although 18.7% of forest owners in a survey carried out in 2000 lived in towns or prefectures away from their holdings (Nagano Prefecture, 2010). The number of FOAs declined from 59 in 1990 to 18 in 2006. The 10 largest FOA regions, their production and yields are shown in Table 4.

Table 4 Yield of timber (2008)

FOA Region	Total Production (m^3)	Production from FOA forests (m^3)	Area managed by FOA (ha)	Yield (m^3/ha)
Saku *	49,328	12,653	50,000	0.25
Kami Komoro	47,969	11,398	28,000	0.41
Suwa	22,372	1,140	28,000	0.04
Kami Ina	21,321	5,349	53,000	0.1
Ina**	31,494	15,563	97,000	0.16
Kiso	69,661	2,330	46,000	0.05
Matsumoto	16,224	4,655	55,000	0.08
Kita-Asumi	8,102	3,210	42,000	0.08
Nagano	31,434	10,653	66,000	0.16
Kita-Shinshu	7,439	4,219	42,000	0.1
Total	305,364	71,170	508,000	0.14

Source: Nagano Prefecture (2009b; 2010).
* Saku includes North, Central and South Saku FOAs.
** Ina includes the separate Ina Upper and Lower FOA.
Note: Figures from Nagano's 2008 timber distribution survey (Nagano Prefecture, 2009b: page 39).

Of the total production of 305,364 m^3 in Table 4, 136,354 m^3 were produced from national forest under the management of the Forestry Agency's Chubu Division, and a further 97,840 m^3 from private forests by timber-producing companies. Timber extracted by FOAs from their own areas of forest totalled 71,170 m^3 (Nagano Prefecture, 2009b). The yield (amount of timber per hectare of forest) in each FOA area ranges from 0.04 to 0.4 m^3/ha with a mean of 0.14 m^3/ha (Table 4). These rates of timber production are much lower than those in Scotland, where an average yield of 4.83 m^3/ha forest was achieved in 2007 (Norton, 2008). However, Nagano's national and private forests include large areas designated as protection forest[2], where use for timber production is restricted.

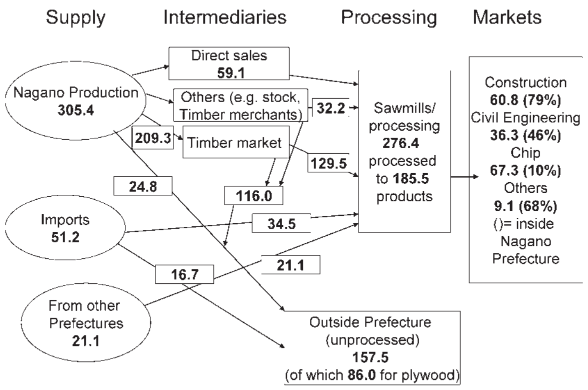

Fig. 2 Timber flow in Nagano Prefecture (2008)
Source: Nagano Prefecture (2009b). All figures in 1,000 m^3.

Timber Flow and the Supply Chain

The mass flow of timber in 2008 is shown in Fig. 2. 157,500 m^3 left the prefecture unprocessed compared with 72,300 m^3 entering as imports from overseas or shipments from other prefectures; thus a net amount of 85,200 m^3 left the prefecture unprocessed. As shown in Table 3, self-sufficiency has increased over the last decade through substitution of imports and 70.6% of the prefecture's internal demand (252,000 m^3) was met by the prefecture's own timber in 2008. Prefectural processing has been declining as shown in Fig. 3; in 2000, 381 sawmills produced 326,000 m^3, while in 2008, 216 mills produced 185,500 m^3. The proportion of sawmill products used inside the prefecture ranges from 79% for use in construction to just 10% for pulp; overall, 55% of sawmill output leaves the prefecture (Nagano Prefecture, 2009b).

While direct sales allow shipment in one stage from the roadside to the user, with potential for economies of scale, the amount of timber delivered by this method fell between 2007 (66,400 m^3) and 2008 (59,100 m^3), and comprised only 19.3% of the 305,400 m^3 of timber produced in 2008 (Nagano Prefecture, 2008, 2009b). The majority thus continues to be handled by intermediaries, and involves a more complex transport and distribution system, whereby timber is first transported from dispersed locations in relatively small loads to collection points where logs are sorted, stocked and sold, before a separate transport stage to the user. This reflects the preference of smaller sawmills, who are used to the flexibility offered by the traditional log market, where they can purchase the amounts of wood required to meet their immediate needs.

Japan has depended on imports for over 70% of its timber supplies for 20 years (Japan Forestry Agency, 2010), which means that many of the larger wood processors (especially paper and board plants) have been located near coastal ports, and thus tend to be far from forests in the central mountains (Fig. 4). Timber producers in the central prefectures such as Nagano thus incur road transport costs[3] when competing to supply such large-scale users. Despite this, Nagano increased its shipments to board manufacturers (the nearest of which is in Ishikawa Prefecture) to 86,000 m^3 in 2008 from 29,500 m^3 the previous year (Nagano Prefecture, 2008; Nagano Prefecture, 2009b).

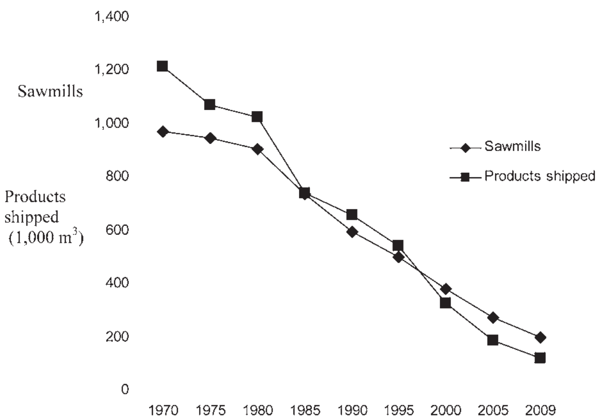

Fig. 3 Trends in the number of sawmills in Nagano Prefecture and the quantity of their products shipped
Source: Nagano Prefecture (2010)

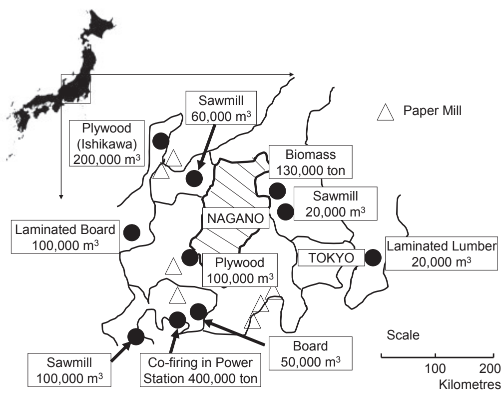

Fig. 4 Location of large facilities in adjoining prefectures and their annual capacity
Source: Nagano Prefecture (2011)

[2] In 2008, 345,828 ha of national forest and 213,414 ha of private forest were designated under the Forest Protection and Maintenance Law (page 60 in Nagano Prefecture, 2010).
[3] Over longer distances, transport costs were quoted as around 3-4,000 yen/m^3 (Interview with Prefecture Forestry Official).

Markets

Of the 185,500 m^3 of products from processing within the prefecture (Fig. 2), 60,800 m^3 (33%) were used for construction, and 36,300 m^3 (29%) in civil engineering. In addition, 67,300 m^3 (36%) of sawmill output is in the form of chip; some is used in Nagano for packaging manufacture, but the majority (90%) is shipped outside the prefecture. As noted above, the amount of timber for board manufacture has increased substantially and now represents a significant flow of resource from the prefecture. Small markets for biomass (pellet and wood-burning stoves) are emerging for FOA by-products (660 m^3 in 2008). A biomass power station has also been built which burns wood chips from forest residues and waste construction timber[4]. The 'others' category in Fig. 2 includes markets in furniture, and niche markets such as local crafts.

Prefectural Policies

Nagano's policies on forestry have been developed through a series of 'White Papers' (e.g. NAGANO PREFECTURE, 2009a) describing the aims and budgets for a range of programmes covering biodiversity, environmental protection (including its contributions to combating global warming), erosion and disaster prevention, water resources, environmental services (air quality, noise, and climate moderation), recreation and health, culture and production (timber, food and fuel). The total expenditure in 2008 across all these areas was 18.17 billion yen (NAGANO PREFECTURE, 2009c). A special levy of 500 yen per taxpayer per year was introduced in April 2008; this yielded a total income of 510 million yen in the fiscal year 2008/9 (UEKI, 2009).

In 2010/11, a comprehensive 'Shinshu Forest Action Plan' (SFAP) was developed which aims to strengthen the local forestry industry and its contribution to the prefectural economy. The plan envisages a sustainable forest with a balanced age distribution, and a shift in the conifer/ broadleaf ratio (from the current 60:40 to 40:60) over the next 100 years.

Table 5 Targets in the Shinshu Forest Action Plan

Aspect	Current	10 years later
Timber Production (m^3)	305,000	750,000
Thinning production from private forest (m^3)	143,000	238,000
Internal processing (m^3)	128,000	373,000
Road length (km)	12,829	14,429
Road network density (m/ha)	18.9	21.2
Workforce (numbers employed)	2,567	3,000
Market for Chip/biomass (m^3)	60,000	217,000
Market for Board (m^3)	76,000	119,000
Market for Construction (m^3)	65,000	133,000
Market for Civil works (m^3)	42,000	84,000

Source: NAGANO PREFECTURE (2011).

It also sets quantitative targets (Table 5) for a substantial increase in harvest volumes over the next 10 years from the current 305,000 to 750,000 m^3/year, with an associated increase in the amounts processed within the prefecture (NAGANO PREFECTURE, 2011). Major increases are envisaged in the use categories of chip/biomass (from 60,000 to 217,000 m^3/year), board manufacture (from 76,000 to 119,000 m^3/year), construction (from 65,000 to 133,000 m^3/year) and civil works (from 42,000 to 84,000 m^3/year).

Achieving such targets requires measures (Table 6) across the supply chain from timber production, through distribution, to markets. A more reliable and cost-efficient (and therefore economically competitive) timber supply requires attention to roads, equipment, workforce training and supply, grouping of small lots into larger and more economic 'coupes', as well as a move away from dependence on thinning to clear-cutting and replanting. The distribution chain is acknowledged to be 'first generation' with too many separate steps and players between the timber supplier (often the FOA) and the end-user. The SFAP aims to improve information flow and contacts across the chain, leading to a more integrated supply chain which is capable of meeting the demands of major users by providing timber of appropriate quality. In order to improve communications between stakeholders and facilitate supply chain integration, a Shinshu Forest Forum has also been

Table 6 Specifies measures in the Shinshu Forest Action Plan

Stage	Measures
Supply	Improve forestry roads; more high-capability equipment; boundary mapping and grouping of small lots into coupes of 30ha or more; shift from reliance on thinning to clear-cut and replanting to achieve a balanced year class distribution and shift in conifer/broadleaf ratio; support for workforce education and training to ensure an adequate supply of skilled labour.
Distribution chain	Information system to match supply and demand between suppliers and users (sawmills, board manufactures etc.); creating links and networks across the supply chain; improve the efficiency of transport to large users outside the Prefecture.
Markets	Use local wood for public projects (schools, local engineering works, etc.); subsidy for houses built with local timber; campaigns emphasise the environmental and health benefits (e.g. pleasant aroma and freedom from allergy-causing chemicals). Local provenance and quality certification label; develop Shinshu specialities based on the local dominance of larch- e.g. in larch cladding; market survey to establish why users do not use local wood; expand markets in biomass- both via pellet and wood stoves, and biomass electricity generation; local R&D to develop new wood products and markets.

Source: NAGANO PREFECTURE (2011).

[4] The Iizuna power station has a 1.2 MW generating capacity, and is operated by Miyazawa Timber company.

established.

Regarding markets, the SFAP encourages use of local timber supply for public projects; continuation of the subsidy for houses built with local timber; and campaigns emphasising the environmental and health benefits of wood (NAGANO PREFECTURE, 2009d). Quality and provenance will be assured through labelling, and efforts made to develop markets for Shinshu's local species (e.g. in larch cladding). Import substitution remains a key target and a market survey has been conducted to establish why users do not use local wood (this found that current barriers to replacing imports by local wood include user concerns over both price and quality). Markets in biomass (via pellet and wood stoves, and biomass electricity generation) will also be promoted and local R&D encouraged on new wood products and markets. Currently, the lack of large scale processing capacity in the prefecture (Fig. 4) limits the economic benefit to Nagano of the growth in supply anticipated in the SFAP. The trend over the last 30 years has been for the number of sawmills and the amount of wood processed to decline each year (Fig. 3), and the SFAP is unclear on how to reverse this trend. One possible model is that used in one municipality (Ina Town), which took over a failing sawmill, and is working with the local FOA to develop local markets for local timber (NAGANO PREFECTURE, 2011).

NAGANO: APPLYING LESSONS FROM SCOTLAND

From the above overview, it is apparent that Nagano Prefecture's current challenge to capture value from an increasing growing stock is the same as Scotland's objective 10 years earlier (NORTON, 2008; NORTON and UEKI, 2009); there is thus the opportunity to consider what aspects of Scotland's experience over the intervening 10 years may be relevant to Nagano. We first consider the relative starting positions of Nagano (2010) and Scotland (1999), before moving to the potential role of organisational models exemplified by the SFIC.

Firstly, although its forested area is only some 20% less than that in Scotland, Nagano starts from a position of low production volumes and yields per area of forest (Table 2 and 3), with the majority of supply provided by thinning[5] rather than clear-cut (Table 2). This means that current forest management is not yet addressing the skewed age distribution (Fig. 1). Scotland's yields in 1999 were not only an order of magnitude higher but the flatter age distribution will allow yields to be maintained more readily.

Secondly, in contrast to Scotland[6], Nagano's highly fragmented forest ownership complicates private forest management through having to deal with large numbers of smallholdings via intermediary organisations such as FOAs. This inevitably increases administrative costs but the fragmented ownership also adds to the costs of extraction due to the smaller areas involved. Moreover, the dominance of thinning may also contribute to higher unit costs[7]. In contrast, harvesting in the larger Scottish forests is on the basis of 25-50 ha coupes which are clear-cut allowing optimum use of high efficiency equipment and minimum labour costs. The Nagano policy to define larger coupes and increase the proportion of clear-cut (Tables 5, 6) is thus a critical part of the move towards higher productivity.

Thirdly, the proportion of direct sales in Nagano is low and the distribution chain thus often involves shipment from the roadside to an intermediate area, storage and sorting, and then transhipment to the end user, who may be distant due to the limited processing capacity in Nagano. The decline in the number of local sawmills (Fig. 3) limits the ability to process an increase in supply, so that much of any supply increase in the short term may have to be transported to larger processors outside the prefecture (e.g. to Ishikawa for board). Scotland faced the same danger in 1999 but, helped by the action of the SFIC, local Scottish sawmills expanded their facilities (including new production lines) through private investment based on the attractiveness of a reliable long-term supply. For instance, the largest district in Scotland (Galloway) produces an annual supply of 630,000 m^3, which led to the Kenmuir sawmill (capacity of over 300,000 m^3 per year) being built nearby. As a result, direct sales dominate with short distances between the roadside and many users. One potential role for the new Shinshu Forest Forum would be to encourage a similar process whereby the local scale of processing would expand in line with the increase in supply envisaged in the SFAP.

Fourthly, Scotland has various organisations which straddle the supply chain; for instance, a forest owner can contract with a single company for all stages from planting, through maintenance, to harvesting and marketing the timber. Even for single stage activities (primarily felling), contractors are the main method of operation which allows optimal utilisation of specialised equipment and manpower. In Nagano, contractors are used by the Forestry Agency in the national forest, but in private forests many of the same functions (cutting, hauling, sorting, stocking etc.) are dispersed and duplicated among FOAs. The North Shinshu Timber Centre[8] provides 'supply chain straddling' services but as yet deals with only small volumes.

Fifthly, turning to markets, Scotland's local demand in 1999 was insufficient to consume an expanded supply of products, and a critical part of the strategy for Scottish

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[5] The focus on thinning arises from the large areas of artificial forest which have not been adequately maintained since the decline in timber prices during the 1990s rendered forest maintenance uneconomic for many owners (NAGANO PREFECTURE, 2009a).

[6] Half of Scotland's yield comes from National Forest under one single management organisation (Forestry Commission Scotland), while the remainder from private sources is dominated by large holdings (NORTON and UEKI, 2009).

[7] For instance in one US study (MILLER and SARLES, 1986), the total logging cost increased from \$35 per m^3 for clear cut to \$44 per m^3 when 25% of the stand was thinned.

[8] The North Shinshu Timber Centre was established in 1995 by 9 companies who collaborate to provide forest management services to FOAs and individual forest owners across the supply chain from planting, through maintenance, cutting (thinning and clear-felling), transport and processing, and contract sales. The Centre's main objectives are to increase production, reduce costs, and ensure a stable supply. By centralising such services it offers a way of overcoming the weaknesses of individual smaller FOA units where lack of mechanisation, labour shortages (or age structures) create a barrier to improved efficiency or reliable supply.

processors was to increase sales in the adjoining English market by displacing imports; this made price and quality assurance critical factors. Processors thus introduced certification schemes to demonstrate that the quality of Scottish timber matched that of imports, in parallel with the measures under the SFIC to reduce unit costs. Nagano faces similar challenges due to its limited internal demand, and also sees import substitution as an important target, where user surveys show concerns over quality as well as price. The SFAP already includes a certification mark for Shinshu timber, and this could provide a mechanism through which concerns over quality by potential customers are resolved.

A critically important market for Scotland has been that of biomass. Renewable energy policies[9] have provided incentives for generators to use biomass and the amounts consumed for power generation exceed 400,000 m^3/year (Norton and Ueki, 2009). In addition, 'renewable heat' demand is growing and led to an investment in a 100,000 tons/year pellet manufacturing plant in Inverness in 2009. This growth in biomass demand has created a buffer against fluctuations in other markets, such as the decline in construction demand following the 2008 financial crisis. Biomass markets are also recognised in the SFAP with its target to more than triple the amount for chip and biomass (to 217,000 m^3) over the next 10 years. Other similarities include the focus in both Scottish forestry policy and the SFAP on new applications and market development through R&D, and promoting the benefits of wood (especially in housing). Nagano is able to specify local wood in public buildings, and to offer subsidies for prefectural wood, whereas such measures are ruled out by European competition policy in Scotland.

THE ROLE OF CLUSTER NETWORKS AND THE VALUE CHAIN

Cluster Networks and Their Benefits

The above sections provide a comparison of Scotland and Nagano forestry, activities and priorities. We now turn to the role of cluster theory in seeking to place the differences identified in a theoretical context. Returning to Porter's cluster theory (Porter, 1990) which provides the theoretical foundation for the SFIC, a primary function is to gain the potential benefits from networks between individuals and organisations which are created and supported through the actions of the cluster. Such benefits featured prominently in the results of the SFIC survey (Norton and Ueki, 2009) which ranked them (in declining order of importance): a) information (e.g. market trends, technology, standards), b) exchange of experience with similar companies, c) facilitation of supply chain links, d) insights into improving productivity, e) source of potential partners, and f) public funding opportunities. The benefits reported by SFIC members are consistent with the generic benefits of networks identified by Hotz-hart (2000)[10].

In their study of networks and their potential role in clusters, Tracey and Clark (2003) drew three main conclusions:

(1) Flexibility in terms of network formation is crucial for problem solving, innovation, and competitiveness;

(2) Networks contain powerful forces which inhibit flexibility, encourage conformity and increase the likelihood of market failure; and

(3) Firms and the networks of which they are part have the capacity to overcome these barriers and 'learn how to learn' on a collective basis.

Network management is thus critical. Tracey and Clark (2003) argued that establishment and initial running costs are common goods and thus suitable for sponsorship by the public sector. Network managers should be sufficiently qualified and work efficiently to minimise expenses and maximise benefits for participants. Managers need to demonstrate value to stimulate stakeholders' commitment to participate, and in the case of the SFIC, the initial role of public support for formation and active stimulation of cluster activities by creative individuals in the early years was an important factor in the successful launch of the SFIC (Ecotec, 2005).

Network Diversity

Network theory also emphasises the importance of 'Weak' and 'Strong' ties (Grabher, 1993; Sabel, 1995). Strong ties (relationships) are those of customer-client relations, contractual relations and those between a company and its sub-contractors. They tend to transmit detailed information relevant to existing activities but do not necessarily generate new ideas and ways of working. Weak ties are those outside the direct area of current business, include links to firms and networks with different interests and viewpoints, and thus may be more effective at introducing new ideas and perspectives. Innovative firms rely on a dynamic combination of strong and weak ties, and an important characteristic of networks is thus their openness to all stakeholders (whether connected by strong or weak ties) and the flexibility to adapt and respond to the needs of members. The breadth of membership and coverage of the SFIC contributed to both kinds of relationships by including the entire forestry production chain in the cluster network (Table 1 of Norton and Ueki, 2009).

[9] Under Government policies for encouraging and supporting renewable energy, electricity suppliers are required to source an increasing proportion of electricity from renewable sources, which includes biomass. Currently the required proportion is 11.1% (Scottish Government, 2010).

[10] These comprised:

1. Better access to information, knowledge, skills and experience.
2. Improved linkages and cooperation between network members, particularly between users and suppliers.
3. Networks allow participating firms to respond more quickly and to anticipate changing competitive circumstances, and to learn about new forms of technology.
4. Networks of firms with complementary assets allow resources to be shared and reduce costs.
5. Alliances encourage shared values, goals, norms, and ways of working which facilitate problem-solving, collective action and innovative behaviour, often through a complex combination of competition and cooperation.

Value Chains

Effective networks can also create a sense of ownership and shared aims where a process of 'value co-creation'[11] may be forged across the supply (value) chain (VARGO *et al.*, 2008). Value chains are often expressed in terms of a sequence of transactions (often linear) from raw material to final product and then sale to the consumer. For instance, a substantial proportion of Nagano's forestry business is conducted separately at each stage of the value chain in Fig. 5. Instead, 'value co-creation' describes a systems process in which stakeholders in the value chain work with the end-users (customers) to co-create value. This reflects the reality that consumer value is not just possession of the product concerned, but the way in which it is used to meet their needs; the consumer thus contributes his/her own knowledge and skills (via product use) to co-create value.

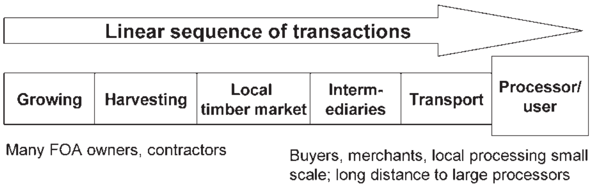

Fig. 5 Value Chains in Nagano Prefecture

This way of thinking switches the focus from the individual interactions at each stage of the supply chain (which are governed by exchange value; e.g. the price of the wood at auction, the price when the wood is sold on to the user) to the overall system in which producers and consumers work together to co-create value. Effective cluster organisations may facilitate this process through the networks they create and the systems approach they encourage. They rise above the narrow binary value propositions of the multistage linear supply chain, and facilitate integration of resources and interactions between stakeholders at different stages of the supply chain that are mutually beneficial. For instance, wood producers and intermediate processors combined with end-users in the SFIC to co-create value by developing quality control systems to overcome fears over the quality of Scottish timber. The experience of the house buyer was enhanced by stressing the health and environmental benefits of local wood. Power generators were able to improve their environmental reputation and strengthen their social contribution by stressing the sustainable and local source of wood biomass. Value co-creation also provided a focus for simplifying the supply chain- e.g. by expanding the role of straddling organisations and increasing long-term direct sales.

In contrast with Nagano, the Scottish value chain is dominated by direct sales between roadside and larger users; in addition smaller private owners can contract companies which straddle the supply chain. The value chain is thus short and specialised, making full economic use of human and machinery resources. The SFIC- mediated value chain can thus be represented by Fig. 6 where the shorter chain (due to the dominance of contract services referred to above) also facilitates stronger links between the various stages of the value chain, and makes the process of value co-creation simpler.

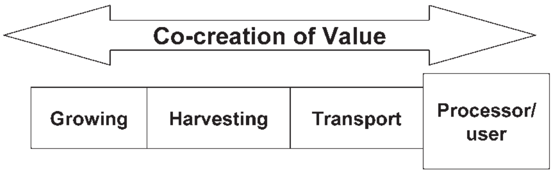

Fig. 6 Value Chains in Scotland

Large owners, contractors, straddling organisations to integrate the supply chain; large processors near to supplies

DISCUSSION

Comparisons above show many similarities between the aims and policy measures selected by both Scotland and Nagano to increase the scale and competitiveness of their respective forestry industries. However a key lesson from the 10 years 'lead' of the SFIC is its role in providing a broad framework in which stakeholders can co-create value through the personal and organisational networks which have developed through the creation and operation of the SFIC. The question can thus be posed of what organisation in Nagano could offer analogous functions. Stakeholders include the various forest owners (Prefecture Forestry bureau, Chubu Division of the Forest Agency, FOAs and wood producing companies), participants in the supply chain, end-users, as well as links to sources of new ideas (R&D, standards and procurement organisations). Forestry Revitalisation Committees (JAPAN FORESTRY AGENCY, 1991) have similar objectives to the SFIC in that they envisage measures to improve supply chain efficiency, measures to better match supply and demand and promotion of markets, but their geographical scope is not the prefecture. Consequently, the SFAP provides for a Shinshu Forest Forum and specific networks or links between parts of the supply chain. Our analysis suggests that whichever local model is used to provide the network functions for prefectural forestry revitalisation, it is important that it supports both strong and weak ties, provides appropriate support for network administration, and employs creative managers to encourage value co-creation thinking.

Local cluster networks would have three urgent priorities. The first would be to provide a predictable, reliable and long-term sustainable expansion in supply, and to define the long-term cutting and planting strategy required. This requires effective collaboration among the prefecture, national and private forestry owners and managers. In Scotland this function is carried out by the Forestry Commission for Scotland which combines the role of Japan's Forest Agency in its responsibility for managing national forests, and also some of the roles discharged by prefectures in Japan in setting

[11] Value co-creation is a holistic way of looking at the value chain and is often applied in marketing, but here we use it as a tool for conceptualizing overall systems such as clusters.

conditions for cutting and replanting in private forests and in administering grants for forest improvement, replanting, etc. Forging such a strategy in Japan is complicated by the large number of small-scale owners, and the fact that the Forest Agency Divisions span several prefectures[12]. Nevertheless, the lesson from the SFIC is that a predictable and reliable long-term supply is a necessary precondition for private investment into processing and market expansion.

The second is Nagano's challenge (following the SFIC model) of capturing more added value within the prefecture. Current provisions in the SFAP envisage improving the competitiveness of Nagano timber to users outside the prefecture by reducing transportation costs over longer distances. However the Scottish experience would indicate a higher priority for expanding internal processing capacity to capture more of the added value within the prefecture. One such model can be found adjacent to Nagano where one company[13] has built a business model around intermediate processing hubs near to the source of the timber — analogous to the SFIC model. This not only reduces the costs of transport (only products need to be transported the longer distances to the end user) but also has the advantage of maintaining local employment. New markets have been obtained through cooperating with user companies to switch from imports to domestic wood through appropriate guarantees of supply, price and quality- analogous to the SFIC-mediated strategy of the major Scottish sawmills. The SFAP could embrace this model of encouraging the development of processing hubs close to major supply sources, supported with efforts to replace imports (against the background of a decreasing total market in Japan, replacing imports remains an area of potential growth).

A third priority would be to seek opportunities for value co-creation with other forestry objectives- especially those of carbon absorption and environmental sustainability. Current national targets for CO_2 emission reduction envisage a role for forests to contribute 3.8% towards Japan's Kyoto target (Ministry of The Environment, 2010). This has a potential monetary value since locking carbon away in forests reduces the need for potentially more expensive abatement measures to meet the target. Value co-creation would seek to connect these two aspects; possibilities could be through an 'eco-points' system designed to reward the use of local timber, or a direct financial payback (in either case the system would seek to differentiate between domestic timber which contributed to meeting national environmental targets and imported timber which did not). A further opportunity for value co-creation could be through measures to substitute fossil fuels with biomass; for example through new biomass-based combined heat and power facilities, or through co-firing in existing thermal power stations. Net national emissions of CO_2 could be reduced, the electricity generator would be able to point to the local economic and social contribution made, and environmental impact outside Japan would also be reduced if imported wood chips from unsustainable logging overseas were replaced by local sources. Such approaches can be exemplified by the experience of one FOA (Ota, 2007) which succeeded in co-creating value through obtaining FSC certification for its forests and supplying FSC certified timber to a builder of eco-houses.

In conclusion therefore, this analysis suggests some potential factors from the 10 years' experience of the SFIC which could support current strategies to expand the contribution of forests to the prefectural economy. There are however, two aspects which may warrant further consideration in applying these to the Nagano situation.

The first relates to the role of individuals. Our research has been based on the hypothesis that the successes of the SFIC have an organisational origin; that is to say that they flow from the creation and activities of the cluster model based on Porter's economic theories. While the evidence in Norton and Ueki (2009) and Ecotec (2005) supports this hypothesis, there is also the less quantifiable influence of individuals. In the SFIC survey, we were told that the initial cluster staff, through their enthusiasm and personal skills, helped motivate the industry to participate at an early stage. In addition, some of the major sawmill owners in Scotland are family businesses with close links to the areas in which they operate, and this may have also strengthened motivation to expand facilities locally. In seeking to apply organisational lessons from our work therefore, it is important not to overlook the potentially critical role of individuals in developing a future vision for prefectural forestry, and to fully explore the potential of existing local businesses to expand their use of an increasing supply of timber.

The second factor relates to the geographical scale of the cluster. In the SFIC, the cluster comprises the key participants in an industry producing and using over 6 million m^3 of timber per year. Although the geographical scale is the country (Scotland), the number of participants in the networks and cluster activities is typically only 100-150 (Norton and Ueki, 2009). The cluster operations are thus 'dense' in the sense that the actions of a few companies (or individuals) can significantly impact the course of the industry. In Nagano, timber production is only 5% of Scotland's, and many of the potential larger users reside outside the prefecture (Fig. 4). To bring together the key stakeholders therefore, the cluster scale would have to include adjoining prefectures, potentially increasing the number of participants and interests represented. Forging a sense of joint purpose in such circumstances could make the cluster management and direction potentially more challenging than in the SFIC.

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[12] The Chubu Division of the Forest Agency covers Nagano, Toyama, Gifu and Aichi Prefectures.

[13] The Tohsen group comprises a group of sawmills whose production can be optimized according to available sources and markets, offering flexibility to respond swiftly to different market applications.

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Article

Classification of a Leaf Image using a Self-organizing Map and Tree-based Model

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ABSTRACT

The purpose of this article is to attempt classification of leaf images using a self-organizing map (SOM) and tree-based model. The number of samples was 420 (84 species), which were collected at the Kyoto Prefectural University campus. Data input into the models were used as 10 dimensions: circularity, ratio of minor axis to major axis, four capacity dimensions and four information dimensions. Both the capacity and information dimensions were calculated from the distance feature, which was calculated as the distance from the center of gravity in the figure to the circumference and was shown as the function of an angle, using the fractal dimensions of states with ε-entropy. As a classification method, SOM illustrated the 10 dimensions data on a two-dimensional plane as a nonlinear map. Moreover, the classification accuracy of decision trees derived from tree-based models was examined. Additionally, the samples were divided into five groups based on differences in leaf shape, as follows: simple leaves with leaf teeth, simple leaves without leaf teeth, lobed leaves, needle leaves and compound leaves. It was found that: (1) The fractal dimension showed different values, and this dimension was found to be effective as a factor for estimating and classifying; (2) when the number of leaning times and map sizes of SOM increases, all tree species were clearly classified on SOM map; and (3) as for classification by tree-based models, the correct ratios of each model varied widely, ranging from 42.1% (REPTree) to 100.0% (RandomTree) without cross-validation, and ensemble learning can improve the estimation accuracy of the models.

Keywords: Fractal dimensions of states, leaf image, self-organizing map (SOM), tree-based model

INTRODUCTION

Recently, progress in computer resources and network techniques has made it possible to access a variety of information, and useful information can be easily found using the Internet. At first, the use of the Internet was restricted to indoor spaces because wired Local Area Networks (LANs) were the primary means of access. However, at present, we are able to acquire vast amounts of information both inside and outside of buildings by utilizing wireless LANs through mobile terminal units or cellular phones. As a result, various studies or services involving these mobile units have begun in many fields. For example, in the field of forest science, Hasegawa *et al*. (2002) and Inoue *et al*. (2002) studied an approach to environmental education that involved the use of a Personal Digital Assistant (PDA). However, there are various restrictions on the use the PDA; for example, the saturation level of the PDA is lower than that of the cellular phone, thus students have to buy or rent the PDA in order to participate in this form of environmental education. Moreover, to connect Internet service, an exclusive card must be applied or a cellular phone must be used. Cellular phones are extremely easy to use for our purposes because their use is widespread throughout the world and most models of cellular phone can connect to the Internet at purchase. Therefore, using cellular phones to access the Internet is likely to be of great value in environmental education and research.

One of the authors studied the construction of the tree retrieval system with a cellular phone (Nakanishi, 2005). This system can search for 84 species that grow on the Kyoto Prefectural University campus by selecting either "Leaf characteristic" or "Tree name" on the web page accessed with a cellular phone. Searching on the leaf characteristic can narrow down the corresponding tree species by selecting a characteristic of the target tree from question-and-answer categories. However, since this system outputs up to nine kinds of tree species according to how the question-and-answer categories are combined, it is not possible to locate a single kind of tree using this type of search. As a solution to this problem, the searching performance can be improved by increasing the number of question categories. Since the question in that case becomes complex, it is anticipated that

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the system would not be easy for many users to navigate. Thus, it is important to improve both the accuracy and usability of the system. One potential method of solving that problem involves specifying a target tree using an image taken with a digital camera. In previous studies, automatic recognition of wild flowers (SAITOH and KANAEKO, 2001), an image retrieval system of flowers (NODA *et al.*, 2001; TABATA *et al.*, 2005), and other applications. However, there are few reports on a system that automatically searches for a tree by processing a leaf image. We aimed to construct a system that a user who is not skilled at tree identification can use to identify a tree automatically using only a leaf image from a cellular phone. To construct such a system, we need an image database to form the basis of the search engine. Thus, the object of this article is to construct discrimination models using various data-mining algorithms such as the decision tree, ensemble learning and cross-validation, and to map and classify multidimensional information onto a two-dimensional plane using a self-organizing map (SOM). For input data, this study used the image features by extracting from a leaf image data to be taken a picture of with the digital camera. Moreover, when the image features were input into the model, we used the information entropy, which was calculated by converting some of image features with the fractal dimensions of states.

MATERIALS AND METHODS

The materials used in the leaf images included 84 species collected on the Kyoto Prefectural University campus. Each leaf was placed on a white paper background and photographed using a digital camera (COOLPIX L12, Nikon Co. Ltd., Tokyo, 7.1 million pixels). For the image processing, we used Scion Image (KOJIMA and OKAMOTO, 2001; Scion Image web site, 2007) and Adobe Photoshop (Adobe Corp.).

Leaf Image Features

The leaf image features are shown as the vector including spatial characteristics such as light and shade, color, optical spectrum and texture, and geometrical characteristics such as the shape features of an area and the perimeter (TAKAGI and SHIMODA, 2004). Generally, many different features are used in botany classification: how the leaf is attached, the whole shape of the leaf, the presence or absence of leaf pubescence, the shape of the leaf margin and the appearance of the veins of the leaf. However, given the limitations of searching using a cellular phone, the presence or absence of leaf pubescence, the shape of the leaf margin, and the appearance of the veins of the leaf were excluded from this study. That is, it is necessary to increase the image resolution considerably to extract these factors, but the resolution of the camera attached to the cellular phone was not sufficient. This study focused on the how the leaf was attached, the whole shape of the leaf and the shape of the leaf margin.

Circularity, Ratio of Minor Axis to Major Axis

Circularity (*Cir*) is the feature that describes how close the outer shape of leaf is to a circle and is calculated using the following equation.

$$Cir = \frac{4\pi S}{L^2} \tag{1}$$

where "*S*" refers to the leaf area and "*L*" refers to the perimeter of the leaf. "*Cir*" falls within the $0 < Cir \leq 1$ range and its value approximates 1 when the figure is nearer to a circular shape. The ratio of the minor axis to the major axis (*Rmm*) can be calculated by applying the ellipse that seems to best fit the leaf image as an object.

$$Rmm = \frac{Minor\ axis}{Major\ axis} \tag{2}$$

As with "*Cir*," "*Rmm*" falls within the $0 < Rmm \leq 1$ range.

Distance Feature

The distance feature $r(\theta)$ can be calculated as the distance from the center of gravity in the figure to the circumference and is shown as the function of an angle. This index is used to govern shape recognition, and it is the waveform of the 2-π intervals that show the contour (TSUCHIYA and FUKADA, 1990). In this study, when considering the shape of the leaf blade and petiole, we used the boundary point between the leaf blade and petiole as the standard position instead of the center of gravity and defined the distance from that point to the circumference as the distance feature (Fig. 1).

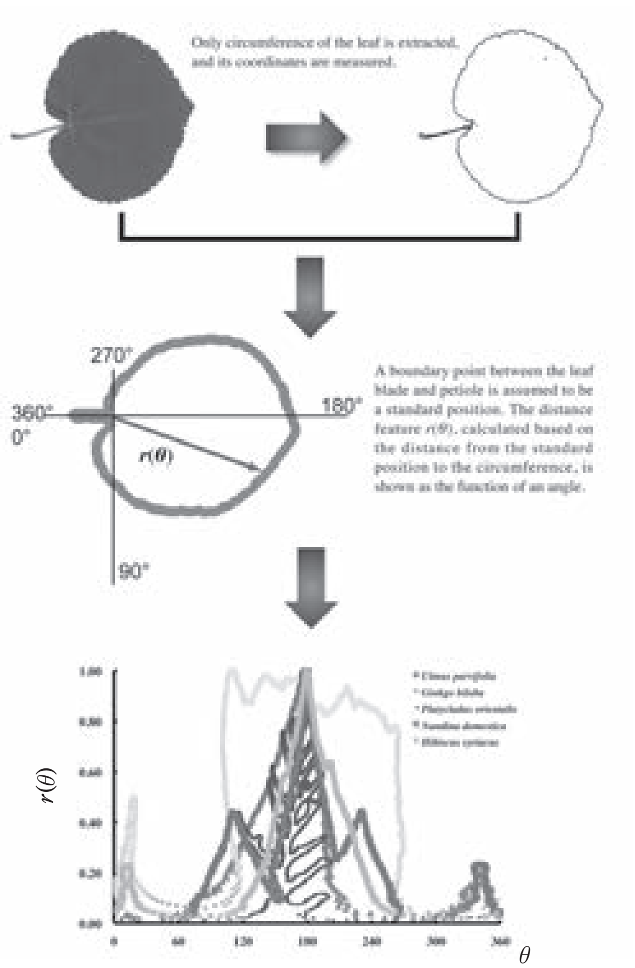

Fig. 1 Circumference extraction from leaf image and calculation of distance feature $r(\theta)$

ε-Entropy and Fractal Dimensions of States

Here we discuss the size of the observation point number because it differs greatly among different tree species. However, even within the same tree species, the observation point number of each sample is different; thus we consider it to be difficult to compare the difference in leaf shape using only the observation point number. Additionally, we think that statistics such as the average and variance of the observation point number cannot represent the difference in leaf shape as well as the size of the observation point number, and we consider that a substantial amount of information related to leaf shape is lost if we use these statistics. To develop a comparison method that retained as many of the characteristics of the leaf shape as possible, we tried to quantify the distance feature using the fractal dimensions of states (OHYA, 1989, 1991).

A conventional method for determining the fractal dimension could not be strictly computed unless the property of self-similarity was added to the figure. That is, when we exactly analyze a certain phenomenon with a fractal dimension, we need to prepare a self-similar set corresponding to that phenomenon. OHYA (1989, 1990, 1991) expanded the ε-entropy introduced by KOLMOGOROV (1963) into the states of the general quantum mechanics system (C*- mechanics system) and formulated the concept of the fractal dimension that MANDELBROT (1982) had proposed on a general state-space. This entropy was defined as the fractal dimension of states by OHYA. The effectiveness of this entropy was suggested by many studies such as a study of the complexity of craters and rivers (OHYA and MATSUOKA, 1996), an analysis of earthquakes (INOUE *et al.*, 1998), a study characterizing stock price fluctuations (KOZAWA *et al.*, 1999), and others. The algorithm of the fractal dimensions of states is simply described in the following (OHYA, 1990; MATSUOKA and OHYA, 1998).

First, we show both the need for the ε-entropy to quantify the fractal dimensions of states and the capacity dimension that is one of the fractal dimensions of a geometric figure. The capacity dimension $d_c(X)$ is shown in the following equation.

$$d_c(X) = \lim \frac{\log N_x(\varepsilon)}{\log(1/\varepsilon)} \tag{3}$$

where $N_x(\varepsilon)$ is the minimum number of convex bodies that are needed to cover the $X(\subset R^d)$ set by a convex set of diameter ε. In equation (3), $\log N_x(\varepsilon)$ in the numerator is referred to as the ε-entropy in metric space. That is, the capacity dimension is defined by the ε-entropy and can give the fractal dimension with information entropy (OHYA, 1990; MIYAZAKI, 1992).

Next, we describe the derivation of the fractal dimensions of states. One pair (X, P) is referred to as a complete event system, where X is a set composed of n events (*i.e.*, $X=\{x_1, x_2, \ldots, x_n\}$), and P is a probability distribution of X (*i.e.*, $P=\{p_1, p_2, \ldots, p_n\}$, $\Sigma_{i=1}^{n} p_i = 1$, $p_i \geq 0$). P is known as the state of the system. The ε-entropy of P is defined by the mutual entropy of the complete event system. Given two compete event systems (X, P) and (Y, Q), the compound event of X and Y is denoted by $X\times Y(=\{(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\})$ and the compound state of the two systems is the joint probability distribution Φ $(\{r(i, j); 1 \leq i \leq n, 1 \leq j \leq m\})$. The mutual entropy of the compound event of X and Y is shown by the following equation (OHYA, 1990; TOYODA, 1997; MATSUOKA and OHYA, 1998).

$$I(X, Y) = \sum_{i=1}^{n}\sum_{j=1}^{m} r(i, j)\log \frac{r(i, j)}{p_i \times q_j} \tag{4}$$

Let X be an input space and Y be an output space. This mutual entropy means that an amount of information about P is contained in Q (and information about Q is contained in P). Hereafter, it is assumed $n = m < +\infty$ for the sake of simplification. The joint probability distribution $r(i, j)$ is in the state of the $X\times Y$ system, which is satisfied by equation (5).

$$\sum_{i=1}^{n} r(i, j) = p_i, \quad \sum_{j=1}^{m} r(i, j) = q_j \tag{5}$$

Thus, the mutual entropy $I(X, Y)$ can be expressed as a function with P, Q and Φ.

$$I(X, Y) = I(P, Q, \Phi) \tag{6}$$

Then the ε-entropy $S(P ; \varepsilon)$ of P is defined by equation (7).

$$S(P ; \varepsilon) \equiv \inf\{J(P, Q); \| P - Q \| \leq \varepsilon\} \tag{7}$$

where $\| P - Q \| \equiv \Sigma_{i=1}^{n} | p_i - q_i |$ and $J(P, Q) \equiv \sup \{I(P, Q; \Phi); \Phi \in P(P, Q)\}$. The ε-entropy $S(P ; \varepsilon)$ is the least information transmitted from P to another state Q in the ε-neighborhood. Therefore, using this ε-entropy, the following dimensions of a state in the classical discrete systems are defined as in equations (8) and (9) (OHYA, 1990; MATSUOKA and OHYA, 1998).

The capacity dimension of order ε:

$$\alpha(P ; \varepsilon) \equiv \frac{S(P ; \varepsilon)}{\log(1/\varepsilon)} \tag{8}$$

The information dimension of order ε:

$$\beta(P ; \varepsilon) \equiv \frac{S(P ; \varepsilon)}{S(P)} \tag{9}$$

where $S(P)$ is a state of entropy $S(P) = -\Sigma_{i=1}^{n} p_i \log p_i$ and the log is a natural logarithm. When the degree of complexity is large, the fractal dimensions of states as well as conventional entropy show high values in both the capacity dimension and the information dimension. Independent of conventional entropy, the fractal dimensions of states can be used to distinguish the states that cannot be distinguished by conventional entropy, for example, the degree of complexity for two distributions which have equal entropy. In this respect, these fractal dimensions of states are new indexes that can show the states of complexity (OHYA and MATSUOKA, 1996).

Self-Organizing Map

The self-organizing map (SOM) is an unsupervised neural network algorithm proposed by KOHONEN (1996). It is a data analysis method that can create nonlinear mapping of high-dimensional data onto a two-dimensional plane. The effectiveness of SOM has been suggested by many studies including research on business strategy and management, economic analysis and its application to construction fields (TOKUTAKA *et al.*, 1999), face image authentication (TOKUTAKA *et al.*, 2002; YUNO *et al.*, 2007), and image databases (HYUGA and NISHIKAWA, 2002).

SOM is composed of a two-layered neural network,

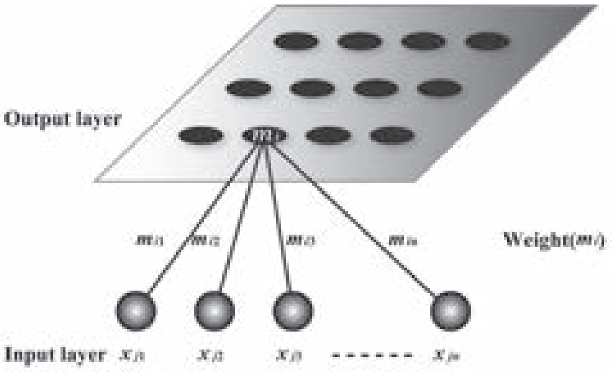

Fig. 2 Basic structure of Self-Organizing Map

which has an input layer and an output layer (Fig. 2). There are feature vectors x_j (= $x_{j1}, x_{j2}, \ldots, x_{jn}$) in the input layer and k (i = 1, 2, ... , k) units in the output layer. A certain unit in the output layer is linked with all feature vectors in the input layer. A feature vector in the input layer is weighted with a random number and is denoted by m_i (= $m_{i1}, m_{i2}, \ldots, m_{in}$) (JIN, 2006a). We describe the algorithm of SOM in the following (KOHONEN, 1996; TOKUTAKA *et al.*, 1999; JIN, 2006a).

Step 1) SOM determines the winner units, which are very similar to the input vector for the SOM, and the following equation is applied throughout the entire output (competitive) layer.

$$\|x_j - m_c\| = \min\{\|x_j - m_i\|\} \tag{10}$$

Step 2) The winner units and their neighborhood units are renewed by the following equations.

$$m_i(t+1) = \begin{cases} m_i(t) + h_{ci}(t)[x_j(t) - m_i(t)] & i \in N_c \\ m_i(t) & i \notin N_c \end{cases} \tag{11}$$

$$h_{ci}(t) = \alpha(t)\exp\left(-\frac{\|r_c - r_i\|^2}{2\sigma^2(t)}\right) \tag{12}$$

where $h_{ci}(t)$ is a neighborhood function and adjusts the influence of x based on the distance between unit c and unit j, the latter of which is neighbor of unit c. $\alpha(t)$ is a learning-rate factor, and r_c and r_j are coordinate vectors in two dimensions of units c and i. $\sigma^2(t)$ is a function which adjusted the radius of the N_c area near unit c. Both $\alpha(t)$ and $\sigma^2(t)$ are monotonically decreasing functions in which a learning iteration (or time) is assumed to be a variable.

Step 3) Repeating Step 1) and Step 2) for all input feature vectors

SOM maps multi-dimensional information on the two-dimensional plane using the above algorithm. SOM arranges similar units as the same unit or as at a location very close to both when the distance between two units is very small. The result of SOM is output as a grid (square) or honeycombed (hexagon) on the computer screen. The grid tone illustrates the distance between adjoining units; the longer the distance is, the blacker the color is.

Pattern Recognition by Tree-based Model

The "Decision Tree/Model Tree," which is basically a tree-based model, is typically called a "regression tree" in the case of regression problems and a "classification tree" or "decision tree" in the case of classification problems (JIN, 2005a). A decision tree is used to express knowledge for the purpose of classification; this algorithm is able to clarify the decision-making sequence with a "tree-like" graph (MORIMURA *et al.*, 1999). In order to construct a tree-based model, a WEKA was used in the present study. A WEKA is a machine learning tool for data mining that is programmed in the Java machine language (WEKA web site, 1999; WITTEN and FRANK, 2005; JIN, 2005b). WITTEN, FRANK and other researchers in the field of machine learning developed the WEKA. In this study, we used five algorithms for constructing the decision tree, and these were mounted in a WEKA.

J48 is the WEKA version of the C4.5 algorithm. The C4.5 is a descendant of an earlier program called Iterative Dichotomizer Version 3 (ID3) (QUINLAN, 1993). The information entropy, called the gain ratio, was used as the criterion for evaluating the branching in C4.5. NBTree, developed by KOHAVI (1996), is a classifier for inducing a decision tree based on Näive Bayes rules. Näive Bayes is a simple system based on Bayes' probability model, called "Näive" because of the assumption that each attribute is independent and that latent attributes do not exert an influence. RandomForest is the method for repeating the bootstrap and is for combining the decision trees in each sub dataset. RandomTree is an algorithm that randomly utilizes explanatory variables for the branching. In order to use duplicate variables for the branching, RandomTree induces more growing "trees" than C4.5 (JIN, 2005c). REPTree is an algorithm for constructing a decision tree with Gini's coefficient (DUDA *et al.*, 2001) or the variance calculated from training data, and has the benefit of performing calculations at higher speeds than other algorithms (JIN, 2005c).

Ensemble Learning and Cross-Validation

The ensemble learning algorithm and cross-validation method are methods for improving learning accuracy and generalizability by combining or integrating multiple learning results whose accuracies are not very high (JIN, 2005c). Generalizability refers to the validity of applying learning results calculated from learning-sample data to unknown data (ASO *et al.*, 2003). In general, the recognition performance for unknown data is worse than that for learning-sample data. However, it is said that the generalizability is high when the discriminated accuracy for unknown data is not much lower than that for the learning-sample data (ASO *et al.*, 2003). Bagging and boosting denote a representative method for use with the ensemble learning algorithm (ASO *et al.*, 2003; JIN, 2006b). The m-fold cross-validation method is a technique for constructing a higher-generalizability model from a small sample dataset (JIN, 2004). In cross-validation, a sample dataset N is divided randomly into m parts (sub dataset N_i=N_1,

Table 1 Calculation conditions of SOM

Learning pattern	Map size (X × Y)	Condition of first step			Condition of last step			Neighborhood function
		Learning times	Learning rate	Radius	Learning times	Learning rate	Radius	
Pattern 1	48x36	1,000	0.05	10	10,000	0.02	3	Bubble
Pattern 2	48x36	1,000	0.05	10	10,000	0.02	3	Gaussian
Pattern 3	48x36	1,000	0.05	10	50,000	0.02	3	Bubble
Pattern 4	48x36	1,000	0.05	10	50,000	0.02	3	Gaussian
Pattern 5	48x36	1,000	0.05	10	100,000	0.02	3	Bubble
Pattern 6	48x36	1,000	0.05	10	100,000	0.02	3	Gaussian
Pattern 7	60x48	1,000	0.05	10	10,000	0.02	3	Bubble
Pattern 8	60x48	1,000	0.05	10	10,000	0.02	3	Gaussian
Pattern 9	60x48	1,000	0.05	10	50,000	0.02	3	Bubble
Pattern 10	60x48	1,000	0.05	10	50,000	0.02	3	Gaussian
Pattern 11	60x48	1,000	0.05	10	100,000	0.02	3	Bubble
Pattern 12	60x48	1,000	0.05	10	100,000	0.02	3	Gaussian
Pattern 13	84x72	10,000	0.05	10	100,000	0.02	3	Bubble
Pattern 14	84x72	10,000	0.05	10	100,000	0.02	3	Gaussian
Pattern 15	84x72	10,000	0.05	10	500,000	0.02	3	Bubble
Pattern 16	84x72	10,000	0.05	10	500,000	0.02	3	Gaussian
Pattern 17	84x72	10,000	0.05	10	1,000,000	0.02	3	Bubble
Pattern 18	84x72	10,000	0.05	10	1,000,000	0.02	3	Gaussian

Note: X and Y are the numbers of units, and $X \times Y$ shows the map size of the SOM. "Bubble" is a step function and "Gaussian" is a Gauss-type function. Radius shows the neighborhood area.

..., N_m, i = 1, 2, ... , m) for learning and verification. Then, the cross-validation method would obtain a number of samples equal to (m - 1) × N for the purpose of learning a dataset on appearance, where m is the number of sub-datasets and N is the all-learning dataset (Ootaki *et al*., 1998).

Calculation Conditions of SOM and Tree-based Models

A total of 420 (= 84 × 5) samples, which consist of images of five samples of each of 84 species of leaves, were used in this study. Four factors consisting of 10 dimensions, namely circularity, the ratio of the minor axis to the major axis, four capacity dimensions and four information dimensions, were calculated as the average of five samples from each tree species. SOM_PAK (Version 3.1), which was developed by Kohonen (1996), was used as a SOM calculation, and we made maps of 18 learning patterns (Table 1). Five decision trees, including J48, NBTree, RandomForest, RandomTree and REPTree, were used for constructing the discrimination model. Additionally, we performed classification by combining the ensemble learning and cross-validation methods. By combining either bagging (WEKA module name, Bagging) (Breiman, 1996) or boosting (WEKA module name, AdaBoostM1) (Freund and Schapier, 1997) with five classification types, the calculation was carried out. For cross-validation times, “none” and “10 times” were used. In a cross-validation in WEKA, for example, when validation was performed two times, the training data were simply divided into two sub-datasets based on the order in which they were loaded to WEKA. If the order of the training data differed, then the WEKA output would differ. Thus, we prepared 10 datasets that were randomly ordered for calculation, and 10 calculations were carried out for each model. The minimum-average-maximum values for 10 iterations are shown as the calculation results. In the scale of discriminated accuracy, this study was used to derive the correct ratio (CR) using the following equation (13):

$$CR(\%) = \frac{\{1-(\text{number of error which couldn't be correctly classified})\}}{\text{number of all learning data}} \times 100 \quad (13).$$

RESULTS AND DISCUSSION

Circularity, Ratio of Minor Axis to Major Axis

Figs. 3 and 4 illustrate the circularity and the ratio of the minor axis to the major axis according to leaf shape, respectively. In this study, we classified sample data into five types based on differences in leaf shape. The five types included: simple leaves with leaf teeth, simple leaves without leaf teeth, lobed leaves, needle leaves and compound leaves. Values in parentheses show the minimum-average-maximum values for five samples in each category.

The average values of the circularity (*Cir*) for the sets of five samples ranged from 0.02 (*Acer palmatum* var. *amoenum, Pinus taeda*) to 0.77 (*Cercidiphyllum japonicum*), and the average value of all samples (n = 420) was 0.39. In a comparison among the different leaf shapes, the *Cir* of simple leaves resulted in approximately the same value with/without leaf teeth and tended to be higher than those of other leaf shapes. The differences in *Cir* among compound leaves

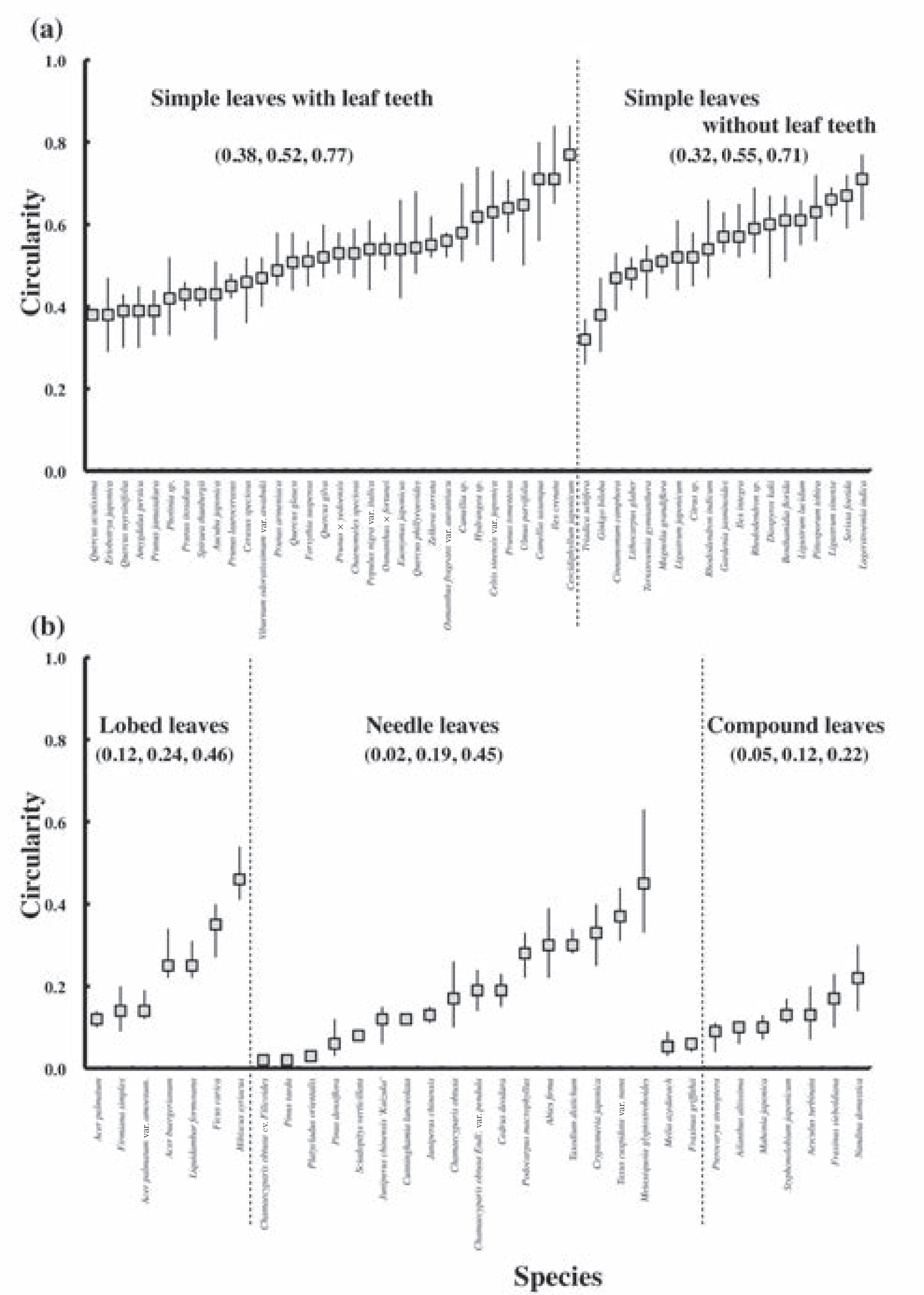

Fig. 3 Circularity of leaf image according to leaf shapes. (a) simple leaves with/without leaf teeth, (b) lobed leaves, needle leaves and compound leaves. The squares and error bars indicate the mean value and maximum-minimum values. Values in parentheses show the minimum-average-maximum values for five samples in each category.

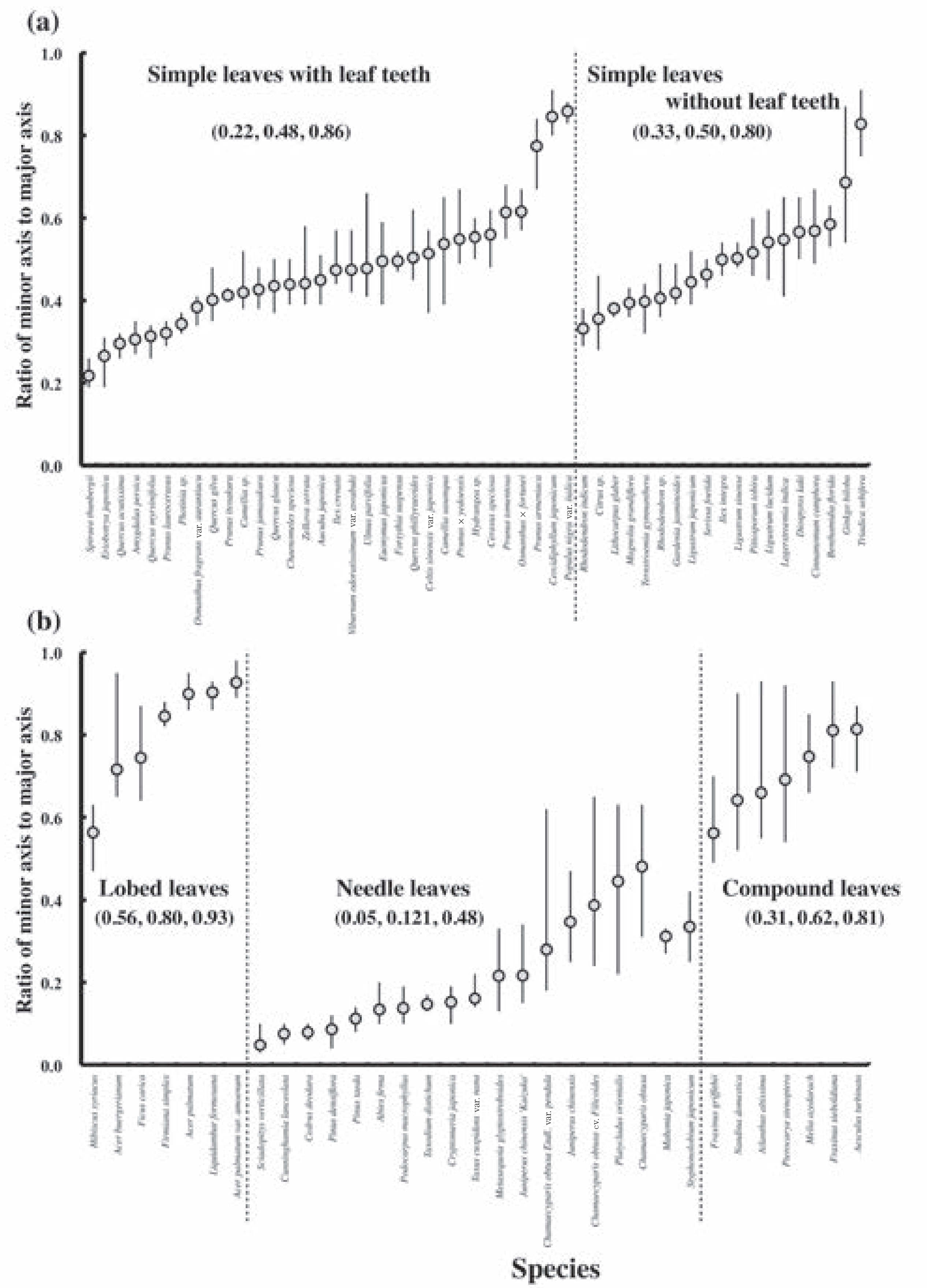

Fig. 4 Ratio of minor axis to major axis of leaf image according to leaf shapes. (a) simple leaves with/without leaf teeth, (b) lobed leaves, needle leaves and compound leaves. The circles and error bars indicate the mean value and maximum-minimum values. Values in parentheses show ths minimum-average-maximum values for five samples in each category.

between tree species were small. As for needle leaves, *Cir* was low for elongated leaves (*i.e.*, *Pinus densiflora*). *Metasequoia glyptostroboides* or *Taxus cuspidata* var. *nana*, which have a comparatively flat leaf shape and a short leaf blade, tended to show higher *Cir* values than other needle species.

The five-sample average values of the ratio of the minor axis to the major axis (*Rmm*) ranged from 0.05 (*Sciadopitys verticillata*) to 0.93 (*Acer palmatum* var. *amoenum*), and the average value of all samples (n = 420) was 0.47. The *Rmm* values of simple-leaf samples were approximately the same with/without leaf teeth, as for *Cir*. The *Rmm* values of compound-leaf samples, except for *Mahonia japonica* and *Styphonolobium japonicum*, were higher than those of other leaf shapes, with an average of 0.62 and a maximum of 0.81. In contrast, the *Rmm* values of needle-leaf samples were lower overall (with an average of 0.21) than those of other leaf shapes.

Fig. 5 illustrates the relationship between *Cir* and *Rmm*. Each value shown is the average value for five samples. Simple-leaf samples with leaf teeth and lobed-leaf samples showed a relatively high correlation. The correlations among other leaf shapes were low, and the statistical significance of correlation coefficient of those samples was denied from the results of the correlation coefficient *t*-test (the uncorrelated test). Therefore, we input both *Cir* and *Rmm* as data in the SOM and the tree-based model.

Distance Feature

The number of observation points for the distance feature differed by tree species. The species with the fewest observation points was *Aucuba japonica* (the lowest sample had 221; the average of five samples was 261) and the species with the most was *Melia azedarach* (the highest sample had 5,506; the average of five samples was 4,206). As stated above, we used the information entropy, which was calculated by converting the distance feature using the fractal dimensions of states. Four capacity and information dimensions were calculated based on the distance features with different order-ε values (Fig. 6). According to the different order-ε values, Fig. 6 shows the average value for each leaf shape and the minimum-maximum values for all tree samples. The inclinations of the two graphs for the capacity and information dimensions are different. The capacity dimension tended to increase gradually with increasing order-ε, while the information dimension was approximately flat and was slightly decreased when order-ε was 0.001. The capacity dimensions of simple leaves with/without leaf teeth and needle leaves showed nearly the same average values, and the information dimensions of the two simple leaf types showed similar average values. Overall, the fractal dimensions of states resulted in different values for each leaf shape, and those of all tree kinds were widely distributed within the range of minimum-maximum values. Thus, we determined the efficiency factor for classification and estimation by SOM and used it as an input data for both the SOM and the tree-based model.

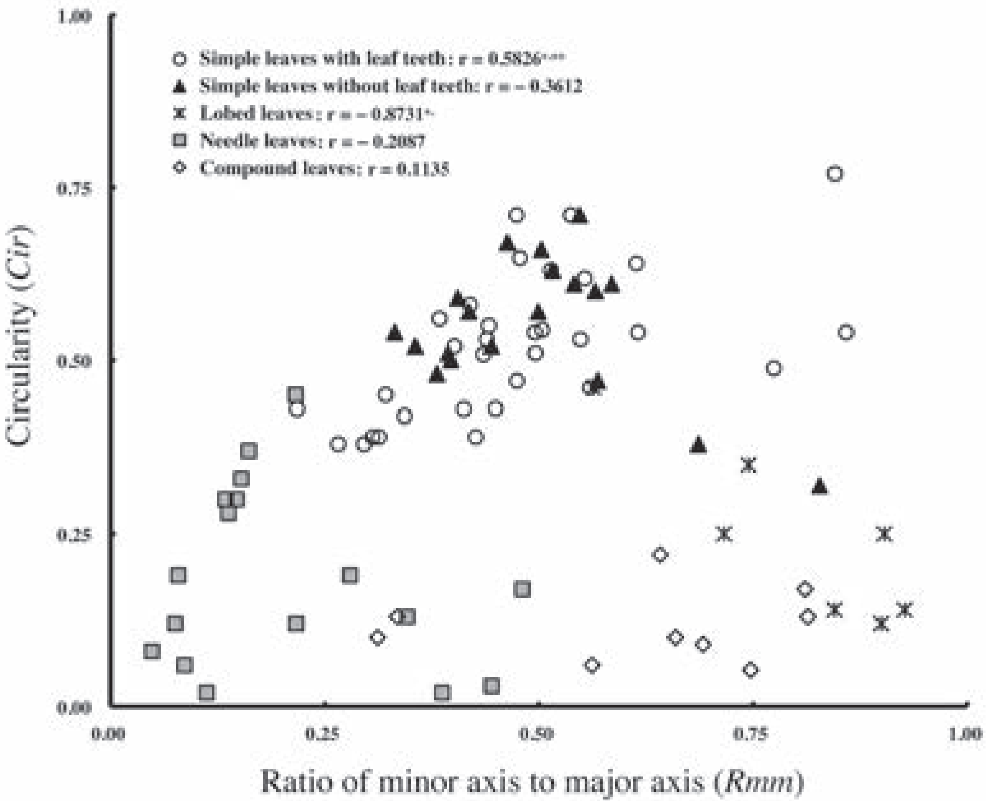

Fig. 5 Relationship between circularity (*Cir*) and ratio of minor axis to major axis (*Rmm*). *: p<0.05; **: p<0.01.

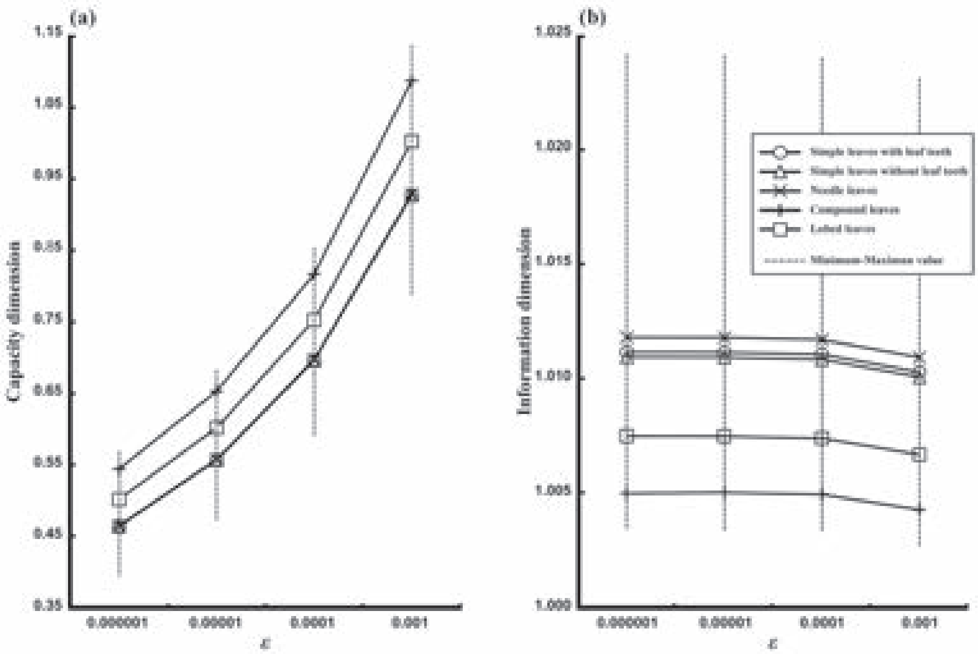

Fig. 6 The fractal dimensions of states with order-ε are calculated from the distance feature $r(\theta)$. (a) shows the capacity dimension and (b) shows the information dimension.

Table 2 Classification results of leaf image according to tree-based models

WEKA Module name	Validation times	Ensemble leraning		Correct ratio		
		type	times	Minimum	Averege	Maximum
J48	None	None	-	75.2	75.2	75.2
			10	98.0	99.0	99.8
		AdaBoost	100	100.0	100.0	100.0
			10	91.9	92.7	94.3
		Bagging	100	96.7	97.3	97.9
	10	None	-	24.5	26.8	29.5
			10	26.9	30.3	32.1
		AdaBoost	100	29.0	30.1	31.0
			10	28.3	30.7	32.6
		Bagging	100	29.8	32.4	34.5
NBTree	None	None	-	55.0	59.8	67.9
			10	55.0	59.8	67.9
		AdaBoost	100	55.0	59.8	67.9
			10	87.6	90.2	92.4
		Bagging	100	*	*	*
	10	None	-	20.0	22.2	24.5
			10	20.0	22.2	24.5
		AdaBoost	100	20.0	22.3	25.5
			10	25.0	28.1	31.0
		Bagging	100	*	*	*
RandomForest	None	None	-	99.0	99.6	100.0
			10	100.0	100.0	100.0
		AdaBoost	100	100.0	100.0	100.0
			10	99.0	99.6	100.0
		Bagging	100	99.8	100.0	100.0
	10	None	-	26.9	29.3	31.9
			10	29.0	31.3	33.1
		AdaBoost	100	30.5	32.2	34.3
			10	30.5	32.5	33.8
		Bagging	100	30.7	33.5	35.5
RandomTree	None	None	-	100.0	100.0	100.0
			10	100.0	100.0	100.0
		AdaBoost	100	100.0	100.0	100.0
			10	99.0	99.6	100.0
		Bagging	100	100.0	100.0	100.0
	10	None	-	22.1	25.1	26.9
			10	23.3	25.1	28.1
		AdaBoost	100	23.3	25.1	28.1
			10	26.9	29.3	31.9
		Bagging	100	30.5	32.6	34.8
REPTree	None	None	-	35.2	42.1	47.4
			10	35.2	42.1	47.4
		AdaBoost	100	35.2	42.1	47.4
			10	73.6	75.4	77.6
		Bagging	100	84.8	86.0	87.9
	10	None	-	15.2	17.1	18.3
			10	15.2	17.1	18.3
		AdaBoost	100	15.2	17.1	18.3
			10	24.5	28.6	31.0
		Bagging	100	30.7	32.0	34.0

Note: This simulation made an exception of the cases in NBTree that ensemble learning times in Bagging is 100, which show "*" in table, because that a memory of computer is overflowed for the specification of Java. The correct ratio was computed by Eq. 13 in the text.

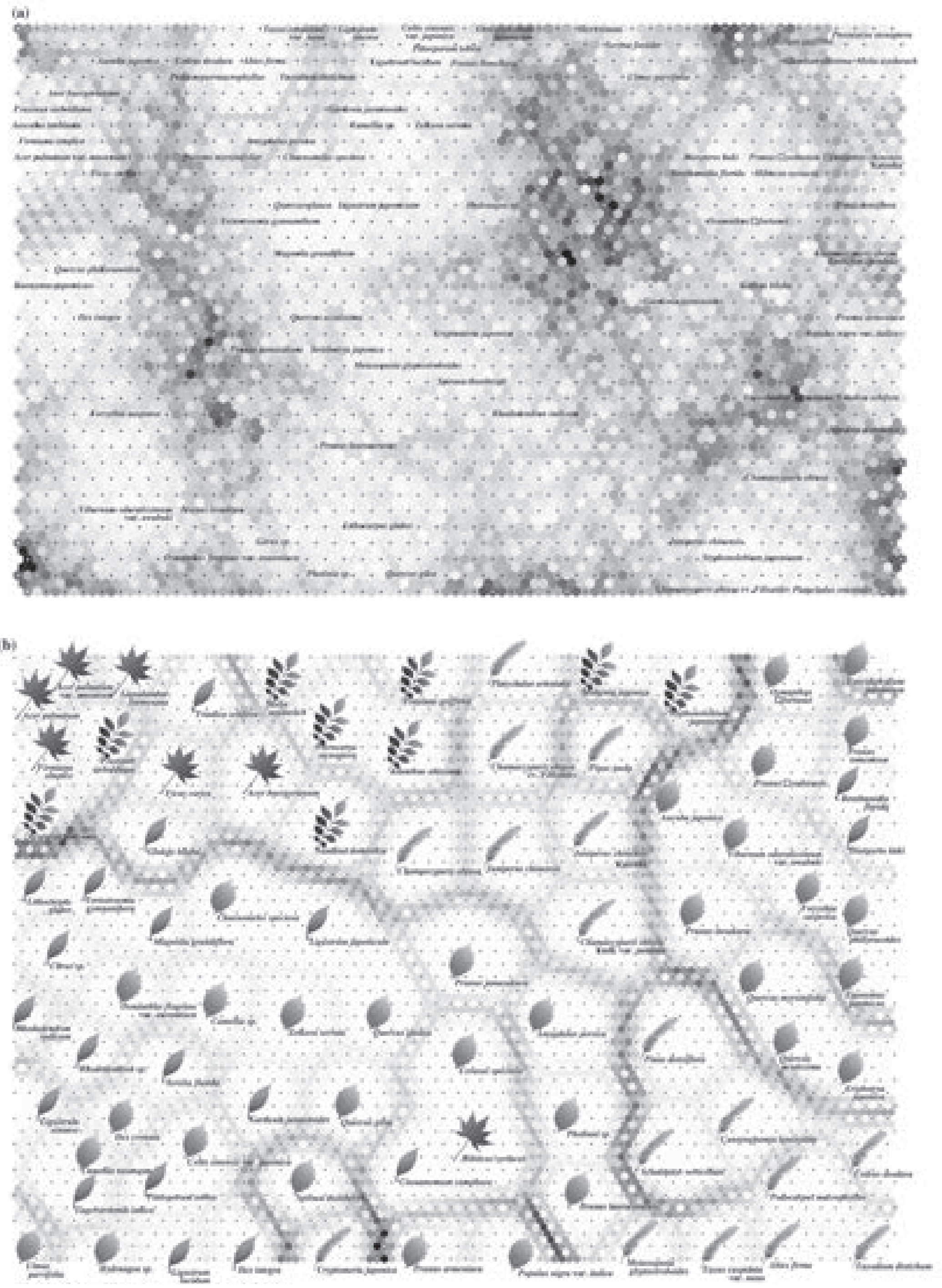

Fig. 7 Classification result by SOM.
(a) map size: 48×36, learning times: 10,000, neighbohood function: gaussian, (b) map size: 84×72, learning times: 1,000,000, neighborhood function: gaussian

Self-Organizing Map

Using the same neighborhood function, which is "gaussian," and the different map sizes and learning times in the 18 patterns (Table 1), we compared "pattern-2 (48×36, 10,000 times)" with "pattern-18 (84×72, 1,000,000 times)" in extreme cases (Fig. 7). As for pattern-2, the boundary of the SOM was not well defined in part, and some trees were not illustrated in the map. Consequently, classification by SOM was not satisfactory. In contrast, the boundary of the SOM at pattern-18 was clearly illustrated and worked to classify all tree species. From the standpoint of leaf shape, a group of leaves of similar shape were arranged physically close together. However, the SOM used in this study is the Basic SOM, which is the first model proposed by KOHONEN (OOKITA *et al.*, 2008). A node of the Basic SOM is arrayed in a grid, and adjoined nodes are united with each other. The node with a reference vector that looks most like the input vectors is called the Best

Match-Unit (BMU). When a node near an edge of the map is selected as the BMU, the learned circle, which centers on the BMU, reaches past the edge of the map and the outside part is not learned. Compared with the case in which the vicinity of the center of the map is selected, a difference in the amount of learning occurs between the edge of the map and the center of the map. Thus, proceeded a learning of SOM, Basic SOM gave rise to the fault that a label of map after learning is biased to a corner of map (OOKITA *et al*., 2008). Overall in this study, though the SOM was able to classify most of the leaf shapes throughout the entire map, some of the sample data were distributed near an edge of the map.

Tree-based Model

Table 2 shows the classification results for the leaf images according to tree-based models. Without cross-validation, the average CR for each set of five samples ranged from 42.1% (REPTree) to 100.0% (RandomTree), and the CR of the tree-based model varied widely. By adding the without cross-validation cases to ensemble learning, CR tended to improve as a whole, and bagging was shown to have good results; for example, when the number of bagging iterations of REPTree was 100, the CR in that case was improved from 42.1% to 86.0%. With cross-validation, the average CR for five samples was about 30 percent overall, and we were not able to obtain the expected results. We considered that: (1) The number of tree samples, five in this study, was too small for carrying out cross-validation; (2) The variation in the amount of features in each sample was large, even within the same tree species. However, when the without cross-validation cases were added to ensemble learning, the CR tended to improve the same tendency as without cross-validation. In addition, the classification results of bagging were superior to those of boosting.

CONCLUSIONS

The fractal dimensions of states showed different values for each leaf shape and those of all tree kinds were widely distributed within the range of minimum-maximum values. Thus, this dimension was found to be effective as a factor for classifying of leaf image features. In the case the number of learning times of SOM was small, classification by SOM was not satisfactory. However, when the number of leaning times and map sizes of SOM increases, all tree species were clearly classified on SOM map. As for classification by tree-based models, the correct ratios of each model varied widely, ranging from 42.1% (REPTree) to 100.0% (RandomTree) without cross-validation, and ensemble learning can improve the estimation accuracy of the models.

In future studies, we will try to increase the number of leaf samples and tree species. In particular, a great deal of data are needed for machine learning by the tree-based model and for the validation of generalizability by the cross-validation method. As for the number of data, OOTAKI *et al*. (1998) pointed out that, for example, when using a classification tree such as Automatic Interaction Detection (AID) or the Classification and Regression Tree (CART), it is desirable that sample data of over 1,000 cases are used in order to obtain significant results; moreover, sample data of over 2,000 cases should be used as verification. Basic SOM is an effective method for classifying a leaf image and constructing a leaf image database, but this algorithm has some faults as mentioned above. To overcome these problems, several algorithms such as Torus SOM, Spherial SOM and Geodesic SOM have been suggested as ways to improve the weak points of Basic SOM (OOKITA *et al*., 2008). Moreover, there is additional useful information that was not used in this study, such as color, texture. We suggested that color information is not useful for discriminating a leaf image because many leaf images include similar colors; however, texture information can be used to discriminate a leaf image by virtue of good image processing.

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