Analysing spatial patterns of land cover/use change derived from satellite remote sensing and knowledge-based contextual information

S. Koukoulas*, I. Gatsis, K. Gkoltsiou, and A. Vafeidis

Dept. of Geography, University of the Aegean,University Hill,Mytilene 81100
(skouk, john_gats,agkolt,nbaf)@geo.aegean.gr
*Corresponding author

Abstract – This paper describes a methodological framework for assessing land cover/use changes that have taken place in Lesvos (Greece) since 1975, using landscape metrics and spatial statistics combined with Remote Sensing and Geographical Information Systems (GIS) techniques. Remote sensing techniques were employed in order to map land cover changes that have taken place in the last 25 years. The latter was achieved by devising a simple and operational rule-based approach to map land cover changes, based on the classification of Landsat imagery and the conceptual analysis of the information regarding change detection. The use of ancillary GIS data such as a Digital Elevation Model, existing thematic maps and the knowledge of the island's vegetation dynamics, formed the basis for setting the rules for the post-processing of the classified images that led to a more accurate assessment and mapping of land cover changes. Landscape metrics and spatial statistics were derived from the land cover change map of the classified Landsat MSS and TM5 images, in order to quantify the characteristics of patches, such as size, shape and edges and their spatial arrangement (spatial autocorrelation, fragmentation, connectivity, diversity, density metrics, isolation / proximity and contrast metrics).

The above framework proved to be a promising and practical approach in order to quantify, understand, conceptualize and better present the dynamics of land cover/use changes in Lesvos.

Keywords: spatial patterns, autocorrelation, landscape metrics, land cover/use change, Lesvos-Greece.

1. INTRODUCTION

Remote Sensing and GIS (Geographic Information Systems) play an important role in our quest to understand land cover/use changes in the environment that we live in. Satellite imagery and aerial photographs are used to map land cover for several time periods and quantify land cover changes. Despite their significance for scientists and for policy makers, detection and monitoring of land cover/use changes, their size and dynamics as well as the identification of the causal factors are not yet fully understood. The quantification of uncertainty in the estimations and the correct interpretation of the findings still rank high in the research priorities.

Change detection studies have widely focused on post-classification comparison and image differencing (Coppin *et al.*, 2004; Carlson and Sanchez-Azofeifa, 1999; Symeonakis *et al.*, 2006). Only recently it has been suggested that the use of landscape metrics can aid the study of land cover/use change and help in understanding and inferring the processes involved in the spatial distribution of land uses and the patterns created (Herzog and Lausch, 2001; Narumalani *et al.*, 2004; Herold *et al.*,2005). These studies have focused on the application of landscape metrics to each classified image and the comparison of the indices derived. This is an important step towards the correct interpretation of change patterns as it provides additional information about the structure of changes (e.g. changes in patch size, fragmentation of the landscape etc) but it is still difficult to infer on the causal factors of these changes and proceed with the modeling of land cover/use change dynamics. Are changes randomly distributed? Are they aggregated? Do they follow the same pattern everywhere in the study area? These are some questions that we can not answer by simply calculating landscape metrics from land cover maps and comparing them for different time periods.

A new path is proposed in this research with regard to the meta-analysis of classified satellite images. Our approach focuses on: 1) Using common GIS overlay techniques (e.g. buffers, cost distance, spatial queries) to find where the changes occur in relation to physiographical characteristics and the structured environment of the study area; 2) Using Landscape metrics on the change map to characterize the geometrical properties of the “changed” patches; and 3) Using spatial statistics to study the spatial distribution of patches and reveal the “hot spots” of changes.

It is demonstrated that by using a combination of spatial exploratory data analysis, within a GIS framework where other physiographical and socioeconomic data are stored, it is possible to enhance the interpretation of the patterns of change, reach more reliable conclusions, reveal the main causal factors and/or prove hypotheses made *a priori*.

2. METHODOLOGY

2.1 The study area

The study area is the island of Lesvos (North Aegean - Eastern Greece) (Figure 1). It was selected due to the fact that the island’s ecosystems are faced with disturbance as a result of limited available natural resources, insularity, and the development of monocultures in the agricultural sector (Giourga *et al*., 1994). At the same time, Lesvos has limited prospects for development other than that of tourism.

Extensive fields of olive groves and variable natural and agricultural landscapes characterize the island, while the main income of the local population comes from the agricultural and stock-farmer activities. The size of farm holdings in the island is very small with the average area of a farm being approximately 2.3 ha, of which 2 ha are olive groves. Olive cultivation in Lesvos had been in the past a monoculture that virtually sustained the island’s economy. However, the agricultural sector currently suffers from significant underemployment as employment in olive groves is required for only 70 days per year and per holding (Loumou *et al*., 2000). Moreover, the spread of competitive substitute products of olive oil, such as seed oils, has resulted in its economic decline followed by integral migration to the capital or to the bigger urban centers of the mainland (Giourga *et al*., 1994). Thus, socioeconomic processes that have taken place, combined with the physiographic characteristics of the island, have played a significant role in the formation of the natural, agricultural and urban land cover, and are responsible for the alterations of the agricultural landscape. In particular, the last three decades the island has experienced significant land cover/use changes despite being far from the mainland and without intense tourist growth.

Figure 1: Study area

2.2 Land cover mapping

Two satellite images, a Landsat MSS scene (July 1975, 4 bands, nominal pixel size 59m) and a Landsat 5 TM scene (July 1999, 7 bands, nominal pixel size: 30m), were employed for identifying land cover changes in the island of Lesvos. Geometric correction of the images was performed using 2^{nd} order polynomials and nearest neighbour resampling with a RMS smaller than one pixel. The two scenes were referenced to a common projection (Transverse Mercator). Additional data were derived from aerial photographs at a scale of 1:40.000, dating from 1960, and Quickbird data from 2001 which were orthorectified for this purpose. Additionally a Digital Elevation Model (DEM) of the study area was acquired (30m resolution).

The two images were classified using the Maximum likelihood classification rule with randomly selected samples for each land cover class. Initially eight (8) land cover classes were used; bare land, garrigue (phryganic vegetation including natural pastures), maquis vegetation (open and dense), pine forest, broadleaved forest, olive cultivations, urban areas (including quarries) and water bodies. Some types of land cover such as specific arable crops (‘other crops’), marsh and saltworks were excluded from the classification process due to their high spectral variability and confusion with other classes. These classes were added later, during the rule-based approach.

The samples for the MSS image classification (1975) were collected from orthophotos, dating from 1960 as there was no availability of aerial photographs nearer 1975. The samples were distributed randomly within the land cover zones of a vegetation map dating from 1960 . This map was a useful guide especially in areas where identification of land cover types was difficult (e.g. between maquis and olive trees). Manual editing of the samples ensured the match of sampled land types between the orthophotos and the MSS image.

The samples for the TM image classification (1999) for the identification of the current land cover were collected randomly by interpretation of Quickbird imagery (2001) and land surveys using GPS. Despite the thorough sampling framework, the produced thematic maps of land cover/use alone were not suitable for change detection. For the year 1975, the poor spatial and spectral resolution of Landsat MSS produced classifications of low accuracies (58%). In the early years of remote sensing these accuracies were considered adequate. Currently, the challenge is to improve on this (using MSS imagery) and subsequently use the results for change detection purposes. The significance of the latter is obvious if we consider the large existing archive of MSS data (mostly available for free) that could provide useful insights to the status of land cover 30 years ago. The rule-based approach used was combined with manual editing which allowed us to produce classified images with accuracies of 90% for the 1975 image. It is shown that rule-based enhancement can also improve accuracies of Landsat TM classified products, which were also low. The lower accuracies of Landsat TM are due to the higher spectral confusion among three classes, namely olive trees, maquis and garrigue that cover a large part of the island (approximately 75%). Following the same approach (as for MSS) for Landsat TM classified images the final classification reached 90% accuracy.

Rule-based enhancement of both classified images that was mentioned above, involved corrections with regard to topography of the area (e.g. Olive cultivations found above 350m for a certain zone of the study area were reclassified to maquis vegetation (spectrally and texture similar class)), correction of urban areas where they we confused with bare land based on ancillary GIS data and identification of false changes. The latter involved identification of erroneous changes using field and ecological knowledge (e.g. changes that are impossible to happen in the time span studied) and correction of the classified images focusing on the areas where erroneous changes occurred. More details on this rule based approach can be found in Gatsis *et al.,* 2006.

The accuracy of the produced land cover change map was estimated, using samples from orthorectified aerial photographs and Quickbird data, to 85%.

2.3 Analysis of spatial patterns of land cover changes

Three main paths were followed in order to study the spatial patterns of change. First, common GIS techniques were applied to relate the patches of change with elevation and main touristic areas. Polygon to polygon queries and cross-tabulations were applied in order to calculate the area of changes in different elevation zones. In combination with classical statistical exploratory techniques such as Boxplots we were able to visualise the distribution of different land cover changes over the digital elevation model of the area (as applied in Neteler and Mitasova, 2004). A cost (elevation) distance surface was generated from main touristic areas in order to visualize and explore the relation of land cover changes to the touristic development.

Second, we have applied landscape metrics such as patch size, patch shape index (including fractal dimension), connectivity, aggregation index (see McGarigal *et al.*, 2002 for descriptions) in the change map in order to study the patches formed from specific land cover changes. With these measures we were able to characterize the nature of changes; e.g. Patch size distribution and aggregation index were useful in order to identify whether changes happened in small, scattered and disconnected patches or in large and interconnected patches. Patch size and shape complexity was indicative of sudden or progressive changes (Koukoulas and Blackburn, 2004).

Third, exploratory spatial statistics were applied to the change map in order to study the spatial distribution of particular land cover changes. Kernel density and spatial autocorrelation using Moran's I index (global and local) were applied in order to estimate the intensity of changes in space and to test for spatial dependency in patches of change (see Bailey and Gatrell, 1995 for description of these techniques). Local spatial autocorrelation maps (Anlselin, 1995) were produced for the most important categories (such as abandonment of olive cultivations) and we were able to identify local "hot spot" areas of change.

3. RESULTS & DISCUSSION

The distribution of land cover changes over the DEM (Digital Elevation Model) is shown with the boxplots in figure 2. The width of the boxplot is indicative of the area of the particular category (or the size of change). Category with code 11 shows the abandonment of olive trees and it is obvious from the width of the box that it is largest change that occurred in the island, observed over200 m of elevation. The next largest change is the new olive trees cultivation (gains) with code 13 and it is observed mainly in lower altitudes, below 200 meters.

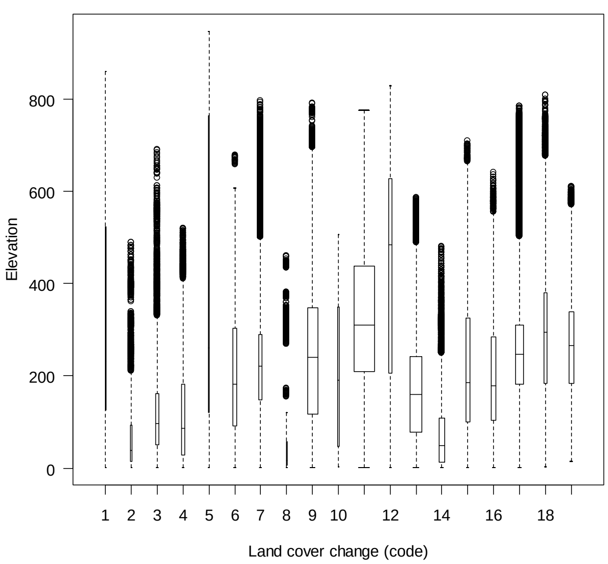

Figure 2: Boxplot of land cover changes by elevation. The box width represent the relative area contribution of the land cover change categories. 1:Gariggue to Bare Land, 2:Olives to Urban, 3:Bare Land to Gariggue, 4:Other Crops to Gariggue, 5:Maquis to Gariggue, 6:Olives to Gariggue, 7:Pines to Gariggue, 8:Olives to Other Crops, 9:Gariggue to Maquis, 10:Other Crops to Maquis, 11:Olives to Maquis, 12:Pines to Maquis, 13:Gariggue to Olives, 14:Other Crops to Olives, 15:Maquis to Olives, 16:Pines to Olives, 17:Gariggue to Pines, 18:Maquis to Pines, 19:Olives to Pines

In figure 3, we explore further this relationship and we map the losses, gains and persistence of olive cultivations over a cost distance map from the main touristic areas. The 3rd and 4th zones are the more distant ones and 1st and 2nd the closest to the touristic areas (shown in the map as dots with labels). It is shown that most olive cultivation losses (abandonment) take place in the 3rd zone and most gains in the 1st and 2nd zones. An interrelation of olive cultivation maintainability and touristic development is evident. This is in support to the theory that olive cultivation has benefited by sustainable touristic development which complements the income of local farmers (Loumou *et al.,* 2000).

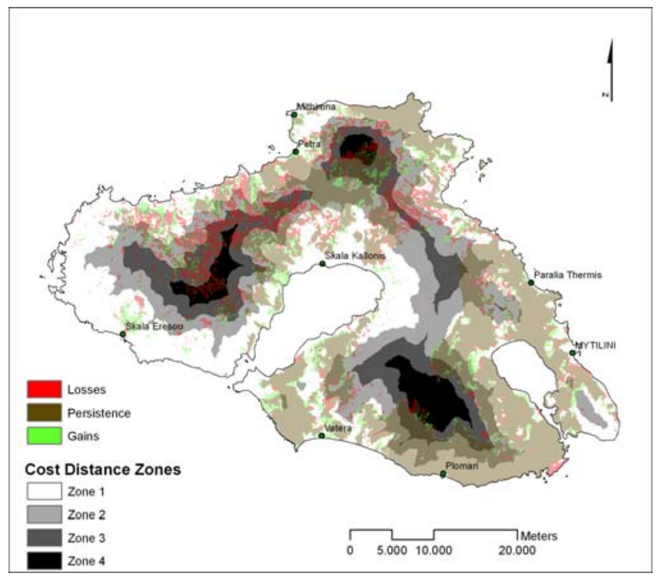

Figure 3: Distribution of olive cultivation changes and persistence in relation to cost distance zones (derived from the main touristic areas show as dots with labels)

Landscape metrics were calculated at class level. Higher Mean Patch Size (MPS) has been observed for the change classes 17,11,14, 4 and 7 representing regeneration of Pine forests, abandonment of olive cultivations, olive cultivation gains from other crops, abandonment of other crops and losses for pine forests respectively. Mean shape index (MSI) is almost similar for all classes with maximum 1.18 (square ha SI equal to 1). This alone is not so informative and therefore the distribution of shape index and fractal dimension in space was derived. Shape complexity index for olive cultivation abandonment reaches a maximum of 2.1 and the larger values appear in the NW and NE part of the island where the intension of the phenomenon is higher. This together with a maximum fractal dimension of 1.1 show that in general the patches of this change are not particularly complex. Aggregation index (AI) was high (90-100) for the same areas for the abandonment of olive cultivations. It is possible that changes have progressed in stages as local knowledge suggest, but in large and neighboring patches. Results of landscape metrics are discussed but not shown with graphs/maps here, due to space limitations.

All land cover changes were found to be autocorrelated with Moran's I equal to 0.6. This is indicative of changes that happened in large areas and the common underlying factors in the particular areas. In particular, both losses and gains of olive cultivations are positively autocorrelated and aggregated in particular areas confirming the results from landscape metrics presented above. Both losses and gains of olive cultivations are scattered in the study area with the largest patches of the losses concentrated to the NW and NE part of the island. Using local indices of spatial autocorrelation we were able to identify the statistically significant changes as they clustered with high percentage of change (calculated in cells of 590x590, see figure 4). To the contrary kernel density estimation applied to the centroid of patches, failed to produce reliable results due to its inability to distinguish between the size and therefore importance of patches.

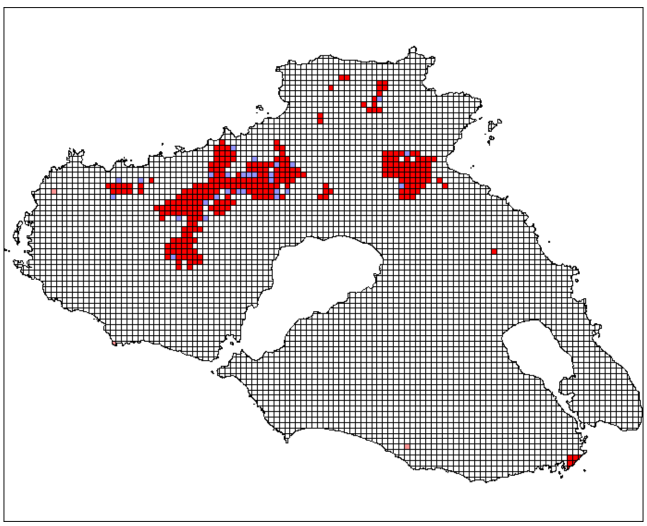

Figure 4: Local Moran's I (with red color the high-high autocorrelation)

5. CONCLUSIONS

A new approach for studying land cover change patterns is presented based on the combination of GIS analysis, landscape metrics and spatial data exploratory analysis. We were able to interpret the results, confirm knowledge derived by field observations and make connections with previous research in order to accept or reject their hypotheses.

Most changes with regard to olive cultivation abandonment occurred evidently in high altitudes with steep slopes where conditions were not suitable to sustain agricultural activities. Conversion of cultivated areas to urban occurred in very low altitudes and mainly near the coast as an expansion of the established structured environment. Changes are scattered in the whole study area but using local autocorrelation indices we were able to identify the statistically significant areas, often called “hot spots” in spatial statistics terminology.

The above framework proved to be a promising and practical approach in order to quantify, understand, conceptualize and better present the dynamics of land cover/use changes at a local scale.

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