Title page

(1) Title:

Application of high-resolution airborne data using individual tree crowns in Japanese conifer plantations

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Abstract

We investigated conifer plantation management in Japan using high-resolution airborne data based on an individual tree crown (ITC) approach. This study is the first to apply this technique to Japanese forests. We found that forest resources can be measured at the level of a single tree. We also produced a tree crown map for a test site with *Chamaecyparis obtusa*, *Pinus densiflora*, *Larix kaempferi*, *Cryptomeria japonica*, other conifers, and broadleaved trees, with a classification accuracy of 78%. Forest stand polygons with tree cover types were generated from this map, a tree density map, and a crown-occupied area map. Forest information for the stand polygons was extracted automatically and compared to detailed field survey data. The error rate between our ITC estimates and the field survey data ranged from 0.3 to 30.2%, depending on tree crown size, density, and other factors. Errors were highest for high-density stands with mixed compositions and tree crown diameters of ≤5.0 m. However, the error for stands with crown diameters ≥6.2 m was 11.6% or less. Therefore, this technique is best suited to pure Japanese conifer plantations without multiple layers or high-density stands.

Keywords: Remote sensing, individual tree crown, species identification, stand generation, ITC

I. Introduction

The area of forest land (37.79 million ha) in Japan accounts for about 66% of the country's area. Man-made forests comprise about 10 million ha and are composed of conifers including *Chamaecyparis obtusa*, *Pinus densiflora*, *Larix kaempferi*, and *Cryptomeria japonica*. These main plantations with 31- to 50-year-old trees are managed by thinning or selection cutting. However, management operations have been abandoned in some forests following decreases in timber prices and as the land owners age and retire. More accurate information on the condition of forest resources is required for forestry officers and landowners.

Satellites make it possible to obtain data on several areas simultaneously. Since 1995, several countries have launched satellites that can obtain images with resolutions of 10 m or less. In addition, the commercial satellites IKONOS, QuickBird, and OrbView-3, which have high spatial resolutions of 1 m or less, were launched in 1999, 2001, and 2003, respectively. As a result, the acquisition of detailed forest information from space has become possible, and the technique could potentially be used to assess large areas of forest cover. However, a shortcoming of these optical satellites is that data cannot be obtained when an area is covered by clouds.

Since 2004, airborne remote sensing with high-resolution digital sensors has been conducted in Japan. Forestry studies with high-resolution aircraft data have been successful in Canada and the United States (Leckie and Gillis 1993, Hill and Leckie 1998, Franklin 2001, Jensen 2007). Tree quantification, tree crown delineation, species identification, crown density estimation, and forest stand polygon delineation have been conducted with high-resolution data collected with the airborne Multi-detector Electro-optical Imaging Sensor (MEIS) and the Compact Airborne Spectrographic Imager (CASI). A fundamental assumption inherent to crown delineation methods is that the main part of a crown is brighter than the lower edge of the crown (valley), in particular the boundary between crowns. Several algorithms can automate tree crown delineation. Extraction methods for delineating tree crowns include three main approaches: bottom-up, top-down, and template-matching algorithms. The valley-following method is a bottom-up algorithm. Top-down algorithms can be divided into watershed, multiple-scale edge segments, threshold-based spatial clustering, and double-aspect methods. The template-matching algorithms match a synthetic image model or template of a tree crown to radiometric values (Pollock 1994, Culvenor 2003, Erikson and Olofsson 2005).

The valley-following method developed by Gougeon (1995) has been applied several times to mature conifer forests in Canada. The individual tree crown (ITC) approach using the valley-following method can be used to gather detailed crown information at the stand level for forest inventories (Gougeon and Leckie 2003, 2006). Threshold-based spatial clustering was developed by Culvenor (1999), and is best suited to the high-density forests of Australia. The double-aspect method was developed by Walsworth and King (1999), who used the technique to identify aspen tree apices in black and white archival aerial photographs. The watershed method (Wang et al. 2004) is an improvement on the double-aspect method. It consists of inverting image brightness, and then applying a flooding model based on a growing region that treats crown apices as seeds (Erikson 2003, Lamar et al. 2005, Pouliot and King 2005). Pollock (1994) and Larsen and Rudemo (1998) developed template-matching algorithms based on the template crown model.

These tree crown delineation methods have not been applied to high-resolution airborne data in Japan. On the other hand, the digitization of forest information has progressed with the use of geographic information systems (GIS) in this country. High-resolution remote sensing data are required to characterize forest conditions and generate GIS data corresponding to field investigations by forestry officers or landowners. It is likely that Japan will change from using analog aerial photographs taken every 5 years to high-resolution airborne sensor data and satellite data in the future.

Crown delineation methods using high-resolution airborne data have not yet been fully applied, and neither the possibilities nor the limits for their use are clear in Japan. It is desirable to manage and monitor conifer plantations, which cover about 10 million ha of the country. High-resolution remote sensing would be a feasible means of assessing management operations such as thinning.

The aims of this research were to apply the tree crown delineation method to conifer plantations in Japan using high-resolution airborne data, and to clarify the usefulness of this method in various conifer plantations. The ITC approach with the valley-following method was used to extract tree crown information from conifer plantations typically dominated by *C. obtusa*, *C. japonica*, *P. densiflora*, and *L. kaempferi*. The accuracy of the image analysis was verified by comparing the results to data from a precise field investigation.

II. Study Area and Materials

1. Study Area

The study area was the campus forest of the Faculty of Agriculture at Shinshu University in Nagano Prefecture, central Honshu Island, Japan (Fig. 1). The campus forest in the village of Minamiminowa, Kamiina District, Nagano Prefecture, is located at an altitude of 770 m above sea level. The center of the area is at 35°51" N, 138°56"E, and the area consists of smooth geographical features and flat land. The campus covers 52.7 ha, which includes about 15 ha of forest. The forest is composed of conifer plantations, in which the dominant tree species are *Chamaecyparis obtusa* (Co), *Pinus densiflora* (Pd), *Larix kaempferi* (Lk), *Cryptomeria japonica* (Cj), *Metasequoia glyptostroboides* (Mg), and broadleaved trees. The campus forest is a unique multipurpose educational training and research facility with wood production aimed at sustainable forest management. The forest consists of high-density plantations with trees ranging from 22 to 84 years old and 8 to 36 m in height. The forest conditions are summarized in Table 1.

2. Airborne digital data

The airborne sensor used on an aircraft was developed by PASCO Corporation and contained an UltraCamD (UCD; Vexcel Co). Image data were acquired on 28 July 2005 during good weather and clear skies. Full size images had multi-color (Multi) data consisting of four bands (visible blue, green, red, and near-infrared [NIR]) for 3680 lines × 2400 pixels at nadir with 16-bit data stored. The original images with sensor orientation, topographic relief displacement, and systematic errors were rectified by ortho-correction based on X, Y, and Z values for sensor positions derived from a GPS system and principal points and focal length of the sensor. The geometric projection was converted to Japan JGD2000 Zone 8. The ground resolution of the Multi image was 50 cm after correction.

3. Field Data Collection

The field investigation was conducted from April 2005 to June 2007. The stand information was available for the forest compartments which varied from 0.3 to 1.5 ha in size (Table-2). For compartments 1–7, full stem maps of each tree were available, whereas for compartments 8–15, only sample plots (0.1 ha) were available, usually 3–5 plots per compartment. All trees ≥10 cm in diameter at breast height (DBH) were measured in forest compartments 1–7. The survey noted species, DBH, height (H), tree position, and stratum (upper, intermediate, or understory layer). The tree position map with three strata in compartments 1–7 is shown in Figure 2. The two-story plantations in which young *C. obtusa* or *C. japonica* were planted under older *P. densiflora* stands were crowded. Species, age, area, count, average DBH and H, timber volume, and growth per ha were calculated by forest compartment, as shown in Table 2. Most *C. obtusa*, *P. densiflora*, and *L. kaempferi* stands ranged from 40 to 84 years old, with high timber volume and high density.

4. GIS data

Forest compartment boundaries, forest roads, forest survey data, and geographic data such as contour lines on the forest base map of the campus research forest were created for this study as a forest database. Moreover, all tree positions in forest compartments 1–7 from the field survey were transferred and displayed using GIS, and then compared to the image analysis of delineated crowns, as shown in Figure 2.

III. Methods

The flow chart in Figure 3 provides an overview of the methods. Image processing and analysis were performed using ortho-correction processing with ERDAS IMAGINE8.6 (Leica Co. 2002), a tree stand map based on field data processed with ArcGIS 9.0 (ESRI Co. 2005), and tree crown delineation processed with ITC Suite (Gougeon and Leckie 2003) and Geomatica 9 (PCI Co. 2005). Briefly, data on the forest area were extracted using forest boundaries in the GIS database to separate forest from non-forest areas. The valley-following method from the NIR band of the UCD multi-color image was used to delineate ITCs (Gougeon 1995). This method treats the spectral values of the imagery as topography with shaded and darker areas representing valleys and bright pixels of the tree crowns. It produces a bitmap of segments of valley and crown materials. A rule-based system follows the boundary of each segment of crown material to create isolations, which are taken to represent tree crowns. The training areas with *C. obtusa*, *P. densiflora*, *L. kaempferi*, *C.*

japonica, *M. glyptostroboides*, and broadleaved trees were selected from the field investigation. The spectral characteristics of the bands were compared among species using a line chart. The ITC image was classified into species using a supervised classification process of multi bands based on comparing crown signatures. Forest stand polygons with tree cover types were generated from the classified ITC, density, and canopy closure images (Gougeon and Leckie 2003). The forest attribute data within the selected stand polygons were extracted automatically and compared to the field investigation data, and the effectiveness of this approach was verified.

IV. Results

1. Tree crown delineation

Preprocessing was necessary to normalize the NIR and red bands based on their own ranges in the illumination image, which was done twice to smooth using an averaging filter of 5×5 pixels (2.5 by 2.5 m). Because the diameter of the tree crowns ranged from 3 to 8 m, a filter size of 5×5 pixels was more suitable than 3×3 or 7×7 pixels. It was important to mask non-forested regions of the image, such as roads, grass, and man-made structures. The ITC isolation image was produced using valley-following procedures. Two kinds of error were generated from the automatic extraction in the tree crown delineation image. First, larger crowns (≥8 m diameter) of broadleaved trees or *Pinus densiflora* were often split up because their canopy apices were uncertain, given their irregular crown shapes. Second, small tree crowns or co-dominant trees were often merged in high-density stands. Stands with a mixture of small and large trees were difficult to optimize for tree crown isolation. For extraction of irregular crowns, i.e., those that were two or more times as long than wide, connection or separation processing was done manually by delineating crowns on the screen using the image editor of the Geomatica software (Geomatica9 2005).

2. Spectrum characteristics of tree species

The test pixels for each tree species identified in the field survey were examined using enlarged false-color images and individual crown images. It was easy to identify individual trees in the study area with a spatial resolution of 50 cm. Crowns in the images corresponded well to dominant trees in the field. More than 50 pixels per species were extracted from the lit side of the tree crowns in the images, and the mean values and standard deviations were calculated using the ITC Suite program. A straight-line map was used to compare the spectral characteristics of the tree species using the mean digital number (DN) of the test pixels of each tree species for all multi-color bands (Fig. 4). Band DNs for the spectral values were highest for band 4 (ranging from 700–1100), followed by band 2 (180–210), band 1 (150–170), and band 3 (50–70). Conifer DN values for *M. glyptostroboides* and *L. kaempferi* were greater than for the other conifers, and that of *C. obtusa* was the lowest. The DN value of broadleaved trees was higher than those of conifers in band 4. The same results have been reported using data from Landsat TM, JERS-1 OPS, and IKONOS (Katoh 1995, 2002, 2004a,b). The DNs of band 4 differed markedly among tree species, and they were effective for classifying tree species.

3. Tree species identification

The ITC isolation image and multispectral images were fed into a supervised classification process, to identify species on a per-crown basis (Fig. 5). Some differences from the usual supervised classification process were as follows. First, the lit and shaded sides of each crown were separated according to above and bellow the mean value of the crown. The signature of each crown was based on the pixels found only on the lit side (multispectral mean and covariance of the pixels). For training, crowns of the same species were gathered to create a species signature based on the mean of the means found for each crown and the covariance of those means. Second, the individual trees (objects) were assigned to the species with the closest signature to that of the tree using a maximum likelihood decision rule and a confidence interval.

Figure 5 shows tree crown species, size, density, and position. Patches of *C. obtusa*, *P. densiflora*, and *L. kaempferi* were clear, indicating good representation of conifer plantations in the area.

We then verified the effectiveness of producing a visual map from the composition of tree species, crown size, density, and mixture per stand for making decisions about thinning or management, and assessed the potential for zoning of stand types through screen interpretation. The verification samples were selected randomly from the test area. The overall classification accuracy was 78%, with 989 out of 1270 sample trees classified correctly to the species level. *Pinus densiflora* (84%), *L. kaempferi* (71%), *C. japonica* (93%), and broadleaved trees (97%) were identified with the greatest accuracy. *Chamaecyparis obtusa* (35%) had the lowest accuracy, primarily because pure stands of this species were rare; it typically inhabits mixed stands with *P. densiflora* or broadleaved trees.

4. Generation of stand polygons

Forest stand delineation plays an essential role in forest management. There are usually two steps to generate forest stand polygon data in Japan. First, data on newly generated forest stands are extracted from an existing forest inventory or field survey, and some stands are obtained by conventional photo interpretation methods. Second, these polygons are transferred to maps and added to the forest database.

A possible approach to stand delineation is segmentation based on edge-following or region-growing criteria (e.g., Definiens 2007). Some reports have used object-based analyses with IKONOS satellite data in Japan (Wada 2007). However, in the segmentation process, which is automatically based on the features of objects with a particular size, form, and color, the setting of the segmentation parameter and the texture factor depend on the software used. Moreover, they are generally designed to pick up distinct objects, and have difficulties with subtle boundaries that can typically be found by forestry interpreters (Leckie et al. 2003a).

The regrouping of individual crowns based on species composition, stem density, and canopy closure was fed into a pixel-based unsupervised classification process where classes corresponded to a variety of stand types of different species compositions and densities (Gougeon and Leckie 2003). Classes were regrouped until the desired breakdown was achieved, although some smaller regions remained and were considered noise classes. Noise-removal processing merged those smaller regions into larger stands, and raster-to-vector processing was performed to produce the final boundaries (Fig. 6). The generated stand polygons were clearly different from the stand boundaries in the forest inventory map (Fig. 1). The present stand conditions are more complex because of the existence of poor growth regions, the intrusion of natural broadleaved trees in plantations after planting, and planting that exceeded stand boundaries. The computer-generated forest stands shown in Figure 6 corresponded to a wider variety of stand conditions than the forest inventory stands.

5. Tree crown information in the generated forest stands

Some of the conifer plantations of *C. obtusa*, *P. densiflora* (84%), and *L. kaempferi* (71%) are shown enlarged in Figure 7a. Five stand polygons with different stand conditions (species or densities), identified visually, were selected. Tree crown information (stand area, total number of crowns, number of crowns per ha, average crown area, and average crown diameter) within the selected polygons was extracted automatically using the program (Table 4). Average crown diameter ranged from 4.3 to 4.9 m and density ranged from 277 to 337 stems/ha. The number of tree crowns, stems per ha, and average crown diameter varied by tree species. Stand No. 1 had 350 *P. densiflora* trees out of 562 trees, and an average crown diameter of 4.3 m. Stand No. 2 had 148 *L. kaempferi* trees out of 174 total. In stand No. 3, *C. obtusa* was dominant with 371 of 605 total trees, and the average crown diameters of *P. densiflora* and *L. kaempferi* were larger than those of *C. obtusa* and *C. japonica*.

6. Accuracy verification based on field investigation

All trees ≥10 cm DBH were investigated in detail within the stand polygons and verified, as shown in Table 5. The upper, intermediate, and understory trees in the stands were characterized by age, height, DBH, crown diameter (CD), stems/ha, and volume/ha. Except in Stand No. 4, there were more broadleaved trees and *C. obtusa* in the understory than in the upper or intermediate strata. In Stands No. 1 and No. 3, there were more intermediate trees than upper-level trees. There were about 293–397 upper-canopy trees, with a CD ranging from 5.6 to 6.9 m.

There was a stronger correlation between CD and density (stems/ha) than between species and density. In the image analysis, density was similar to that of upper-story trees in the field survey. Thus, the error in density measurements was derived from these data to verify accuracy.

The error rate between density from the image analysis and upper-story trees in the field investigation ranged from 0.3 to –30.2%. In Stand No. 4, the error rate was large because *L. kaempferi* and *C. obtusa* occurred in mixed stands with trees with small crown diameters, and the average upper-layer tree crowns were small (5.6 m diameter). All other stands had low error rates; crown diameters averaged ≥6.2 m, and *L. kaempferi* and *P. densiflora* were dominant. However, both the understory trees and intermediate trees, with tree heights about 3–5 m lower than the upper-layer trees and average crown diameters of <5 m, were difficult to extract using image analysis.

Only upper-story trees as determined by the field survey are shown in Figure 7b. Upper tree crown position, species, and density per selected stand were similar to the derived analysis map (Fig. 7a) using the ITC approach. These results indicate that this approach is effective for delineating upper-canopy trees in pure conifer plantations without multiple layers or high-density stands.

V. Discussion

During image data preparation, the extraction of upper-layer trees using a mean filter of 5 × 5 pixels (2.5 × 2.5 m) was effective because there were many tree crowns ≥5 m in diameter in the study area (Gougeon and Leckie 2003). A filter size approximately three times greater than the average crown diameter is the optimum size for enhancing the shadows between crowns (Warner et al. 1998). However, the tree crowns of co-dominant and underlying trees could not be extracted. It may be possible to extract such information by using a 3 × 3-pixel filter if small-crowned trees are interpreted on the image after excluding the upper-layer trees by mask processing.

In mixed stands of conifer and broadleaved trees, the delineation of coniferous species was inferior to that of broadleaved trees when the broadleaved crowns were extracted, and the adjoining conifer crowns were occasionally identified as shadows of the broadleaved trees using the valley-following method. This occurred because the radiance value of broadleaved trees is higher than that of coniferous trees. Thus, this approach may be limited in mixed stands or in natural forests composed of different species. The analysis should be selected to characterize either conifer or broadleaved stands, using the applied threshold setting on the algorithm to delineate shaded and bright areas of the tree crowns (Leckie et al. 2003a, 2005).

The generated stand polygons were derived from ITC classifications, stem density measurements, and canopy closure images. The advantages of generating stand polygons by this procedure are that it can be interactively operated using those images, and the operator’s intention can be better reflected than that which is possible using object-based software. Stand polygon generation may by improved by using other forest layers. For example, LiDAR height data or a canopy height model could be used with a simple threshold to separate trees of different heights in the canopy (upper, intermediate, understory layers) or regenerate stands from non-forested areas, and also improve tree crown delineation (Gougeon and Leckie 2003).

The field verification showed that characteristics of the tree crown for upper-layer trees could be obtained using this approach, whereas neither intermediate nor understory trees were characterized with high accuracy. However, for tree crown diameter averages of ≥6.2 m, it was possible to extract information at an error rate of 11.6% or less. Because it is possible to verify ITC image analysis results via field investigation, the technique should be investigated further.

At present, the coverage of high-resolution airborne data is expanding. More detailed field data are necessary, although field investigations are labor-intensive and costly. Therefore, an effective method using the ITC approach for delineating single trees, generating stand polygons, and extracting stand attributes will improve the management of conifer plantations in Japan.

Further application and testing are needed to extend our results to larger areas, multiple scenes, varied topographies, and different forest conditions.

VI. Conclusions

ITC data were extracted semi-automatically from airborne Ultra CamD color images using the valley-following method. An ITC map was produced using maximum likelihood decision rules. The map had sufficient accuracy to help guide decisions about thinning or management based on species composition, crown size, and density per stand. New stand polygons were automatically generated based on species composition, density, and canopy closure. The generated stand polygons were different from the stand boundaries in the forest inventory map, which were the original boundaries after planting and did not reflect any recent changes. The number of tree crowns and the crown diameter of different species within the stand polygons were automatically extracted and compared to field data. The number of trees in the image analysis was similar to that of the upper-story trees documented in the field investigation. Stem density correlated more strongly with CD than with species. The tree crown extraction error rates of upper-level trees ≥6.2 m in average crown diameter were 11.2% or less.

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Tables & Figures

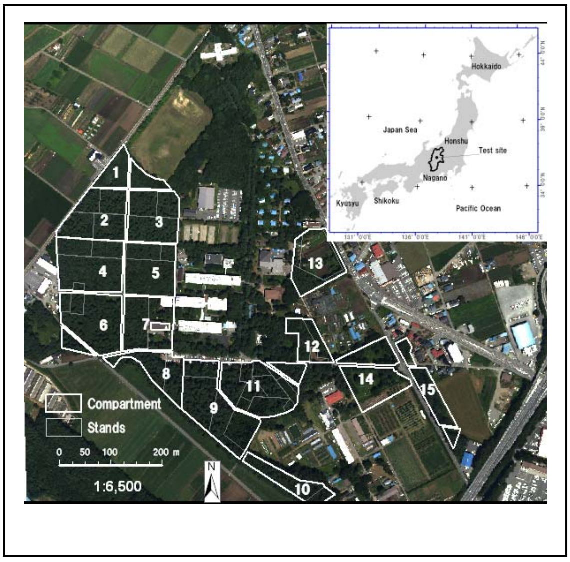

Fig. 1. Study area at the Shinshu University Campus Forest in Nagano Prefecture, central Honshu Island, Japan

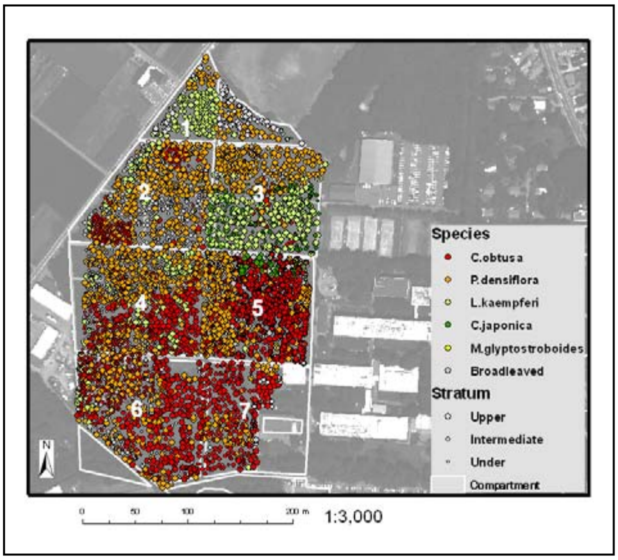

Fig. 2. Tree stand map with stratum from field survey data.

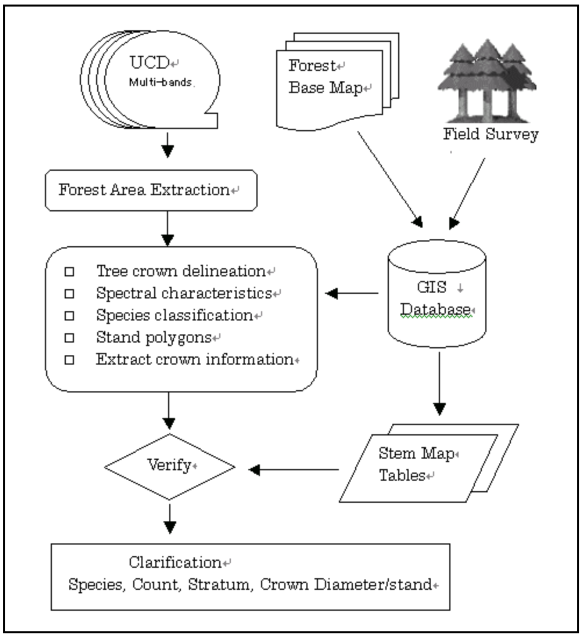

Fig-3 Overview of approach

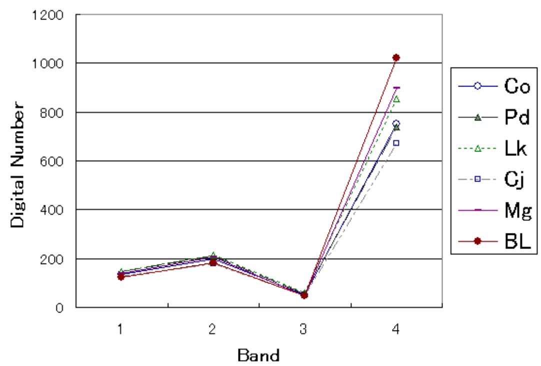

Fig. 4. Comparison of the mean values of the conifer tree species using a line chart

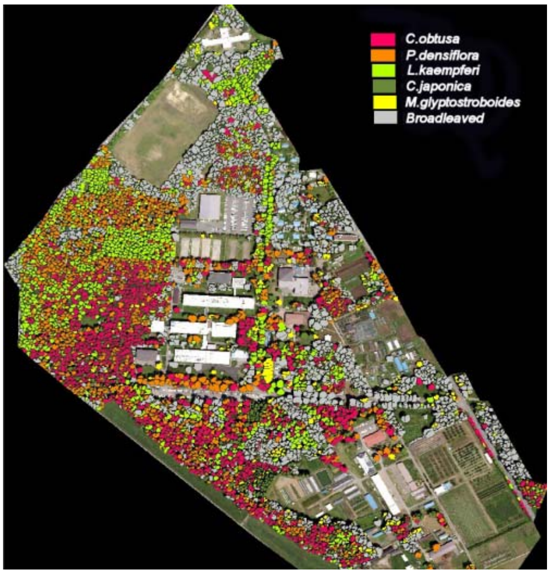

Fig. 5. Conifer tree species classified using the ITC approach

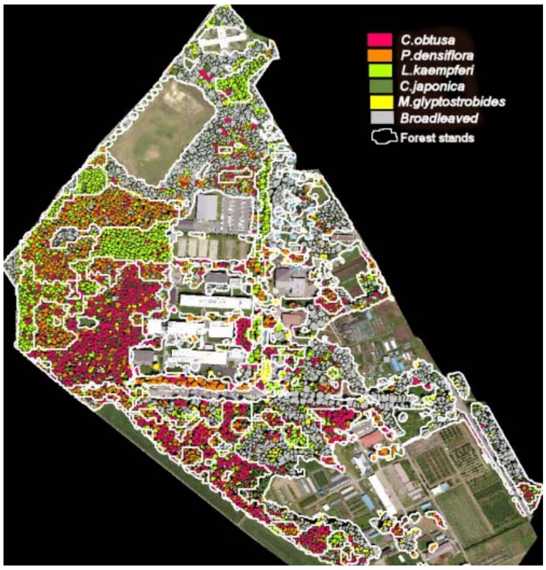

Fig. 6. Computer-generated forest stand polygons with individual crowns and species classification.

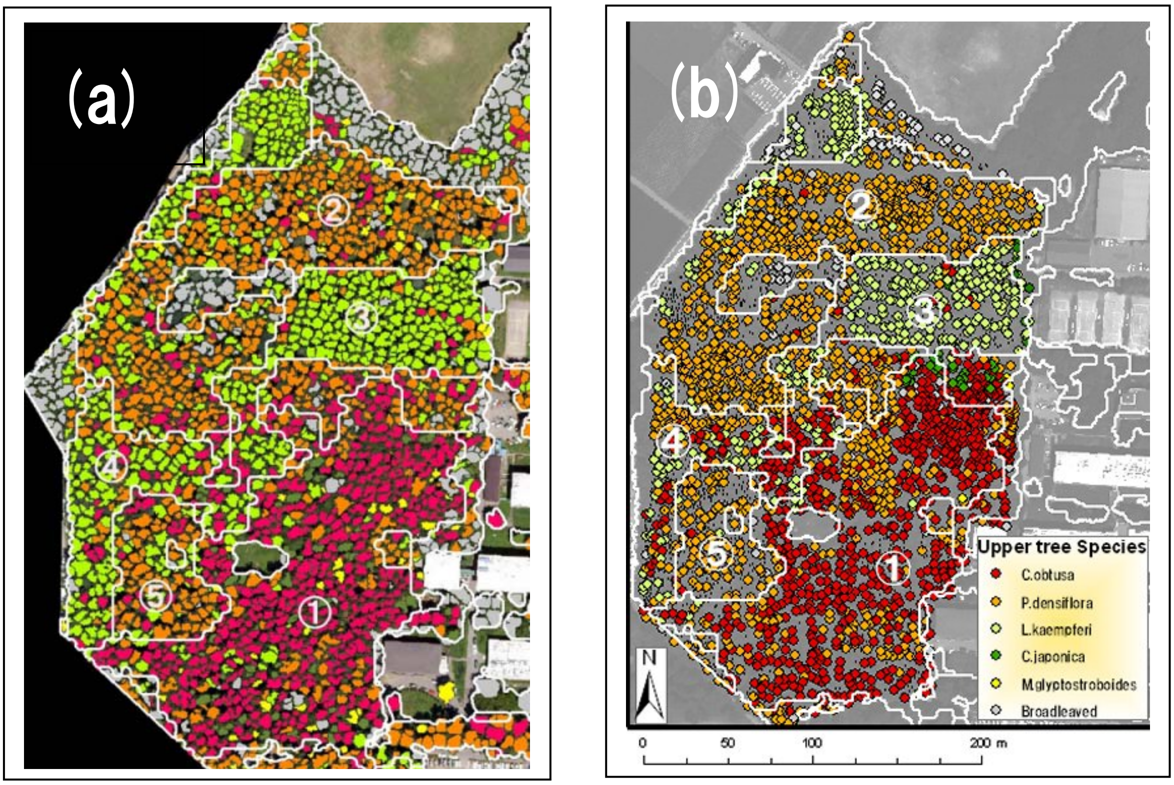

Fig.-7 (a) Five stand polygons selected from the ITC classification image, as shown enlarged in Fig.6. (b) A composite map overlaid upper tree species by field data

Table 1. Conditions and abbreviations of conifers investigated in this study.

Scientific name	Age	DBH* (cm)	H** (m)	CD*** (m)
Conifers (N)				
Chamaecyparis obtusa (Co)	26−75	16−50	13−26	2.6−6.7
Pinus densifolia (Pd)	44−84	30−80	17−27	5.1−13.5
Lalix kaempferi (Lk)	49−84	30−55	20−31	3.1−8.9
Cryptomeria japonica (Cj)	22−84	14−49	13−25	3.5−6.1
Metasequia glyptostroboides (Mg)	55	47−84	17−36	8.1−13.0
Broad leaved trees (BL)	−	8−126	8−25	1.3−10.2

*:Diameter at breast height **:Tree Height ***:Crown Diamter

Table 2. Forest resource conditions by compartment in the study area at the Shinshu University Campus Forest.

Compart. No.	Sub-compart. No.	Species**、 land use	Age	Area (ha)	Count /ha	DBH* (cm)	H* (m)	Volume (m^3)	Growth (m^3)	Crown Density
1	3	Pd, Lk, BL	44–49	0.58	1760	13.7	15.6	60	1.45	9
2	5	Lk, Co, Pd, BL	44–56	1.06	906	23.7	18.6	509	8.56	9
3	3	Lk, Pd, Cj	24–61	1.00	743	21.3	19.5	474	6.86	9
4	4	Co, Pd, Lk	22–84	1.17	984	23.6	16.0	504	10.2	6
5	3	Co, Pd, Cj, BL	34–64	1.00	856	23.8	16.5	481	7.30	6
6	4	Co, Pd, Lk,, BL	34–74	1.25	810	23.6	16.0	473	7.28	9
7	2	Co,Pd, Cj, Lk, BL	29–64	0.72	691	27.2	17.2	435	3.50	9
8	2	Pd, Co, BL	34–59	0.81	850	23.6	18.6	479	3.53	9
9	4	Pd, Lk, Co, Cj, BL	22–74	1.47	1480	19.2	14.4	529	6.34	7
10	2	Pd, Lk, BL	34–74	0.76	774	24.8	18.0	513	4.57	6
11	10	Pd, Cj, Lk, Co, BL	29–84	1.43	1220	18.3	14.1	389	4.43	7
12	2	Lk, Pd, Co. BL	39–74	0.43	460	19.1	14.6	117	1.51	5
13	2	Nursery	–	0.32	–	–	–	–	–	3
14	2	Demonstration forest	–	0.82	–	–	–	–	–	7
15	3	Demonstration forest	–	0.65	–	–	–	–	–	8
Total				13.47				4962	65.53	

*: DBH, H showed the average value of majority speceis

**:For species names, see Table-1

Table 3. Accuracy assessment of randomly selected pixels at the species le

	Field Survey data							User's
	Co	Pd	Lk	Cj	Mg	BL	Total	Accuracy
Co	**63**	86	13	15	2	3	182	35%
Pd	12	**146**	11	1	1	3	174	84%
Lk	4	16	**112**	7	6	13	158	71%
Cj	3	13	5	**91**	7	2	121	93%
Mg	1	8	3	2	**18**	28	60	30%
BL	0	8	7	1	0	**559**	575	97%
Total	83	277	151	117	34	608	1270	
Producer's Accuracy	76%	53%	74%	78%	53%	92%		**78%**

Table 4. Tree crown information within stand polygons using image analysis.

Stand	Total				Co			Pd			Lk			Cj			Mg			BL		
No.	Crowns	Stems /ha	Cr.D	Cr. Area	Crowns	Stems /ha	Cr.D	Crowns	Stems /ha	Cr. D	Crowns	Stems /ha	Cr.D	Crowns	Stems /ha	Cr.D	Crowns	Stems /ha	Cr.D	Crowns	Stems /ha	Cr.D
1	562	337	4.3	14.3	41	24	4.3	350	211	4.3	101	61	4.6	0	0	0	21	12	3.6	49	29	4.2
2	174	309	4.6	17.0	9	16	3.8	15	26	5.1	148	265	4.7	0	0	0	1	1	4.3	1	1	6.2
3	605	281	4.6	16.8	371	174	4.7	93	43	4.7	32	15	4.9	56	26	4.1	29	12	4.1	24	11	5.2
4	141	277	4.9	18.8	27	53	4.4	27	53	4.4	83	165	5.2	3	5	3.5	1	1	2.8	0	0	0
5	116	294	4.5	15.6	13	33	5.3	68	173	4.6	30	76	4.5	0	0	0	0	0	0	5	12	3.4
Total	1598	307	4.6	16.5	461	300	4.5	553	506	4.6	394	582	4.8	59	31	2.5	52	26	3.7	79	53	4.8

Crowns: Count of Crowns, Cr.D: Average Crown Diamter (m) Cr.Area:Average crown area (m^2)

Table 5. Comparison of the field survey data to image analysis in the stand polygons.

Stand No.	Dominant Species	Upper story tree						Intermediate tree					Under story tree					Image Stems /ha	Stem Error* (%)
		Age	H (m)	DBH (cm)	Cr.D (m)	Stems /ha	Vol /ha	H (m)	DBH (cm)	Cr.D (m)	Stems /ha	Vol /ha	H (m)	DBH (cm)	Cr.D (m)	Stems /ha	Vol. /ha		
1	Pd	57	23.9	35.5	6.9	302	343	17.2	18.4	4.4	221	49.2	12.7	13.0	3.5	383	35.9	337	11.6
2	Lk	62	26.1	32.3	6.2	335	359	17.1	18.1	4.7	86	19.1	13.3	13.3	3.7	321	21.5	309	−7.8
3	Co	65	22.3	36.6	6.5	306	340	18.5	26.7	3.9	228	119.7	9.5	10.8	3.1	322	21.5	281	−8.2
4	Lk、Co	52	23.5	35.1	5.6	397	440	18.3	26.4	4.9	97	58.3	12.0	14.0	3.7	218	22.8	277	−30.2
5	Pd	65	24.0	40.2	6.4	293	409	17.7	25.0	3.7	90	39.0	10.2	11.8	2.8	427	25.5	294	0.3

*: Stem Error = (Image Stems/ha - Upper story tree Stems/ha) ÷Upper story tree Stems/ha ×100