International Journal of Remote Sensing
Vol. 27, No. 9, 10 May 2006, 1825–1838

Methods for fuzzy classification and accuracy assessment of historical aerial photographs for vegetation change analyses. Part II: Practical application

F. OKEKE and A. KARNIELI*
The Remote Sensing Laboratory, Jacob Blaustein Institute for Desert Research, Ben Gurion University of the Negev, Sede Boker Campus 84990, Israel

(*Received 5 March 2005; in final form 18 August 2005*)

This paper is a presentation of the practical application of the algorithms developed in Part I of this series. It is based on the assessment of tree changes with respect to topography in a part of the Adulam Nature Reserve, Israel, between 1945 and 1996. The study is an input to ongoing ecological studies to determine the rate and pattern of tree invasion of plant species in the Adulam Nature Reserve. Datasets available for this study are images of the project site for the years 1945, 1956, 1965, 1967, 1980, 1984 and 1996. For the change detection process, a post classification image differencing method was adopted. In order to enhance the change detection and analysis processes as well as minimize errors, image differencing was applied to grid images generated from image classification products. Since ground data for the accuracy assessment of classification results were unavailable, a method of fuzzy classification and accuracy assessment of classification was employed. Results of this study show a significant general increase in percentage cover of trees in the study area between 1945 and 1996. A peak percentage range of tree cover (35–36%) was observed between 1980 and 1984. Also, a statistically significant interaction between topography and rate of change of tree cover was observed.

1. Introduction

This work is aimed at evaluating and quantifying long-term tree changes as well as tree changes with respect to popular topographic indices of elevation, slope, and aspect, in a part of the Adulam Natural Reserve, Israel. The work is an input to an ongoing ecological study aimed at determining the rate and pattern of tree dominance of plant species in the Adulam Nature Reserve, Israel. It involves the application of analytical methods based on digital image processing of panchromatic aerial photographs. Such studies are also important for other applications including deforestation assessment, vegetation damage assessment, detection of invasive tree species, and nature reserve inventory.

In the past, the majority of such studies were carried out by manual measurement of the quantity and location of vegetation species within a specified area of interest in combination with photo-interpretation. Later with the advent of satellite image technology, satellite imagery became the major source of data for the construction of thematic maps of vegetation species. Recently, an increasing number of

*Corresponding author. Email: karnieli@bgu.ac.il

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online © 2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160500315691

researchers are employing digital processing of aerial panchromatic photographs as an effective procedure for extracting reliable vegetation data (Barnes 1989, Carmel and Kadmon 1998, Hudak and Wessman 1998, Kadmon and Harari-Kremer 1999, Turner *et al.* 1996).

Panchromatic aerial photographs have the disadvantage of having spectral information that is limited to grey-scale values (single band), yet they are the most common type of aerial photograph and the only type for which long-term sequences are available, and they are also available at high spatial resolution. In addition, digital processing of aerial photographs has become easier and cheaper with advances in computer technology and GIS.

In this work, a method of post classification image differencing for change detection is applied. The method requires that the datasets be classified to generate thematic maps of trees and subsequently a change detection procedure is applied with the thematic maps as input. Datasets available for this study spanned a period of 51 years, from 1945 to 1996. Unfortunately, ground data useful for evaluating the accuracy of the classification products for all the datasets were not available. For this reason, the algorithms of fuzzy classification and accuracy assessment of classification products, described in Part I were employed. These methods are useful for the classification of application cases where ground truths are not available.

2. Methods

2.1 *Data source*

The study site is part of the Adulam Nature Reserve, Israel, and covers a distance of 1.78 km in the east–west direction and 1.59 km in the north–south direction with minimum and maximum heights above sea level of 308 m and 390 m, respectively. The Adulam Nature Reserve itself is located in the Judean coastal plain of Israel, and the topography comprises hills separated by valleys. Major tree vegetation consists of Mediterranean Maquis whose density varies according to topography and orientation.

To cover the area of interest, seven sets of panchromatic aerial photographs were acquired. These are photographs for the years 1945, 1956, 1965, 1967, 1980, 1984 and 1996. The photographs are of varying scales ranging from 1 : 12 000 to 1 : 26 000. Also available for the study is a digital elevation model (DEM), of 25 m resolution, covering the project site.

2.2 *Image pre-processing*

All the photographs were scanned with an A3 UMAX Mirage IIse flatbed scanner at a resolution of 400 dpi, into uncompressed, grey-scale tiff format images. Change detection studies require that all spatial information be registered to a common coordinate frame. To achieve this, the digital image of 1984 was orthorectified using Erdas Imagine software, orthobase module to the New Israel Grid. Ground control points were provided by a GPS measurement of selected targets on the image. Using the orthorectified image of 1984 as a reference image, the remaining sets of 1945, 1956, 1965, 1967, 1980, and 1996 were co-registered to the 1984 orthorectified image. This procedure has been shown to be a reliable technique for image registration for change detection studies (Israel *et al.* 1997). In order to cover the project site, an image mosaic of two images from 1945 was generated with Erdas Imagine Dataprep Module. For the rest of the dataset, one single photograph each covers the project site. Subsequently, a subset of the project site was extracted for each of the georeferenced datasets using a common area of interest polygon, which has been digitized in the New Israel Grid.

Since the datasets have different scales and image sizes, the whole set was further reshaped and resized to a 0.5 m resolution and common image size. To provide consistent digital number (DN) values for all the datasets, the two photographs that make the image mosaic of 1945 were radiometrically normalized using a histogram matching procedure (Erdas Imagine software). Subsequently, all the other images were radiometrically normalized to the image mosaic of 1945.

2.3 *Image classification and accuracy assessment*

Photo interpretation of the seven datasets revealed three distinct classes that can easily be identified. These are classes of trees, shrubs and herbaceous plants, and bare soil. The three classes intermix so much that it was not possible to further distinguish different subclasses of trees or shrubs. Fuzzy classification and accuracy assessment of the seven datasets, in the absence of ground data, were performed in accordance to the procedure described in Part I based on the following steps:

(1) The base dataset (1945 dataset) was classified into 10 classes using the fuzzy c-means algorithm to yield 10 class centroids and a partition matrix. A defuzzification process was performed to identify pixels that show the highest degree of 'belonginess' to each of the 10 classes. This is equivalent to the traditional hard classification of the dataset into 10 classes.
(2) The hard product was used in the Erdas Imagine software environment to visually identify the classes that most likely belong to the class of trees, shrubs and herbaceous plants, and bare soil.
(3) Using the result of step 2, the appropriate classes of the 10 classes were then merged to form the three major classes of trees, shrubs and herbaceous plant, and bare soil.
(4) Using the membership grades obtained in step 3, defuzzification was again performed to obtain pixels most likely to belong to the three classes of trees, shrubs and herbaceous plants, and bare soil. Thus we now have a hard product as well as a fuzzy product of the three classes.
(5) A hard product of a subset of the project area was taken as the classification data, and the fuzzy membership grades of the same subset as the reference data. Then, a fuzzy error matrix (Binaghi *et al.* 1999) was computed. Using the computed fuzzy error matrix, accuracy assessment parameters were then computed. Subsequently, the bootstrap resampling algorithm was used to estimate standard errors of the accuracy assessment parameters.
(6) The class centroids from the classification of the 1945 dataset, obtained in step 3, were then used in a supervised fuzzy classification mode to compute fuzzy membership grades for the rest of the datasets (1956, 1965, 1967, 1980, 1984 and 1996).
(7) Steps 4 to 5 were followed for the accuracy assessment of the rest of the datasets.

The hard products from step 2 above were used to build thematic images of class trees for each dataset. The thematic images of class trees were further transformed into raster (grid) maps of percentage of tree cover using programs developed in Matlab. Grids at a resolution of 10 m $\times$ 10 m (20 $\times$ 20 pixels) were generated to cover the whole project area. The total number of pixels classified as trees within each cell of the grid was used to build the percentage values of trees for each cell and further transformed to grey-scale values. The grid images were used for the change detection and analysis in this study. This is similar to the procedure described in Kadmon and Harari-Kremer (1999). The use of the grid images for change detection enhances the change detection and analysis processes, as well as minimizing errors in the change detection process caused by errors in the georeferencing of images.

2.4 *Change detection*

The goal of change detection is to discern those areas on digital images that depict change features between two or more image dates. The basic premise in using remote sensing data for change detection is that changes in land cover result in changes in radiance values, which can be detected by a remote sensing procedure. Some of the most commonly used change detection techniques are image differencing, post-classification comparison, principal component analysis, and change vector analysis (Lillesand and Kiefer 2000, Mas 1999).

Out of all the change detection methods, image differencing was found to be the most useful for this project. Image differencing is a practical and straightforward method for a single band change detection procedure. This method is widely used as one of the change detection algorithms for various kinds of environmental assessment in relation to topographic factors as is the case in this study. Also, many investigators favour this method for its accuracy, simplicity of computation, and ease in interpretation.

In the image differencing procedure for change detection, the corresponding pixel values (DNs) from one date are simply subtracted from those of the other. The difference in areas of no-change will be very small approaching zero (0), on the other hand areas of change will manifest larger negative (−) or positive (+) values.

A major weakness of this technique is its sensitivity to misregistration and radiometric consistency (Lillesand and Kiefer 2000, Mas 1999). Again, an important consideration in using this technique is how to decide where to place the threshold for change in the differenced image. To address these problems, image differencing for change detection is performed on the classified grid images instead of raw images as stated in §2.3. The use of percentage tree coverage of $10\,\mathrm{m} \times 10\,\mathrm{m}$ grid cells alleviates the problem of possible misregistration, as well as making it simpler to determine thresholds for positive change, no change, and negative change.

2.5 *Terrain analysis*

The terrain analysis stage of this study is the representation of information relating to the shape of the terrain with respect to the quantitative changes in the trees. In this study, three important terrain indices—elevation, aspect, and slope—were used to evaluate the quantity of change of trees over the time period of investigation.

The digital elevation model (DEM) of 25 m resolution covering the project site obtained for this study was initially transformed into 0.5 m resolution in order to correspond to the resolution of the difference images to be processed. Subsequently, the transformed DEM was further processed to provide terrain products (elevation, aspect and slope), which would then be used for the analysis.

To obtain these terrain products, the DEM image was first classified into seven classes using an unsupervised classification procedure (Erdas Imagine software).

Then the height ranges of these classes were computed. An aspect image and a slope image were generated using the Erdas Imagine Topographic Analysis module. In this terrain analysis stage, it is in our interest to identify areas of the project site that fall within a specific range of elevation, slope and aspect. To achieve this, a program was scripted in the Spatial Modeler module in Erdas Imagine to produce images that correspond to the union of the intersection of change-detected images and the different classes of elevation, slope and aspect.

When comparing the means of three or more groups, the statistic of choice is the F ratio, computed via a one-way analysis of variance (ANOVA) (Zar 1996). In this case if the computed statistic (F) exceeds the critical value for the chosen significance level, the null hypothesis is rejected and its alternative is accepted, i.e. the means of the groups do indeed differ. In this work, the null hypothesis of no change was tested using a one-way ANOVA, one for the whole area of the project, and one test each for classes of elevation, slope and aspect. Before applying the tests, tree cover estimates were arcsine-square-root transformed as applied in Kadmon and Harari-Kremer (1999). This is in order to generate datasets that are normally distributed, in accordance to the requirement of ANOVA. The basic requirements or assumptions underlying data analysed by one-way ANOVA are that the group data should represent independent samples drawn from normal distributions (Zar 1996).

3. Results

Figure 1 shows panchromatic images of the area of interest for all the datasets. Based on the hard products of classification from §2, the percentage coverage of trees, shrubs and herbaceous plants, and bare soil for all the datasets are shown in figure 2. Figure 2 shows a significant general increase in the percentage cover of trees in the study area between 1945 and 1996. A peak percentage range of tree cover (35–36%) was observed between 1980 and 1984. By contrast there is a noticeable trend in the reduction of percentage cover of shrubs and herbaceous plants in the study area between 1945 and 1996. The average percentage cover of shrubs and herbaceous plants for the whole range of years is 60%, with the lowest value of 53% in 1984, and a maximum value of 63% in 1945. The average percentage cover of bare soil for the whole range of years is 10.6%, with a minimum value of 9.86% in 1945, and a maximum value of 11.34% in 1956.

Results of the accuracy assessment of the fuzzy classification of all the datasets are summarized in figures 3, 4 and table 1. Figure 3 shows the overall accuracy, Kappa Coefficient (K), and modified Kappa Coefficient (K_e) for all the datasets. K_e is kappa with random chance agreement as defined by Foody (1992). All the datasets have higher overall accuracy values than kappa coefficients values. Overall accuracies for all datasets exceeded 85%, while kappa coefficients for all datasets exceeded 80%. Figure 4 shows bootstrap standard errors of the overall accuracy, Kappa Coefficient (K), and modified Kappa Coefficient (K_e) for all the datasets. Both kappa coefficients show lower standard errors than the overall accuracy.

Null hypothesis was constructed to test whether the error matrices differ significantly with one another. Result revealed no significant difference between all paired combinations of the dataset at 0.05 significant levels. The computed z statistic for testing significant differences between paired combinations of fuzzy error matrices for the whole dataset is listed in table 1.

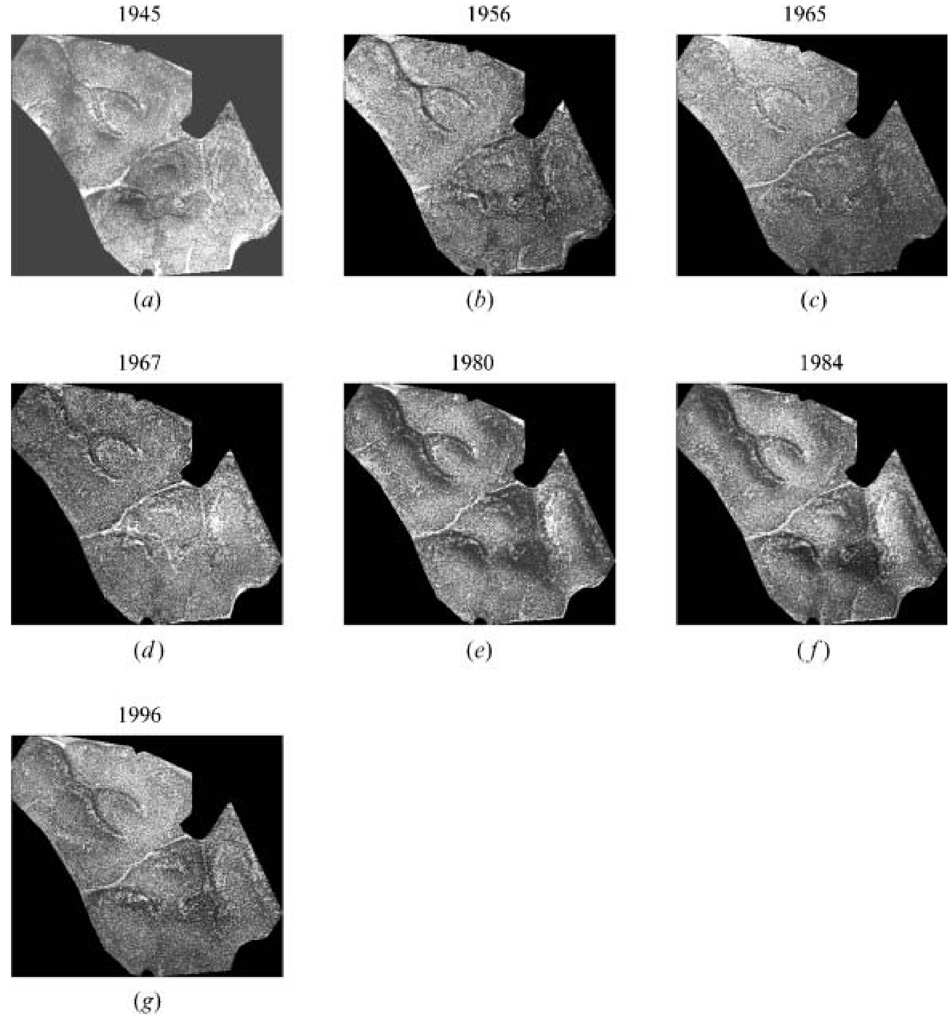

Figure 1. Panchromatic images of area of interest for (*a*) 1945, (*b*) 1956, (*c*) 1965, (*d*) 1967, (*e*) 1980, (*f*) 1984 and (*g*) 1996 datasets.

From the hard classification products of §2, thematic images of classes of trees only for all the datasets are shown in figure 5. In figure 5, dark patches represent trees, and white patches represent areas of no trees. The class of trees only was used to build grid images of percentage tree cover. A one-way ANOVA was carried out to test whether the grid images of all the datasets were actually different. Result (F=179.55, p<0.0000) strongly supports the alternate hypothesis that the grid images are drawn from populations with different means. Image differencing was then performed with the grid images to yield image differences of grid images between 1945 and all other years, as well as between each subsequent year. Results correspond to the percentage coverage of trees as shown in figure 3.

The height ranges of the generated height classes are shown in table 2. Images showing the areas of grid images and the areas of the change-detected image that correspond to different classes of the elevation were generated.

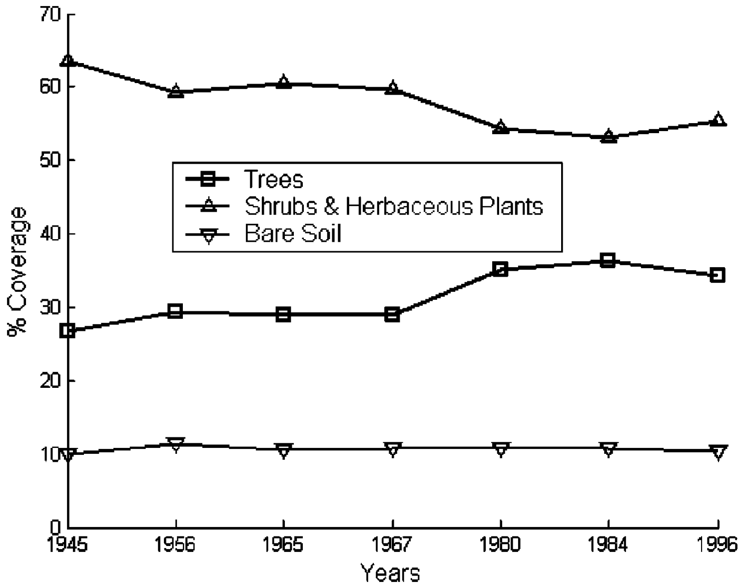

Figure 2. Percentage coverage of trees, shrubs and herbaceous plants, and bare soil for all the datasets.

A one-way ANOVA was carried out to test whether areas of the grid images that correspond to different classes of elevation were different for the whole dataset. The result (F=132.65, p<0.0000) strongly supports the alternative hypothesis that the grid images corresponding to different classes of elevation are different for the whole dataset. Figure 6(*a*) shows the percentage coverage of height classes for all years,

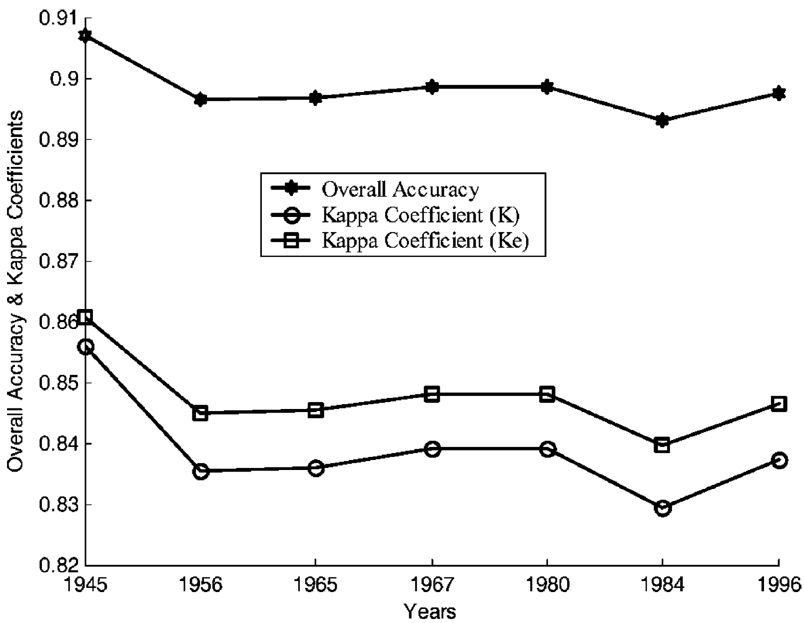

Figure 3. Overall accuracy and kappa coefficients for all the datasets.

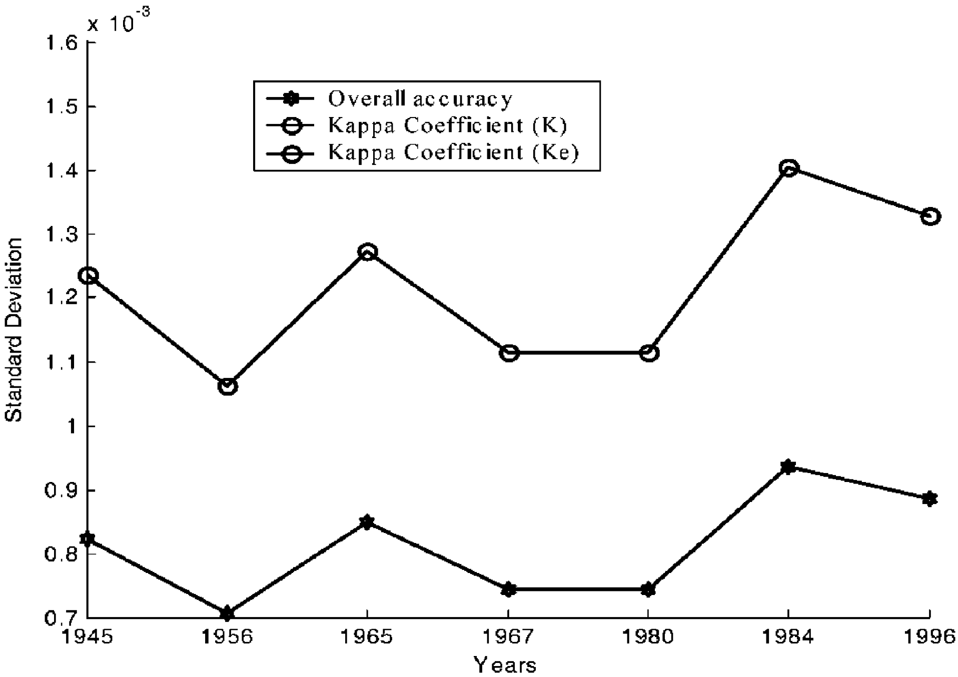

Figure 4. Standard deviations for the overall accuracy and kappa coefficients for all the datasets.

while figure 6(*b*) shows the percentage changes of tree cover with respect to the classes of elevation from 1945 to each other year, and figure 6(*c*) shows the percentage changes of tree cover with respect to the classes of elevation between subsequent years.

As in the case of elevation, images showing the areas of grid images and areas of the change-detected image that correspond to different classes of slope were generated for all years. The values of the classes of slope of the project site are shown in table 3.

A one-way ANOVA was again carried out to test whether areas of the grid images that correspond to different classes of slope are different for all years. The result (F=96.64, p<0.0000) strongly supports the alternative hypothesis that the grid images corresponding to different classes of slope are different for the whole dataset. Figure 7(*a*) shows the percentage coverage of slope classes for all the years, while

Table 1. *Z* statistics for testing significant differences between paired combinations of fuzzy error matrices for all the datasets.

	1945	1956	1965	1967	1980	1984	1996
1945	–	0.55	0.13	0.37	0.63	0.50	0.91
1956		–	−0.39	−0.17	0.09	−0.06	0.38
1965			–	0.22	0.47	0.34	0.74
1967				–	0.26	0.11	0.54
1980					–	−0.16	0.29
1984						–	0.45
1996							–

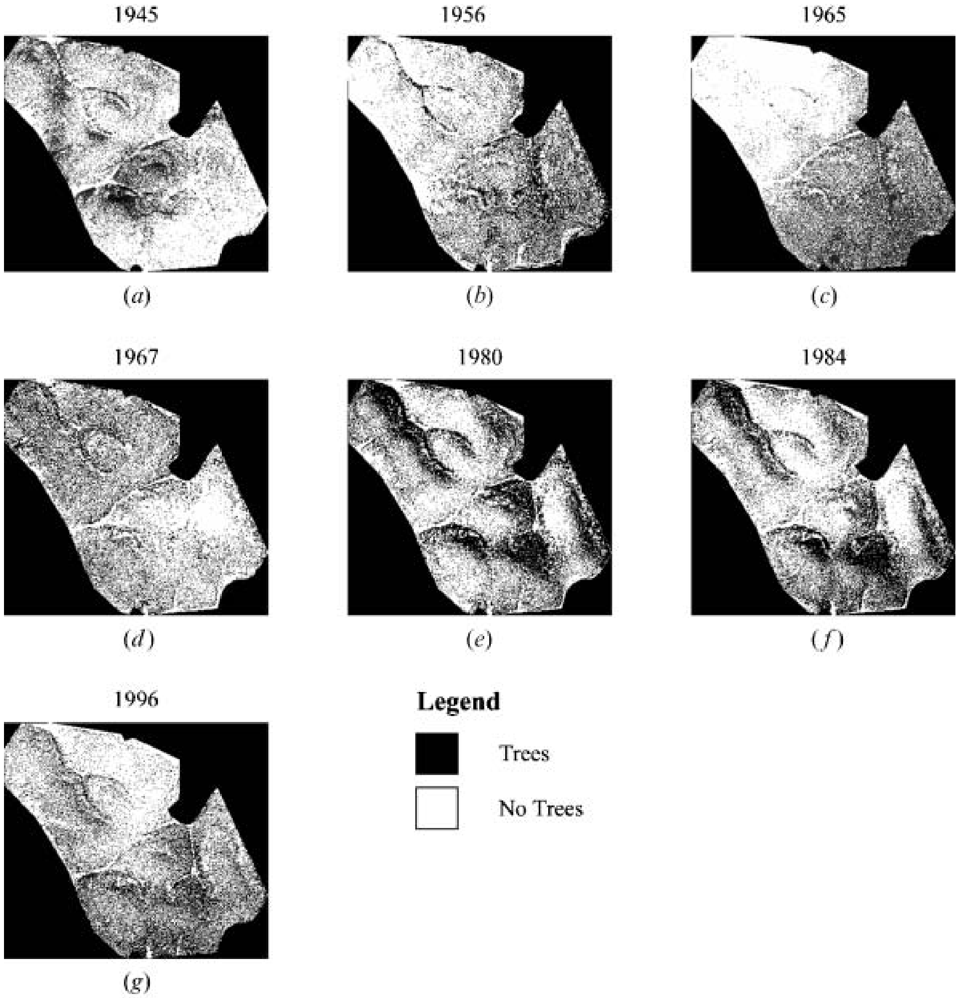

Figure 5. Hard products of tree classes for (*a*) 1945, (*b*) 1956, (*c*) 1965, (*d*) 1967, (*e*) 1980, (*f*) 1984 and (*g*) 1996 datasets.

figure 7(*b*) shows the percentage changes of tree cover with respect to the classes of slope from 1945 to each other year, and figure 7(*c*) shows percentage changes of tree cover with respect to the classes of slope between subsequent years.

Again, images showing the areas of grid images and areas of the change-detected image that correspond to different classes of aspect were generated for all the years. The values of the 5 classes of aspect of the project site are shown in table 4 below.

Table 2. Height ranges of the seven elevation classes.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Maximum height (m)	341.05	350.70	357.31	363.21	369.16	377.01	390.97
Minimum height (m)	308.49	341.05	350.70	357.31	363.21	369.16	377.01

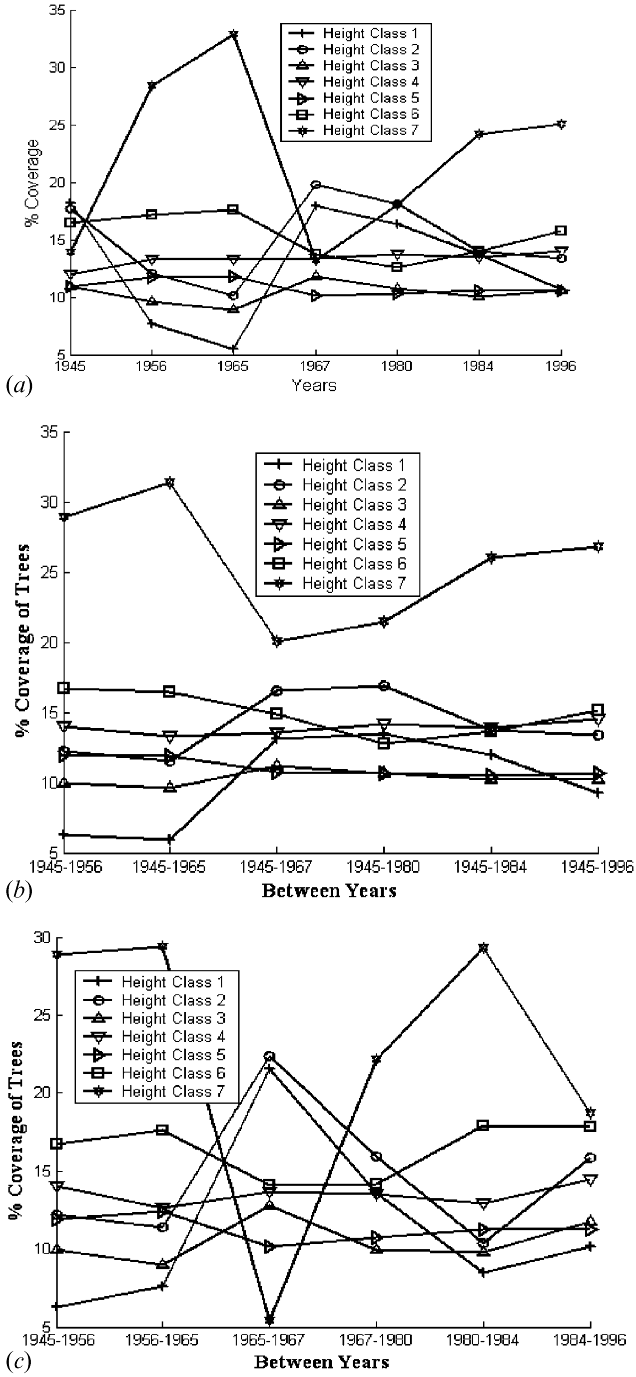

Figure 6. (*a*) Percentage coverage of elevation classes for all years. (*b*) Percentage changes of tree cover with respect to the classes of elevation (from 1945 to every other year). (*c*) Percentage changes of tree cover with respect to the classes of elevation (between subsequent years).

Table 3. The five slope classes.

Slope classes	Slope values
1	0–10
2	11–20
3	21–30
4	31–45
5	46–90

As above, a one-way ANOVA was carried out to test whether areas of the grid images that correspond to different classes of aspect were different. The result (F=67.26, p<0.0000) strongly supports the alternative hypothesis that the grid images corresponding to different classes of aspect are different for the whole dataset. Figure 8(*a*) shows the percentage coverage of aspect classes for all years, while figure 8(*b*) shows the percentage changes of tree cover with respect to the classes of aspect from 1945 to each other year, and figure 8(*c*) shows the percentage changes of tree cover with respect to the classes of aspect between subsequent years.

4. Conclusion

This paper presents the practical application to the algorithms developed in Part I, and is based on the assessment of quantitative tree changes with respect to topography of part of the Adulam Nature Reserve, Israel from 1945 to 1996. The result of this study is an input to ongoing ecological studies to determine the rate and pattern of tree invasion of plant species in the Adulam Nature Reserve, Israel. Results show a significant general increase in percentage cover of trees in the study area between 1945 and 1996. A peak percentage range of tree cover (35–36%) was observed between 1980 and 1984.

The results of the analysis of tree changes with respect to topography show statistically significant interaction between topography and rate of change of tree cover. It is observed that the percentage tree cover on the highest elevation class (377.01 m–390.97 m) was the largest for positive tree cover changes, for the periods 1945–1956, 1945–1965, 1945–1967, 1945–1980, 1945–1984, 1945–1996. Also height classes 1 (308.49–341.05 m) and 3 (350.70–357.31 m) recorded the least percentage tree cover for positive changes of tree cover between the above stated periods. The same observations are made for the periods 1956–1965, 1967–1980, 1980–1984, 1984–1996. The period between 1965 and 1967 did not show this pattern.

Topographic analysis of this study also reveals that about 75% of positive changes in tree cover for the project site occurred in the area with a slope value range of 0–10. This observation is for the periods 1945–1956, 1945–1965, 1945–1967, 1945–1980, 1945–1984, and 1945–1996, as well as for the periods 1956–1965, 1967–1980,

Table 4. The five aspect classes.

Aspect classes	Aspect values (°)
1. North Facing Slopes	0–45, 315–360,
2. East Facing Slopes	45–135
3. South Facing Slopes	135–225
4. West Facing Slopes	225–315
5. Flat Surface	361

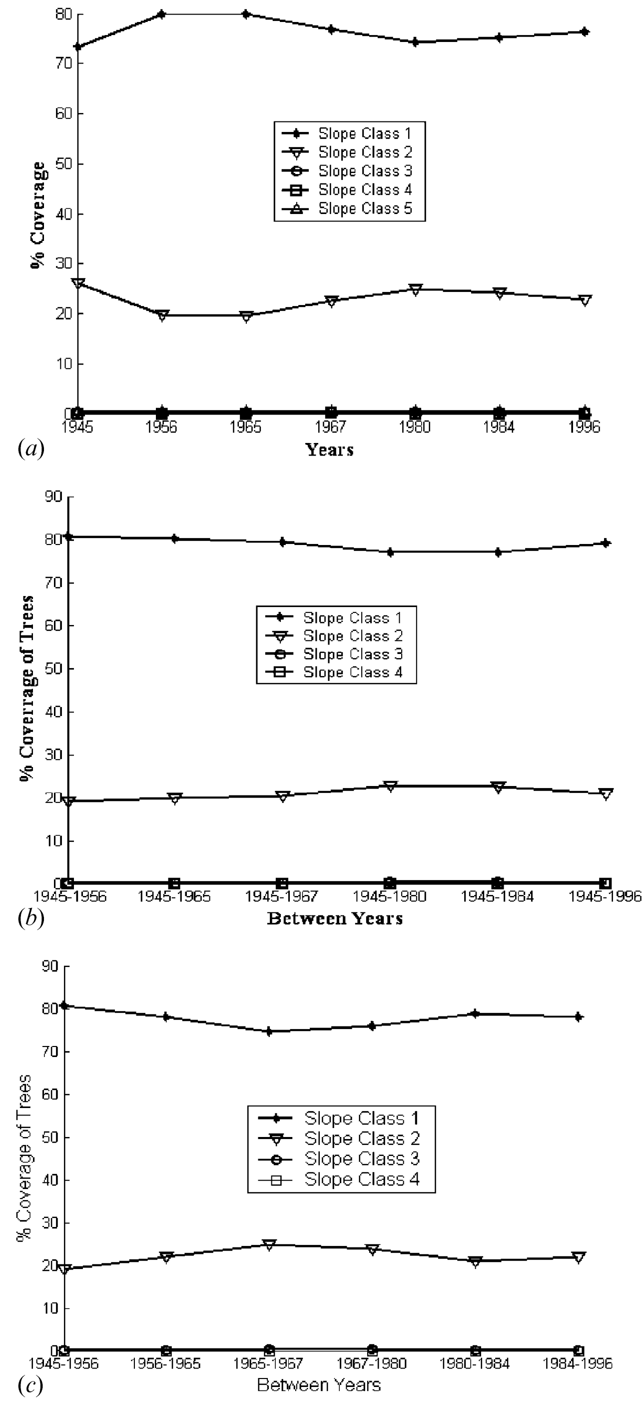

Figure 7. (*a*) Percentage coverage of slope classes for all years. (*b*) Percentage changes of tree cover with respect to classes of slope (from 1945 to every other dataset). (*c*) Percentage changes of tree cover with respect to classes of slope (between subsequent years).

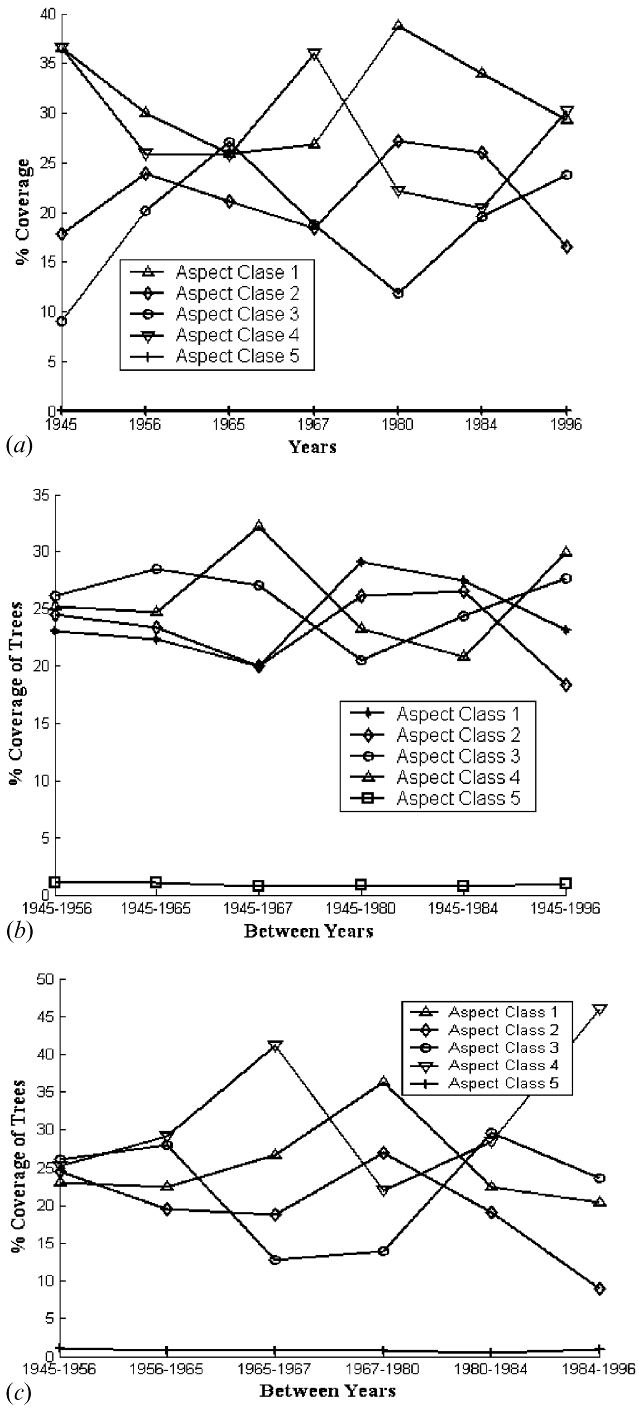

Figure 8. (*a*) Percentage coverage of aspect classes for all years. (*b*) Percentage changes of tree cover with respect to classes of aspect (from 1945 to every other year). (*c*) Percentage changes of tree cover with respect to classes of aspect (between subsequent years).

1980–1984, 1984–1996. Areas lying within the slope range 31–45 recorded the least (about 0%) positive changes in tree cover for the project site, and for the periods of time under investigation.

South facing slopes recorded the largest percentage tree cover for positive changes in tree cover for the periods 1945–1956, and 1945–1965, as well as for the periods 1956–1965, and 1980–1984. On the other hand, the north facing slopes contained the largest percentage tree cover for positive changes in tree cover for the periods 1945–1980 and 1945–1984, as well as the period 1967–1980.

References

BARNES, W.J., 1989, A case history of vegetation changes on Meridian Island of West-Central Wisconsin USA. *Biological Conservation*, **49**, pp. 1–16.

BINAGHI, E., BRIVIO, P.A., GHEZZI, P. and RAMPINI, A., 1999, A fuzzy set-based accuracy assessment of soft classification. *Pattern Recognition Letters*, **20**, pp. 935–948.

CARMEL, Y. and KADMON, R., 1998, Computerized classification of Mediterranean vegetation using panchromatic aerial photographs. *Journal of Vegetation Science*, **9**, pp. 445–454.

FOODY, G.M., 1992, On the compensation of chance agreement in image classification accuracy assessment. *Photogrammetric Engineering and Remote Sensing*, **58**, pp. 1459–1460.

HUDAK, A.T. and WESSMAN, C.A., 1998, Textural analysis of historical aerial photography to characterize woody plant encroachment in South African savanna. *Remote Sensing of Environment*, **66**, pp. 317–330.

ISRAEL, S.T., HELFERT, M.R. and DUGGIN, M.J., 1997, Image registration issues for change detection. *Proceedings of GeoComputing '97 & SIRC' 97*, University of Otago, New Zealand, 26–29 August 1997 (Geocomputation), pp. 15–20.

KADMON, R. and HARARI-KREMER, R., 1999, Studying long-term vegetation dynamics using digital processing of historical aerial photographs. *Remote Sensing of Environment*, **68**, pp. 164–174.

LILLESAND, T.M. and KIEFER, R.W., 2000, *Remote Sensing and Image Interpretation* (New York: John Wiley and Sons).

MAS, J.F., 1999, Monitoring land-cover changes: a comparison of change detection techniques. *International Journal of Remote Sensing*, **20**, pp. 139–152.

TURNER, I.M., WONG, Y.K., CHEW, P.T. and IBRAHIM, A., 1996, Rapid assessment of tropical rain forest successional status using aerial photographs. *Biological Conservation*, **77**, pp. 177–178.

ZAR, J.H., 1996, *Biostatistical Analysis* (London: Prentice-Hall International).