Forest stand delineation using Ikonos image and object based image analysis

Ulaş Yunus Özkan [1*] , Ahmet Yeşil [1]

[1*] Istanbul University, Faculty of Forestry, Department of Forest Management, 34473, Istanbul, Turkey

[*] **Corresponding author e-mail (İletişim yazarı e-posta):** uozkan@istanbul.edu.tr

Abstract: Together with the developments in satellite technology, it is considered that high resolution satellite data may be used as an alternative source of information to aerial photos in delineation of stand types. The study aims to reveal how detailed one could work to generate the map of stand types which form the basis of forest management plans using IKONOS satellite data. For this purpose, object based classification was applied to satellite image. Firstly, image segments which represent target objects were generated applying image segmentation algorithm to the satellite image. The image segments generated at three different levels according to different scale parameters and homogeneity criteria were classified according to standard nearest-neighbor approach. Classification accuracy was determined using both the stand maps of study area and ground control points. Overall accuracy was calculated as 58% (Kappa=0.54). Accordingly, it was understood that it was not possible to generate a stand map with sufficient accuracy from the IKONOS satellite image using automatic classification.

Keywords: Ikonos, forest inventory, image segmentation, object based classification, stand map

Ikonos görüntüsü ve obje bazlı görüntü analizi kullanılarak meşcere tiplerinin ayrılması

Özet: Uydu teknolojisindeki gelişmelerle birlikte yüksek çözünürlüklü uydu verilerinin, meşcere tipleri ayrımında hava fotoğraflarının yerine alternatif bir bilgi kaynağı olarak kullanılabileceği düşünülmektedir. Çalışmada, IKONOS uydu verisinden amenajman planlarının temelini oluşturan meşcere tipleri haritasını düzenlemek için ne kadar ayrıntıya gidilebileceğinin ortaya konulması amaçlanmıştır. Bunun için uydu görüntüsüne obje bazlı sınıflandırma işlemi uygulanmıştır. Uydu görüntüsüne öncelikle görüntü dilimleme işlemi uygulanarak, hedef objeleri temsil edecek görüntü dilimleri oluşturulmuştur. Farklı ölçek parametreleri ve homojenlik kriterlerine göre üç farklı seviyede oluşturulan görüntü dilimleri, standart en yakın komşu yaklaşımına göre sınıflandırılmıştır. Sınıflandırma sonuçlarının doğruluk değerlendirmesi çalışma alanına ait meşcere tipleri haritasından ve arazi çalışmaları sırasında alınan denetim noktalarından faydalanılarak yapılmıştır. Meşcere tipleri düzeyinde yapılan sınıflandırma sonuçlarının toplam doğruluk değeri %55 (Kappa=0.52) olarak hesaplanmıştır. Buna göre, IKONOS uydu görüntüsünden otomatik sınıflandırma ile yeterli doğrulukta meşcere tipleri haritasının üretilmesinin mümkün olmadığı anlaşılmıştır.

Anahtar Kelimeler: Ikonos, orman envanteri, görüntü dilimleme, obje bazlı sınıflandırma, meşcere haritası

1. INTRODUCTION

People's views of forests and mentality to utilize such resources vary depending on differences in their socio-cultural life styles within society. It is required to operate the forests in accordance with sustainable forest management (SFM) principles in order to meet such different requirements of different parts of society in a continuous manner. Updated and reliable information is needed with respect to current situation of forest resources in order to carry out sustainable forest management. Such information is provided using Forest Inventory system (Asan and Yeşil, 2005; Günlü et al., 2008; Stoffels et al., 2012).

Various sources of information such as terrestrial measurements, maps, aerial photos and satellite data are used to identify forest ecosystems and their sub-communities (Köhl, 1993; Leboeuf and Fournier, 2013; Huang and Lin, 2015). Terrestrial measurements and observations are the most common source of information used in forest inventory. It is possible to perform an inventory study based completely on terrestrial measurements in order to identify stand borders and determine wood volume. However, terrestrial measurements and observations are time-consuming and expensive methods. Moreover, forest inventory based on terrestrial measurements and observations often fail at obtaining spatial data, updating at frequent intervals and supporting visualization (Corona et al., 2003; Holopainen and Kalliovirta, 2006; Ozdemir and Karnieli, 2011; Arockiaraj et al., 2015). Therefore, combined inventory method combining aerial photos and terrestrial measurements has been used in Turkey since 1963 in order to reduce terrestrial studies in forest management planning and obtaining spatial data in a more accurate and easier way (Eler, 2001).

Classical approach in distinguishing between stand types is based on visual interpretation of 3D aerial photos. However, the success of this method depends on experience of interpreters. Some studies indicate that there might be substantial differences between the results of aerial photo interpretations from different interpreters (Gong et al., 1999; Tuominen and Pekkarinen, 2005). Once the first satellite of LANDSAT programme was launched in 1972, it was considered that satellite image might be an alternative source of information to aerial photo. It was thought that reliable results can be obtained with respect to land features with less cost and in a shorter time by analyzing reflectance values obtained through different spectral channels in lands too vast to interpret visually in the computer environment (Asan, 1999; Asan et al., 2001, Köse et al., 2002).

With the developments in remote sensing technology, production of new sensors providing high resolution image, significant decreases in price of satellite data and developments in digital image processing techniques increased the researches which claimed satellite images could be alternative to aerial photos (Plattier et al., 2006; Hajek, 2006; Rego et al. 2007; Ozdemir, 2008; Kim et al., 2011; Immitzer et al., 2012; Dalponte et al., 2014; Kamal et al., 2015; Arockiaraj et al., 2015). Obtaining high resolution satellite data and participation of them in forest inventory brought together some issues causing difficulty in image analysis such as mixed pixels. Mixed pixels are defined as pixels containing multiple groups of plant cover or land usage classes (Hung, 2002). Indeed, a single tree may comprise of spectral values of many pixels in high resolution satellite images. Therefore, there might be big changes in reflectance within stands and classification accuracy might decrease due to spectral irregularity of species while obtaining map of stand types from satellite image using pixel based classification method. Such problems were partially overcome with object based classification approach developed as an alternative to pixel based classification (Antunes et al., 2003; Özdemir, 2004; Drăguţ et al., 2010)

The study aimed to reveal how detailed one could work to arrange the map of stand types which form the basis of forest management plans using Ikonos satellite data considered as alternative source of information in place of aerial photos. For this purpose, Ikonos satellite images were classified automatically according to object based classification method and results were compared to the stand maps obtained using aerial photo.

2. MATERIAL AND METHODS

2.1 Study Area

The study are located between 29° 04' 25" - 29° 57' 32" east longitudes; 40° 48' 12" - 41° 14' 10" north latitudes according to Greenwich cover borders of Sahilköy, Şile, Ağva, Yeşilvadi, Beykoz, Kanlıca, Ömerli, Alemdağ, Sultanbeyli, Kartal Forest Sub-District Directorates (Figure / Şekil 1). 99867 ha of study area with a land of 180155 ha is forest land. Such forest lands comprise of stands with many species as pure or mixed such as *Fagus orientalis, Carpinus betulus, Quercuss* sp., *Castanea sativa, Pinus pinaster, Pinus radiata, Pinus nigra, Arbutus unedo, Phillyrea latifolia, Erica arborea, Pyrus* sp.
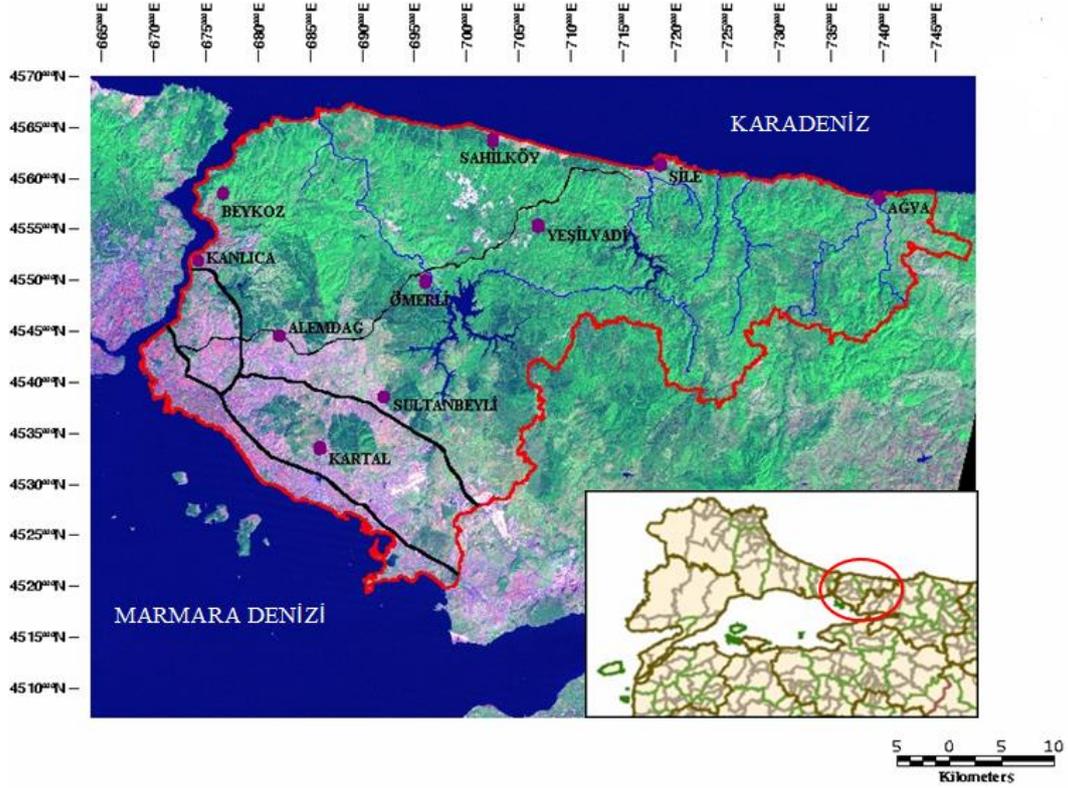
Figure 1. Geographical location of study area
Şekil 1. Çalışma alanının coğrafi konumu

2.2 Satellite Data

Ikonos satellite image with a spatial resolution of 4x4 m dated June 2006 was used in this study. Ikonos satellite image has 2 detectors, PAN and Multispectral. In multispectral detector with 4 bands, the first three bands receives image on visible section and the 4th band receives image on infra-red (NIR) section (0.45-0.53, 0.52-0.61, 0.64-0.72, 0.77-0.88 μm). It has 4 m geometric, 11-bit radiometric and 3.5-5 days temporal resolution and is capable of three dimensional (stereo) receiving (Yener, 2005).

Firstly, geometric correction was applied to satellite image using 1/25000 scaled topographical maps and 1/5000 scaled present maps. Geometric conversion error was calculated as less than 5 m. Vegetation indices were developed using original bands to provide detailed data with respect to areas covered with vegetation in multispectral images (Jensen, 1996). The most common of them is the normalised difference vegetation index (NDVI) (Ozdemir, 2014). In addition to NDVI, Band Ratio Index (RVI) and Transformed Vegetation Index (TVI) were generated in the study (Table / Tablo 1). Such new data groups generated were used both while generating image segments and classifying images.

Table 1. Vegetation indexes obtained from the satellite image
Tablo 1. Uydu görüntüsünden üretilen vejetasyon indeksleri

RapidEye	Equation	Author
NDVI	$\dfrac{NIR - RED}{NIR + RED}$	Rouse et al., 1974
RVI	$\dfrac{NIR}{RED}$	Birth and McVey, 1968
TVI	$100\,x\,(\dfrac{NIR-RED}{NIR+RED+0,5})^{0,5}$	Deering and Rouse, 1975

2.3 Classification of Satellite Image

Object based classification approach was employed in classification of satellite images in the study. Object based classification was developed as an alternative to pixel based classification in order to increase accuracy of classification in classification of high resolution satellite views such as Ikonos. Conversion of view into meaningful objects is the basis of object based classification. Classification is performed based on image objects instead of pixels (Antunes et al., 2003; Drăguţ et al., 2010). Therefore, object based classification firstly starts with an image segmentation by grouping the neighbour pixels within homogeneous areas (Figure / Şekil 2). Grouping starts with a pixel shaping an image object and continues until reaching the criteria set by the user (Antunes et al., 2003; Blaschke et al., 2004; Marcal et al., 2005; Definiens, 2006).
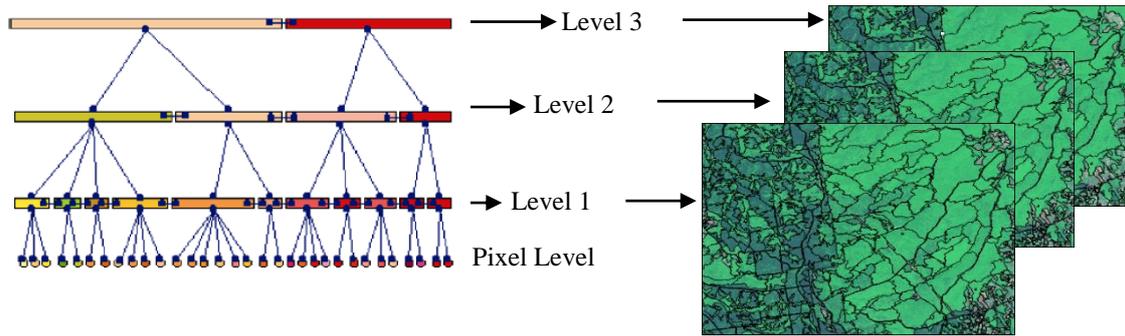

Figure 2. Image segmentation on a hierarchical order
Şekil 2. Hiyerarşik olarak görüntü dilimleme

In image segmentation, firstly the spectral bands to use must be selected and weights of such bands in the segmentation must be defined. Then, the scale parameter defining the average size of image objects to be generated and colour and shape criteria, being the homogeneity criteria must be identified (Rego, 2003; Ozdemir et al., 2008). Four bands of Ikonos satellite images (Blue, Green, Red and Near Infra-red) and NDVI Vegetation index were used for image segmentation in study. Weights of such bands in the segmentation were taken at an equal level. Scale parameters and homogeneity criteria were identified to enable generating the image segments to represent target objects. It was determined with many systemic trial-and-error actions which were repeated until representation rate of target objects of image objects obtained reached an acceptable level.

Classification of images follows image segmentation in object based classification. In additional spectral features of objects, shape and texture features are also utilized in the classification (Definiens, 2006). Object based classification can be performed with two different classification methods, standard nearest neighbour and fuzzy logic. It is suggested that fuzzy logic does not work well since use of many features is required for classification algorithm where the number of classes is too big and thus classification can be performed more easily with the nearest neighbour approach (Maxwell, 2005). Standard nearest neighbour approach which provides a faster and simplified classification process for the user was chosen in the study since there were many subclasses in classification to be performed at stand level. Classification process contains a hierarchical order performed at 3 different levels according to different scale parameters. This hierarchical order contains classification studies starting with classification of study area to 3 general land usage classes and ending with subclasses corresponding to types of stand in management plans. General procedure in hierarchical classification covers defining the classes easier to deduct first and then using such classes as additional information while creating the other classes (Rego et al., 2007).

2.4 Accuracy Assessment of Classification Results

The final step of image classification includes accuracy assessment of thematic map generated as a result of classification. Accuracy of classification results in remote detection is described as the conformity between selected reference data and classified satellite data. Therefore, accuracy assessment is performed by comparing the reference data of study area, accuracy of which is known certainly (stand maps, ground control points based on GPS measurements) with classified satellite image. For this purpose, an error matrix is obtained by comparing the image objects selected over classified satellite data with the reference data corresponding to the same. Columns of error matrix represent reference data while lines represent classified image. This error matrix is analyzed statistically with Kappa coefficient. Kappa coefficient is calculated using sums of lines and columns in error matrix and the items on diagonal of error matrix and gets values between 0 and 1 (Jensen, 1996).

$$K = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} \left(x_{i+} \times x_{+i} \right)}{N^2 - \sum_{i=1}^{r} \left(x_{i+} \times x_{+i} \right)} \tag{1}$$

Where; K is Kappa coefficient, r is number of lines in matrix, x_{ii} is diagonal value at line i and column i, x_{+i} is total value of column i, x_{i+} is total value of line i, N is total number of samples.

3. RESULTS AND DISCUSSIONS

The appropriate image segments of 3 hierarchical levels generated in study were revealed using trial-and-error method which was repeated multiple times (Figure / Şekil 3). The most appropriate scale parameters and homogeneity criteria determined as a result of such repetitions are given in Table / Tablo 2.

When obtained image segments are evaluated, it is observed that appropriate image objects representing target objects can be obtained when rate of colour criteria is employed higher than shape criteria (0.9/0.1, 0.8/0.2) as homogeneity criteria. The results obtained are in line with the similar studies carried out earlier. In majority of such studies, it is found that colour criteria is employed higher than shape criteria while creating image segments representing target objects according to objective of study. (Herold et al., 2002; Laliberte et al., 2004; Mathieu and Aryal, 2005; Hajek, 2006; Asan et al., 2007; Furuya et al., 2007; Mathieu et al., 2007; Renaud et al., 2007; Chen et al., 2009)

Table 2. Scale parameters and homogeneity criteria determined
Tablo 2. Kararlaştırılan ölçek parametreleri ve homojenlik kriterleri

Satellite Image	Level	Scale Parameter	Homogeneity Criteria	
			Colour/Shape	Smoothness/Compactness
Ikonos	I	100	0.8/0.2	0.5/0.5
	II	125	0.8/0.2	0.5/0.5
	III	150	0.9/0.1	0.5/0.5

A: 150   B: 0.9   C: 0.1   A: 150   B: 0.1   C: 0.9

A: 125   B: 0.8   C: 0.2   A: 125   B: 0.2   C: 0.8

A: 100   B: 0.8   C: 0.2   A: 100   B: 0.2   C: 0.8
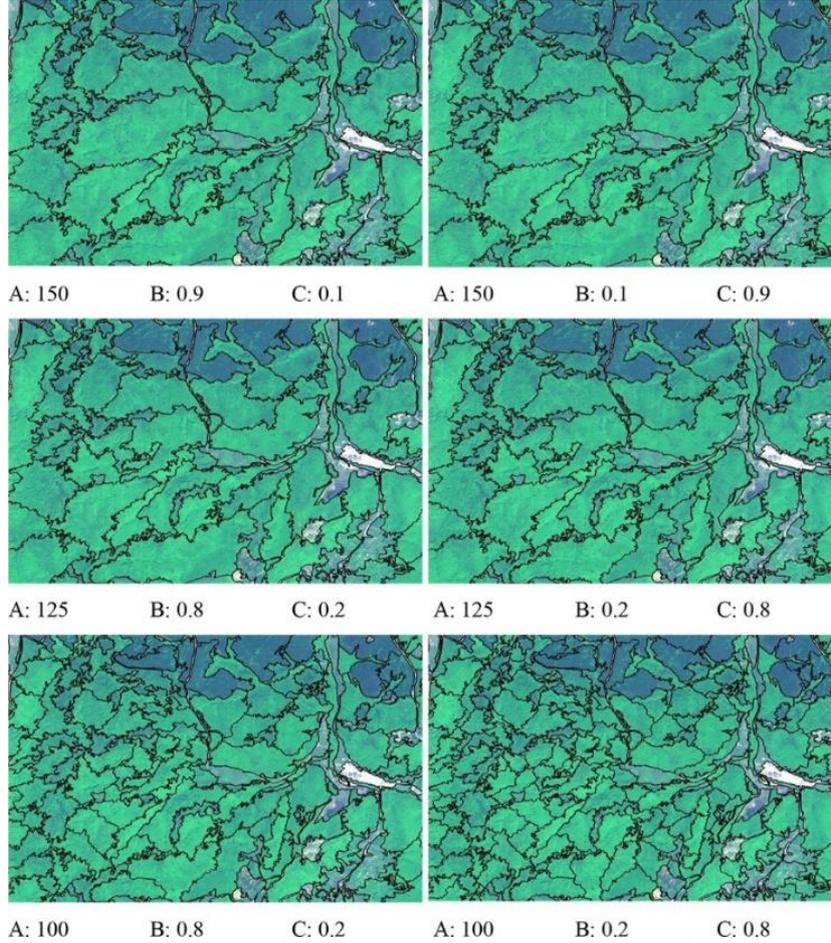
Figure 3: Image segments according to different scale parameters and colour/shape factors (A: scale parameter B: colour factor C: shape factor)

Şekil 3. Farklı ölçek parametreleri ve renk/şekil faktörlerine göre görüntü dilimleri (A: ölçek parametresi B: renk faktörü C: şekil faktörü)

Classification process was performed at 3 different levels according to different scale parameters after image segmentation processes. Firstly, satellite image was classified to separate study area into 3 general land usage classes, namely "*forest - non forest - water*" (Figure / Şekil 4). 4 bands of Ikonos satellite image (red, green, blue, near infra-red) and NDVI were used in classification. Classification was performed only based on spectral features of objects since spectral features of "*forest - non forest - water*" classes were highly different from one another in general. Given the circumstances of Turkey, it is observed that *"forest - non forest - water"* classes can be distinguished easily in satellite images such as Landsat and Spot which have rougher spatial resolution compared to Ikonos satellite image in the studies carried out by Yeşil et al. (1999), Musaoğlu (1999), Özkan (2006), Koç and Yener (2006), Asan et al. (2007), Gunlu et al. (2009). Therefore, accuracy assessment was not performed on the classification results obtained initially and only visual evaluation was employed. During visual observations, it was observed that regeneration areas, clearance in forest, degraded forest and non-forest areas were mixed with each other to a high extent, however classification result was insufficient.
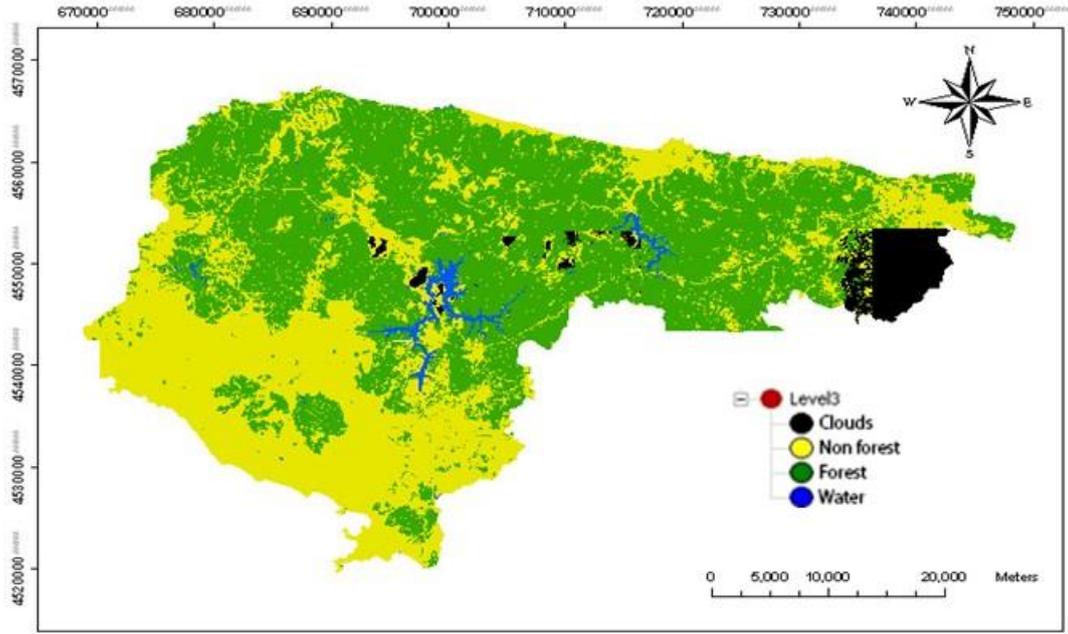
Figure 4. Classified satellite image (I. Stage)
Şekil 4. Sınıflandırılmış uydu görüntüsü (I. Aşama)

Following the first level classification, forest lands were divided into 5 sub-classes which were more homogeneous using the nearest neighbour method again, namely *broadleaved, conifer, mixed broadleaved mixed, unproductive*. Variables concerning spectral and shape features of objects were used for the second level classification. 18 out 74 variables were defined as the most appropriate combination using Feature Space Optimization algorithm of Definiens software (Figure / Şekil 5). Second level classification results are given in Figure / Şekil 6. The stand maps and ground control points (GCPs) received during fieldwork were utilized as reference data in accuracy assessment performed to decide whether classified satellite image reflects the truth. An error matrix was created using such GCPs (Table / Tablo 3). Classification accuracies are 81% (Kappa=0.75) according to result of accuracy evaluation given in Table / Tablo 3. Classification result was reliable since classification accuracies were higher than 80%.

Table 3. Accuracy assessment of the classified satellite image (Level 2)
Tablo 3. Sınıflandırılmış uydu görüntüsünün doğruluk değerlendirmesi (Seviye 2)

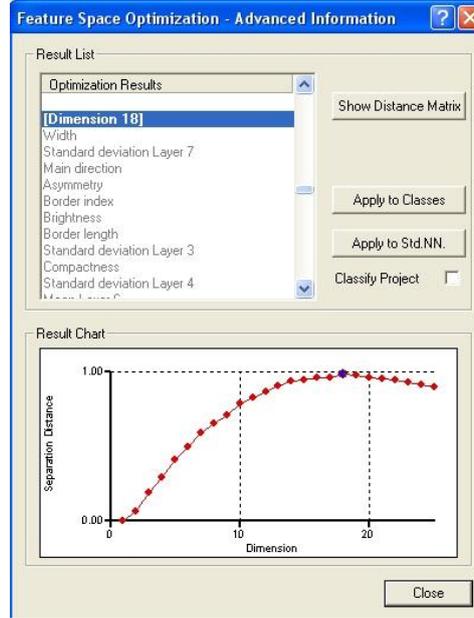| IKONOS CLASSES	REFERENCE DATA						
	Conifer	Broadl.	Mixed broadl.	Mixed	Unpro.	Non forest	Total
Conifer	45			2			47
Broadl		69	14		1		84
Mixed broadl.		12	100		5		117
Mixed	2			4	1		7
Unproductive		2	7		9	6	24
Non forest		4			5	32	41
Total	47	87	121	6	21	38	
Total Accuracy = % 81			Kappa = 0.75				

Figure 5. Determining the variables to use in classification
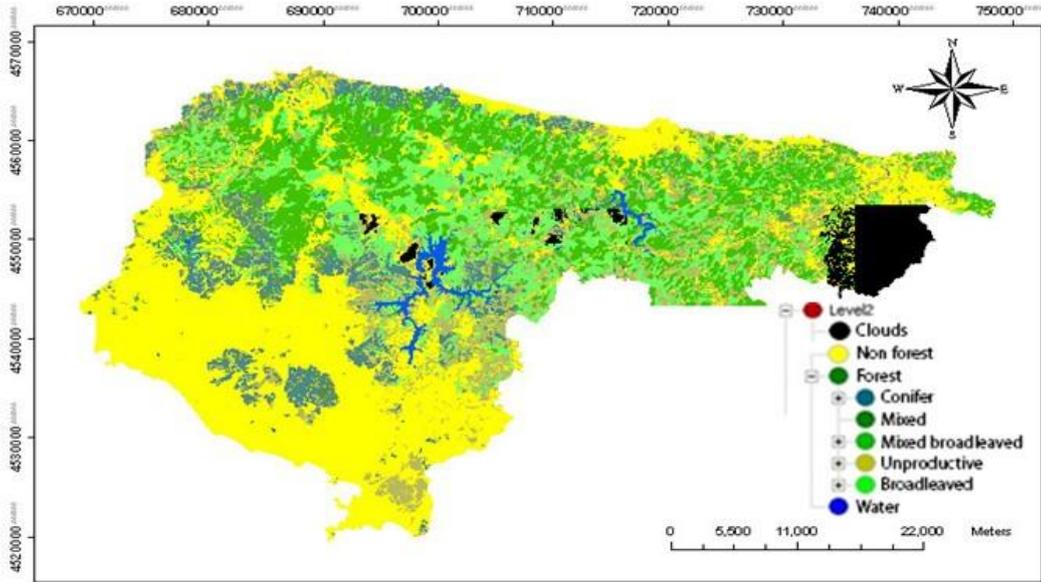Şekil 5. Sınıflandırmada kullanılacak değişkenlerin kararlaştırılması

Figure 6. Classified satellite image (II. Stage)
Şekil 6. Sınıflandırılmış uydu görüntüsü (II. Aşama)

Each of *broadleaved, conifer, mixed broadleaved, mixed* classes were divided into subclasses according to present types of stand in study area. All bands of Ikonos satellite image and vegetation indices were used in classification. Classification was performed based on variables to spectral, shape and texture features of image objects. The most appropriate combination for classification out of such variables were determined using Feature Space Optimization algorithm again. Third stage classification results are given in Figure / Şekil 7 and accuracy assessment of classification results is given in Table / Tablo 4. Total accuracy value calculated as 58% (Kappa=0.54) with respect to classification results was below the acceptable level. Since the image objects of stands at a and ab development stage, which needed to be divided as separate stands due to difference of development stage in study area had similar features, it was not possible to distinguish

them as separate classes with automatic classification. Similarly, stands at b and bc, c and cd stage were not distinguished. Therefore, such stands were combined under the same class during classification. Even if classes comprising of pure broadleaved and pure conifer species were classified relatively with a high accuracy, it was not possible to distinguish the classes comprising of mixed species with the expected accuracy using automatic classification. Mixed stands are also mixed with pure stands depending on rate of mixture. All of such negativities caused calculation of classification accuracy low, as obtained at stand level from Ikonos satellite image using automatic classification.
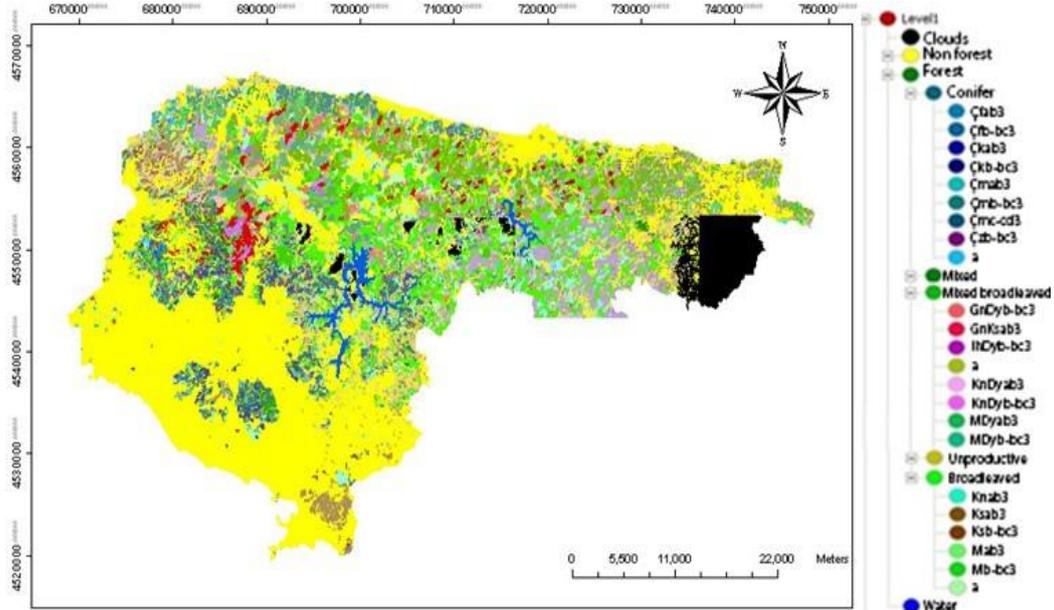

Figure 7: Classified satellite image (III. Stage)
Şekil 7. Sınıflandırılmış uydu görüntüsü (III. Aşama)

Similar results were obtained in distinguishing plant cover classes using high resolution satellite images in former studies performed. In their study conducted using object based classification technique on QuickBird image, Bock et al. (2005) suggested that classification results with the desired accuracy could not be achieved as the number of classes increased. Hajek (2006) evaluated the classification results of original IKONOS satellite image with 4x4 m spatial resolution and Ikonos Pan-Sharpened satellite images with 1x1 m spatial resolution. The average accuracy of classification results with respect to classes at stand level comprising of few species such as Alder, Oak, Spruce, Birch and Larix is calculated as 83% (Kappa=0.80) for Ikonos and 83% (Kappa=0.81) for Ikonos Pan-Sharpened. In the study conducted by Renaud et al. (2007) total accuracy of classification was calculated as 64% (Kappa=0.52) for 15 classes extracted from Ikonos satellite image. Total accuracy of classification performed by reducing to 10 classes was calculated as 77% (Kappa=0.74). It is concluded that it is not possible to obtain maps from Ikonos satellite image as detailed as plant cover maps generated using aerial photos. Kim et al. (2011) classified the forest cover by using Ikonos and overall accuracy of classification performed by using object based classification was calculated as 77% (Kappa=0.73) for 9 classes. In the study conducted by Immetzer et al. (2012), they examined the suitability of WorldView-2 satellite data for the identification of 10 tree species and the overall accuracy for object-based classification was calculated as 82%. In another study conducted by Kamal et al. (2015), they emphasized that there is a need high image spatial resolution, larger object size, and fewer land-cover classes result for a high-accuracy mapping.

As a result of literature review and this study, it is understood that the results obtained with automatic classification of Ikonos satellite image do no render good results as stand maps obtained with traditional visual interpretation of aerial photos. Although image segmentation which forms the first step of object based classification was performed relatively successfully, the success of classification results at stand level was not as high.

608

Table 4. Accuracy assessment of the classified satellite image (Level 1)
Tablo 4. Sınıflandırılmış uydu görüntüsünün doğruluk değerlendirmesi (Seviye 1)

IKONOS CLASSES	REFERENCE DATA																	Total
	Çmab3	Çmb-bc3	Çmc-cd3	Çkab3	Çkb-bc3	ÇkMb-bc3	MDyab3	GnKsab3	MGnab3	MKnab3	KnMab3	MDyb-bc3	Mab3	Mb-bc3	Ksab3	BDy-Di	Non-forest	
Çmab3	4		1		1													6
Çmb-bc3	1	8	2					3								1		15
Çmc-cd3		3	8		1													12
Çkab3		1		2	1													4
Çkb-bc3		2	1	1	5	1												10
ÇkMb-bc3					2	4										1		7
MDyab3							10	1	2	2	2		2	1	1			21
GnKsab3							8	16	4	8	1		3			2		42
MGnab3							1	2	4	2	1					1		11
MKnab3							1	4	2	11	2	1	2			2		25
KnMab3							1			1	4							6
MDyb-bc3							1	1				7		2	1			12
Ma-ab3							1	4	1	6			38	3	2	1		56
Mb-bc3													2	13				15
Ksab3												2			11			13
BDy-Di							1	4	1	1			1		1	9	6	24
Non-forest													4		5		32	41
Total	5	14	11	4	11	7	24	32	14	31	11	9	52	19	16	22	38	

Total Acuuracy = % 58   Kappa = 0.54

4. CONCLUSION

This study evaluated usage potentials of Ikonos satellite image in generating detailed forest maps as a high resolution remote sensing data. For this purpose, object based classification was applied to image segments generated at three hierarchical levels using different scale parameters and homogeneity criteria. Classification was performed based on variables to spectral, shape and texture features of image objects. Classification process started with distinguishing three general land usage classes hierarchically and ended with classification at level of stand types. Although image objects representing target objects were obtained in a relatively successful way with image segmentation, the accuracy of classification results at level of stand types was lower than expected. Therefore, it was understood that it was not possible to delineate stand types with sufficient accuracy from Ikonos satellite image using automatic classification. Considering the success achieved in image segmentation, the possibility to use the borders of image objects obtained automatically with image segmentation in place of draft maps obtained with visual interpretation of aerial photos and manual digitalization should be researched. It is important to compare the real map of stand types generated from draft maps to be obtained automatically with map of stand types obtained using traditional methods and to evaluate the success rates. This method should be tested on digital aerial photos and the possibility to improve accuracy of map of stand types should be further investigated.

ACKNOWLEDGEMENTS (TEŞEKKÜR)

REFERENCES (KAYNAKLAR)

Antunes, A.F.B., Lingnau C., Centeno, J.A.S., 2003. Object Oriented Analysis and Semantic Network for High Resolution Image Classification. *Boletim de Ciências Geodésicas* 9(2): 233-242,

Arockiaraj, S., Kumar, A., Hoda, N., Jeyaseelan, A.T., 2015. Identification and Quantification of Tree Species in Open Mixed Forests using High Resolution QuickBird Satellite Imagery. *Journal of Tropical Forestry and Environment* 5(2): 40-53.

Asan, Ü., 1999. Using Possibilities of Satellite Images in Forestry And The Applications In Turkey. International Symposium on Remote Sensing and Integrated Technologies, Istanbul, 20-22 October 1999, pp. 113-126.

Asan, Ü., Başkent, E.Z., Özçelik, R., 2001. Gelişmiş Ülkelerdeki Ulusal Orman Envanteri Sistemleri ve Türkiye İçin Öneriler. I. Ulusal Ormancılık Kongresi, Ankara, 19-20 Mart 2001, pp. 30-51.

Asan, Ü., Yeşil, A., 2005. Ulusal Orman Envanterinin Türkiye için Önemi ve Model seçiminde Gözetilecek Genel Kriterler. Türkiye Ulusal Orman Envanteri Sempozyumu, İstanbul, 24-28 Eylül 2002, pp. 112-131.

Asan, Ü., Yeşil, A., Özdemir, İ., Özkan, U.Y., Ercan, M., Baş, N., Ün, C., Kündük, H.E., Başaran, M.A., 2007. Türkiye Ulusal Orman Envanteri Konseptine Uydu Görüntülerinin Entegrasyonu, Proje No: TOVAG-JULICH 2002-1, TUBİTAK.

Birth, G.S., McVey, G.R., 1968. Measuring color of growing turf with a reflectance spectrophotometer. *Agronomy Journal* 60: 640-649.

Blaschke, T., Burnett, C., Pekkarinen, A., 2004. Image Segmentation Methods for Object based Analysis and Classification. In: De Jong, S. M., & van der Meer, F. (Eds.), Remote sensing image analysis: including the spatial domain, Kluwer Academic Publishers, USA, pp.211-236.

Bock, M., Xofis, P., Mitchley, J., Rossner, G., Wissen, M. 2005. Object-oriented methods for habitat mapping at multiple scales– Case studies from Northern Germany and Wye Downs, *UK. Journal for Nature Conservation* 13(2): 75–89, doi:10.1016/j.jnc.2004.12.002.

Chen, Y., Su, W., Li, J., Sun, Z., 2009. Hierarchical object classification using very high resolution imagery and LIDAR data over urban areas. *Advances in Space Research* 43(7): 1101-1110, doi:10.1016/j.asr.2008.11.008.

Corona, P., Köhl, M., Marchetti, M., 2003. Advances in forest inventory for sustainable forest management and biodiversity monitoring. Kluwert Academic Publishers, Dordrecht.

Dalponte, M., Ørka, H. O., Ene, L. T., Gobakken, T., Næsset, E., 2014. Tree crown delineation and tree species classification in boreal forests using hyperspectral and ALS data. *Remote Sensing of Environment* 140: 306-317, doi:10.1016/j.rse.2013.09.006.

Definiens, A.G. 2006. Definiens Professional 5 Reference Book. Definiens AG, Munich.

Deering, D. W., Rouse, J. V., Haas, R. H., Schell, J. A., 1975. Measuring forage production of grazing units from Landsat MSS data. In Proceedings of 10th International Symposium on Remote Sensing of Environment, Michıgan, pp. 1169-1178.

Drăguţ, L., Tiede, D., & Levick, S.R., 2010. ESP: a tool to estimate scale parameter for multiresolution image segmentation of remotely sensed data. *International Journal of Geographical Information Science* 24(6): 859-871, doi: 10.1080/13658810903174803.

Eler, Ü., 2001. Orman Amenajmanı, Süleyman Demirel Üniversitesi Yayınları, Isparta.

Furuya, N., Saito, P., Tith B., MEAS, M., 2007. Object-oriented land cover classification based on two satellite images obtained in one dry season in Cambodia. In Forest Environment in the Mekond River Basin, Springer Japan, pp 149-158.

Gong, P., Biging, G.S., Lee, S.M., Mei, X., Sheng, Y., Pu, R., Xu, B., 1999. Photo Ecometrics for Forest Inventory. *Geographic Informayion Sciences* 5(1): 9-14, doi: 10.1080/10824009909480508.

Günlü, A., Sivrikaya, F., Baskent, E. Z., Keles, S., Çakir, G., Kadiogullari, A.I., 2008. Estimation of stand type parameters and land cover using Landsat-7 ETM image: A case study from Turkey. *Sensors*, 8(4): 2509-2525, doi:10.3390/s8042509.

Günlü, A., Başkent E.Z., Kadiogullari, A.I., Altun, L., 2009. Forest site classification using Landsat 7 ETM data: a case study of Maçka-Ormanüstü forest, Turkey. *Environmental Monitoring and Assessment* 151: 93-104, doi: 10.1007/s10661-008-0252-3.

Hajek, F., 2006. Object analysis of IKONOS xs and PAN-SHARPENED imagery in comparision for purpose of tree species estimation.
http://www.commission4.isprs.org/obia06/Papers/13_Automated%20classification%20IC%20I%20-%20Forest/OBIA2006_Hajek.pdf (Ziyaret tarihi: 18 Şubat 2008).

Herold, M., Scepan, J., Muller, A., Gunther, S., 2002. Object-oriented mapping and analysis of urban land use/cover using IKONOS data. In 22nd Earsel Symposium Geoinformation for European-Wide Integration, Prague, June 2002, pp. 4-6.

Holopainen, M., Kalliovirta, J., 2006. Modern Data Acquisition for Forest Inventories, Forest Inventory – Methodology and Applications. Springer, Netherlands.

Huang, W., Li, H., & Lin, G., 2015. Classifying forest stands based on multi-scale structure features using Quickbird image. In Spatial Data Mining and Geographical Knowledge Services (ICSDM), 2nd IEEE International Conference, Gdynia, 24-26 June 2015, pp. 202-208.

Hung, M.C., 2002. Urban land cover analysis from satellite images. In:Proceedings of Pecora, pp. 10-15.

Immitzer, M., Atzberger, C., Koukal, T., 2012. Tree species classification with random forest using very high spatial resolution 8-band WorldView-2 satellite data. *Remote Sensing* 4(9): 2661-2693, doi:10.3390/rs4092661.

Jensen, R.J., 1996. Introductory Digital Image Processing, a Remote Sensing Perspective, Prentice Hall. Upper Saddle River, New Jersey.

Kamal, M., Phinn, S., Johansen, K., 2015. Object-Based Approach for Multi-Scale Mangrove Composition Mapping Using Multi-Resolution Image Datasets. *Remote Sensing* 7(4): 4753-4783, doi:10.3390/rs70404753.

Kim, S.R., Lee, W.K., Kwak, D.A., Biging, G.S., Gong, P., Lee, J.H., Cho, H.K., 2011. Forest cover classification by optimal segmentation of high resolution satellite imagery. *Sensors* 11(2): 1943-1958, doi:10.3390/s110201943.

Koç, A., Yener, H., 2006. Landsat ETM verilerinde topografik normalizasyonun sınıflandırma doğruluğu üzerindeki etkisi. *Journal of the Faculty of Forestry Istanbul University* 56(A2): 57-76.

Köhl, M., 1993. *Forest Inventory*. In: Pancel, L. (ed), Tropical Forestry Handbook, Springer Verlag, Heidelberg, pp. 273-276.

Köse, S., Çakır, G., Sönmez, T., Sivrikaya, F., 2002. Uzaktan Algılamanın Orman Amenajman Planlamasında ve Bilgi Sistemleri Kurulmasındaki Önemi. Orman Amenajmanı'nda Kavramsal Açılımlar ve Yeni Hedefler Sempozyumu, İstanbul, 18-19 Nisan 2002, pp. 148-157.

Laliberte, A.S., Rango, A., Havstad, K.M., Paris, J.F., Beck, R.F., McNeely R., Gonzalez, A.L., 2004. Object-oriented image for mapping shrup encroachment from 1937 to 2003 in southern New Mexico. *Remote Sensing of Environment* 93(1): 198-210, doi:10.1016/j.rse.2004.07.011.

Leboeuf, A., Fournier, R.A., 2013. Estimating stand attributes of boreal forests using digital aerial photography and a shadow fraction method.*Canadian Journal of Remote Sensing* 39(3): 217-231, doi: 10.5589/m13-030.

Marcal, A.R.S., Borges, J.S., Gomes J.A., Pinto Da Costa J.F., 2005. Land Cover Update by Supervised Classification of Segmented ASTER Images. *International Journal of Remote Sensing* 26(7): 1347-1362, doi: 10.1080/01431160412331291233.

Mathieu, R., Aryal, J., 2005. Object-oriented classification and IKONOS multispectral imagery for mapping vegetation communities in urban areas. *The 17th Annual Colloquium of Spatial Information Research Centre Unniversity of Otago*, Dunedin, 24-25 November 2005.

Mathieu, R., Aryal, J., Chong, A., 2007. Object-Based classification of IKONOS imagery for mapping large-scale vegetation communities in urban areas. *Sensors* 7(2007): 2860-2880, doi:10.3390/s7112860.

Maxwell, T., 2005. Object-oriented classification: Classification of PAN-SHARPENED QuickBird images and a fuzzy approach to improving image segmentation efficiency, Thesis (MD), The University of New Brunswick.

Musaoğlu, N., 1999. Elektro-Optik ve Aktif Mikrodalga Algılayıcılarından Elde Edilen Uydu Verilerinden Orman Alanlarında Meşcere Tiplerinin ve Yetişme Ortamı Birimlerinin Belirlenme Olanakları, Doktora Tezi, İ.T.Ü.Fen Bilimleri Enstitüsü.

Özdemir, İ., 2004. Orman envanterinde uydu verilerinden yararlanma olanakları, *S.D.Ü. Orman Fakültesi Dergisi*, A, 1: 84-96.

Ozdemir, I., 2008. Estimating stem volume by tree crown area and tree shadow area extracted from pan-sharpened Quickbird imagery in open Crimean juniper forests. *International Journal of Remote Sensing* 29(19): 5643-5655, doi: 10.1080/01431160802082155.

Ozdemir, I., 2014. Linear transformation to minimize the effects of variability in understory to estimate percent tree canopy cover using RapidEye data. *GIScience and Remote Sensing* 51(3): 288-300, doi: 10.1080/15481603.2014.912876.

Ozdemir, I., Norton, D.A., Ozkan, U.Y., Mert, A., Senturk, O., 2008. Estimation of tree size diversity using object oriented texture analysis and aster imagery. *Sensors* 8(8): 4709-4724, doi:10.3390/s8084709.

Ozdemir, I., Karnieli, A., 2011. Predicting forest structural parameters using the image texture derived from WorldView-2 multispectral imagery in a dryland forest, Israel. *International Journal of Applied Earth Observation and Geoinformation* 13(5): 701-710, doi:10.1016/j.jag.2011.05.006.

Özkan, U.Y. 2006. Uydu görüntüleri yardımıyla meşcere parametrelerinin kestirilmesi ve orman amenajmanında kullanılması olanakları. *Journal of the Faculty of Forestry Istanbul University* 56(A2): 191-218.

Plattier, T., Loureiro, M., Marques, P., Caetano, M., 2006. Spectral analyses and classification of IKONOS images for forest cover characterisation,. Proceedings of the 2nd Workshop of the EARSeL SIG on Land Use and Land Cover, Center for Remote Sensing of Land surfaces, Bonn, 28-30 September 2006, pp. 260-268.

Rego, L.F.G., 2003. Automatic land-cover classification derived from high-resolution IKONOS satellite image in the urban Atlantic forest in Rio de janerio, Brasil by means of an object-oriented approach, Thesis (PhD), Albert-Ludwigs-Universitat.

Rego, L.F.G., Ueffing, C., Vianna, S.B., 2007. Automatic land-cover classification derived from high-resolution IKONOS satellite imagery in the urban atlantic forets of Rio de Janerio, Brazil, by means of an Object-Oriented Approach. In: Netzband, M., Stefanov, W.L., Redman, C. (Eds), Applied Remote Sensing for Urban planning, Governance and Sustainability, Springer Berlin Heidelberg, pp. 25-36.

Renaud, M., Aryal, J., Chong, A.K., 2007. Object-based classification of IKONOS imagery for mapping large-scale vegetation communities in urban areas. *Sensors* 7(11): 2860-2880, doi:10.3390/s7112860.

Rouse, J. W., Haas, R. H., Jr., Schell, J. A., Deering, D. W., 1974. Monitoring vegetation systems in the Great Plains with ERTS. In Proceedings of Third ERTS-1 Symposium, Washington DC, pp. 309–317.

Stoffels, J., Mader, S., Hill, J., Werner, W., Ontrup, G., 2012. Satellite-based stand-wise forest cover type mapping using a spatially adaptive classification approach. *European Journal of Forest Research*, 131(4): 1071-1089, doi: 10.1007/s10342-011-0577-2.

Tuominen, S., Pekkarinen, A., 2005. Performance of Different Spectral and Textural Aerial Photograph Features in Multi-Source Forest Inventory. *Remote Sensing and Environment* 94(2): 256-268, doi:10.1016/j.rse.2004.10.001.

Yener, H., 2005. Ulusal Orman Envanterinde Uzaktan Algılama Verilerinden Yararlanma Olanakları. Türkiye Ulusal Orman Envanteri Sempozyumu, İstanbul, 24-28 Eylül 2002, pp. 424-446.

Yeşil, A., Asan, Ü., Coşkun, G., Örmeci, C., Kaya, Ş., 1999. Statical Modelling and Stand Type Forest Mapping Selected Area Around Istanbul Using Landsat-TM and SPOT Data. Proceedings of the Internatinal Symposium on Remote Sensing & Integrated Technologies, İstanbul, 20-22 October 1999, pp. 151-162.