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Full Length Research Paper

The importance of spatial accuracy in characterizing stand types using remotely sensed data

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This study assessed the potential use of Landsat 7 ETM+ (15 and 30 m spatial resolutions) images to estimate forest stand attributes such as development stages, crown closure and stand types. The study evaluates the performance of spatial and image classification accuracies between Landsat images (15 and 30 m spatial resolutions) and the forest cover type map (FCTM) with the spatial analysis functions of Geographical Information System (GIS). As a base study, the stand parameters were determined by forest cover type generated with high spatial accuracy of infrared color aerial photography interpretation. The study compared the performance of classification accuracies of satellite images into the forest cover type map (FCTM). The result shows that crown closure was the most successfully classified stand parameters with a 0.92 kappa statistic value and 94.2% overall accuracy assessments in 30 m resolution Landsat 7 image and 0.94 and 95.8% in 15 m resolution Landsat image, respectively. The results indicate that 15 m resolution Landsat 7 image can lead to more accurate mapping of stand type with development stages and crown closures, than 30 m resolution Landsat image according to classification accuracy. However, spatial accuracy was lower than classification accuracy in both images. Spatial analysis clearly showed that the spatial accuracy might be more important than the image accuracy in classification of satellite images to determine forest cover types. This study reveals the differences between image accuracy and spatial accuracy of stand parameters in both Landsat images. The differences were quite significant and should be taken into consideration in forest inventory and land use planning.

Key words: Image fusion, Landsat, spatial analysis, stand parameters.

INTRODUCTION

In Turkey, forest management planning process is centralized and management plans are prepared in a 10 or 20-year cycle. The planning process starts with a forest inventory based on both remotely sensed (aerial photo interpretation or satellite image classification) data and field survey with temporary sample plots. Area, increment and growing stocks of each stand type (identified by tree species, development stage and crown closure) are measured in forest inventory process (Başkent et al., 2005, 2008). Forest inventory data is required for ecological, economical and social values of forest and all levels of forest management planning, and is becoming increasingly important for other applications such as biodiversity conservation (Leckie and Gillis, 1995; Chubey et al., 2006). The traditional approach of acquiring forest inventory information through interpretation of aerial photographs works well for traditional timber management, but is costly in terms of time, labor and expense, and generally does not fulfill information requirements of all forest values in terms of detail, accuracy, and timeliness (Wulder, 1998; King, 2000; Chubey et al., 2006). Stand parameters such as tree species, development stages and crown closures are fundamental information in preparing forest management planning. However, the traditional forest inventory process is expensive and time-consuming to conduct (Hyyppä et al., 2000; Günlü et al., 2008).

Abbreviations: FCTM, Forest cover type map; **GIS,** Geographical Information System.

Remote sensing data has played an important role in environmental studies and forestry for several decades, particularly as a tool for acquiring information about the composition and spatial structure of forest ecosystem as part of forest inventory (Chubey et al., 2006).

Investigations showed that satellite data has been an appropriate tool to evaluate and monitor large forest areas with reasonable accuracy levels (Hyyppä et al., 2000). Especially, remote sensing data can be very useful in forest management planning process when determining forest cover types and structure (Anderson et al., 2004).

The estimation of forest/stand attributes such as stand volume, basal area, stand height, development stage, crown closure, biomass and carbon storage and leaf area index has been of considerable interest to those working in satellite remote sensing (Franklin, 2001; Hall et al., 2006; Soudani et al., 2006; Hall and Skakun, 2007; Günlü et al., 2008). The accuracy in estimating forest attributes has been varied and related to the spatial resolution (Salvador and Pons, 1998; Hyyppä et al.; 2000; Hall and Skakun, 2007).

Previous studies with Landsat images demonstrated that there is an empirical relationship among stand attributes such as stand height, age and crown closure (Gerylo et al., 2002; Hall and Skakun, 2007). Recently, Landsat images were used with success for large area applications such as national forest inventories that used satellite data (Tomppo, 1991; Hyyppä et al., 2000). Estimation of stand parameters from satellite imagery and national forest inventory plots has been demonstrated to provide useful and enough information at landscape level (Tomppo, 1990; Nilsson, 1997; Hagner, 2002). However, the classification accuracy of Landsat images at stand level has not been sufficient for operational forest management process (Hagner, 2002).

Moreover, the applications of satellite images in the assessment of forest structure both at regional level and stand level have been intensively investigated over the last decade (Wulder et al., 2000, 2004; Goetz et al., 2003; Chubey et al., 2006; Skakun et al., 2007; Çakır et al., 2008; Keleş et al., 2008). However, few studies have focused on estimating forest stand parameters such as tree species; crown closure, development stages and forest stand types (Skakun et al., 2007; Günlü et al., 2008) and comparing the usability of different remote sensing data and spatial analysis (Chiao, 1996; Hyyppä et al., 2000; Günlü et al., 2008). This study therefore aimed to evaluate and compare the use of the Landsat 7 ETM+ (both 15 and 30 m spatial resolutions) images in estimating forest stand attributes such as development stages, crown closure and stand types. The main objective was to compare the performances of spatial and image classification accuracies between Landsat images for stand type parameters. The study also focused on the classification accuracies based on two different satellite images with the spatial analysis functions of GIS.

Study area

The study area is Yalnızçam planning unit located in Ardahan city in the northeastern part of Turkey (282800-291500 E, 4544500-4547600 N, UTM ED 50 datum Zone 37N) (Figure 1). The study area covers approximately 1682 ha of land and the altitude varies between 1800 and 2920 m above sea level, with an average slope of 23%. The area consists of primarily high mountain forests and scattered settlements such as villages and upland shelter lands. The vegetation is dominantly composed of *Pinus sylvestris* L., the most widely distributed species in the world with two varieties, *Pinus sylvestris.* var*. sylvestris* and *P. sylvestris* var*. hamata* Steven. The study area is located in a transition zone between Colchis sector (in Euxine province of Euro-Siberian region) and Irano-Turanian region of Turkey according to plant geographical aspect.

MATERIALS AND METHODS

Dataset and methods

The data used in this study are forest cover type map of 1/25,000 scale for the year 2005 and Landsat 7 ETM+ satellite image of July 14, 2004. The forest cover types, used as ground truthing, were originally generated from the combination of the stereo interpretation of the aerial photos that were taken in 2005 and ground measurements with 300 × 300 m sampling plots that were scattered to the study area systematically. The Landsat 7 ETM+ images were interpreted with ERDAS image 9.1 analysis programs. Landsat 7 ETM+ sensors have eight bands with a spatial resolution of 30 m for bands 1 to 5 and band 7. The resolution for band 6 (thermal infrared) was 60 m and resolution for panchromatic bands (band 8) is 15 m.

Image fusion technique allows the integration of complementary and redundant information from multiple images to generate a composite image that contains a better description of the scene (Wen and Chen, 2004). Image fusion is a technique to improve the quality and spatial resolution of an image by merging the spectral information of low spatial resolution imagery with high spatial resolution imagery. The resulting image has high spectral resolution and the same quality as a high spatial resolution image (Amer et al., 2009). In this study, we applied image fusion techniques to the same data type. The low spatial resolution (30 m) multispectral Landsat 7 ETM+ imagery was merged with Landsat 7 ETM+ panchromatic imagery. Combining these two images to yield a seven-band data set with 15 m resolution provided better opportunity to the best characteristics of this sensor and the low spatial resolution (30 m) Landsat ETM+ image is resized into (15 m) spatial resolution. The image was subset using the study area boundary and generated six ETM bands and panchromatic bands. Principal component analysis algorithm was used in merging ETM bands and panchromatic bands. These techniques are often used to produce high resolution multispectral imagery (Chavez et al., 1991; Jensen, 2000; Lillesand et al., 2000).

Data processing involved a number of steps. First of all, spatial database of the forest cover type map obtained from ground data (2005) was built with ArcGIS 9.3. Secondly, Landsat 7 ETM+ images were geometrically corrected and classified to create stand type; crown closure and development stage (Table 1). Thirdly, spatial accuracy was evaluated using both derived from forest stand map coverage and satellite image coverage. Polygon themes for stand type, crown closure and development stages were

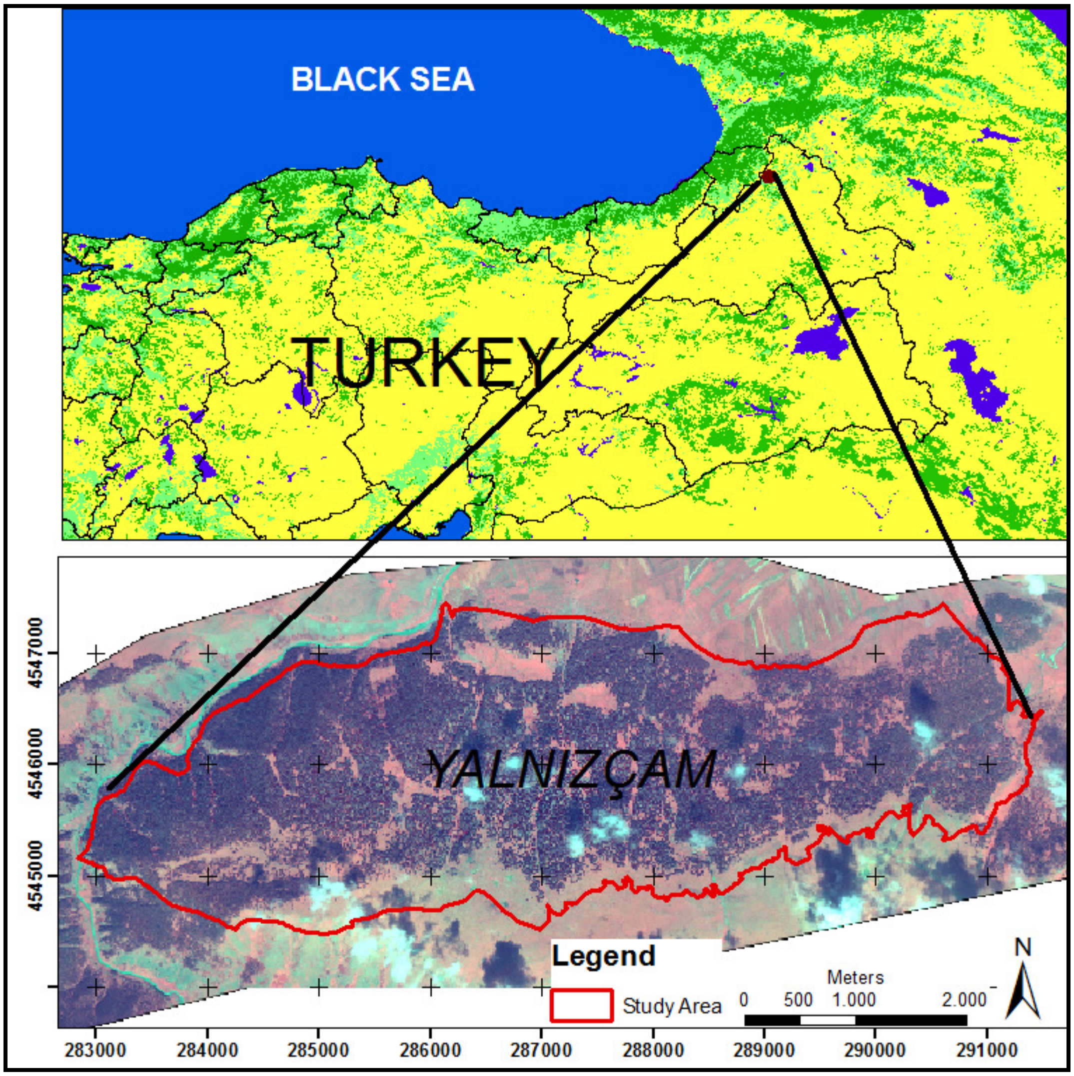

Figure 1. The geographic location of the study area.

Table 1. Classification of crown closures and development stages.

Crown closure type	Criteria (% crown cover)	Development stage	Criteria (average dbh)
Regenerated areas	Not crown cover	Regenerated areas	Not development stage
0 (Degraded forest)	0 – 10	a (Very young)	< 7.9 cm
1 (Low coverage)	11 – 40	b (Young)	8 – 19.9 cm
2 (Medium coverage)	41 – 70	c (Mature)	20 – 35.9 cm
3 (Full coverage)	>71	d (Over mature)	>36 cm
Other areas	Forest openings, settlements, agriculture and range area	Other areas	Forest openings, settlements, agriculture and range area

overlaid between forest cover type map and Landsat 7 ETM+ image coverage obtained from supervised classification. The areas that are in the same classes in both forest cover type map and Landsat 7 ETM+ images were computed using ArcGIS 9.3 software. Two methods were used in estimating the accuracy of classification.

The first one, image estimation method (image accuracy), refers to the general classification of stand parameters for satellite image. While the second, spatial estimation method (spatial accuracy), refers to the classification from forest cover type map and Landsat 7 ETM+ images. According to the second method, forest cover type map and the classified Landsat 7 ETM+ images were overlaid to each other and areas that are spatially in the same or different

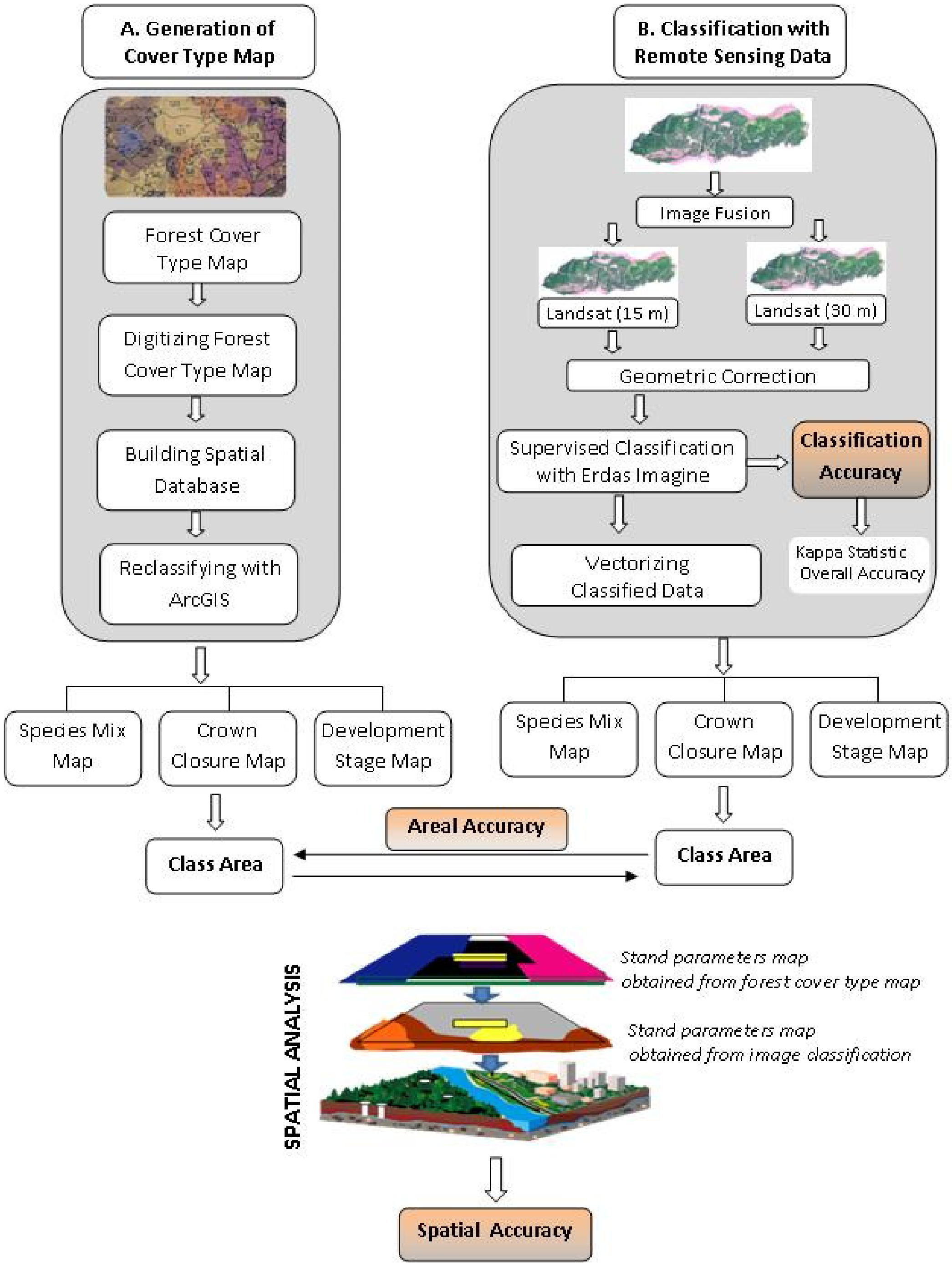

Figure 2. The flow chart of determining stand type parameters process.

classes in forest cover type map and Landsat 7 ETM+ were evaluated (Figure 2). Furthermore, classification accuracy was described as kappa statistics and overall accuracy in Landsat image classification. Image accuracy refers to the ratio of the differences between the class area classified by the Landsat image and the area of the same class in forest cover type map to total area. As the ratio gets smaller, the success of the image accuracy increases. Spatial accuracy is defined as the ratio of a same area of spatial configuration in both forest cover type map and Landsat image to total area. The higher this ratio is the greater the success.

Geometric correction of Landsat 7 ETM Images

Image processing, geometric correction and classification were carried out using ERDAS Imagine 9.1 software. Subsets of satellite image were georegistered by means of 1/25.000-scale topographical maps and GPS data with UTM projection (European Datum 1950). The first order polynomial transformation and nearest neighbor resampling methods were used for registration refinement process. A total of 20 control points were used to register the Landsat 7 ETM+ (15 m spatial resolution) image with a registration

Table 2. Confusion matrix for Landsat supervised classifications in development stage.

Landsat 15 m classification accuracy results						**Landsat 30 m classification accuracy results**					
Classes	**c**	**d**	**Other**	**Total**	**User acc.**	**Classes**	**c**	**d**	**Other**	**Total**	**User acc.**
c	25	4	1	30	83.3	c	27	3	0	30	90.0
d	0	29	1	30	96.7	d	1	27	2	30	90.0
Other	0	1	29	30	96.7	Other	0	0	30	30	10.0
Total	25	34	31	90		Total	28	30	32	90	
Prod. acc.	100.0	85.3	93.5		83	Prod. acc.	96.4	90.00	93.75		84
Kappa	0.77	0.94	0.94			Kappa	0.85	0.85	1.00		

For 15 m resolution, overall classification accuracy was 92% and kappa statistics value was 0.88. While for 30 m resolution, overall classification accuracy was 93% and kappa statistics value was 0.90.

Table 3. Confusion matrix for Landsat supervised classifications in crown closure.

Landsat 15 m classification accuracy results							**Landsat 30 m classification accuracy results**						
Classes	1	2	3	Other	Tota l	User acc.	Classes	1	2	3	Other	Total	User acc.
1	26	1	2	1	30	86.7	1	30	0	0	0	30	100.0
2	0	29	0	1	30	96.7	2	2	27	1	0	30	90.0
3	0	0	30	0	30	100.0	3	0	3	27	0	30	90.0
Other	0	0	0	30	30	100.0	Other	1	0	0	29	30	96.7
Total	26	30	32	32	120		Total	33	30	28	29	120	
Prod. acc.	100.0	96.7	93.7	93.7		115	Prod. acc.	90.9	90.0	96.4	100.0		113
Kappa	0.83	0.95	1.00	1.00	0.83	0.95	Kappa	1.00	0.87	0.87	0.96	1.00	0.87

For 15 m resolution, overall classification accuracy was 95% and kappa statistics value was 0.94. While for 30 m resolution, overall classification accuracy was 94% and kappa statistics value was 0.92.

error 0.45 pixel RMSE. The 30-m resolution Landsat 7 ETM+ image, however, was registered to the already registered 15-m resolution Landsat 7 ETM+ image through image-to-image registration technique with a registration error 0.75 pixel RMSE.

Classification of Landsat 7 ETM Images

In this study, we used all spectral bands except for thermal band in image classification for Landsat 7 ETM+ image. Ground reference data was gathered as signatures for satellite image and the training polygons were equally distributed to each stand type with at least 30 points per class type. These ground reference points were sampled over the ground corrected cover type (stand) maps of 2005. In order to classify cover types from the images, signatures were taken from the ground corrected cover type maps and further controlled based on the Transformed Vegetation Index, Principle Components Analysis-PCA and unsupervised classification image. The maximum likelihood classification algorithm was employed as the classifier for supervised classification analyses. Equal number of control points (at least 30 points for each class) was used in Erdas Imagine 9.1 program to determine the post-classification accuracy (Erdas Field Guide, 2002). However, 30 points could not be collected for each forest cover type class due to insufficient area of some forest stand type classes (Tables 2 to 5). Therefore, the accuracy assessment of image in forest cover type map may not use the equal number of control points, but random points instead.

The accuracy assessment of image was checked for

Table 4. Confusion matrix for Landsat 15 meter in stand type.

Classes	Çsc2	Çsc3	Çscd1	Çscd2	Çscd3	Çsd1	Çsd2	Other	Total	User Acc.
Çsc2	23	0	0	0	0	0	1	0	24	76.7
Çsc3	0	26	0	0	1	0	0	0	27	86.7
Çscd1	0	1	22	4	0	1	0	0	28	73.3
Çscd2	1	0	2	23	1	0	1	0	28	76.7
Çscd3	2	0	0	2	25	0	3	0	32	83.3
Çsd1	0	1	3	0	0	26	0	0	30	86.7
Çsd2	4	2	2	1	3	1	25	0	38	83.3
Other	0	0	1	0	2	0	0	30	33	100.0
Total	30	30	30	30	32	28	30	30	240	
Produce acc.	95.8	96.3	78.6	82.1	78.1	86.6	65.8	90.9		200
Kappa acc.	0.74	0.85	0.70	0.73	0.80	0.84	0.80	1.00	0.74	

Overall classification accuracy is 83% and kappa statistics value is 0.81.

Table 5. Confusion matrix for Landsat 30 meter in stand type.

Classes	Çsc2	Çsc3	Çscd1	Çscd2	Çscd3	Çsd1	Çsd2	Other	Total	User Acc.
Çsc2	19	0	0	0	1	0	0	0	20	63.3
Çsc3	2	24	0	0	1	0	0	0	27	80.0
Çscd1	0	1	19	0	0	2	2	0	24	63.3
Çscd2	0	3	5	24	3	1	1	0	37	80.0
Çscd3	4	3	0	3	18	2	4	0	34	60.0
Çsd1	4	0	1	1	2	24	4	0	36	80.0
Çsd2	2	2	5	2	5	0	18	0	34	60.0
Other	0	0	0	0	0	1	1	26	28	86.6
Total	31	33	30	30	30	30	30	26	240	
Produce acc.	95.0	88.9	79.2	64.8	52.9	66.7	52.9	92.8		172
Kappa acc.	0.60	0.77	0.59	0.76	0.53	0.76	0.53	0,84		

Overall classification accuracy is 72% and kappa statistics value is 0.67.

each image and accepted if the accuracy was higher than 80% (Story and Congalton, 1986; Başkent and Kadıoğulları, 2007). After accuracy assessment, firstly Landsat 7 ETM+ images were clumped, secondly 2 × 2 pixel class areas for Landsat 7 ETM+ (30 m) image and 4 × 4 pixel class areas for Landsat 7 ETM+ (15 m) image were eliminated, and finally outcome images were vectorized using Erdas Imagine 9.1 program. The 30 m resolution Landsat 7 ETM+ image was classified into eight stand type classes (Çsc2, Çsc3, Çscd1, Çscd2, Çscd3, Çsd1, Çsd2) and others such as forest openings, agriculture and range area (Çs: Scotch pine). Çsc2 is expressed as Çs: Scot pine, c: average dbh 20 to 35.9 cm and 2: crown closure of 41 to 70%. The overall accuracy of classification was 72.0% and the kappa statistics was 0.67. Moreover, crown closure was classified into three classes; 1 (low crown closure of 11 to 40%), 2 (medium crown closure of 41 to 70%), 3 (full crown closure of 71 to 100%) and other (forest openings, agriculture and range area). This classification is fully acceptable due to a higher overall classification accuracy of 94.2% and 0.92 kappa statistics value. As for development stages, we defined three classes in 30 m resolution Landsat 7 ETM+ image: c (mature, average dbh 20 to 35.9 cm); d (over mature, average dbh >36 cm), and others (forest openings, agriculture and range area). The overall accuracy of the classification was 93.3% and the kappa statistics was 0.90, which is also acceptable due to higher classification accuracy.

Evaluated in 15 m resolution Landsat 7 ETM+ imagery, the overall accuracy and kappa statistics of stand type classification were 83.3% and 0.81, respectively; 95.8% and 0.94 for crown closure and 92.2% and 0.88 for development stage, respectively. As a result, ETM+ imagery of 15 m resolution can lead to more accurate mapping of stand type, development stage and crown closure than ETM+ imagery of 30 m resolution imagery according to overall classification accuracy and kappa statistics value.

RESULTS AND DISCUSSION

The Landsat 7 ETM+ (15 and 30 m spatial resolution) images were successfully classified into stand type parameters (stand type, crown closure and development stages). Stand type classes were mapped (Figure 3) using the area statistics (Table 6) derived from forest cover type map, and the classified Landsat 7 ETM images. According to the stand type map, there were important differences between stand type class areas obtained from stand types, and classified Landsat 7 ETM image with 15 m spatial resolution and Landsat 7 ETM

Table 6. Changes in stand type class in forest cover type map, Landsat 7 ETM+ (15 and 30 m) images and spatial analysis.

Stand type class	Forest cover type map		Landsat 7 ETM (15 m)						Landsat 7 ETM (30 m)					
	ha	%	ha	%	Image accuracy		Spatial accuracy		ha	%	Image accuracy		Spatial accuracy	
					(+/-)	%	ha*	%			(+/-)	%	ha*	%
Çsc2	22.8	1.3	83.8	5.0	-61.0	3.7	8.8	10.5	40.0	2.4	-17.2	1.1	9.7	24.3
Çsc3	139.4	8.3	141.6	8.4	-2.2	0.1	75.3	53.2	167.0	9.9	-27.6	1.6	100.2	60.0
Çsd1	101.8	6.1	243.9	14.5	-142.1	8.4	36.9	15.1	93.9	5.6	7.9	0.5	25.4	27.1
Çsd2	260.1	15.5	150.4	8.9	109.7	6.6	56.0	37.2	170.8	10.1	89.3	5.4	73.4	43.0
Çscd1	209.3	12.4	252.5	15.0	-43.2	2.6	74.4	29.5	281.5	16.7	-72.2	4.3	92.3	32.8
Çscd2	421.5	25.1	296.2	17.6	125.3	7.5	192.6	65.0	280.3	16.7	141.2	8.4	152.6	54.4
Çscd3	143.4	8.5	170.1	10.1	-26.7	1.6	46.5	27.3	265.7	15.8	-122.3	7.3	58.9	22.2
Others	384.5	22.8	344.3	20.5	40.2	2.3	266.9	77.5	383.6	22.8	0.9	0.0	289.3	75.4
Total	1682.8	100.0	1682.8	100.0	0.0	-	757.4	45.0**	1682.8	100.0	0.0	-	801.8	47.6**

*Classified as a same area of spatial configuration in both forest cover type map and satellite image. Çs, *Pinus sylvestris*; 1,2.3, crown closure; c. d, development stages; Çsc3, pinus stand; mature development stage (20 to 35.9 cm), full crown closure (71 to 100%). Others, forest openings, agriculture and range area.
**Spatial accuracy according to spatial analysis. Spatial achievement percentage= (True classification as a same area of spatial configuration in both forest cover type map and Landsat 7 ETM+ image / Total area) x 100: (757.4/1682.8) x 100 = 45.0%.

image with 30 m spatial resolution. Çsc3 class was the most successfully classified in 15-m resolution Landsat 7 ETM+ image, while Çsd1 was the most successfully classified in the 30-m resolution Landsat 7 ETM+ image. The biggest area difference was in Çsd1 class (142.1 ha, 8.4% of the landscape) in 15-m resolution Landsat 7 ETM+ image and Çscd2 class (141.2 ha, 8.4% of the landscape) in 30-m resolution Landsat 7 ETM+ image. In other words, Çsd1 was the most successfully classified in the 30-m resolution Landsat 7 ETM+ image, while the biggest area difference was in the same class in 15-m resolution Landsat 7 ETM+ image.

The areas of Çsc3 and Çscd3 classes obtained from forest cover type map and classified by 15 m spatial resolution Landsat 7 ETM+ image were pretty much similar to each other. Image accuracy of 15 m resolution Landsat image is more successful than that of 30 m resolution Landsat image. The results indicated that image classification accuracy for stand type is lower than the expected. There are some reasons of lower classification accuracy. One reason relates to the increased structural complexity of a stand type with mixed stand, development stage and crown closure with increasing resolution. A stand type in a planning unit does not have completely homogeneous structure. Areas less than 0.5 ha are not recognized as a separate stand resulting in an underestimation of some stand types in a planning unit. Other reason of the low classification accuracy is that there are lots of similar stand types in planning unit with similar reflectance values.

Crown closure map was classified and mapped according to stand type map, Landsat 7 ETM+ image for 15 and 30 m spatial resolution (Table 7 and Figure 4). The 15 m resolution Landsat 7 ETM+ image was classified successfully into four crown closure classes. The low crown closure (11 to 40%) class was 311.1 ha in forest cover type map, while it was 344.7 ha classified in 15 m resolution Landsat 7 ETM+ image. The medium crown closure (41 to 70%) was 711.4 ha in forest cover type map (FCTM), while it was 610.6 ha in classified 15 m resolution Landsat 7 ETM+ image. The full crown closure (71 to 100%) was 275.7 ha in FCTM, while it was 274.2 ha in classified Landsat 7 ETM+ (15 m spatial resolution) image. The biggest area difference was in medium crown closure class (100.8 ha, 6.0% of the landscape) and low crown closure class (62.8 ha, 3.7% of the landscape) in classified Landsat 15 and 30 m spatial resolution images, respectively. When crown closure values were further analyzed, it was clearly seen that there were no significant differences between areas in full crown closure classes obtained from FCTM and 15 and 30 m resolution Landsat 7 ETM+ images. The full crown closure (71 to 100%) was the most successfully classified in Landsat (15 and 30 m spatial resolution) images. One important reason of such

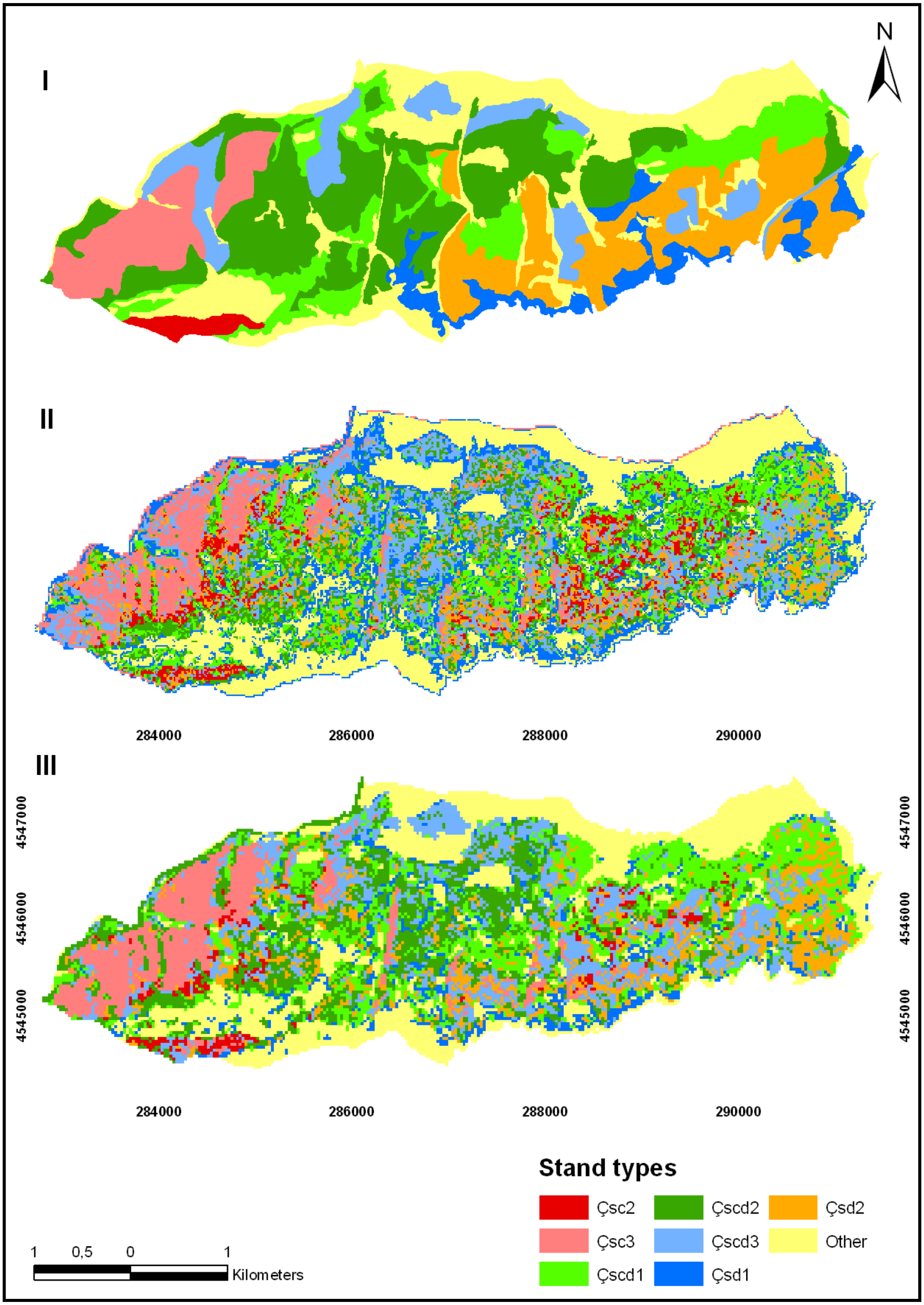

Figure 3. Maps of stand types generated from I) forest cover type map II) Landsat 7 ETM+ (15 m) image and III) Landsat 7 ETM+ (30 m) image.

Table 7. Changes in crown closure class in forest cover type map, Landsat 7 ETM+ (15 and 30 m) images and spatial analysis.

Crown closure**	Forest cover type map		Landsat 7 ETM (15 m)						Landsat 7 ETM (30 m)					
	ha	%	ha	%	Image accuracy		Spatial accuracy		ha	%	Image accuracy		Spatial accuracy	
					(+/-)	%	ha*	%			(+/-)	%	ha*	%
1	311.1	18.5	344.7	20.5	-33.6	2.0	134.1	38.9	373.9	22.2	-62.8	3.7	148.7	39.8
2	711.4	42.3	610.6	36.3	100.8	6.0	431.5	70.7	691.1	41.1	20.3	1.2	467.1	67.6
3	275.7	16.4	274.2	16.3	1.5	0.1	164.4	60.0	302.8	18.0	-27.1	1.6	170.1	56.2
Other	384.6	22.8	453.3	26.9	-68.7	4.1	323.5	71.4	315.0	18.7	69.6	4.1	253.6	80.5
Total	1682.8	100.0	1682.8	100.0	0.0	-	1053.5	62.6***	1682.8	100.0	0.0	-	1039.5	61.8***

*Classified as a same area of spatial configuration in both forest cover type map and satellite image.
**1: Low crown closure, 11 to 40%; 2: medium crown closure, 41 to 70%; 3: full crown closure, 71 to 100% Others, forest openings, agriculture and range area.
***Spatial accuracy according to spatial analysis. Spatial achievement percentage= (True classification as a same area of spatial configuration in both forest cover type map and Landsat 7 ETM+ image / Total area) x 100: (1053.5/1682.8)x100 = 62.6%.

Table 8. Changes in development stage classes in forest cover type map, Landsat 7 ETM+ (15 and 30 m) images and spatial analysis.

Development stage**	Forest cover type Map		Landsat 7 ETM (15 m)						Landsat 7 ETM (30 m)					
	ha	%	ha	%	Image accuracy		Spatial accuracy		ha	%	Image accuracy		Spatial accuracy	
					(+/-)	%	ha*	%			(+/-)	%	ha*	%
c	162.1	9.6	290.0	17.2	-127.9	7.6	113.9	39.3	298.1	17.7	-136.0	8.1	130.5	43.8
d	1136.1	67.5	930.6	55.3	205.5	12.2	834.6	89.7	976.6	58.0	159.5	9.5	874.5	89.5
Other	384.6	22.9	462.2	27.5	-77.6	4.6	328.3	71.0	408.1	24.3	-23.5	1.4	310.3	76.0
Total	1682.8	100.0	1682.8	100.0	0.0	-	1276.8	75.9***	1682.8	100.0	0.0	-	1315.3	78.2***

*Classified as a same area of spatial configuration in both forest cover type map and satellite image.
**c: Mature area, average dbh 20 to 35.9 cm; d: overmature, average dbh >36 cm; Other: forest openings, agriculture and range area.
***Spatial accuracy according to spatial analysis. Spatial achievement percentage= (True classification as a same area of spatial configuration in both forest cover type map and Landsat 7 ETM+ image / Total area) x 100: (1276.8/1682.8) x 100=75.9%.

a case is that the full crown closure is more homogenous than the low crown closure areas resulting in similar reflectance values of full crown closure stands in planning unit.

Furthermore, the development stages were mapped (Figure 5) and analyzed using the area statistics (Table 8) obtained from FCTM, Landsat 7 ETM+ with 15 and 30m spatial resolution images. In this study, mature-overmature stage is evaluated in overmature class. The mature stage was the most successfully classified in both 15 and 30-m resolution Landsat 7 ETM+ images. The areas of mature and overmature classes obtained from forest cover type map and classified Landsat 7 ETM+ with 15 and 30 m spatial resolution images were much similar to each other. When all development stages were evaluated, the classify-cation accuracy of development stage is acceptable in both Landsat images.

There is an increasing need to analyze the spatial structure of forests ecosystem and develop means by which spatial objectives and constraints can be explicitly accommodated in forest planning and decision making process (Bettinger and Sessions, 2003; Başkent and Keleş, 2005). The spatial arrangement of harvest scheduling and decision making has become most important component for forest management planning process. Such effort in forest management model development has altered to better recognize

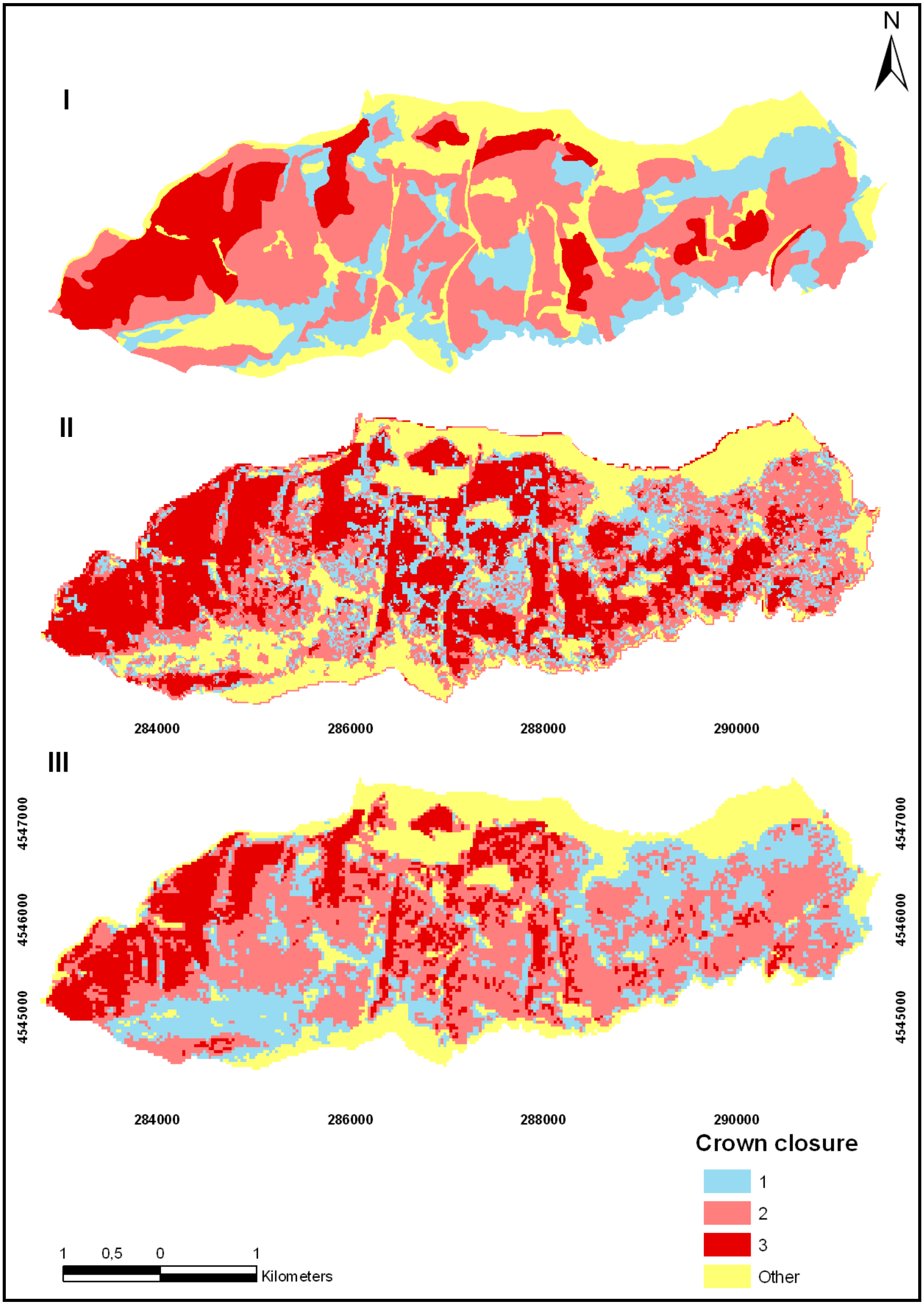

Figure 4. Maps of crown closure generated from I) forest cover type map II) Landsat 7 ETM+ (15 m spatial resolution) image and III) Landsat 7 ETM+ (30 m spatial resolution) image.

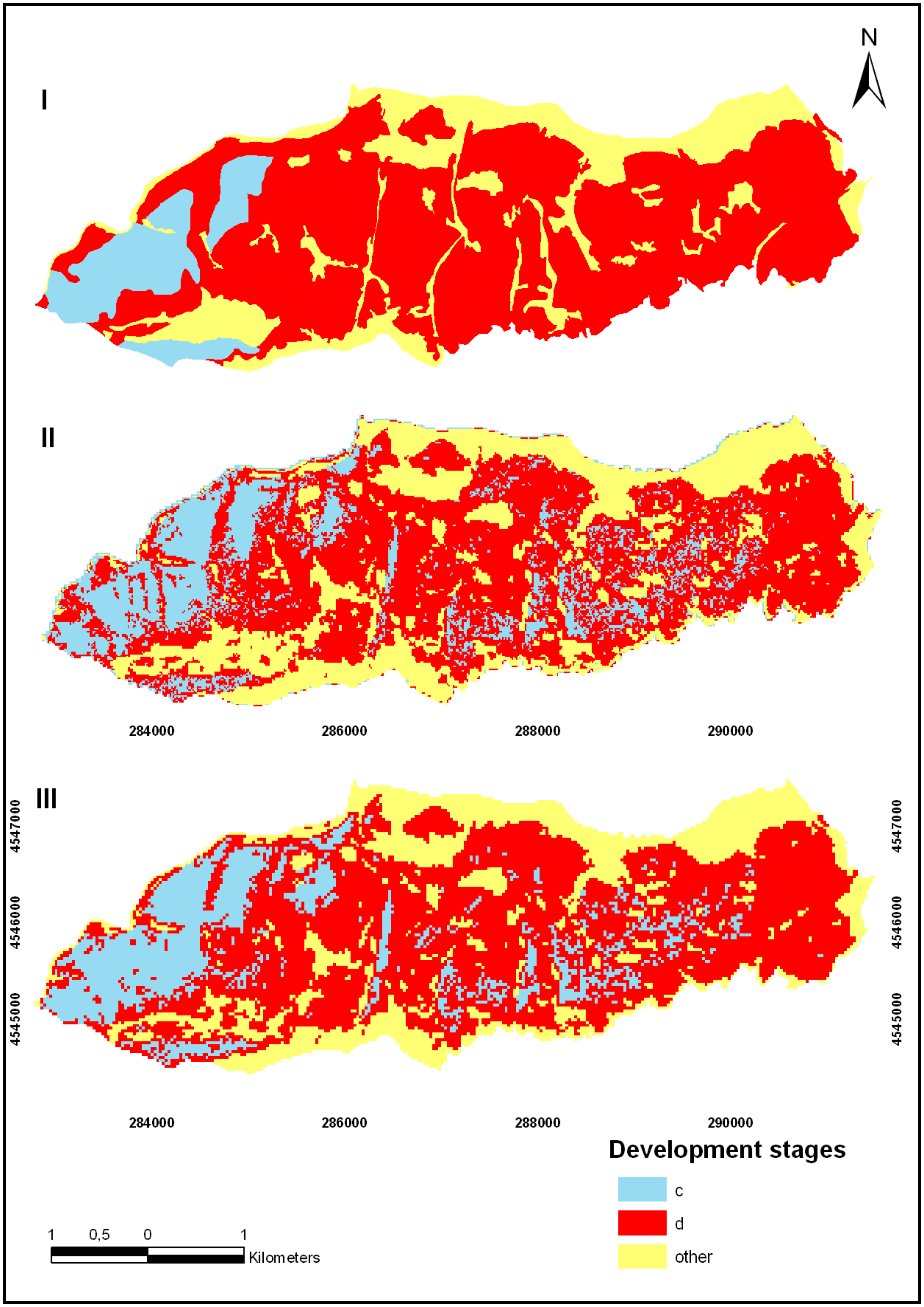

Figure 5. Maps of development stages generated from I) forest cover type map II) Landsat 7 ETM+ (15 m spatial resolution) image and III) Landsat 7 ETM+ (30 m spatial resolution) image.

spatial structure (Borges and Hoganson, 1999). Spatial forest planning focuses on the forest management activities such as harvesting activities and silvicultural prescriptions, and the specific tools used to develop, apply, and assess spatial forest plans and alternative strategies (Bettinger and Sessions, 2003). To make out better decision making in forest planning, evaluation of all forest values, silvicultural prescriptions and alternative policies, spatially explicit stand parameters such as development stages, crown closure and stand type class need to be classified correctly. So far, simple image differences among classes have been evaluated and now the spatial comparison of stand parameters has become crucial in conducting forest management planning.

Polygon themes obtained from FCTM map and Landsat 7 ETM+ images were overlaid into each other and areas that are spatially in the same or different classes in FCTM, 15-m resolution Landsat 7 ETM+ image (Figure 6) and 30 m. resolution Landsat 7 ETM+ images (Figure 7) were determined using ArcGIS 9.3 software to analyze the spatial structure of forest landscape as well as stand parameters such as stand types, crown closures and development stages. According to the results of spatial analyses of stand type classes classified in 15 m resolution Landsat 7 ETM+ image, 8.8 ha Çsc2 (10.5%), 75.3 ha Çsc3 (53.2%), 36.9 ha Çsd1 (15.1%), 56.0 ha Çsd2 (37.2%), 74.4 ha Çscd1 (29.5%), 192.6 ha Çscd2 (65.0%), 46.5 ha Çscd3 (27.3%) and 266.9 ha other class (77.5%) areas were spatially classified successfully. In other words, 192.6 ha Çscd2 was in the same spatial configuration size, shape and spatial configuration in both FCTM and 15-m resolution Landsat 7 ETM+ image. Although, Çsc3 class was the most successfully classified in Landsat 7 ETM+ image according to traditional image classification. In fact, Çscd2 class was the most successfully classified according to spatial analysis. In other words, Çsc3 class was 139.4 ha in forest cover type map, while it was 141.6 ha classified in 15-m resolution Landsat 7 ETM+ image. There was only 2.2 ha area difference between stand type map and classified Landsat image. Hence, although it appears that Çsc3 class was the most successfully classified, however, it is not. The spatial analysis indicated that of the 139.4 ha Çsc3 in FCTM, only 75.3 ha was determined in Çsc3 class; the rest of 64.1 ha was in fact in other stand type classes, indicating significant misrepresentation of sites. Çsc3 was more successfully classified than Çscd2 according to traditional image classification. However, Çscd2 was more successfully classified than Çsc3 according to spatial analysis in 15 m resolution Landsat 7 ETM+ image. Çscd2 class was the most successfully classified in both 15 and 30 m resolution Landsat 7 ETM+ images according to spatial analysis. Evaluated 30 m resolution Landsat 7 ETM+ image, Çsd1 class was the most successfully classified according to traditional image classification, in fact, Çsc3 class was the most successfully classified according to spatial analysis. Spatial analysis clearly showed that the important thing in classification of satellite image was spatial accuracy instead of image accuracy. Furthermore, Çsd1 class was not only the most successfully classified according to traditional image classification but also the worst classified according to spatial analysis. The success of spatial analyses for stand type was 45.0 and 47.6% in Landsat ETM+ with 15 and 30 m images, respectively.

In addition, the results of crown closure according to spatial analysis are quite similar to that of stand type. While the full crown closure class was the most successfully classified according to image accuracy, medium crown closure was the most successfully classified according to spatial accuracy in 15 m resolution Landsat 7 ETM+ image. In other words, medium crown closure class was more successfully classified than full crown closure class according to spatial analysis. However, the medium crown closure class was the most successfully classified in 30 m resolution Landsat 7 ETM+ image according to both image accuracy and spatial accuracy. We therefore concluded that image accuracy and spatial accuracy is similar to each other in both 15 and 30 m resolution Landsat ETM+ images compared to stand type classification. Taking into consideration of all classes in crown closure, spatial accuracy of crown closure class was 62.6 and 61.8% in Landsat ETM+ with 15 and 30 m images, respectively. Moreover, according to the results in development stage classes, while mature class was the most successfully classified according to image accuracy, overmature class was the most successfully classified according to spatial accuracy in both Landsat ETM+ with 15 and 30 m images. Of the 290.0 ha overmature class in classified Landsat ETM+ with 15 m image, nearly 113.9 ha was determined in overmature class correctly according to spatial accuracy. In other words, nearly 176.1 ha was in fact in other development stage class indicating erroneous interpretation of sites. Spatial accuracy of development stage class was 75.9 and 78.2%, in Landsat ETM+ with 15 and 30 m images, respectively.

The results obtained herein are quite comparable to similar other research results. Pilger et al. (2002) classified crown closure using Landsat TM with 0.56 Kappa statistics. Similarly, Günlü et al. (2008) classified stand type using Landsat / ETM+ in Ormanüstü planning unit, Turkey with 78% accuracy and 0.76 the kappa statistics; crown closure with 81% accuracy and 0.86 the kappa statistics; development stage with 92% accuracy and 0.89 the kappa statistics. Evaluated for accuracy and kappa statistics value, stand type, crown closure and development stage in this study were more accurately classified than that in Günlü et al. (2008)'s study. Also, Günlü et al. (2008) found that spatial accuracy of crown closure class, development stage class and stand type class were found as 64.2, 72.2 and 32.8%, respectively. According to spatial analysis, spatial accuracy of both

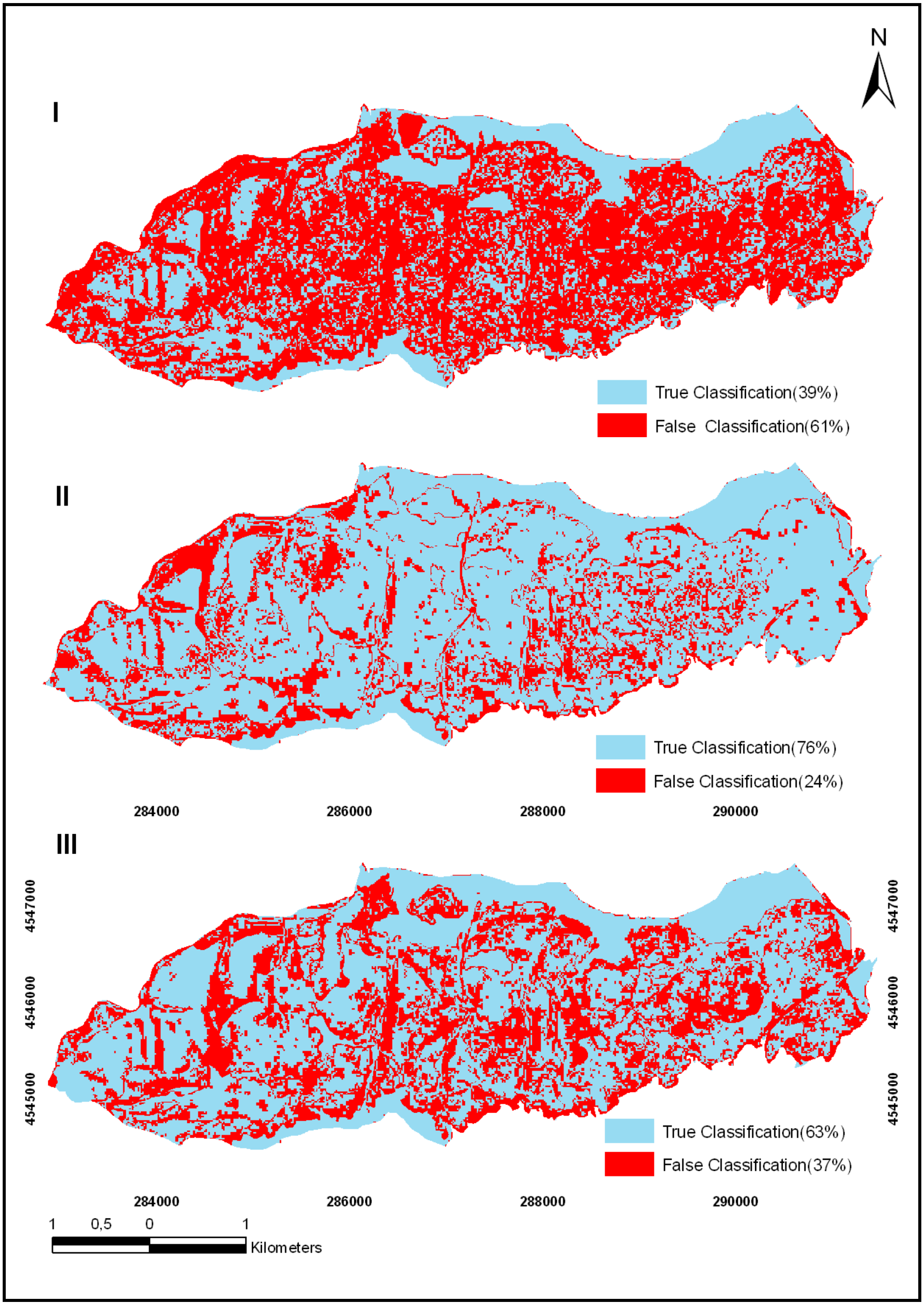

Figure 6. Comparisons of spatial analysis in Landsat ETM+ (15 m) image with I) forest cover type map II) development stages and III) crown closure.

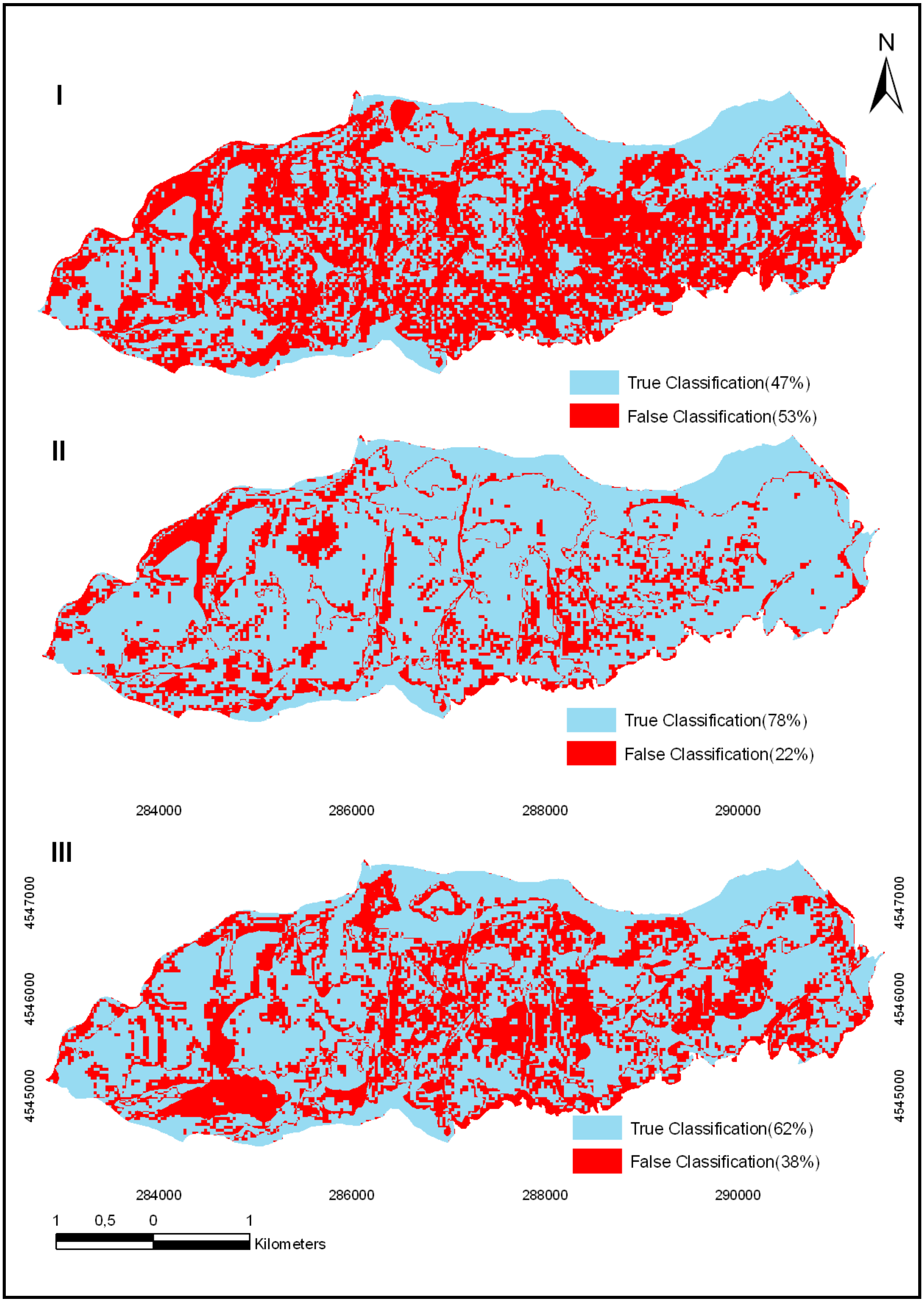

Figure 7. Comparisons of spatial analysis in Landsat ETM+ (30 m) image with I) forest cover type map II) development stages and III) crown closure.

studies for crown closure and development stage was nearly similar. However, stand type and development stage in this study were more accurately classified than Günlü et al. (2008)'s study. One reason relates to the structural complexity of a stand type in Ormanüstü planning unit with much more stand types than Yalnızçam planning unit. Also, all stands in Yalnızçam are pure stand while most of the stands in Ormanüstü are mixed stands. Therefore, this situation may have produced low classification accuracy.

The spatial analysis of classification show that spatial accuracy in classification of satellite images was more important than image accuracy as there is a widespread acceptance of spatial planning approach. Classification accuracy is not the only criteria when it comes to testing the accuracy assessment of satellite images. It could be misleading when considering only the accuracy assessment. Therefore, in addition to classification accuracy, the image accuracy and the spatial accuracy both have to be considered. It does not necessarily mean that the classification accuracy is successful when the real area is close enough to area obtained from classification. In order to obtain the real accuracy, it is important to know how well the areas retrieved from classification according to spatial accuracy. According to crown closure, for example, there is only 1.5 ha area difference between stand type map (275.7 ha) and classified Landsat image (274.2 ha) for the full crown closure (700 to 100%) class. That is to say, classification appears to be successful. However, only 164.4 ha of classified full crown closure class (274.2) was classified successfully according to spatial analysis. In other words, only 164.4 ha was the same spatial configuration in both forest cover type map and Landsat 7 ETM+ (15 m) image, while 109.8 ha was in fact in other crown closure classes, indicating significant misrepresentation of sites.

The 15 m resolution Landsat 7 ETM+ image showed more appropriate results than 30 m resolution Landsat 7 ETM+ image for the classification of stand type parameters according to classification accuracy. A broad level analysis showed that crown closure class and development stage class were more successfully classified than stand type class according to classification accuracy in both Landsat images as there were lots of stand types with heterogeneous structure. Stand type and crown closure were more successfully classified in 15 m Landsat 7 ETM+ image than 30 m Landsat 7 ETM+ image. Moreover, according to the spatial analysis, 30 m Landsat 7 ETM+ image showed more appropriate results than 15 m Landsat 7 ETM+ image for the classification of stand type parameters. A broad level analysis showed that stand type class was worst classified according to classification accuracy and spatial accuracy in both Lands at images. Though, satellite data should be used for stratification of stand type class in Turkey, some specific classification problems may need to be addressed. Due to climatic and topographic conditions, Turkey has a range of vegetation types that are distributed according to altitude and latitude. Furthermore, forest structure in Turkish forests has generally irregular structure and shape due to mismanagement and inappropriate silvicultural treatments. Stand type discrimination was based on three criteria: mixed stand, crown closure and development stages. These factors generally may make possible complication of the stratification of forest cover in the computer-aided classification and result in misclassification (Başkent et al., 2005; Özdemir et al., 2007). Some studies (Hyvonen et al., 2005, Chubey et al., 2006, Kayitakire et al., 2006) reported promising results in the estimation of forest variables using spectral features of high resolution satellite data in homogeneous stands in boreal forests. However, estimating forest structure attributes using spectral features of remotely sensed imagery may be difficult in complex ecosystems due to stand heterogeneity and mixed stand type.

Conclusion

Landsat ETM+ images have the potential for estimating forest stand attributes such as development stages, crown closure and stand type. The performances of spatial and image classification accuracy of 15 and 30 m Landsat 7 ETM+ images were compared for stand type parameters. Stand parameters determined by forest cover type map and remote sensing methods (Landsat images) were compared to evaluate the potential use of the remote sensing methods. The results indicate that 15 m Landsat 7 ETM+ image can lead to more accurate mapping of stand types, development stages and crown closures as defined in forest management regulations than could the 30 m Landsat 7 ETM+ image according to classification accuracy. However, 30 m Landsat 7 ETM+ image have more appropriate results than 15 m Landsat 7 ETM+ image according to spatial accuracy. This study revealed the differences between image accuracy and spatial accuracy of stand parameters in both Landsat image. The differences were quite significant and should be taken into consideration in forest management planning. The results also indicated that the Landsat 7 ETM+ image was not suitable for determining only stand types due to heterogeneity in forest stands in the study area. However, Landsat 7 ETM+ has enough accuracy for development stage and crown closure.

Stand parameters such as stand types, development stages and crown closures derived from Landsat ETM+ data are significantly cheaper than maps produced using aerial photography and field survey. However, stand types may not completely be recognized by Landsat ETM+ satellite data alone. More also, while classifications using Landsat ETM+ data provide less detail information, Landsat ETM+ imagery produced reasonable results that would be useful for broad-scale forest inventories and strategic decisions in which no detailed information is required.

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