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Investigation on changes in complex vegetation coverage using multi-temporal landsat data of Western Black sea region - A case study

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Abstract: *Previous studies have been able to successfully detect changes in gently-sloping forested areas with low-diversity and homogeneous vegetation cover, using medium-resolution satellite data such as landsat. The aim of the present study is to examine the capacity of multi-temporal landsat data to identify changes in forested areas with mixed vegetation and generally located on steep slopes or non-uniform topography. landsat thematic mapper (TM)and landsat enhanced thematic mapper plus (ETM+) data for the years 1987-2000 was used to detect changes within a 19,500 ha forested area in the Western Black sea region of Turkey. The data comply with the forest cover type maps previously created for forest management plans of the research area. The methods used to detect changes were: post-classification comparison, image differencing, image rationing and NDVI (Normalized Difference Vegetation Index) differencing methods. Following the supervised classification process, error matrices were used to evaluate the accuracy of classified images obtained. The overall accuracy has been calculated as 87.59% for 1987 image and as 91.81% for 2000 image. General kappa statistics have been calculated as 0.8543 and 0.9038 for 1987 and 2000, respectively. The changes identified via the post-classification comparison method were compared with other change detetion methods. Maximum coherence was found to be 74.95% at 4/3 band rate. The NDVI difference and 3rd band difference methods achieved the same coherence with slight variations. The results suggest that landsat satellite data accurately conveys the temporal changes which occur on steeply-sloping forested areas with a mixed structure, providing a limited amount of detail but with a high level of accuracy. Moreover, it has been decided that the post-classification comparison method can meet the needs of forestry activities better than other methods as it provides information about the direction of these changes.*

Key words: *Digital change detection, Mixed vegetation change, Landsat, Geographic Information system (GIS)*
PDF of full length paper is available online
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Introduction

Developments on remote sensing and Geographical Information Systems (GIS) have facilitated obtaining comparable and update information about present natural resources and their historical course (Jensen, 1996). These systems are frequently used in detecting the spatial and structural characteristics of forests, one of the world's most important natural resources, in organizing the functions carried out by forests, and in planning the benefits provided by forests. Remote sensors produced for specific purposes and the GIS-based analysis of the data provided by these sensors has lessened the dependency on topographic studies and enabled low-cost and fast access to information.

One of the fields where remote sensing is widely used is in change detection studies. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). In change detection studies conducted on the basis of satellite data, it is of utmost importance to take into account not only the atmospheric and topographic environmental effects but also the bio-physiological characteristics of the vegetation types (Colby, 1991; Jensen, 1996; Song *et al.*, 2001). Moreover, climate characteristics present at the acquisition time and just before the acquisition time influence the results obtained (Campell, 1996; Lillesand and Kiefer, 1999; Coppin *et al.*, 2004). Landsat satellite data, having an image archive of more than 30 yr, are continually used in detecting and monitoring global or regional-scale environmental changes (Howart and Wickware, 1981; Richards, 1984; Vogelman, 1988; Fung, 1990; Jha and Unni, 1994; Cohen *et al.*, 1998; Ridd and Liu, 1998; Sunar, 1998; Mas, 1999; Sader *et al.*, 2001; Hayes *et al.*, 2002; Volcani *et al.*, 2005; Kleinod *et al.*, 2005; Yener and Koc, 2006; Fan *et al.*, 2007). A survey of the literature shows that many change detection methods exist (Singh, 1989; Coppin *et al.*, 2004; Lu *et al.*, 2004). Each method has particular advantages and disadvantages (Lu *et al.*, 2004). Selection of the most suitable change detection method starts with the identification of the problem (Jensen, 1996). Due to the nature of change detection, the data undergoes some specific process steps. Raster or vector-based studies can be carried out depending on the change detection method selected. In addition, while there are some studies in which only remote sensing methods are used, other studies involve GIS-based analysis of the data obtained. In this process, it is possible to choose either those methods which reveal the change in a satellite dataset over a quite short time, such as image differencing or image rationing method, or methods taking too much time but meeting different needs of the users, such as the post-classification method.

Vegetation dynamics of the target area play an important role in the change detection studies conducted on forest lands. Change detection studies conducted via medium-spatial resolution satellite data, like Landsat, produce optimum results in cases where the structural characteristics of the vegetation cover (tree species, crown closure, age, site index, *etc.*) are the same; the vegetation cover is homogeneous over a large area; and the topography of the study area is completely or nearly flat. However, it is more difficult to detect vegetation changes in forested areas which extend over a changing-slope topography; have different structural characteristics, and are composed of heterogeneous stands (*i.e.*, the type of stand changes over short distances) (Kleinod *et al.*, 2005). It is observed that previous studies conducted on such areas roughly group the vegetation cover rather than presenting detailed change analysis (Jha and Unni, 1994; Mas, 1999; Petit *et al.*, 2001; Fan *et al.*, 2007).

The aim of the present study is to examine the capacity of multi-temporal landsat data to identify the detailed changes that occur in forested areas having a complex vegetation structure and generally located on steep slopes, or changing topographies. Forests of the Black sea region, selected as the study area, are generally composed of different tree species, the types of which change over short distances (*i.e.*, heterogeneous stands). The study area also includes a small number of homogeneous stand types, settlements and agricultural land. The present study assessed the capabilities of different change detection methods which are already in use and also investigated the method most appropriate for forestry.

Materials and Methods

Study area: The study area is composed of Aydinpinar, Odayeri and Cicekli forest planning units, located in west black sea region of Turkey. The planning units are located in the inner parts of Black sea region and extend over an area of 19.500 ha (Fig. 1a). Aydinpinar planning unit has an altitude of 120-1600 m, Odayeri of 200-1670 m and Cicekli of 220-1680 m. By producing a digital elevation model of the study area, the aspect and slope have been determined, so as to examine the detailed topographic characteristics of the study area. Examining the aspect data, it can be observed that 66% of the total area is dominated by northwest, north, northeast and east aspects, which are also called "shadowed aspects" (Fig. 1b). Flat land constitutes 3% of the total area. As for slope groups, 65% of the total area is classified as high-slope and steep-slope groups, while 16% of the area is classified within the sheer-slope group (Fig. 1c).

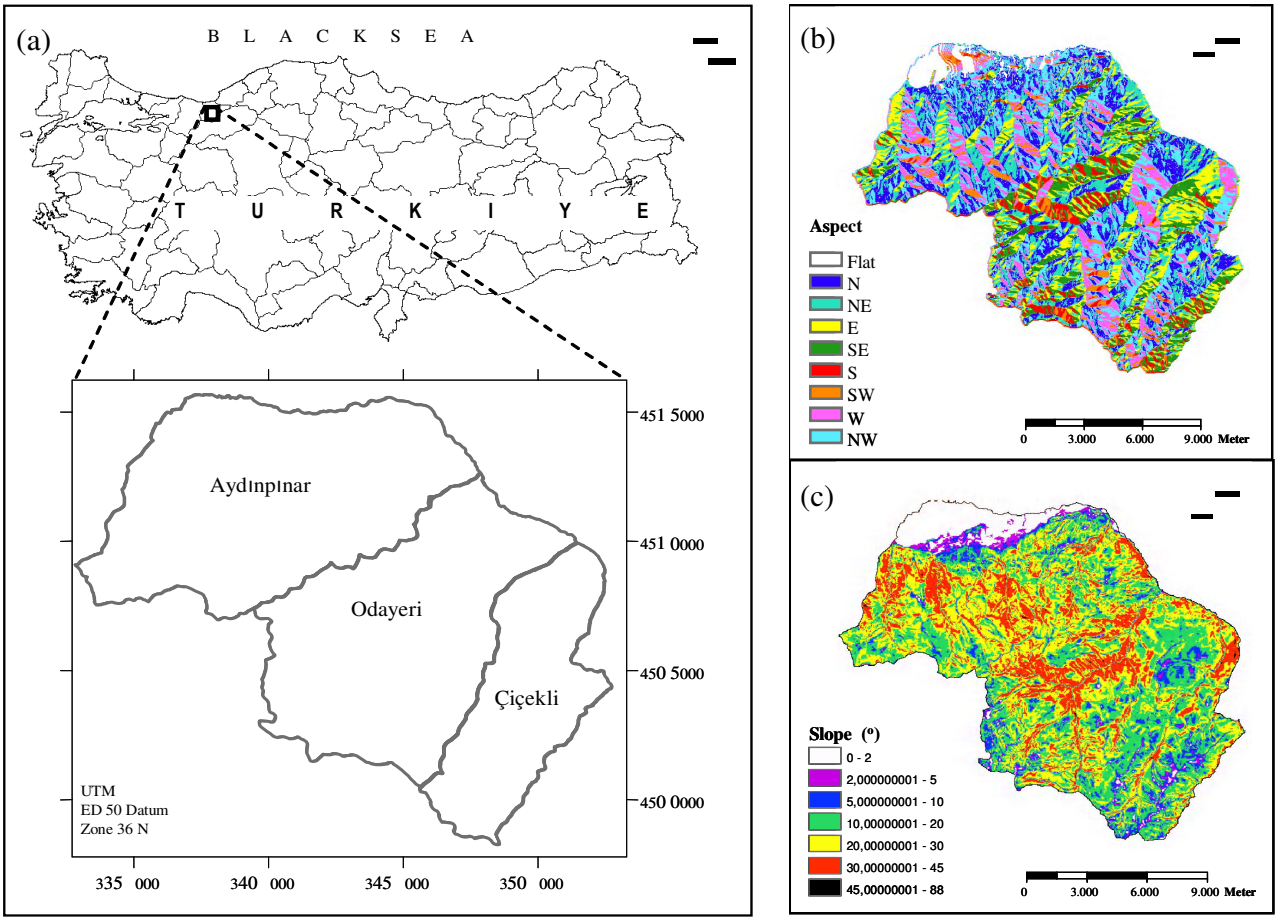

Fig. 1: The geographic location (a), aspect map (b), and slope class map (c) of the study area

Compared to middle and eastern Black sea regions, less precipitation and lower winter-summer temperatures are recorded in the western Black sea region. Average values of some meteorological elements are listed in Table 1, based on data obtained from Düzce meteorology station, located in the region (Çoban, 2006).

The stand description and planning tables present in the forest inventory plans for the planning units show that there are similar tree species in all 3 of the study areas. Species include coniferous trees such as fir, scot's pine and black pine as well as broadleaved tress such as beech, hornbeam, oak, ash tree, chestnut and linden. Moreover, there are also shrubs such as hazelnut, taxus, rhododendron and common laurel and various herbaceous plants (Anonymous, 1986, 2000). The dominant species of the planning units is beech. Beech is resistant to shadow and can live for many years as an undergrowth tree. In addition to its pure stands, beech generally makes group or single tree mixtures with broadleaved trees such as hornbeam, linden, chestnut, oak and ash and also with coniferous trees such as fir and scot's pine species. Fir tree species are also shadow-resistant. They generally produce a mixed stand. Unless they are overstory trees, they can survive for many years as undergrowth trees and they advance towards the overstory as the amount of light received increases. In most of the stands, Scot's Pine has been created via plantation. Scot's pine and black pine, which need a high amount of light, constitute overstory trees of the stand. Oak trees in the study area have also been recorded in mixed stands with species such as beech, hornbeam and linden. While oak constitutes the overstory tree of these mixed stands, other tree species form the undergrowth trees, protect the soil and serve as filler trees (Coban, 2006). By examining such stands within the study area, it was observed that oaks are generally present in groups and sometimes extend to the whole area.

Dataset: Forest inventory plans for two different dates (Table 2) and corresponding landsat satellite dataset for these two dates (Table 3) were used to detect the land cover changes in the study forests. The forest stand types used as ground truthing were originally generated from both the stereo interpretation of infrared aerial photos with an average scale of 1:15,000 and from ground measurements of sample points distributed by 250x250 m grids. No forestry activity that might have an influence on the study was detected during the period between the year of the topographical study and the acquisition dates of satellite images. In addition, no natural disaster such as flood or fire occurred during this period. Topographical raster and vector maps at 1:25,000 scale were used in the study. These topographical maps were produced by the General Command of Mapping by using UTM projection and ED-50 datum. Topographic vector maps of 1:25,000-scale used in the study are composed of digital elevation maps.

Stand type maps covering planning units were digitized and then entered into a geographical information system. A geographical database was created using ArcGIS 8.3 GIS software. Attributes of the stand types and compartment numbers were entered into the geographical database since they will be required for the determination of training fields during the classification of satellite data and for the definition of spectral classes to be obtained after the classification.

Image processing: Described as the processes undertaken before obtaining information and making basic data analysis, pre-processing functions generally include geometric and radiometric corrections (Erdas, 2002). ERDAS imagine 8.7 software was used for the geometric correction of satellite images. During recording from map-to-image (a process which is carried out using raster topographic maps), RMSE (Root Mean Squared Error) values lower than 0.5 pixel -error limit value for satellite images- were achieved (Table 4). After the required accuracy is achieved, the nearest neighbour method was used to obtain re-sampling images. Stand type maps and satellite images used in the study were coordinated by using UTM projections and ED-50 datum.

To improve the images radiometrically by minimizing the degradations caused by environmental effects, the approach of "single image normalization by using histogram adjustment" was applied to both images separately and then the technique of "multi-date empirical radiometric normalization" was adopted (Jensen, 1996). In order to correct for atmospheric anomalies, the year 2000 image was taken as basis and 15 radiometric control points were determined in both images. These control points have sea, lake, bare land and asphalt characteristics and correspond with each other in both images. By using these points, regression equations of each band were created and these equations were then applied to each pixel of the 1987 image. The Minnaert topographic correction method (Colby, 1991) was then applied to the images. Visual interpretation of the effects of the radiometric corrections on the images and the comparison of the crude image histograms with final image histograms show that radiometric corrections have been successful.

To classify the satellite images, a supervised classification technique was applied. This method is composed of training, classification and result phases (Lillesand and Kiefer, 1999). In the training phase, various land cover types are selected as training fields. Each training field is classified as a spectral class. These spectral classes are selected according to a pre-determined classification scheme. Spectral classes obtained this way are transferred to the "signature editor" part of the classification module within the ERDAS software, and descriptive information of each spectral class is entered. Classification was made by using a maximum likelihood algorithm and new thematic images were obtained.

If the information obtained via remote sensing data is to be used in decision-making process, it is of great importance to know the quality of such information. In determining the accuracy of a classification, the method generally used within the literature is a spatial accuracy approach based on an error matrix (Aranoff, 1982; Story and Congalton, 1986; Campell, 1996; Congalton and Green, 1999; Foody, 2002). After the classification, spatial accuracy was evaluated and classification accuracies were determined using error

Table - 1: Meteorological components

Meteorological components	Observation interval	Months												Annual (Averages)
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
Temperature (°C)	1963/1990	3.5	5.2	7.6	12.3	16.3	20.2	22.1	21.5	18.3	13.9	9.4	5.9	13.0
Precipitation (mm)	1963/1990	95.9	74.7	72.2	57.6	62.8	62.2	48.7	49.5	52.2	78.3	86.9	98.5	70.0
Relative humidity (%)	1963/1990	82	78	76	73	74	70	71	73	75	78	79	81	76
Cloudness (0-10)	1963/1990	7.2	6.9	6.5	5.9	4.9	3.7	3.4	3.4	4.0	5.6	6.0	6.9	5.4

matrices. Moreover, kappa statistics (Congalton and Green, 1999) were calculated for each error matrix.

Change detection methods: The present study used a post-classification comparison method, image differencing method, image rationing method and NDVI differencing method to determine changes in land cover over time. A change/no change binary map -which was produced according to the threshold values selected for differencing, rationing and NDVI differencing images was compared with the change matrix obtained via post-classification comparison method (Fig. 2a). Change maps based on threshold values which gave maximum coherence were obtained (Fig. 2b) (Petit *et al.*, 2001).

As for the post-classification comparison method, classified images of sufficient accuracy have been compared pixel-by-pixel, by creating a change detection matrix. Thus, the change map produced by this method includes from-to information. In the process of obtaining difference images, the pixel values of the bands of the 1987 satellite image have been subtracted from the pixel values of the corresponding bands of the year 2000 satellite image (excluding the 6th band) which are pre-processed and corrected in geometric and radiometric terms. Rationing images have been obtained by rationing the pixel values of the bands of the 2000 satellite image (excluding the 6th band) to the pixel values of the corresponding bands of the 1987 satellite image. Due to vegetation sensitivity, the ratio of the 4th band of the 2000 image to the other bands of the 1987 image has also been examined. An NDVI differencing image was obtained by subtracting the pixel values of the NDVI band of the 1987 data from the values of the corresponding pixels of the 2000 NDVI band.

Results and Discussion

Classification of satellite imagery: When applying the supervised classification method, stand type maps included in the geographical database have been used in order to detect and define the training fields. A total of 360 training fields for 1987 and 248 training fields for 2000 landsat satellite images were detected within the forested study areas. As stated above, information about stand types has been used in the selection of the spectral classes obtained. Spectral classes transferred to the signature editor media also represent sub-information classes. These spectral classes were subjected to spectral analysis before classification process. This analysis examined the relations between spectral classes. Classes having similar stand tree types and quite similar spectral patterns were combined. Following the process of recoding according to combined spectral classes, newly classified images were obtained. Thematic maps created by this way were checked visually by using satellite images and stand type maps (Table 5).

Table - 2: Forest management plans used in the study

Years	Field study time	Chief of forest district	Regional forest directorate
1986-1995	1986	Aydinpinar	Bolu
1986-1995	1986	Odayeri	Bolu
1986-1995	1986	Çiçekli	Bolu
2000-2009	2000	Aydinpinar	Bolu
2000-2009	1999	Odayeri	Bolu
2000-2009	1999	Çiçekli	Bolu

Table - 3: Characteristics of the landsat data used in the experiment

Satellite data	Acquisition date	Row/ Path	Data format
Landsat 7 ETM$^+$	June 04th 2000	178/32	GeoTiff
Landsat 5 TM	September 11th 1987	178/32	GeoTiff

Table - 4: RMSE values of geometrically corrected landsat data

Data	Ground control point number	RMSE values		
		X (m)	Y (m)	Total (m)
Landsat 7 ETM$^+$	18	8.1780	7.7158	11.2434
Landsat 5 TM	16	7.0978	7.4487	10.2889

Data related with the areas covered by land cover classes in 1987 and 2000, which were obtained from the classified images, presents the amounts of the main information classes obtained at the end of classification as well as the share of these classes across the total area (Table 6).

After the classification of the satellite images, accuracy analyses were made for the thematic maps obtained. Error matrices created with the help of points randomly stratified over these thematic maps were analyzed. Control points were determined on the classified images in order to obtain error matrices. Planning a minimum 30 points for each class, a total of 300 points were randomly stratified over these maps. Reference codes of the control points were determined by using satellite image and forest stand type maps, which were entered using the same code numbers as those used in the classification. While determining reference values, 10 control points for 1987 and 7 control points for 2000 data were cancelled as they coincided with the stand type threshold (Table 7, 8).

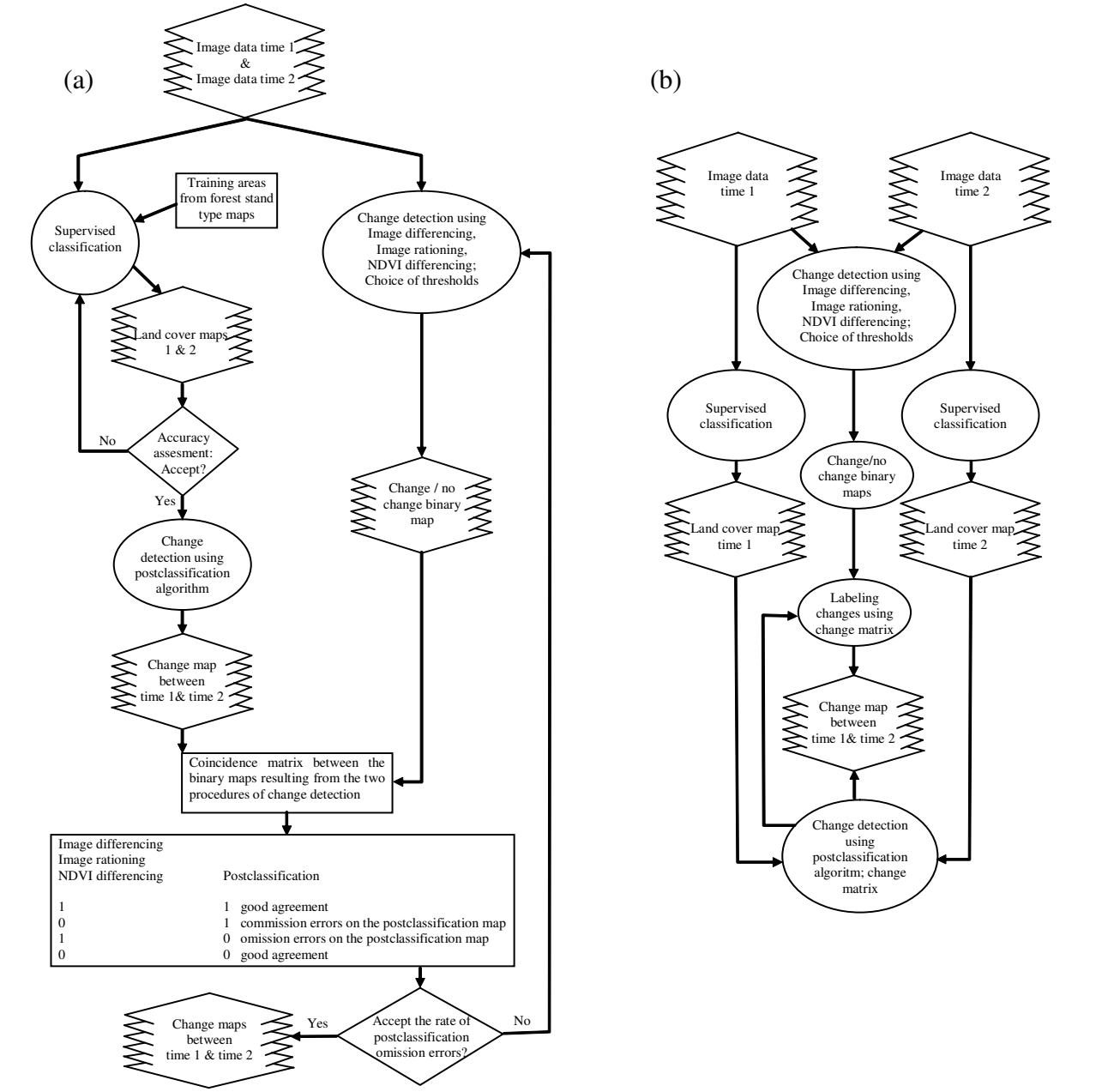

Fig. 2: Flowchart of (a) choice of thresholds used in change detection (b) production of change maps

After the creation of error matrices, kappa statistics were calculated for each matrix (Table 9). In addition to the kappa statistics of the individual classes, kappa statistics of the total general accuracy have also been presented.

Post-classification comparison results: A matrix process has been applied to two classified satellite images (1987 and 2000) using ERDAS software, with the aim of detecting changes in vegetation via a post-classification comparison method. Attribute table of the matrix image obtained include the class values for 1987 and 2000. Thus, information about the direction of the changes between the main information classes in the change matrix and their spatial values have been provided (Fig. 3).

Post-classification comparison method has revealed that an area of 5,796 ha within the total study area has been subjected to change and that no change has been observed in the remaining part of the total area. Examining the areal status of the main information classes for the period covering 1987 and 2000, it has been shown that the main information classes of "non-forest areas", "unproductive forest areas" and "Beech-Fir mixture forest areas" have decreased in areal terms while the main information classes of "marshes and water areas", "Beech and other broadleaved mixed forest areas" and "Scot's Pine areas" have increased in coverage. The main information class of "Fir areas" has remained nearly the same. In addition to areal evaluation, this study has also examined the changes

Table - 5: Land cover classification scheme

Prior land cover class	Final set of land cover class	Class code and symbol
Marshes areas Water areas	Marshes and water areas	(1 / Btk_Su)
Agricultural lands (open area) Agricultural lands (vegetation covered area) Forest openings (treeless areas)	Non-forest areas	(2 / Orman_Disi)
Degraded forest (degraded forest areas with estimated < 10% tree crown cover) Beech areas (low coverage 11-40 %) Scot's pine plantation areas (non-cover)	Unproductive forest areas	(3/Bozuk_Kapali)
Beech areas (medium coverage 41-70 %; full coverage 71-100 %) Oak areas (medium coverage 41-70 %; full coverage 71-100 %) Beech and other hardwood species mixed forest areas (medium coverage 41-70 %; full coverage 71-100 %) Mixed coppice forest areas (medium coverage 41-70 %)	Beech and other broadleaved mixed forest areas	(4 / Kn_Dy)
Beech-fir mixed forest areas (medium coverage 41-70 %; full coverage 71-100 %)	Beech-Fir mixture forest areas	(5 / KnG_GKn)
Scot's pine plantation areas (low coverage 11-40 %)	Scots pine forest areas	(6 / Cs)
Fir forest areas (medium coverage 41-70 %; full coverage 71-100 %) Fir-Scot's pine mixed forest areas (medium coverage 41-70 %; full coverage 71-100 %)	Fir forest areas	(7 / G)

Table - 6: Final set of land cover class areas

Class code	Symbol	1987 year		2000 year		Difference (%)
		Area (ha)	%	Area (ha)	%	
1	Btk_Su	36.72	0.19	180.99	0.93	392.89
2	Orman_Disi	6109.02	31.38	5587.74	28.70	-8.53
3	Bozuk_Kapali	1010.25	5.19	602.64	3.10	-40.35
4	Kn_Dy	6356.79	32.65	7814.61	40.14	22.93
5	KnG_GKn	4547.25	23.36	3653.1	18.76	-19.66
6	Cs	411.75	2.11	627.21	3.22	52.33
7	G	996.66	5.12	1002.15	5.15	0.55
	Total	19468.44	100.00	19468.44	100.00	

Table - 7: Error matrix for thematic map derived from 1987 landsat image

Classification	Reference codes								
	Btk_Su	Orman_Disi	Bozuk_Kapali	Kn_Dy	KnG_GKn	Cs	G	Total	UA (%)
Btk_Su	28	2	0	0	0	0	0	30	93.33
Orman_Disi	1	49	2	0	0	0	0	52	94.23
Bozuk_Kapali	0	1	34	2	0	1	0	38	89.47
Kn_Dy	0	3	7	41	0	0	1	52	78.85
KnG_GKn	0	0	0	2	41	2	2	47	87.23
Çs	0	0	1	0	2	33	0	36	91.67
G	0	0	0	0	4	3	28	35	80.00
Total	29	55	44	45	47	39	31	290	
PA (%)	96.55	89.09	77.27	91.11	87.23	84.62	90.32		
OA (%)	87.59								

between information classes from a spatial perspective (Table 10). Considering Fig. 3 and Table 10 together, the location, direction and amount of the inter-class changes can be easily observed.

Comparison of image differencing, image rationing and NDVI differencing results: A change matrix obtained trough the post-classification comparison method has been used to determine the threshold values to be used for change images, to derive change images on the basis of these threshold values and to label these changes. This change matrix was re-coded as "changed and unchanged" areas to obtain a new matrix, and then compared with the change images obtained via other change detection methods. Changed and unchanged areas in the matrices obtained according to the post-classification comparison method and different threshold values with maximum coherence were

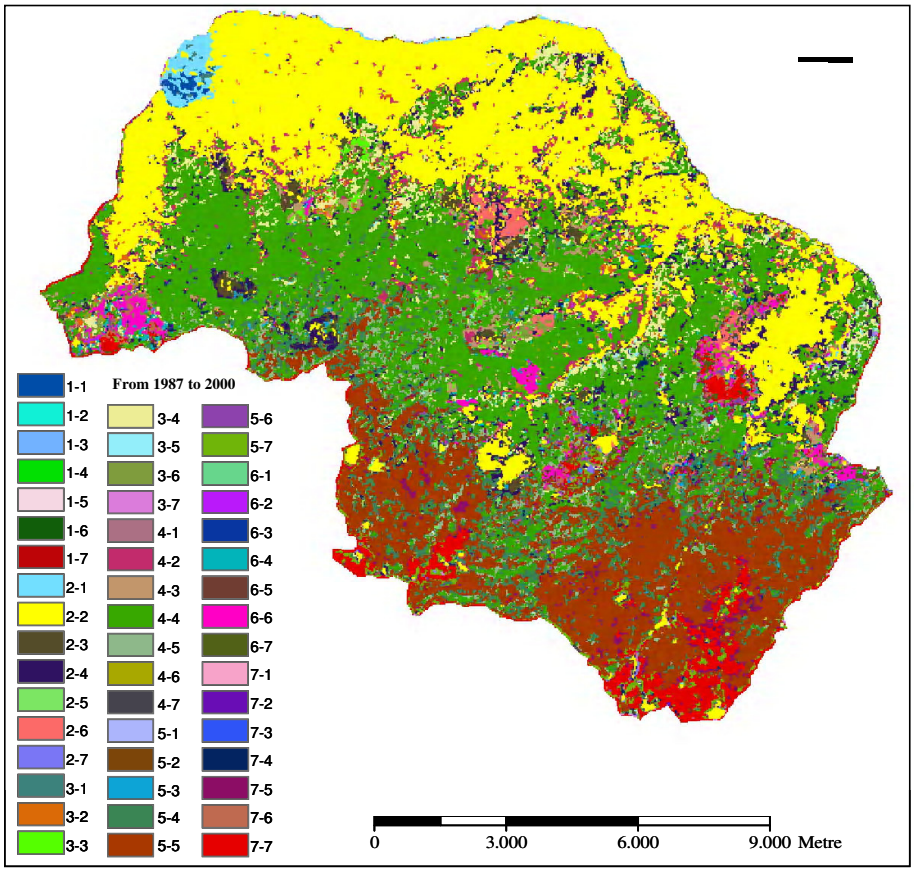

Fig. 3: Change classes obtained from post-classification comparison technique

Table - 8: Error matrix for thematic map derived from 2000 landsat image

Classification	Reference codes								
	Btk_Su	Orman_Disi	Bozuk_Kapali	Kn_Dy	KnG_GKn	Çs	G	Total	UA (%)
Btk_Su	33	2	0	0	0	0	0	35	94.29
Orman_Disi	0	46	0	2	0	0	0	48	95.83
Bozuk_Kapali	0	0	34	2	0	0	0	36	94.44
Kn_Dy	0	1	0	50	4	2	0	57	87.72
KnG_GKn	0	0	0	4	38	1	3	46	82.61
Cs	0	0	0	2	0	34	0	36	94.44
G	0	0	0	0	0	1	34	35	97.14
Total	33	49	34	60	42	38	37	293	
PA (%)	100.00	93.88	100.00	83.33	90.48	89.47	91.89		
OA (%)	91.81								

Table - 9: Kappa statistics for error matrices

Year	Class	Kappa values	Year	Class	Kappa values
1987	Btk_Su	0.9259	2000	Btk_Su	0.9356
	Orman_Disi	0.9288		Orman_Disi	0.9500
	Bozuk_Kapali	0.8759		Bozuk_Kapali	0.9372
	Kn_Dy	0.7496		Kn_Dy	0.8456
	KnG_GKn	0.8476		KnG_GKn	0.7970
	Cs	0.9037		Çs	0.9362
	G	0.7761		G	0.9673
	General	0.8543		General	0.9038

Table - 10: Detail of changes obtained by using post-classification comparison technique

Final set of land cover class of 1987 years	Final set of land cover class of 2000 years	Unchanged area according to total area		Changed area according to total area	
		(ha)	(%)	(ha)	(%)
1	1	31.32	0.16		0.00
1	2			0.00	0.00
1	3			0.00	0.00
1	4			3.78	0.02
1	5			1.17	0.01
1	6			0.00	0.00
1	7			0.45	0.00
2	1			127.17	0.65
2	2	4777.83	24.54	-	0.00
2	3			256.86	1.32
2	4			742.50	3.81
2	5			41.85	0.21
2	6			135.27	0.69
2	7			27.54	0.14
3	1			9.72	0.05
3	2			153.72	0.79
3	3	70.74	0.36	-	0.00
3	4			642.60	3.30
3	5			28.98	0.15
3	6			88.29	0.45
3	7			16.20	0.08
4	1			0.00	0.00
4	2			531.00	2.73
4	3			238.23	1.22
4	4	5060.61	25.99	-	0.00
4	5			444.87	2.29
4	6			70.74	0.36
4	7			11.34	0.06
5	1			10.35	0.05
5	2			91.35	0.47
5	3			27.36	0.14
5	4			1208.25	6.21
5	5	2901.42	14.90	-	0.00
5	6			59.22	0.30
5	7			249.30	1.28
6	1			1.53	0.01
6	2			22.41	0.12
6	3			8.19	0.04
6	4			80.55	0.41
6	5			27.63	0.14
6	6	202.32	1.04	-	0.00
6	7			69.12	0.36
7	1			0.90	0.00
7	2			11.43	0.06
7	3			1.26	0.01
7	4			76.32	0.39
7	5			207.18	1.06
7	6			71.37	0.37
7	7	628.20	3.23	-	0.00
	Total	13672.44	70.23	5796.00	29.77
	Total general area	19468.44			

Table - 11: Detail of changes obtained by using image differencing, image rationing and normalized difference vegetation index (NDVI) differencing methods

Change maps from image differencing, image rationing, NDVI differencing	Change matrix, post classification comparison	Band 3 differencing		Band 3/3 ratio		Band 4/3 ratio		NDVI differencing	
		Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
0 (No change)	0 (No change)	12903.57	66.28	12708.63	65.64	12062.25	62.31	12506.76	64.24
1 (Change)	1 (Change)	1653.3	8.49	1462.23	7.55	2447.37	12.64	2064.96	10.61
1 (Change)	0 (No change)	768.87	3.95	916.02	4.73	1562.4	8.07	1165.68	5.99
0 (No change)	1 (Change)	4142.52	21.28	4272.93	22.07	3287.7	16.98	3730.86	19.16
Total		19468.26	100.00	19359.81	100.00	19359.72	100.00	19468.26	100.00

accepted for each change image. Change maps were produced by selecting these threshold values. Evaluating the results of the change detection methods chosen, it can be concluded that maximum coherence in the change map was achieved at 4/3 band rate with 74.95% (Table 11).

The level of overlap of the inter-class changes detected via image differencing, image rationing and NDVI differencing methods with the inter-class changes in the change matrix obtained via post-classification comparison method has been examined. Transfers from the main information class of "marshy and water areas" to other classes have been detected most at 4/1 band rate with 98.33%; for "non-forest areas", at 4/3 band rate with 70.42%; for "unproductive forest areas", at 4/2 band rate with 70.69%; for "Beech and other broadleaved mixed forest areas", at 4/2 band rate with 38.98%; for "Beech-Fir mixture forest areas", at 4/7 band rate with 28.53%; for "Scot's Pine areas", at 4/3 band rate with 39.77% and for "Fir areas", at 4/7 band rate with 43.92%.

Conclusion: In the first phase of classifying the satellite images, the maximum possible number of sample areas was selected from each stand type present in the region. However, quite low accuracy levels were achieved. Therefore, these first spectral classes -including maximum level of detail- have been combined. The process of creating main information classes by combining high-detail information sub-classes was carried out on the basis of stand type maps. Heterogeneous forest structure has introduced some challenges to the process of combining information classes. Despite meticulous geometric and radiometric corrections to the images, one of the limitations on the accuracy of the change results is the fact that atmospheric and topographic effects have not been completely eliminated. Detailed stand type information obtained at the beginning has been lost during the process of raising the accuracy of the classification results to an acceptable level. Therefore, it can be stated that landsat data can not accurately detect detailed vegetation changes within forest areas having a mixed vegetation structure and generally extending over a high-slope and changing topography, as is the case in the present study. However, temporal changes in the study forests have been detected at a limited detail but a high level of accuracy by using landsat data.

According to the change matrices obtained via the post-classification comparison method, no change has been recorded in 70.23% of the study area, while some changes have been observed in 29.77%. Regarding the level of coherence between the changes detected via other methods and the changed and unchanged areas in the change matrix; maximum coherence has been recorded in the change image obtained at 4/3 band rate with 74.95% coherence. It is followed by the change image obtained by NDVI differencing image with 74.85%; and the 3rd band differencing image with 74.77%. These results are obtained via the control conducted across the whole area. From this perspective, 74.95% of the changed and unchanged areas detected via the classification process including subjective evaluations and pixel-by-pixel comparison of the classified images overlaps with the same changed and unchanged areas obtained at 4/3 band rate. Considering the diversity of the vegetation cover as well as the physical characteristics of the study area, it can be concluded that this result produces an appropriate coherence of sufficient level.

Considering together the features of the satellite data used, the diversity of the vegetation, topographical characteristics, atmospheric conditions and other environmental factors, the results suggest that the post-classification comparison method can meet the needs of forestry activities better than other methods. It is possible with this method to determine the spatial and temporal changes of forested areas, in addition to providing accurate information about the direction of such changes. However, other change detection methods can be used for the instantaneous detection of the changes in a fast manner and without the need for any classification process.

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References

Anonymous: Forest Management Plans of Aydinpinar, Odayeri and Cicekli Forest Districts, Regional Forest Directorate of Bolu, Turkey (1986).

Anonymous: Forest Management Plans of Aydinpinar, Odayeri and Cicekli Forest Districts, Regional Forest Directorate of Bolu, Turkey (2000).

Aranoff, S.: Classification Accuracy: A User Approach. *Photogrammetric Engg. Remote Sensing*, **48**, 1299-1307 (1982).

Campell, J.B.: Introduction to Remote Sensing (2nd Edn.). Virginia Polytechnic Institute and State University. *The Guildford Pres*, New York-London (1996).

Cohen, W.N., M. Fiorella, J. Gray, E. Helmer and K. Anderson: An efficient and accurate method for mapping forest clear cuts in the Pasific Nortwet using Landsat imagery. *Photogrammetric Engg. Remote Sensing*, **64**, 293-300 (1998).

Colby, J.D.: Topographic normalization in rugged terrain. *Photogrammetric Engg. Remote Sensing*, **57**, 531-537 (1991).

Congalton, R.G. and K. Green: Assessing the Accuracy of Remotely Sensed Data Principles and Practices. Lewis Publishers, USA (1999).

Coppin, P., I. Jonckheere, K. Nackaerts, B. Muys and E. Lambin: Digital change detection methods in ecosystem monitoring: A review. *Int. J. Remote Sensing*, **25**, 1565-1596 (2004).

Coban, H.O.: Determination of temporal changes in forest areas with satellite data. Ph.D. thesis, Istanbul University, The Graduate School of Natural and Applied Sciences, Istanbul, Turkey (2006).

Erdas: Field Guide (7th Edn.). Leica Geosystems GIS and Mapping, LLC, Atlanta, USA (2002).

Fan, F., Q. Weng and Y. Wang: Land use and land cover change in Guangzhou, China, from 1998 to 2003, based on Landsat TM /ETM+ imagery. *Sensors*, **7**, 1323-1342 (2007).

Foody, G.M.: Status of land cover classification accuracy assessment. *Remote Sensing of Environ.*, **80**, 185-201 (2002).

Fung, T.: An assesment of TM imagery for land cover change detection. *IEEE Transactions on Geoscience and Remote Sensing*, **28**, 681-684 (1990).

Hayes, D.J., S.A. Sader and N.B. Schwartz: Analyzing a forest conversion history database to explore the spatial and temporal characteristics of land cover change in Guatemala's Maya Biosphere Reserve. *Landscape Ecology*, **17**, 299-314 (2002).

Howarth, P.J. and G.M. Wickware: Prosedures for change detection using Landsat. *Int. J. Remote Sensing*, **2**, 277-291 (1981).

Jensen, J.R.: Introductory digital image processing. Prentice-Hall Series in Geographic Information Science, USA (1996).

Jha, C.S. and N.V.M. Unni: Digital change detection of forest conversion of a dry tropical Indian forest region. *Int. J. Remote Sensing*, **15**, 2543-2552 (1994).

Kleinod, K., M. Wissen and M. Bock: Detecting vegetation changes in a wetland area in Northern Germany using earth observation and geodata. *J. Nat. Conserv.*, **13**, 115-125 (2005).

Lillesand, T.M. and R.W. Kiefer: Remote Sensing and Image Interpretation (4th Edn.). John Wiley and Sons, Inc., USA (1999).

Lu, D., P. Mausel, E. Brondizio and E. Moran: Change detection techniques. *Int. J. Remote Sensing*, **25**, 2365-2407 (2004).

Mas, J.F.: Monitoring land-cover changes: A comparison of change detection techniques. *Int. J. Remote Sensing*, **20**, 139-152 (1999).

Petit, C., T. Scudder and E. Lambin: Quantifying processes of land-cover change by remote sensing: Resettlement and rapid land-cover changes in South-easten Zambia. *Int. J. Remote Sensing*, **22**, 3435-3456 (2001).

Richards, J.A.: Thematic mapping from multitemporal image data using the principal components transformation. *Remote Sensing of Environ.*, **16**, 35-44 (1984).

Ridd, M.K. and J.A. Liu: A comparison of four algoritms for change detection in an urban environment. *Remote Sensing Environ.*, **63**, 95-100 (1998).

Sader, S.A., D.J. Hayes, J.A. Hepinstall, M. Coan and C. Soza: Forest change monitoring of remote biosphere reserve. *Int. J. Remote Sensing*, **22**, 1937-1950 (2001).

Singh, A.: Digital change detection techniques using remotely-sensed data. *Int. J. Remote Sensing*, **10**, 989-1003 (1989).

Song, C., C.E. Woodcock, K.C. Seto, M.P. Lenney and S.A. Macomber: Classification and change detection using Landsat TM data: When and how to correct atmospheric effects? *Remote Sensing of Environ.*, **75**, 230-244 (2001).

Story, M. and R.G. Congalton: Accuracy assessment: a user's perspective. *Photogrammetric Engg. and Remote Sensing*, **52**, 397-399 (1986).

Sunar, F.: An analysis of changes in a multi-date data set: a case study in the Ikitelli area, Istanbul, Turkey. *Int. J. Remote Sensing*, **19**, 225-235 (1998).

Vogelman, J.E.: Detection of forest change in the Green Mountain of Vermont using multispectral scanner data. *J. Remote Sensing*, **9**, 1187-1200 (1988).

Volcani, A., A. Karnieli and T. Svoray: The use of remote sensing and GIS for spatio-temporal analysis of the physiological state of a semi-arid forest with respect to drought years. *For. Ecol. Manage.*, **215**, 239-250 (2005).

Yener, H. and A. Koç: Monitoring changes in forest and other land use forms in Istanbul. *J. Environ. Biol.*, **27**, 77-83 (2006).