OBJECT-ORIENTED IMAGE SEGMENTATION APPROACH FOR TIMBER HARVEST CRUISING STRATEGIES IN MOUNTAINOUS AREAS

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Keywords: segmentation, IKONOS, eCognition, timber harvest cruising

Abstract: *Accurate and efficient measurement of forest resources based upon criteria such as site quality and stocking levels in mountainous areas has always been a challenge, and is one of the primary jobs to gauge overall forest health with regard to sustainable forest management. It is a necessary part of the timber harvest cruising strategies, and is also very time-consuming and expensive. This study explored the implementation of a multi-resolution segmentation approach to site qualify and stocking level estimation using an object-oriented eCognition.*

1. Introduction

Forest operational planning is normally based on stands, owners or regional level as the primary unit of treatment. A forest landscape is a spatial mosaic of arbitrary boundaries containing distinct areas that functionally interact (Turner, 1989). Spatial or landscape structure refers to the relative spatial arrangement of patches and interconnections among them (Baskent & Keles, 2005). In recent years, therefore, interest has been directed towards the use of smaller area units such that the formation of treatment units becomes part of the operational planning (Lu & Eriksson, 2000; Martin-Fernandez & Garcia-Abril, 2005).

Remote sensing is more cost-effective technique than field survey to conduct long-term and broad area census. Internationally, there have been important scientific advances in remote sensing over the last 30 years that have produced mature techniques ready for implementation in the management of forest resources (Suarez *et al.*, 2005). Recently, high spatial resolution satellite data become commercially available, making possible fine-scale studies over large areas. The commercial IKONOS satellite (Space Imaging, USA), one of several new satellites collecting high spatial resolution data, was launched in September 1999 and provides, on request, effectively global coverage of 1 m panchromatic data and four bands of 4 m multi-spectral data in the blue, green, red and near infra-red portions of the spectrum, respectively (Read *et al.*, 2003; Turner *et al.*, 2003).

High spatial resolution data with fewer spectral bands in aerial photography and new high spatial satellite images (IKONOS or Quick Bird) can create classification problems due to greater spectral variation within a class and a greater degree of shadow (Laliberte *et al.*, 2004). On the other hand, it contains much information in the relationship between adjacent pixels, including texture and shape information, which allows for identification of individual objects as opposed to single pixels.

Image segments are a way of summarizing information from a contiguous cluster of homogeneous pixels. Each image segment then becomes a unit of analysis for which a number of attributes can be measured. These attributes can include dozens of measures of spectral response, texture, shape, and location (Benz *et al.*, 2004; Thomas *et al.*, 2003). Ecologically speaking, it is more appropriate to analyze objects as opposed to pixels because landscapes consist of patches that can be detected in the imagery with object-based analysis (Laliberte *et al.*, 2004).

The main objective of this study was to explore the viability of the object-oriented image analysis for the formation of treatment units in order to appropriate forest operation based on site quality and stocking levels, using the high spatial resolution satellite image (IKONOS) and the digital elevation model (DEM).

2. Study area and data source

2.1 Study area

Mie Prefecture is located in the center of the Japanese islands and on the eastern portion of the Kii Peninsula. The prefecture is long and thin with the Kushida River running along the Central Construction Line. The line divides the prefecture into the Northern region of the interior and the Southern region facing the Pacific Ocean. Mie Prefecture has an area of approximately 5,800 km^2 with forest according for around 65 %, which is close to the national average for forest lands. However, the region of concern is located in the ocean-facing southern region and, excluding the plains of Miyagawa, is very mountainous with forests according for more than 90 % of the land. Within the prefecture, national forest total about 240 km^2, the remaining 3,520 km^2 is private forest, which includes public forests. Private forests account for approximately 94 % of forest lands. Hinoki (Japanese cypress) occupy about 1,020 km^2 and Sigi (Japanese cedar) about 960 km^2, which represents a total of 1,980 km^2 of coniferous plantation forests. Plantation forests account for 53 % of forest lands, but account for over 90 % of the forests in the region of ocean. And the region of concern composes a part of the forestry region famous for Owase Hinoki and Kumano Sugi.

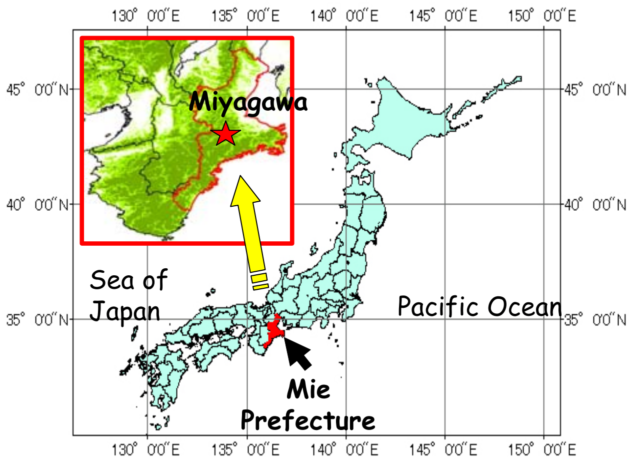

Figure 1: Location of the study area

The study area managed by the Miyagawa Forestry Association is situated in the central portion of Miyagawa village and covers with around 1,600 ha of mountain forest. Most of area is steep slope terrain of 30 degrees or more and elevations range from 200 to 1,000 m above sea level (a mean annual precipitation of 2,400 mm). The area located in the upper portion of the Miyagawa river watershed was specifically selected because of active interest in the well-managed forestry and adaptive watershed management. The forest is an artificial forest characterized by coniferous tree species (Japanese cedar account for about 50 % and Japanese cypress for about 30 %) Basically, the forest landscape can be described as very homogeneous since the plantation forests account for 80 % of the study area. Most stands are young about 30-50 year olds. Although operational cares have been taken to have a small scale clear-cutting, commercial thinning, and tending along forest road sides, most remote sites within the forest have not been thinned and diverse broadleaved trees from valley lines have invaded and have created a mixed stands. Although the forest management in Miyagawa is facing severe circumstances due to the current stagnant timber market conditions, the forestry still occupy a prominent position in socio economic activities (Figure 1).

2.2 Data source

We used IKONOS satellite (Space Imaging™ processing level: standard geometrically projected) multi-spectral (4 m / pixel) data for about 1600 ha study area. The data were acquired on 23 November 2004. In this study, the red, blue and green bands were used for a false-color composite image, which was an available image format (Erdas Imagine image) in the eCognition. Near infra-red and red bands were used to calculate a normalized difference vegetation index NDVI.

DEM was delivered from Geographical Survey Institute in Japan. Spatial resolution was 50 m / grid. DEM was interpolated by the bilinear interpolation method to 4 m / grid in order to coordinate with the IKONOS data. The slope and the aspect were calculated by using GIS (Arc View 3.2a / ESRI, USA). Calculated topography data was 4 m / grid, which was an available grid format (ESRI ASCII GRID) in the eCognition. The output unit of the slope was a degree. The aspect assigned eight aspects to 1-8 after having output a unit with a degree, which was clockwise from the north. The flat assigned 0 (Figure 2).

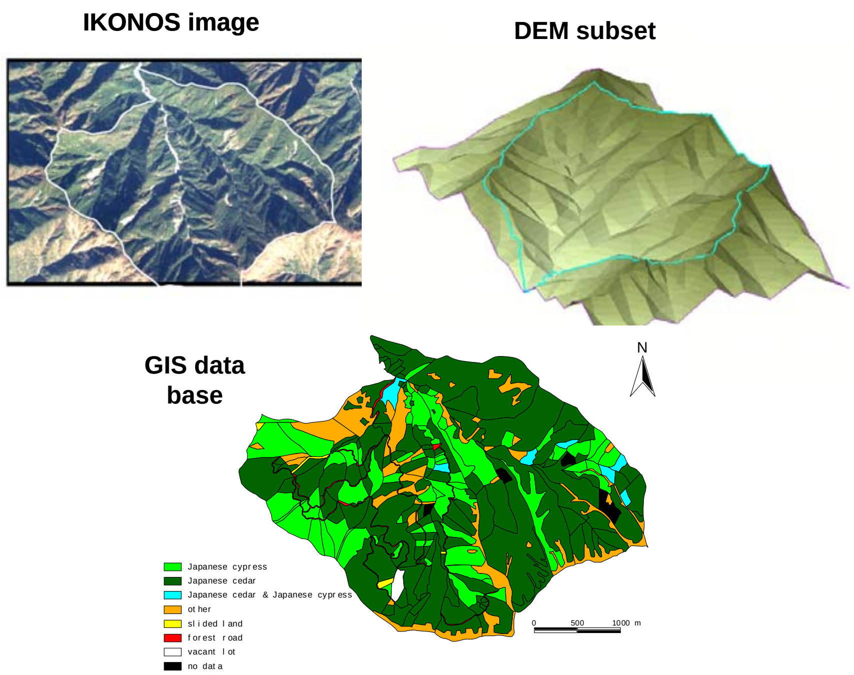

Figure 2: Data sources

2.3 Analysis procedure

In order to form treatment units for appropriate forest operation based on site quality and stocking levels, a false-color composite image, a calculated NDVI image, grid data of slope and aspect were used. A false-color composite image and NDVI image were used to obtain land cover information. Grid data of slope and aspect were used to obtain estimation of topographically adequacy for forest operation. Based on these data, the forest treatment units were segmented by eCognition (Figure 3).

The eCognition segmentation algorithm creates image or grid data segments based on three criteria: scale, color and shape (smoothness and compactness), where color and shape parameters can be weighted from 0 to 1. Within the shape setting, smoothness and compactness can also be weighted from 0 to 1. In the case of grid data, each value of grid was treated like color. These criteria can be combined in numerous ways to obtain varying output results. Scale is the most important parameter and affects the relative size of output polygons, although there is not a direct relation between the input scale and the number of pixels per polygon. Scale is heterogeneity tolerance within a segment. Color, smoothness, and compactness are all variables that optimize the segment's spectral homogeneity and spatial complexity. The balance at which these criteria are applied depends on the desired output. Assigning a high weight value to color (spectral information) with no weight on shape information resulted in highly jagged polygons with narrow spectral range. In contrast with that, when shape information was strongly emphasized rather than color, the resulting polygons were amorphous and did not closely follow feature boundaries. A high weight for compactness also outputs amorphously shaped feature polygons that do not adhere to major features. Emphasizing smoothness rather than compactness allows for polygons that follow natural features more naturally (Benz *et al.*, 2004; Definiens, 2000; Laliberte *et al.*, 2004; Thomas *et al.*, 2003).

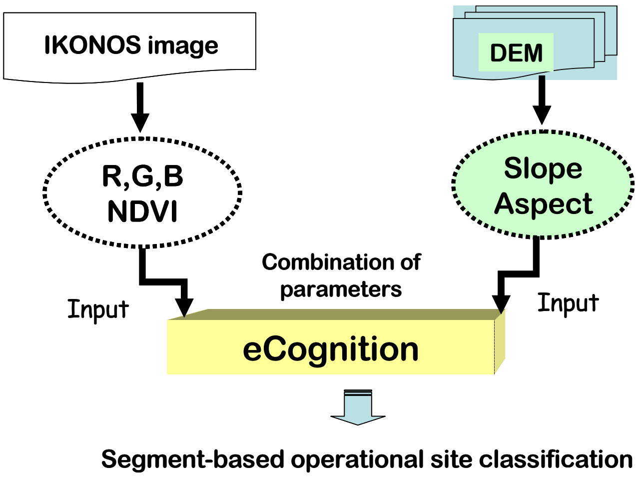

Figure 3: Flow chart for the segment-based classification approach using IKONOS and DEM data

Table 1 shows segmentation parameters used in this study. The segmentation used in eCognition is a bottom-up region merging technique. In subsequent steps, smaller image objects are merged into larger ones based on the set scale, color, and shape parameters, which define the growth in heterogeneity between adjacent image objects. This process stops when the smallest growth exceeds the threshold defined by the scale parameter. A larger-scale parameter results in larger image objects (Benz *et al.*, 2004).

Table 1: Segmentation parameters

Scale level	Scale parameter	Shape factor	Compactness	Smoothness
1	10	0.2	0.5	0.5
2	30	0.2	0.5	0.5
3	50	0.2	0.5	0.5

3. Results

The study area was segmented by using a false-color composite and NDVI images at lower (level 1), middle (level 2) and higher level (level 3) based on the image object hierarchy. The number of the objects obtained was 3076 (mean area 0.24 ha, fractal dimension 1.49) at level 1, 424 (mean area 1.76 ha, fractal dimension 1.42) at level 2, and 170 (mean area 4.40 ha, fractal dimension 1.40) at level 3 (Table 2). According to GIS maps, visual interpretation and field survey, the segmentation which used the parameter of level 2 could be provided with good results.

Considering topography is important to estimate of appropriateness of forest operation, since most forest area in Japan is steep and complicated landforms. The study area was segmented by using topography data at three levels as well as IKONOS image data. The number of the objects obtained was 2385 (mean area 0.31 ha, fractal dimension 1.44) at level 1, 340(mean area 2.17 ha, fractal dimension 1.39) at level 2, and 132 (mean area 5.59 ha, fractal dimension 1.38) at level 3.

Table 2: eCognition segmentation results at level 1, level 2 and level 3

Scale parameter	No. objects	Mean area± SWD (ha)	MFD+ SD[1)]
10	3076	0.24+ 0.23	1.49+ 0.09
30	424	1.76+ 1.63	1.42+ 0.08
50	70	4.40+ 3.96	1.40+ 0.09

Remark 1) MFD: Mean Fractal Dimension

Finally for the formation of treatment units in order to appropriate forest operation, the study area was segmented by using a false-color composite image, NDVI image and topography data (slope and aspect) at level 2, according to above-mentioned analysis results. The number of the objects obtained was 367 (mean area 2.01 ha, fractal dimension 1.40) and the segmentation result also reflect the existing forest inventory map (Table 3, Figure 4).

Table 3: eCognition segmentation results at level 2 (IKONOS RGB, NDVI and DEM)

Scale parameter	No. objects	Mean area+ SD (ha)	MFD+ SD
30	367	2.01+ 1.70	1.40+ 0.07

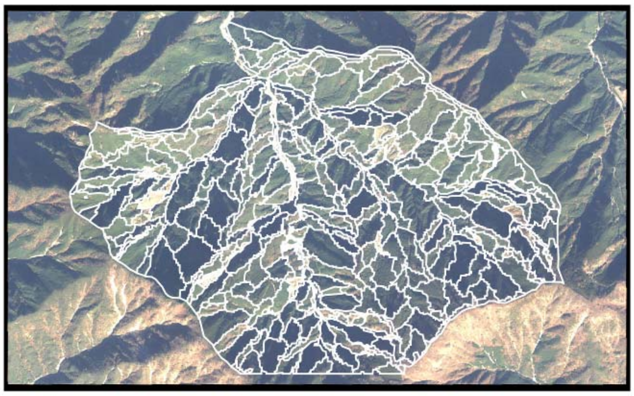

Figure 4: Segmentation of study area at level 2 using a false-color composite image, NDVI image and topography data

4. Discussion and outlook

The importance of concepts in sustainable and nature-oriented forest management has become increasingly recognized in recent years. In addition to governmental institutions, non-governmental organizations such as the Forest Stewardship Council (Forest Stewardship Council, 1994) have developed new, nature-oriented forest management and certification standards (Morse, 2001). Therefore, we should depart from the traditional management method by units of stands, owners or regional level.

The use of object-oriented image analysis was proved to be advantageous in this study. Treatment units to appropriate forest operation were generated smaller area compared to that of the stand base planning. The segmented result was the aggregation of pixels sharing similar characteristics in terms of land cover and topography. Forest management planning strives after a desirable course of action for the management of a forest estate (Hologram *et al.*, 1997). Forest management practices imposed at one spatial scale may affect the patterns and processes of ecosystems at other scales (Tang & Gustafson, 1997). By using the method of this study, operation units which reflect the current condition of the forest was segmented and the management which is based on these units can be practiced. Results indicate that object-oriented approaches have great potential for improved resource management information and monitoring system in decision-making processes for precision forestry purposes.

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