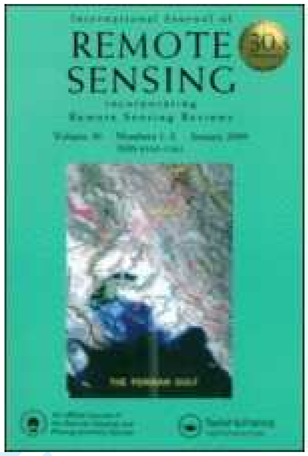

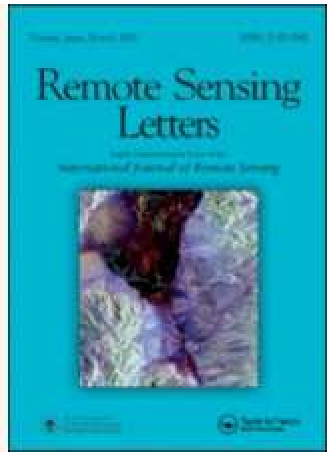

Multi-temporal land use change mapping with Landsat data applied to the Mediterranean island of Lesvos (Greece)

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Abstract. The present study uses a series of Landsat images to map the main land use types on the Mediterranean island of Lesvos, Greece. We compare a single-year maximum likelihood (ML) classification with a multi-temporal land use mapping approach, with time series class labels modeled using a first order hidden Markov model comprising continuous and discrete variables. A rigorous validation scheme shows higher producer's and user's accuracy figures for the multi-temporal approach. Land use change accuracies were also greatly improved by the proposed methodology: from 48% to 70%. The results show that when only two dates are used and therefore, no multi-temporal processing can be applied, the mapping of land use/cover is unreliable and a large number of the changes identified are due to the individual-year commission and omission errors.

1. Introduction

Land use and land cover (LULC) change has received a lot of attention over the last decades as it is seen by the wider scientific community as one of the major factors contributing to global climate change (Turner *et al.* 1995). The mapping of LULC can be performed in a cost effective manner using Earth observation remote sensing (EO/RS) technologies in conjunction with geographical information systems (GIS; Ehlers *et al.* 1990, Meaille and Wald 1990, Treitz *et al.* 1992, Westmoreland and Stow 1992, Weng 2002). It involves the use of multi-date imagery to appraise differences in LULC due to environmental conditions and human actions between the acquisition dates of the images (Singh 1989, Yang and Lo 2002). Landsat data have commonly been employed to map LULC and LULC change, mainly due to the availability of historical archives, spanning some 35 years (Rees *et al.* 2003, Liu *et al.* 2005, Yuan *et al.* 2005, Yemefack *et al.* 2006, Huang *et al.* 2007, Kennedy *et al.* 2007). The specific imagery is also attractive for its spatial and spectral resolutions which allow for relatively accurate mapping of the different LULC types at the regional scale.

Most methods for spectral classification of EO/RS images are per-pixel based and have been used with varying degrees of success, greatly depending on the spatial homogeneity of the cover type being mapped. For mapping change, algorithms apply a post-classification comparison (PCC) or, less commonly, an image-to-image comparison looking at spectral change between different dates (Singh, 1989, Green *et al.* 1994, Eastman *et al.* 2005, Berberoglu and Akin 2009). PCC methods present the advantage of being able to identify and map the location, extent, as well as the nature of changes (Jensen *et al.* 1993, Chen 2002, Foody 2002, Hung and Wu 2005). However, one of their main limitations, augmented by the aforementioned weakness of the per-pixel based classifiers, is that it allows for the recording of false change due to individual-year land use map inaccuracies (Jensen *et al.* 1993, Rutchey and Vilcheck 1994, Foody and Boyd 1999).

Progress has been made over the last years in methods for classification that consider not only the spectral information but also the spatial domain i.e. the supplementary spectral information of neighbouring pixels when analysing and classifying imagery (Atkinson and Quattrochi 2000, de Jong and van der Meer 2006, Sluiter *et al.* 2006). Such methods vary from variogram (Atkinson and Lewis 2000) and fractal methods (de Jong and Burrough 1995, Myint 2003), to segmentation algorithms (Blaschke *et al.* 2006) and methods that refine previously classified images (Barnsley and Barr 1996, Barr and Barnsley 2000) and Spatial and Spectral Classification method (de Jong *et al.* 2001).

Several studies that have employed Landsat data (Tatem *et al.* 2005, Gatsis *et al.* 2006, Kilic *et al.* 2006, Tatem *et al.* 2006, Symeonakis *et al.* 2007, Huang *et al.* 2008) have commonly made use of only two dates from the freely available GeoCover Landsat archive (Tucket *et al*. 2004) for identifying LULC and LULC change. When ustilising only the free data, the degree of correspondence between the temporal frequencies of the two dates used with change event processes can affect the completeness of change detection efforts (Lunetta *et al.* 2004, Symeonakis *et al.* 2006). Here we use a multi-temporal model (Kiiveri and Caccetta 1998) along with the operational broad-scale processing methodology described by Furby (2002). It consists of a series of algorithms which use long-term sequences of images along with discriminant analysis techniques to define the spectrally separate classes of interest and spatio-temporal models incorporating error rates of the initial interpretations to reduce classification errors. We describe the application of the image pre-processing, individual-year and multi-temporal classification to the Mediterranean island of Lesvos (Greece). We also investigate the impact of imagery temporal frequency on LULC change detection by comparing the change maps obtained by using only two dates to maps acquired from using twice as many images along with the multi-temporal approach.

2. Area of study

Lesvos is situated in the eastern Mediterranean Sea and is the third largest Aegean island of Greece (figure 1). It covers an area of approximately 1630 km^2 and has a maximum altitude of 947 m. The climate is characterised by strong seasonal and spatial variations of rainfall and high oscillations between minimum and maximum daily temperatures, typical of the Mediterranean region (Gatsis *et al.* 2006). Extensive fields of olive groves, Mediterranean maquis, phrygana, pine and deciduous oak forests as well as various types of irrigated and non-irrigated agricultural uses dominate the landscape. Great changes occurred in the last century in the geographical distribution and the total area occupied by the various types of land use (Giourga *et al.* 1994). Forested areas were cleared without any accompanying measures against soil erosion which, along with desertification, are identified as the most serious environmental threats to the island (Marathianou *et al.* 2000).

Insert figure 1 about here

3. Datasets and methods

Six MSS, TM and ETM+ images were used spanning 26 years from 1975 till 2001 (table 1).

Insert table 1 about here

Other ancillary datasets included a 30-m Digital Elevation Model (DEM), black and white 1:50 000 aerial ortho-photos of 1960, a 1:100 000 LULC map of the Ministry of Agriculture Forestry Department (MAFD) published in 1985 (largely based on the 1960s aerial photographs and other ancillary data such as 1:20 000 ortho-photo maps, bioclimatic and soil maps); black-and-white 1:33 000 aerial ortho-photos of 1995; a multi-spectral QuickBird 2000 image with a nominal pixel size between 2.44 m and 2.88 m (at nadir), resampled at 3 m. Furthermore, the facility provided by Google Earth (Google 2010) was also employed which covers the study area with QuickBird fused multi-spectral and panchromatic data (61 to 72 cm pixels at nadir).

The following sections give an overview of the image pre-processing, single-year and multiple-date classifications, LULC and LULC change mapping and the various stages of accuracy assessment.

3.1. Image pre-processing

Ortho-rectification of the available images was first performed using the viewing-geometry and block adjustment model with Toutin's approach (Toutin 1994). The 2000 image, one of the free ortho-rectified Landsat imagery, was chosen as the ortho-rectification reference. Approximately one hundred GCPs were collected from it for rectifying the purchased scenes and to check the ortho-rectification of the 1975 and 1987 images. The over-all size of the mean errors (RMSE) was between 9.7 and 10.3 m in both directions for all TM and ETM+ images, and 41.2 m in the x- and 47.1 m in the y-direction for the MSS image which is less than one pixel. However, absolute pixel errors of more than one pixel can also be a cause of concern in multi-temporal studies. A cross-correlation matching algorithm was used to check the accuracy of the registered images to the base image, resulting in what appeared to be two systematic concentrations of negative residuals in the y-direction between the 1987 image and the 2000 base. On the x-direction, a concentration of relatively low values was also detected.

The image data was then calibrated to produce radiometrically consistent images. The images were normalised to a reference (or base) image, as a reliable correction to absolute reflection units is not possible. This calibration process, although not strictly necessary for the land use/cover classifications over this study area that falls within the limits of a single Landsat scene, allows easy comparison of image data through time. First, satellite calibration coefficients were used to calculate top-of-atmosphere reflectance (Vermote *et al.* 1997). A Bi-directional Reflectance Distribution Function (BRDF) model was then applied to correct for sun-satellite viewing geometry (Danaher *et al.* 2001*,* Wu *et al.* 2001). Finally, calibration to 'like-values' was applied using S-estimation (Rousseeuw and Leroy 1987*,* Furby and Campbell 2001), to correct for atmospheric differences between the reference and subsequent images.

Terrain illumination correction was also applied to each image to correct for the illumination effects, resulting in bright and dark sides of hills and mountains. This is particularly important for time series imagery where terrain effects vary with different dates. The terrain illumination correction used here is based on the C-correction (Teillet *et al.* 1982) and incorporates a ray-tracing algorithm for identifying true shadow (Wu *et al.* 2004).

3.2. Single-year classifications

The single-year classification was an iterative process. First, ground-truth data showing the location and extent of representative land cover classes to train the land cover mapping process were derived from the aerial photographs, the QuickBird data and the MAFD map. A systematic sampling scheme (within the land use/cover MAFD zones) was employed, the samples varying from 10-50 Landsat TM pixels in size. Canonical variate analysis (CVA; Campbell and Atchley 1981) was then used to investigate the spectral separability of the training sites from the nominal land cover categories. CVA is widely used to analyse group structures in multivariate data, and as a means of separating a group of samples from different populations. In brief, CVA finds linear combinations of the original variables (Landsat bands, in this case) that maximize the separation between the different groups while minimizing the within group variance. Land cover types that are well separated can be reliably mapped. The ordination plots from the CVA also provide the basis for grouping the training sites into spectrally consistent 'information classes' into which the image data can be classified. Moreover, the canonical vectors give the directions of maximum site separability and the canonical roots give a measure of the amount of site separation in these directions. Figure 2 is an example of canonical variate ordination plots for the year 1999 TM data.

Insert figure 2 about here

Depending on the separability of the land cover classes in each date image, 12 to 19 classes of land cover were mapped. Some of the land cover classes were spectrally very similar, which made them difficult to map, for example bare and the sparsely vegetated scrubland (or garrigue). In this specific case, we trained the classifier so that only the bare rocky outcrops were labeled as ‘bare’ land cover class. In general, the ambiguous cover classes were further analysed by including new training sites or omitting existing ones until the ability to separate between classes was decided. The CVA analyses were therefore applied iteratively to examine particular class separability problems, errors and ambiguity.

A maximum likelihood (ML) classification, perhaps the most popular classifier for optical data, was then applied to assign pixels to one of the spectral classes identified. Based on our extensive knowledge of the study area, the classified images were reviewed visually to identify areas where the classification was clearly incorrect. The analyses were repeated, often with additional training sites, aimed specifically at correcting the observed errors. The newly classified images were assessed and the training samples were revised, when necessary.

Finally, the 12 to 19 land cover classes mapped using the ML classifier were grouped to form the desired seven main land use classes of the island, namely: (i) bare (ii) urban (iii) scrubland and Mediterranean maquis (iv) olive groves (v) other crops (irrigated and non-irrigated) (vi) forests (coniferous and deciduous), and (vii) water bodies.

3.3. Multiple-year classifications

Kiiveri and Caccetta's (1998) approach using Conditional Probability Networks (CPNs) was employed that combines the multi-temporal land cover information from the single-year classifications to produce land use maps. The CPNs provide a probabilistic framework for combining data, typically with the view to classifying the data. A CPN can be represented by a graph, where the nodes of the graph represent random variables and the edges of the graph represent (conditional) independence assumptions between the variables. (figure 3).

Insert figure 3 about here

The circles and rectangles represent vertices or nodes of the graph. The rectangles represent the estimate of the true land use map from the classification of the images for each year. The circles represent variables the true land use map at each date. The graph edges or ‘arrows’ represent relationships between the variables. Observing a particular value for a variable provides some information about all the other variables to which it is connected. The strength of these relationships can also depend on the time interval between image dates. For example, less change would be expected between images one year apart than between images several years apart (Kiiveri *et al*. 2001).

The rules, or the relationships between the variables, are expressed in terms of conditional probability tables. These tables need to be specified or estimated from the data available. Error-rates tables link the estimated land use map to the true land use at each date (vertical arrows in figure 3). Temporal rules link the true land use maps through time (horizontal arrows in figure 3).

3.4. Land use change mapping

Land use change maps for the period of study (i.e. 1975-2001) were produced from the single-year (pre-CPN) and multi-temporal (post-CPN) classification results by using the post classification comparison (PCC) technique which constitutes the most frequently applied method for the mapping of land use changes (Foody 2002). Results from the CPN are typically less accurate for the dates at the start and the end of the period because in the multi-temporal processing, the first and last dates are considered less reliable for having no 'before' or 'after' image in the temporal sequence. It was therefore of essence to also look at mapped land use changes between the period that is formed by excluding the 1975 and 2001 classifications from the calculations, i.e. the changes between 1987 and 2000.

3.5. Accuracy assessment

The accuracy assessment involved image pre-processing accuracy, land use classification accuracy, and land use change accuracy assessment, pre- and post-CPN. With regards to pre-processing, the accuracy of the ortho-rectification of the 2000 base image to the DEM was assessed using the Root Mean Square Error (RMSE) and 30 independent GCPs that were not used in the model fit. The registration of the rest of the images to the 2000 base image was also assessed using the RMSE and another 36 independent GCPs. The accuracy of the terrain illumination correction was not assessed at this stage.

When undertaking change detection using multi-temporal images, it is often difficult to make the land use classification accuracy assessment which involves simultaneous collection of reference data for all dates. In our case, only the 1995 and 2000- images were validated using same-year ancillary data (aerial photographs and QuickBird data, respectively). For the validation of the classification outputs with non-contemporaneous data, some suggest a rule-based rationality evaluation with post-classification comparison approach (Liu and Zhou 2004). This method was not applied here since an issue arises as to how comparable the assessment results of the contemporaneous and the non-contemporaneous data are.

For the assessment of the 1995 and 2000 classifications pre- and post-CPN, four independent sets of reference points were collected (i.e. one set per year per method) using a stratified random sampling frame across the seven land use types that cover the study area. For each validation, a total number of 350 random points was distributed across the scene with a minimum number of 50 points allocated to the smallest class (i.e. urban) to ensure that an adequate number of samples was used for the assessment of every class. Contingency matrices, omission and commission errors, overall classification accuracies and overall kappa indices (Cohen 1960), were estimated.

The accuracy assessment of change/no-change areas was performed for the 1995-2000 period to coincide with the available validation data**.** We assessed the performance of mapping change/no-change using only the free imagery (i.e. pre-CPN) and with the multi-temporal approach (i.e. post-CPN). For each method a set of 100 sample points was distributed across the scene, half over the changed and half over the unchanged areas. A comparison between the satellite images, the land use maps and the reference data was made, in order to draw conclusions on the validity of the mapped changes and thus create a summary table that gives a quantitative description of their accuracy (Macleod and Congalton 1998, Khorram *et al.* 1999, Foody 2002).

4. Results and discussion

4.1. Pre- and post-CPN classifications

The error matrices for the assessment of the 1995 and 2000 single-year and multi-temporal classifications are summarized in table 2. The CPN seems to improve the single-year outputs for both epochs of validation with producer's and user's accuracies being higher for most classes. Overall accuracies are also higher by 15% in 1995 and 11% in 2000, while overall Kappa statistics are up from 0.65 in 1995 and 0.69 in 2000 to 0.83.

Insert table 2 about here

A number of issues arose primarily during the investigation of the separability of the training sites. In all years, the main land use type of the island, mapped by both single-year and multiple-date approaches, is the olive groves (table 3), a highly important component of the island's economy. These were generally difficult to separate as they were confused spectrally with the Mediterranean maquis, mainly the *Quercus* family and other broad-leaved evergreen shrubs. This was especially so in the western part of the island, where abandoned olive groves are often succeeded by holm oak (*Quercus Ilex*; Giourga *et al.* 1994, Gatsis *et al.* 2006, Koukoulas *et al.* 2007).

Insert table 3 about here

The second largest land use type appears to be the various scrubs and Mediterranean maquis (table 3). These were the most difficult to map with spectral separability issues arising mainly from the similarities with certain 'olive' pixels resulting in generally high omission errors. In general, forests were well separated from other land use types with the exception of the deciduous forests in the west which in some dates could not be separated from the Mediterranean maquis.

'Other crops' appear to fluctuate a lot in terms of the area covered through the years. This can be attributed to the fact that the images do not all belong to exactly the same phenological period. Four images are from summer months (June, July) while two belong to late spring (May; table 1); the maximum difference between images is actually more than two months: 11th May (1987) to 16th July (1975).

'Bare' areas, were also difficult to map. Pre-CPN classifications identify almost two to three times as many 'bare' pixels. The specific land cover type is confused spectrally with the lower end of the 'scrub and maquis' type i.e. the very sparse scrub, since there is a vegetation density continuum with a rather fuzzy border between the two types, at the Landsat scale. Bare land was also confused with some urban pixels and the irrigated crops after harvest. The multiple-year approach was more successful in mapping the bare areas in both validation dates.

Settlements, i.e. towns and other urban infrastructure, have a high within-pixel heterogeneity which made it difficult to find adequate (i.e. homogeneous) training sites. Nevertheless, it was generally possible to separate them from the other classes, especially post-CPN, with the exception of some 'bare' overlap.

4.2. Land use change results

The island appears to have undergone dramatic changes in most land use types and years when the multiple-year processing is not applied (table 4). Moreover, in most cases, these fluctuate significantly and abruptly between years due to the individual-year classification (commission and omission) errors. In general, post-CPN changes are smaller and with fewer fluctuations. Figure 4 provides a graphic illustration of the CPN effect in reducing the amount of false change due to individual-year classification (commission and omission) errors.

Insert table 4 about here

Insert figure 4 about here

In terms of stability (or no-change), between 1975 and 2001 the amount of pixels that remain unchanged (in bold in table 4) are again higher according to the post-CPN results. The relatively low unchanged percentage for 'crops', together with the high percentage of 'crops' that have changed to 'olives', are most likely due to the issues related with the phenology and the MSS resolution as well as the separability issues between certain crop types and the olive groves.

The post-CPN land use change results were smaller and fluctuated less than their pre-CPN counterparts. Nevertheless, in the 26-year results between 1975-2001 some of the stability (or no-change) figures appear to be higher than expected from expert knowledge of the study area (table 4). For example, the estimated percentage of the areas mapped as urban in 1975 that change to other land use in 2001, seems quite high: in reality, one would anticipate that almost all areas that were settlements or some urban infrastructure in Lesvos in 1975 should remain urban in 2001, too. These are probably errors that have not been dealt with by the multi-temporal processing due to the fact that the first and last dates are less reliable since they have no 'before' or 'after' image in the temporal sequence. The lower spatial and spectral resolutions of the MSS data of 1975 also amplify this problem.

The 1987-2000 LULC change results which, as previously mentioned, are more accurate due to the exclusion of the start and end dates in the multi-temporal sequence, reveal two important changes from a land and environmental management perspective: the area covered by the various pine and deciduous forests appears to have decreased by ~4% and that olive groves have also decreased by ~2%. The first provides evidence that specific mitigation and protection measures need to be considered for the reversal of the reported deforestation rates in the island (Vasilakos *et al.* 2007). The decrease in the area covered by olive groves comes to support existing findings of abandonment (Giourga *et al.* 1994) due to economic and social changes that can lead to increased rates of soil erosion and land degradation if combined with steep slopes (≥25%; Koulouri *et al.* 2007).

Accuracy figures for the areas mapped as 'changed' and 'not-changed', for the period matched by the validation data, i.e. between 1995 and 2000, are summarized in table 5. The land use change assessment exercise for the 1995-2000 period (table 5) shows that accuracy figures are higher when the CPN is applied: percentage correct for changed areas is up 24%. For the unchanged areas, accuracy figures are high, pre- and post-CPN alike (96% and 100%, respectively).

Insert table 5 about here

It is important to stress here that only two out of six dates (1995 and 2000) were validated. Nevertheless, the results have shown that if only two dates are used to map LULC change then, consequently, a multi-temporal approach cannot be applied, and the change results are susceptible to false labeling of change, due to the high commission and omission errors. Even if three dates are employed, a multi-temporal approach cannot provide significant assistance in identifying false change. This demotes the importance of the temporal rules and therefore a higher proportion of (both commission and omission) errors may occur. It is therefore recommended that a fuller set of Landsat data is employed for accurately mapping land use and land use change.

5. Conclusions

Here we attempted to produce LULC and LULC change maps for the island of Lesvos using Landsat multi-date imagery. We also compared the results from a multi-temporal re-classification approach (post-CPN) with results obtained from single-year ML classifications (pre-CPN). The pilot study in the Mediterranean island of Lesvos has implemented a processing stream for the production of land use maps based on single date Landsat imagery, and land use change maps derived from them. Certain LULC types where difficult to delineate but the use of discriminant analysis techniques (to spectrally separate the classes of interest) and spatio-temporal models incorporating error rates of the initial interpretations (to reduce classification errors) have improved results considerably. Dependent on suitable historical imagery, operational implementation at regional or even national scales should be feasible for all the steps from basic image processing through to classification, map production and validation.

An important finding from the results of this study is that, using only two dates to map LULC and LULC change, an approach that has commonly been applied in a number of land use change studies, can introduce false change due to commission and omission errors of the individual-year classifications. This is an issue that needs to be treated with caution, especially when quantitative analyses of the land use changes are sought.

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Imagery date	Satellite/Sensor/Path-Row	Source
16 July 1975	**Landsat 1 (MSS, p195/r33)**	**NASA (Global Land Cover Facility, GLCF)**
11 May 1987	**Landsat 5 (TM, p181/r33)**	**NASA (GLCF)**
4 July 1995	Landsat 5 (TM, p181/r33)	Eurimage
28 May 1999	Landsat 5 (TM, p181/r33)	Eurimage
7 June 2000	**Landsat 7 (ETM+, p181/r33)**	**NASA (GLCF)**
26 June 2001	Landsat 7 (ETM+, p181/r33)	Eurimage

Table 1. Landsat data used and their source. Free data are depicted in bold.

1995		Reference														Classif. totals		Prod. accur. (%)		User. accur. (%)	
		Bare		Urb.		Sc&Ma		Oli.		Crop.		Fore.		Wat.							
		pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Classified	Bare	26	36	5	8	13	1	6	2	1	3	0	0	0	0	51	50	74.3	90.0	51.0	72.0
	Urban	7	1	34	49	4	0	2	0	3	0	0	0	0	0	50	50	85.0	84.5	68.0	98.0
	Sc&Ma	1	2	0	0	52	55	2	2	4	2	2	0	0	0	61	61	52.5	79.7	85.3	90.2
	Olives	0	1	1	0	13	6	44	58	0	1	9	4	0	0	67	70	65.7	82.9	65.7	82.9
	Crops	1	0	0	1	13	4	10	7	29	38	0	1	0	0	53	51	78.4	86.4	54.7	74.5
	Forest	0	0	0	0	4	3	3	1	0	0	51	54	0	0	58	58	82.3	91.5	87.9	93.1
	Water	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	100.0	100.0	100.0	100.0
	Refer. totals	35	40	40	58	99	69	67	70	37	44	62	59	10	10						

Overall Classification Accuracy (%) pre 70.29
post 85.71
Overall Kappa Statistics pre 0.65
post 0.83

2000		Reference														Classif. totals		Prod. accur. (%)		User. accur. (%)	
		Bare		Urb.		Sc&Ma		Oli.		Crop.		Fore.		Wat.							
		pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Classified	Bare	28	41	0	0	11	4	6	0	2	5	0	0	0	0	47	50	68,3	83,7	59,6	82,0
	Urban	7	5	29	41	2	0	6	3	3	1	0	0	0	0	47	50	96,7	100,0	61,7	82,0
	Sc&Ma	3	1	0	0	61	53	1	5	0	2	3	0	0	0	68	61	70,9	77,9	89,7	86,9
	Olives	1	0	0	0	4	3	47	63	3	1	13	4	0	0	68	71	66,2	82,9	69,1	88,7
	Crops	2	2	1	0	6	3	9	5	29	39	1	2	0	0	48	51	76,3	81,3	60,4	76,5
	Forest	0	0	0	0	2	5	2	0	1	0	58	52	0	0	63	57	77,3	89,7	92,1	91,2
	Water	0	0	0	0	0	0	0	0	0	0	0	0	9	10	9	10	100,0	100,0	100,0	100,0
	Refer. totals	41	49	30	41	86	68	71	76	38	48	75	58	9	10						

Overall Classification Accuracy (%) pre 74.57
post 85.43
Overall Kappa Statistics pre 0.69
post 0.83

Table 2. Pre-CPN ('pre') and post-CPN ('post') classification accuracy assessment results for the years 1995 and 2000. 'Sc&Ma' is the 'Scrubland and Maquis' land cover class.

	1975		1987		1995		1999		2000		2001	
	Pre-CPN	**Post-CPN**	**Pre-CPN**	**Post-CPN**	**Pre-CPN**	**Post-CPN**	**Pre-CPN**	**Post-CPN**	**Pre-CPN**	**Post-CPN**	**Pre-CPN**	**Post-CPN**
BARE	37	13	57	25	46	18	37	21	54	17	52	17
URBAN	29	23	17	9	27	11	29	25	28	13	22	13
SCRUB + MAQUIS	439	436	531	454	431	453	439	435	375	445	426	445
OLIVES	749	780	650	824	674	810	749	826	795	811	747	812
CROPS	115	87	80	27	142	57	115	61	86	67	86	66
FOREST	292	323	330	321	326	311	292	311	331	307	334	307

Table 3. Area covered, in km^2, by each of the six non-water classes according to the single-year (pre-CPN) and the multiple-year (post-CPN) classification results

Change from class…	…to class	Pre-CPN (%) 1975-2001	Post-CPN (%) 1975-2001	Pre-CPN (%) 1987-2000	Post-CPN (%) 1987-2000
bare	**1**	**22**	**85**	**20**	**42**
	2	16	1	13	30
	3	26	1	27	1
	4	20	6	20	1
	5	13	6	13	21
	6	1	0	5	3
	7	2	0	2	2
urban	1	21	30	13	0
	2	**14**	**51**	**54**	**100**
	3	45	10	10	0
	4	7	1	8	0
	5	8	4	14	0
	6	1	0	1	0
	7	4	3	1	0
Scrub+Maquis	1	4	0	6	1
	2	1	0	1	0
	3	**57**	**90**	**53**	**91**
	4	27	5	33	5
	5	4	4	4	4
	6	6	0	3	0
	7	1	1	0	0
Olives	1	1	0	1	0
	2	1	0	0	0
	3	8	4	9	3
	4	**80**	**95**	**78**	**95**
	5	3	1	3	2
	6	8	0	9	0
	7	0	0	0	0
Crops	1	7	4	2	0
	2	5	6	2	0
	3	12	2	4	2
	4	39	47	48	6
	5	**32**	**40**	**41**	**92**
	6	4	0	3	0
	7	0	0	0	0
Forest	1	1	0	0	0
	2	0	0	0	0
	3	4	1	4	1
	4	16	4	18	4
	5	0	0	0	0
	6	**78**	**94**	**77**	**95**
	7	1	0	0	0
Water	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
	4	0	0	0	0
	5	0	0	0	0
	6	0	0	0	0
	7	**100**	**100**	**100**	**100**

Table 4: Land use and land cover (LULC) changes (%) between the entire period of study (1975 and 2001) as well as between 1987 and 2000 before and after the multi-temporal processing (CPN) is applied. The land use types are coded as follows: 1 = bare; 2 = urban; 3 = scrubs and maquis; 4 = olives; 5 = crops; 6 = forest; 7 = water.

		Reference			
		Pre-CPN		Post-CPN	
		No Change	**Change**	**No Change**	**Change**
Classification	**No Change**	48	2	50	0
	Change	27	23	15	35

Table 5. Accuracy of land use change results between 1995 and 2000 before and after CPN is applied.

Figure 1. Location of study area, the island of Lesvos (Greece)
160x140mm (300 x 300 DPI)

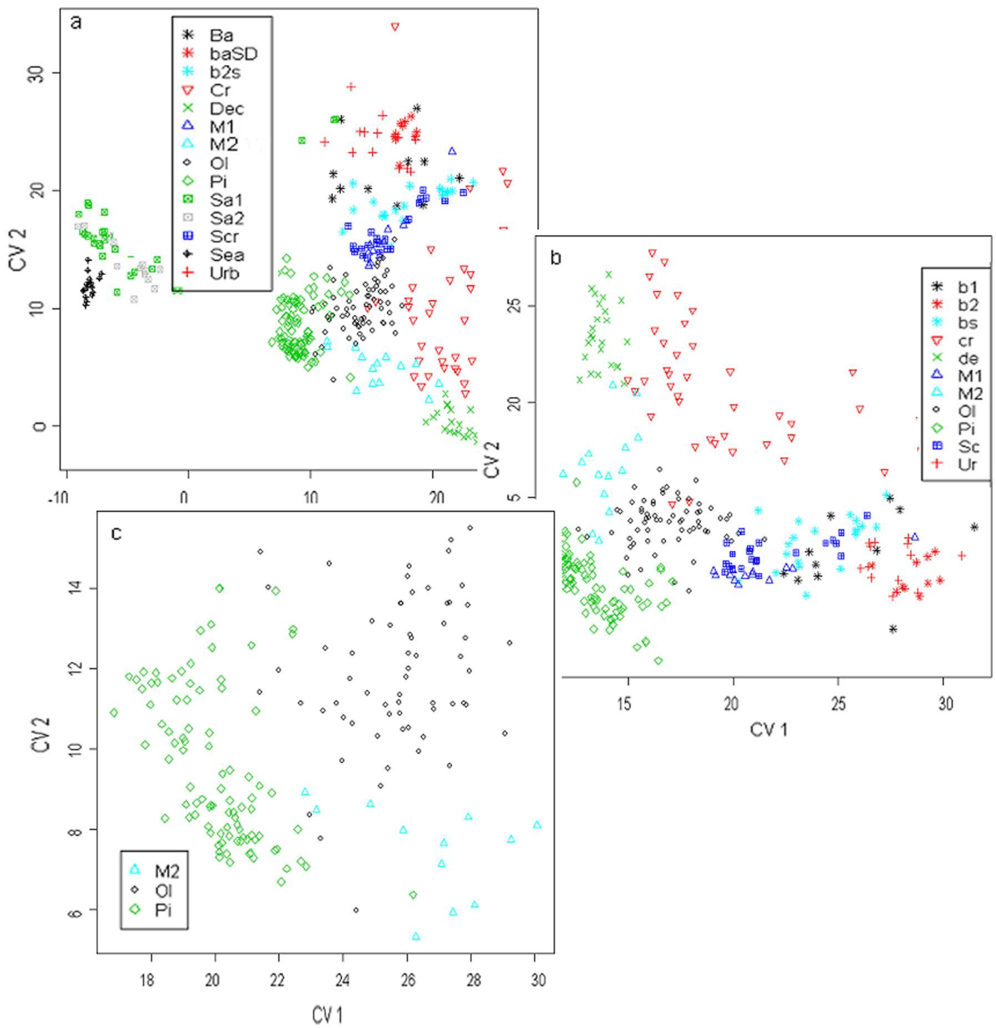

Figure 2. Canonical variate ordination plots for the 1999 data. (a) All 14 spectral groupings identified from the image. (b), (c) Iterations for the investigation of ambiguities between Mediterranean Maquis (M1, M2), Olives (Ol) and Pines (Pi).
304x313mm (300 x 300 DPI)

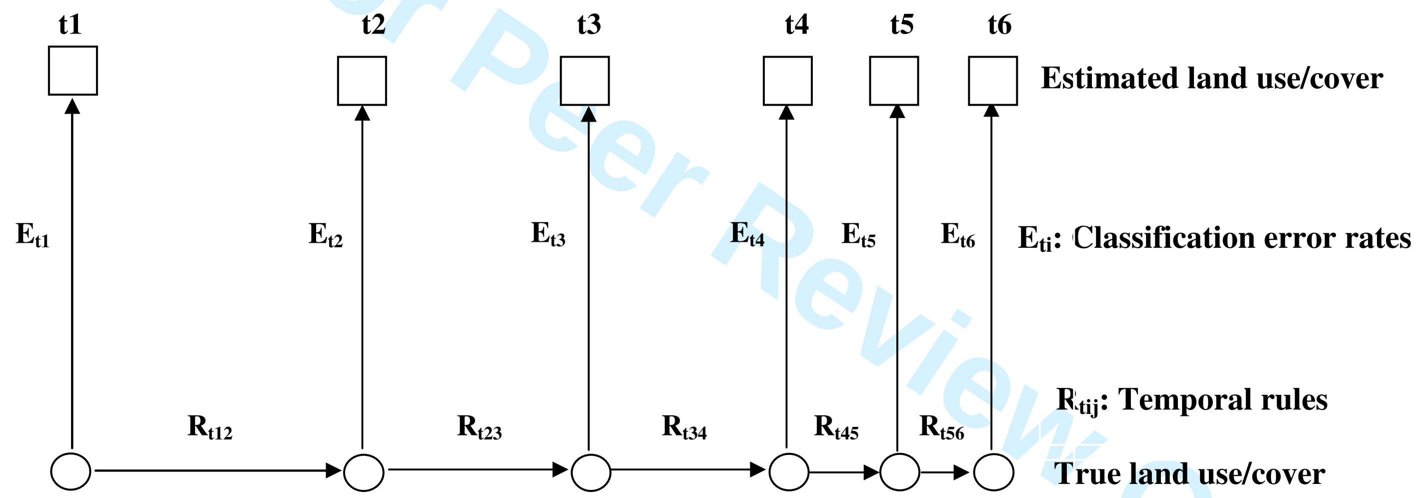

Figure 3. A graphical depiction of the conditional probability network (CPN) applied to land use/cover mapping in the Lesvos study area.

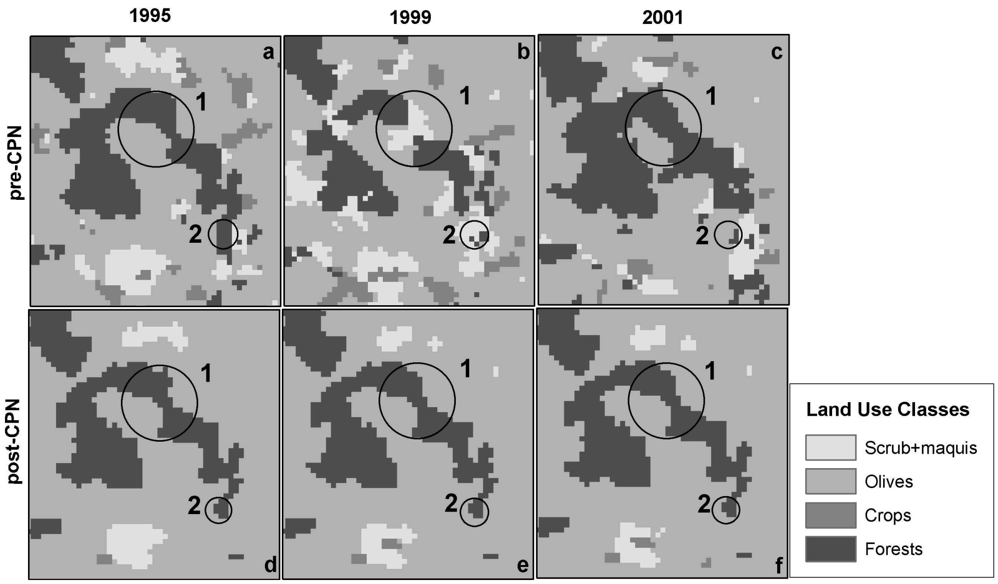

Figure 4. Samples from the western part of the island of pre- and post-CPN classification results for the years 1995, 1999 and 2001. The individual-year classifications (i.e. pre-CPN: a,b,c) in circle No1 identify the unlikely change from forest to maquis and back in 7 years-time while in circle No2 the area is changing from forest to maquis to olives in the same period of time. The multiple-year processing (i.e. post-CPN: d,e,f) is able to reduce the amount of false change.
220x127mm (300 x 300 DPI)