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APPLICATION OF HIGH-RESOLUTION SATELLITE IMAGES IN FORESTRY AND HABITAT MAPPING - EVALUATION OF IKONOS IMAGES THROUGH A HUNGARIAN CASE STUDY

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ABSTRACT:

The launch of Ikonos satellite at the end of September 1999 marked the beginning of a new era for the application of satellite images. Being able to provide up to one-metre resolution panchromatic and four-metre resolution multispectral images, thus available in the past for military purposes or from aerial surveys only, this satellite offers considerable improvements and broadens the application possibilities of satellite imagery. In our study, two of the lower-price "Ikonos Carterra Geo" images were processed. Geometric accuracy enhancement and thematic data extraction possibilities were examined in order to evaluate this sensor for forestry applications. The whole study focuses on a selected Hungarian research area, but the results can be useful in a more general context.

1   INTRODUCTION

1.1   Challenge

In Hungary, large-scale forest management is primarily based on special geographical information systems, with "traditional" airborne orthophotos as a base map. The characteristics of Ikonos make it an interesting sensor for large-scale forestry and environmental applications. Temporal resolution of image databases can be largely increased, due to the known revisit time and pointing capabilities of the satellite platform, which facilitates large-scale change-detection and monitoring of selected areas in order to keep GIS databases up-to-date. However, the practical application of such images for the above-mentioned purposes requires a geometrical accuracy comparable to airborne orthophotos. As the satellite is owned by a profit-oriented private company, image prices are relatively high, and the images are priced in function of the geometric accuracy. Being extremely price-sensitive, sectors such as forestry won't be able to purchase the geometrically most precise images, although their work requires this precision.
Furthermore, the above-mentioned applications require efficient thematic data extraction methods. Compared to airborne photography, high-resolution satellite imagery has the advance of being meaningful from a radiometric point of view, therefore not only qualitative but quantitative analysis can be carried out. As the image resolution increases, large-scale mapping becomes possible, but digital image interpretation such as thematic data extraction becomes harder and harder, requiring new and more efficient methods.

1.2   Aims

As a consequence of the above-mentioned facts, the first aim is to *improve the geometrical accuracy* of a lower-price image. This goal doesn't seem to be easily acquired, since the sensor and orbit parameters are kept in strict confidence by Space Imaging and therefore aren't available to the public. Arising from the above-mentioned facts, multiple methods, including polynomial*, rational polynomial* and *satellite orbital modeling* calculations were tested and compared in order to find the method that provides the highest geometrical accuracy.
The *extraction of thematic information* is always crucial for forestry and environmental applications. In the second part of our paper, the efficiency of *visual interpretation*, *spectral* and *texture-based* classification and *image segmentation* methods are compared. *Data fusion* with other raster- and vector-based databases was also examined.

2   DATA

2.1   Study Area

As this study deals with forestry applications of Ikonos images, a study area characterized by important forestry activities had to be selected. The area of the town Zirc and surroundings was chosen, where more than 40% of the surface is covered by woodland, which makes it one of the most forested regions of Hungary. The study area lies in the western part of Hungary, and covers about 192 square kilometres, between the latitudes going from 47°19' to 47°13' North and longitudes going from 17°45' to 17°58' East. The area is a rolling, hilly terrain, characterized by hills and valleys with elevations going from 200 to 680 meters above sea level, so the maximal variations reach about 500 meters.

2.2   Ikonos images

Two images, covering together the study area, were purchased to carry out the research. These separate, partially overlapping images can be identified by the product order number: the western, larger image has the number 69566, and the number of the smaller eastern image is 69567. *Table 1* shows the most important characteristics of the two images.

Product order number	69566	69567
Product level	Ikonos Carterra Geo 1 m (Pan-sharpened)	Ikonos Carterra Geo 1 m (Pan-sharpened)
Sensor	IKONOS-2	IKONOS-2
Date and time of acquisition	02 may 2001. 10:00 am	02 may 2001. 9:59 am
Raw image pixel size • Cross scan • Along scan	0.92 m 0.87 m	0.94 m 1.01 m
Nominal Collection Azimuth	262.46°	335.81°
Nominal Collection Elevation	70.66°	62.58°
Sun Angle Azimuth	159.48°	159.38°
Sun Angle Elevation	56.99°	56.98°
Image product pixel size • Cross scan • Along scan	1.00 m 1.00 m	1.00 m 1.00 m
Projection	UTM north zone 33	UTM north zone 33
Ellipsoid	WGS 84	WGS 84
Upper left corner (UTM, meters)	X: 707899.86 Y: 5244719.30	X: 718426.72 Y: 5244867.12
Columns (pixels)	12704	6104
Rows (pixels)	12672	12436
Bit/pixel/band	11 (stored on 16)	11 (stored on 16)
Number of bands	4 (R,G,B,NIR)	4 (R,G,B,NIR)
File format	GeoTIFF	GeoTIFF

Table 1. *Most important characteristics of the two Ikonos images (from the product metadata file).*

2.3 Topographic maps

To carry out geometric accuracy examinations and enhancements, topographic maps of scale 1 : 10,000 covering the totality of the study area were purchased. The maps have been scanned and georeferenced in order to obtain a highly accurate reference database. *Table 2* shows relevant data about the topographic map-based reference database.

Number of map sheets	12
Scanned pixel size on ground	0.8 m
Nominal horizontal accuracy of paper maps	3 m
Nominal vertical accuracy of contour lines	0.7 – 0.8 m
Projection	EOV (Hungarian Uniform National Projection System)

Table 2. *Characteristics of the digital 1 : 10,000 topographic map database.*

Some features, e.g. important and well-visible roads, railways were digitized using the topographic map raster files. These vectorized line features were used for visual geometric accuracy examination of Ikonos images.

2.4 Digital Elevation Model (DEM)

Digital elevation model of the entire study area is required to examine geometric accuracy tendencies depending on surface relief and also for geometric accuracy enhancement (Davis and Wang 2001).

Digitized contour lines of the above-mentioned 1 : 10,000 topographic map database have been used to calculate DEM of the study area.

The topographic maps contain one contour line on every 2.5 meters, with the values of the current elevation above sea level. After digitizing all of the contour lines of the entire geocoded topographic map database, line coverage has been created containing every contour line and the appropriate elevation value. Linear rubber sheeting interpolation method was used to produce a raster DEM. The resulting DEM has a pixel size of 2.5 m, and contains interpolated elevation data for each pixels (or grid cells) of the entire research area.

2.5 Digital Forestry Map Database

To test, evaluate and develop data extraction techniques, digital forestry map database was purchased from the National Forest Service.

The forestry map database was shipped in Arc/Info Export format. This vector database, covering most of the woodland area of the research site, is composed of 2534 polygons altogether, with each polygon containing one forest subcompartment. The database linked to each polygon contains over 70 attributes describing climatic, water and soil properties, tree species, mixture rate, closure and many other descriptive and administrative properties.

2.6 Other data sources

Although this study focuses on the application of Ikonos images, it is also important to make a comparison between this new high-resolution satellite image product and other available remote sensing data. Therefore, other images, including Landsat 5 TM, SPOT-4 HRVIR satellite images, true-colour and false-colour infrared aerial photographs have also been investigated during our work.

2.7 Software used

Geometric accuracy investigations, polynomial geometric corrections and classifications were carried out using ERDAS Imagine 8.4 Professional. PCI OrthoEngine 8.2 Satellite Edition with Ikonos Model was used to carry out geometric corrections based on rational polynomials and satellite orbital modeling. For image segmentation, Definiens eCognition 2.0 software was used. Digital forestry map database operations were carried out using ESRI ArcView GIS 3.1.

3 METHODOLOGY

3.1 Image geometry evaluation and enhancement

Both geometric accuracy and price of Ikonos images depend on product level. In our study, lowest-price Ikonos Carterra Geo images were purchased and post-processed in order to make practical investigations on geometric accuracy and to improve cost-efficiency.

Raw Ikonos images can contain errors due to
- angular tilt
- the Earth curvature
- atmospheric refraction
- surface topography.
(Guienko, 2001.)

The image supplier offers multiple product levels, with different levels of geometric correction. It is not possible to order raw

images. During pre-processing of Ikonos Geo images, errors are mostly eliminated, except those due to surface topography.

According to Guienko (2001), Ikonos images acquired with 26 degrees cross track pointing view angle can contain errors up to 243,8 pixels for areas with surface topography variations of 500 m.

Space Imaging claims that all Ikonos Carterra Geo images have the following geometric accuracy, *not including topographic displacements* (*Table 3*):

Circular Error for the 90% of points (CE90)	50.0 m
Mean RMS error	23.6 m

Table 3. *Geometric errors of Ikonos Carterra Geo images.*

It is important to note here that Space Imaging doesn't provide any information about the Ikonos satellite sensor nor orbit parameters. It is therefore impossible to carry out normal orthorectification on Ikonos images.

3.1.1 Evaluation of geometric accuracy

Actual geometric accuracy of both Ikonos Geo images was measured by comparing control points selected on both the reference map database and each of the images.

The images were reprojected from UTM/WGS84 projection to EOV (Hungarian Uniform National Projection System) using the ERDAS Imagine EOV definition add-on module developed at the Institute of Geodesy, Cartography and Remote Sensing. Rigorous transformation with bicubic resampling was used in order to obtain maximal reprojection accuracy. The maximal errors of the reprojection process using rigorous transformation don't exceed some decimetres.

After reprojection, the topographic map database and the images became directly comparable. Check point pairs were selected manually on both of the images and the topographic map reference database. All the points were carefully selected and positioned on surface elements that can be clearly identified both on the satellite images and the topographic maps. Using digital elevation model of the area, points were taken at multiple different heights to examine the effect of surface topography on the errors of original Ikonos Geo images.

On the larger left image (69566), 38 points, on the right image (69567), 16 points were selected. Most of these points were also used as ground control points in geometric correction processes. Difference of meter-based EOV coordinates measured on the reprojected original images and on the reference map database were used to calculate X and Y errors for each point. RMS errors were calculated using a simple distance equation.

Visual examination of geometric errors was also performed using line features (roads, railways) vectorized from the 1 : 10,000 topographic maps.

3.1.2 Geometric accuracy enhancement

As the Ikonos Geo images were found not to be accurate enough for large-scale (1 : 10,000) mapping, multiple methods were tested to improve geometric accuracy.

Since all of the tested methods require highly accurate reference data, carefully selected ground control points were used. These thoroughly tested points were already used for geometric accuracy evaluation.

Original georeferenced Ikonos Geo images were used for GCP collection. After importing the original GeoTIFF files, image map model was deleted, and raw image (pixel) coordinates were stored for each GCP as input coordinates.

The same ground control points were identified with high accuracy on the reference map database. EOV X and Y coordinates were stored as reference coordinates.

During image resampling, cubic convolution resampling method was used in each case to ensure good quality results.

3.1.2.1 Simple polynomial method

This method doesn't require sensor nor topographic information, so the digital elevation model couldn't be used. This simple but method is generally used to rectify images of smaller areas with relatively flat terrain. Distortions that can be described or approximated using polynomial functions can be eliminated using this method.

Simple 2nd, 3rd and 4th order polynomials were used for image transformation. For both of the images, RMS errors for all of the GCPs were calculated. GCP input coordinates were raw image pixel coordinates (column/row number), reference coordinates were given in EOV map projection system.

3.1.2.2 Rational polynomial method

Rational function model is essentially a generic form of polynomials. It defines the formulation between a ground point and the corresponding image point as ratios of polynomials. (Tao and Hu 2001). As this method uses Z coordinates (elevation), elevation data for all control points is needed. Rational function model doesn't require sensor information. According to Toutin and Cheng (2001), this method can be useful for areas with gentle terrain.

Rational polynomial function (RPF) rectification process was carried out on both of the images using the same GCPs as for geometric accuracy evaluation and for every other methods. GCP input coordinates were raw image pixel coordinates (column/row number), reference coordinates were given in EOV map projection system. Elevation data was for each point was given using digital elevation model. RMS errors for all of the GCPs were calculated for comparison.

3.1.2.3 Satellite orbital modeling

Satellite orbital modeling is an implementation of the Canada Centre for Remote Sensing (CCRS) rigorous model.

This model reflects the physical reality of the complete viewing geometry, and corrects distortions due to the platform, sensor, Earth, and sometimes the deformation due to the cartographic projection. It then takes into consideration the satellite-sensor information. (Toutin and Cheng 2001).

The method is based upon principles related to orbitography, photogrammetry, geodesy and cartography. Except some basic considerations, all data required for the calculations is available in the metadata file provided by Space Imaging with every Carterra product (see *Table 1*).

This method requires digital elevation model and takes elevation data into consideration in every point of the image.

The orthorectification process requires GCP reference coordinates and elevation data in the same map projection/coordinate system as the original images have. Reference coordinates were therefore recalculated from EOV into UTM/WGS84 coordinates. Digital elevation model was also reprojected using rigorous transformation and bicubic resampling. GCP input coordinates were, as usual, raw image pixel coordinates (column/row number).

3.2 Thematic data extraction

3.2.1 Image characteristics
Both Ikonos images are pan-sharpened products, provided by fusioning 4-m resolution multispectral and 1-m resolution panchromatic data. The data for each band is stored on 11 bits, providing dynamic images with high radiometric resolution. The values of all of the four bands (red, green, blue, near infra-red) have Gaussian distribution on both images. Despite panchromatic-multispectral data fusion, the values are radiometrically meaningful, as dynamic range adjustment (DRA) was not applied.

3.2.2 Visual interpretation
The extremely high spatial and radiometric resolution of Ikonos images facilitates visual interpretation. Visual quality of both the original and resampled images is very good.

Colour composites of the images were created. As the images contain all of the three visible wavelengths (red, green and blue), it is possible to create true-colour composites. However, these composites don't contain the additional information provided by the NIR band that is very useful for vegetation mapping purposes.

"Standard" composites containing green, red and near infrared wavelengths (R: NIR, G: green, B: blue) were created to evaluate Ikonos images in order to obtain detailed information about woodland area.

Digital forestry map database and orthorectified false-colour composite were displayed to examine map updating possibilities (see *Figure 1*). Selected attributes such as tree species, age class, closure and mixture rate were estimated and updated by visual interpretation.

Figure 1. *One part of the research area. False colour composite (R: Ikonos NIR band, G: Ikonos green band, B: Ikonos blue band). Orthorectified image with digital forestry map database polygons. Image copyright Space Imaging 2001. Image resolution was digitally degraded.*

3.2.3 Vegetation indices
Vegetation indices were calculated in order to have meaningful quantitative results depending on vegetation cover. Normalized Difference Vegetation Index (NDVI) calculation was performed on both images. In order to insure data comparability and to eliminate sensor effects, image DN values were recalculated to provide radiance images. DN/Radiance coefficients were obtained from Space Imaging website. Resulting NDVI images were also included in colour composites in order to improve visual interpretation accuracy.

3.2.4 Classification
Two classification methods were used in order to examine digital data extraction possibilities. Classifications were carried out on a subsetted image covering one part of the research area. The classifications were realized on two types of images. In the first case, raw image pixel (DN) values were classified directly. Alternatively, in the second case, image segmentation was carried out on the subsetted image. After that, the resulting group of segments (image objects) with each object containing the mean value of pixels it was created from, was classified.

The two methods were compared for accuracy using ground truth data.

3.2.4.1 Ground truth data collection

Ground truth data was collected during two field check and ground truth data collection campaigns.

For the first campaign, field check sites and ground truth data collection areas have been selected during visual comparison of Ikonos images, non-supervised classification results and digital forestry map database. Ground truth data collected during the first campaign was then used to identify classes of non-supervised classifications and also to delimitate training areas for supervised classifications. It was also useful to improve visual interpretation reliability. Global positioning system and field datalogger were used to store every relevant information *in situ* provided by local forestry experts.

The principal aim of the second field check campaign was the evaluation of classification results. Field check areas were selected at sites where evident contradictions were found between classification results and the digital forestry map database. Data acquired during this campaign served primarily to validate classification results and to improve classification accuracy.

3.2.4.2 Unsupervised classifications

Unsupervised classifications were carried out using Isodata clustering method (Tou and Gonzalez 1974) with 30 classes. Classes of the resulting classified image were identified using ground-truth data and digital forestry database.

3.2.4.3 Supervised classifications

Training areas for supervised classifications were selected using ground truth data and visual image interpretation. Classifications were carried out using Maximum Likelihood method (Hord 1982). Classes were selected primarily based on tree species. Multiple different age class training samples were selected for each species to evaluate species and age class separability together.

3.2.4.4 Image segmentation

Image segmentation is an object-based approach to image analysis. Instead of pixel representation of the Earth's surface, usually called "image", segmentation provides image objects from groups of pixels according to specific homogeneity criteria. These image objects, represented for example by the mean values of the pixel group they were created from, can be classified based on spectral properties and/or spatial relationships. Image segmentation was performed on the above-

mentioned subsetted image. Scale parameter was adjusted in order to create image objects of appropriate size.

Each resulting image object contained mean pixel values.

4 RESULTS AND DISCUSSION

4.1 Geometric accuracy of original Ikonos Geo images

Visual comparison of reprojected original Ikonos Geo images with some vectorized line features of the topographic reference maps makes it clear that the images contain distortions (*Figure 2a*). The distortions vary depending on surface topography.

The results of more accurate examinations based on selected check point pairs are presented in *Table 4*.

Image	69566	69567
Number of check points	38	16
Minimal error	2.81 m	3.61 m
Mean error	16.11 m	14.43 m
Maximal error	96.91 m	29.25 m

Table 4. *Errors of the original Ikonos Carterra Geo images reprojected to EOV map projection system, based on check points from the 1 : 10,000 topographic map database as reference.*

Although this sample cannot be considered representative due to the relatively low number of points, it shows clearly that, for both images, the distortions make it impossible to use these images for large-scale mapping. Maximal RMS error for the image 69566 reaches almost 100 m that can be explained by topographic effects. The point with the largest RMS error is situated on a hilltop.

Topographic effects can be important for both of the images not only in cross-track direction due to scanner geometry but also in other directions due to collection elevation values (see *Table 1*).

4.2 Geometric accuracy enhancement

Results of geometric accuracy enhancement examinations of multiple methods are shown in *Table 5*.

Image	69566			69567		
	Min	Mean	Max	Min	Mean	Max
Poly2	1.58	13.82	70.71	2.06	7.13	19.32
Poly3	1.41	13.26	41.35	0.68	5.98	20.13
Poly4	2.07	13.68	42.25	0.25	5.98	22.24
RPF	5.09	18.93	35.24	1.51	6.32	15.54
Ortho	0.98	6.61	20.08	0.20	4.38	9.38

Table 5. RMS errors of control points using different models of geometric correction.
Polyx: Polynomial transformation of xth order
RPF: Rational polynomial function of 2nd order
Ortho: Orthocorrection using satellite orbital modeling

If we compare *Table 4* and *Table 5*, we can have some information about the overall effects of the methods tested for geometric accuracy enhancement.

Simple polynomial transformations cannot eliminate distortions due to surface topography. However, these simple and robust methods can slightly decrease these effects. After the 3rd order, RMS errors begin to increase for the 4th order polynomial transformation.

Rational polynomial functions didn't perform as well as expected with our imagery. This is maybe due to non-perpendicular image acquisition angle and high surface relief.

It is clearly shown that orthorectification based on satellite orbital modeling provided the best results, however, for some points it didn't work as well as expected. We can state that the mean RMS error of 4..7 meters of the control points makes it possible to use the geometrically corrected images for large-scale mapping purposes (*Figure 2b*). It is possible to directly compare the images with other existing large-scale databases i.e. the digital forestry map database. Geometric accuracy obtained by orthorectification is sufficient for large-scale forest mapping, management and database updating.

The accuracy of the corrected Geo images are between the accuracy of Ikonos Carterra Map (5.7 RMSE) and Pro (4.8 m RMSE) product levels.

Figure 2a

Figure 2b

Figure 2. *Vectorized linear features (roads, in red) shown on the original (2a) and orhtorectified (2b) Ikonos images. Image copyright Space Imaging 2001. Image resolution was digitally degraded.*

4.3 Thematic data extraction possibilities

The high spatial and radiometric resolution and geometric accuracy of the orthocorrected images ensure good visual interpretation possibilities. Trained image interpreters can easily interpret near-infrared false-colour composites as the colours and resolution are similar to false-colour infrared photographs. Visual interpretation and data comparison can be used efficiently for forestry map database updating.

However, it is important to note that the lack of middle infrared band sometimes makes the discrimination of different vegetation types difficult.

Vegetation indices such as NDVI may help to interpret vegetation types more clearly. These indices are also useful for vegetated area delimitation and for classification mask band creation. When displayed in colour composites, vegetation indices improve the efficiency of visual interpretation. However, direct relationship wasn't found between any of the forestry map attributes and NDVI.

Both unsupervised and supervised pixel-based classification results were very poor on the original images. The confusion matrix for the supervised classifications showed 31..58% of well-classified pixels for the control areas of the different classes. The poor results can be explained by the relatively poor spectral information content of the images and by the extremely high spatial resolution (*Figure 3a*). The visible bands (red, green, blue) are highly correlated and don't give many information for the discrimination of vegetation types (species, closure, mixture rate etc.) The near infrared band clearly

improves classification accuracy, containing one of the maxima of vegetation reflectance curves. Some additional bands including middle infrared would be needed to improve pixel-based classification results.

It is also important to note that high spatial resolution doesn't facilitate spectra-based classification (see Franklin et al., 2000). Medium-resolution satellite images, such as SPOT HRVIR or Landsat TM images, have the advantage of "self-calculating" mean spectral values. This means that, from the forestry point of view, the coarser spatial resolution makes "average" pixels, where for example brighter and darker sides of individual tree crowns aren't visible. Instead, there are "tree crown averages" in each 10- or 28-m pixel of the image. The 1-meter pixel size of Ikonos makes spectral variations much greater.

Segmentation, however, improves largely the accuracy of both the supervised and unsupervised classifications. Confusion matrices of supervised classifications performed on previously segmented images showed 73..95% accuracy. The improvement is very important compared to the classifications on pixel-based images (*Figure 3b*).

The results show that segmentation, developed initially for microwave remote sensing image analysis, can be used and should be used on very high-resolution optical imagery to obtain good classification results. Spectral and textural information can be treated simultaneously during segmentation and subsequent classification.
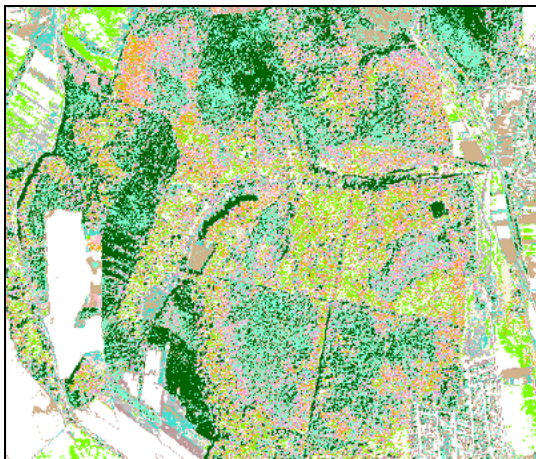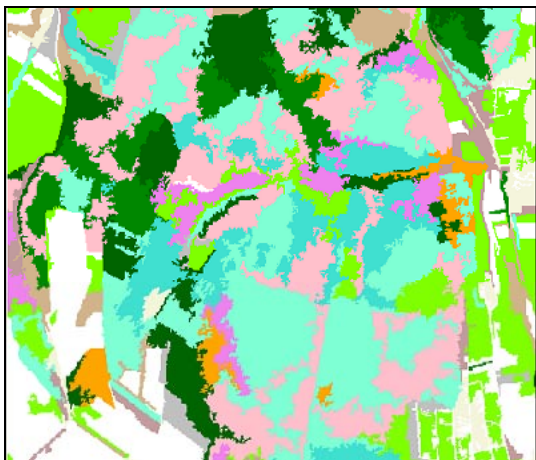

Figure 3a

Figure 3b

Figure 3. *Unsupervised classification results on original (3a) and segmented image (3b) Similar colours indicate similar classes.*

5   CONCLUSION

Ikonos Geo images, as provided by the image supplier, don't have sufficient geometric accuracy for large-scale mapping. Price-sensitive users such as forestry sector are not able to purchase geometrically more accurate Ikonos Carterra image products. It is possible to improve geometric accuracy of Ikonos Geo images, and a higher accuracy level can be reached depending largely on the original image acquisition circumstances and topography of the area represented by the image. Orthorectification using satellite orbital modeling method seems to be the most effective and accurate modality to obtain high geometric accuracy. Visual interpretation works well on Ikonos images. Pixel-based classification techniques provide poor results due to extremely small pixel size and relatively poor spectral content. Image segmentation and subsequent classification improves largely the efficiency and accuracy. Tree species data can be well derived from Ikonos satellite imagery.

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