MONITORING AND MAPPING OF LAND COVER/USE CHANGES IN AN AGRICULTURAL AND NATURAL ENVIRONMENT, USING MULTITEMPORAL SATELLITE DATA AND GIS (LESVOS ISLAND, GREECE)

I Gatsis, S Koukoulas, A Vafeidis, E Lagoudakis, and K Gkoltsiou

Department of Geography
University of the Aegean,
Mytilene, Lesvos
81100
Greece

Abstract

This paper describes a methodological framework for assessing land cover/use changes that have taken place in the island of Lesvos since 1975, using remote sensing and GIS techniques. Landsat MSS and TM images were employed in order to monitor and map land cover and their changes in the last 25 years.

The research presented here has focused on 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 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.

The landscape of the island is characterized by extensive fields of olive groves, pine forests and pastures, while the main income of the local population comes from the agricultural and stock-farming activities. The land cover changes observed during the last three decades are significant, even though the island is far from the mainland and without any intense tourist growth. The main changes are the rapid expansion of the urban shell, deforestation, the expansion of cultivations into natural vegetation zones, the abandonment of olive groves and overgrazing.

The above framework has 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.

1 Introduction

In recent years, there has been a growing recognition of the importance of identifying the rates and location of land cover change. Mapping, monitoring and quantifying land use/cover change has been a key element in the understanding of global change and in the formulation of national and international policies aiming at the mitigation of its impacts (Reid et al., 2005). Multi-temporal and multi-spectral satellite data have demonstrated significant potential in detecting modifications and in monitoring and quantifying abrupt and rapid changes occurring on the Earth's surface (Lambin and Ehrlich 1997, Loveland et al. 2002, Mas 1999, Serra et al. 2003, Gatsis 2006, Symeonakis et al. 2006). Furthermore, the increasing interest in protection from natural disasters and the need for sustainable management of natural resources, mainly in the last 20 years, have concentrated the thoughts of the scientific community on the monitoring and assessment of changes on a regular basis.

However, change detection based on satellite data is a difficult task to perform (Coppin et al., 2004) and aerial photography analysis and interpretation is still a widely used tool for mapping and monitoring land use/cover changes (Treitz and Rogan, 2004). Although aerial photo interpretation does not offer the advantages that satellite imagery possesses, such as low data acquisition costs, consistent image-interpretation procedures and use of non-optical data, it can, in most cases, produce more accurate results (Edwards 1990 in Coppin et al. 2004). Nevertheless, the advantages that satellite data offer combined with recent advances in satellite technologies and image analysis techniques have further enhanced the potential of satellite imagery and satellite data currently constitute the primary data source in the detection of changes in land use/cover. Consequently, there now exist numerous applications in land use/cover change detection from space using various types of data and analysis techniques and performed at various scales. Such examples are the studies of Coppin and Bauer (1996), Carlson and Sanchez-Azofeifa (1999), Foody and Boyd (1999), and Wessels et al. (2004). In many cases, researchers have also employed combinations of existing methods. At the same time, increasing emphasis is being given to the use of Geographic Information Systems (GIS) in classifications using ancillary GIS data (Megier et al. 1991, Smith and Fuller 2001, Keuchel et al. 2003).

According to Rogan et al. (2002), the most widely used change-detection approaches in Mediterranean-type ecosystems are image differencing and post-classification comparison. Advantages of these techniques include the fact that both methods are cost-effective and that in the case of post-classification techniques radiometric corrections are not necessary. Common limitations include the need for “perfect data”, post-classification detection techniques’ limitations in detecting subtle changes and the fact that accuracies in results of the post-classification techniques are usually similar to the multiplication product of the individual accuracies (Rogan et al., 2002).

The aim of the present study was the development of a practical framework for assessing land cover/use changes that have taken place in the island of Lesvos since 1975, using standard classification techniques and knowledge-based rules. Landsat MSS and TM images were employed in order to monitor and map land cover/use and their changes for the past 25 years.

The application presented here has focused on:

a) The mapping of land cover/use using Landsat images and the analysis of the information regarding change detection during the 25-year span (1975-2000).

b) The integration of Remote Sensing imagery with other ancillary GIS data such as Digital Elevation Model (DEM), thematic maps and field measurements, using a rule-based approach which aims to provide a more accurate identification, assessment and mapping of land cover/use changes. Additionally, this framework should help in detecting and mapping environmentally sensitive areas, with an emphasis on serious erosion and desertification phenomena.

The proposed framework can assist in the repeated monitoring and mapping of land cover/use changes which is imperative for the suitable management of land cover/use, the conservation of natural environment and the sustainable management of the natural resources.

2 Description of 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 (National Statistical Service of Greece, 1981). 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 since the 16th century, 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. Consequently, in the last three decades the island has experienced significant land cover/use changes despite being far from the mainland and without intense tourist growth.

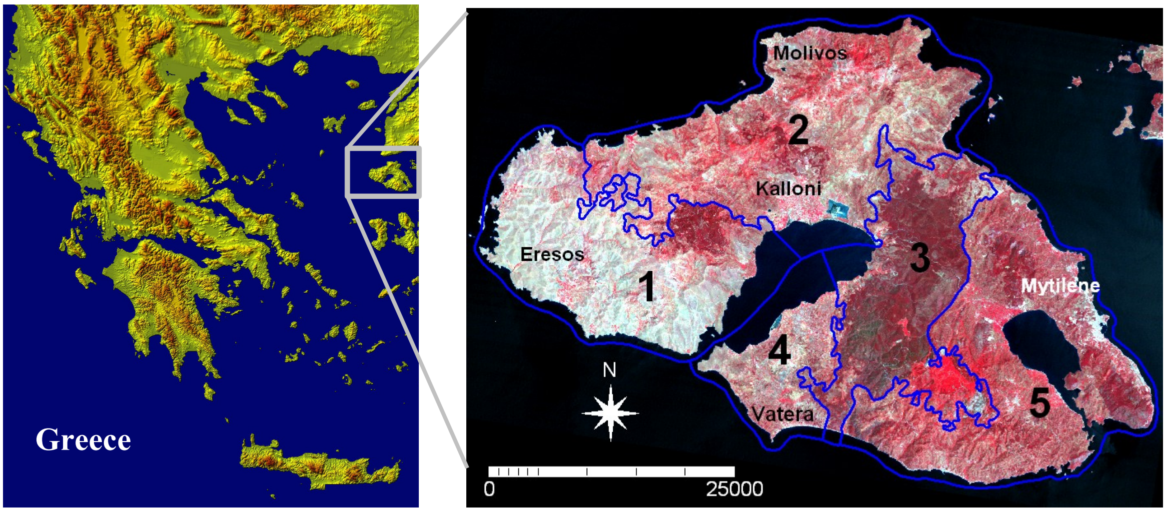

Figure 1. Landsat-5 TM image illustrating the study area

The systematic observation and detection of land cover/use changes has therefore become very important for financial and environmental reasons. These changes are mostly due to human activities and interventions in the urban, agricultural and natural environment, which are manifesting in many ways, such as the rapid expansion of the urban shell at the expense of the fertile cultivated land, the modernization of the road networks, fires, the vegetation degradation and deforestation, the penetration of cultivations into natural vegetation zones, land abandonment, inappropriate dry-farming agricultural practices on marginally productive land, overgrazing, and the appearance of serious erosion phenomena and desertification. In addition to these factors, the slow but stable shift to tourism-related activities and the transformation of natural coastal areas to recreational facilities has important implications for the economy and this in turn leads to the increase of urban land and a more complicated coexistence with agriculture.

3 Data and methodology

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 2nd 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 (Richards 1993, Mather 2004) 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.

During the process of supervised classification, the collection of training data constitutes a very critical stage and it is essential that all the required classification classes are sampled. A good sampling design is essential for the recognition of surface characteristics and especially for mapping land cover. The importance of the sampling design has been emphasised in the past (Congalton and Green 1999, Khorram et al. 1999).

The samples for the MSS image classification (1975) were collected from the 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 (Ministry of Agriculture, 1986). 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 (around 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 over 90% for the 1975 image. It is shown that rule-based enhancement can also improve accuracies of Landsat TM classified products, which are also low (around 53%). 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 (almost 75%).

3.1 Rule- based enhancement of both classified images

At this stage, the study area was initially divided into five (5) zones depending on surficial and geomorphological characteristics, and the type of vegetation/land cover that dominated each area (Figure 1).

The **first zone** includes the western part of the island where serious erosion phenomena and desertification occur (Eresos and Sigri villages – 429km^2). The vegetation of garrigue and bare land cover almost 75% of this zone. Live-stock farming activities and the mild tourist growth sustain the local economy, due to the infertile, unproductive and eroded soils met in this area.

The **second zone** comprises a completely different landscape (NW part of the island – Molivos and Petra villages - 560km^2), where olive trees and arable crops dominate while maquis, pine forest and garrigue are also encountered. The **third zone** contains the main pine forest and the unique broadleaved forest (chestnut trees) of the island (310km^2 - central part of island). A large part of the third zone is covered by natural vegetation (almost 90%), except of some patches of olive trees and arable crops met in the margins of this zone.

The **fourth** zone comprises mostly olive trees and arable crops (almost 80%). It includes a part of the southern island (167km^2 - Polichnitos village and saltworks) where elevation is low and the land is cultivated. The **fifth** zone includes the city of Mytilene and an extensive area of olive trees which occupy nearly 80% of this zone. It is located in the east and south-east part of the island (508km^2) where the land is fully exploited from the agricultural population. A significant urban growth and expansion is observed, due to the internal migration, the mild tourist growth and the construction of the University of Aegean campus facilities.

After the division of the island in relatively homogeneous zones (with regard to land cover), post classification processing took place in three stages. The first two stages aimed to improve the classification accuracy of the images using ancillary data and rules while the third stage (described in the next section) involved change detection mapping, identification of erroneous changes using knowledge-based rules (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.

In the first stage, correction initially focused on errors that were due to the terrain complexity and errors in the identification of urban areas. Topographic correction using a Lambertian model did not produce satisfying results and some olive cultivations being on the shaded slopes were erroneously classified as "maquis". Although further topographic correction techniques will be examined in the future a simple but effective approach was undertaken at this stage. The hillshade surface was derived using the DEM based on the Sun angle values recorded in the header file of the satellite images. Erroneously classified areas were identified with interpretation of aerial photos using a mask of hillshade values lower than 160 in order to correct the classified "maquis" pixels to "olive cultivations".

In the second stage, the correction of urban areas was performed. This process was based on a mask generated using a polygon layer of current urban coverage. Pixels being classified as garrigue vegetation (sparse vegetation up to 30cm high) and that fell within the masked area were reclassified as "urban".

Furthermore, this stage involved the use of DEM for vegetation zoning. Many studies have referred to the usefulness of DEM as ancillary data, on the discrimination of disparate types of vegetation with similar spectral signatures, improving thus the precision of classification (Bruzzone et al. 1997, Smith and Fuller 2001, Ostir et al. 2003). Detailed photo-interpretation (on both aerial orthophotos and Quickbird data) aided by the DEM, and the two (2) classified images within each zone, led to the generation of a subset of rules for the detection and correction of erroneously classified pixels of olive trees and broadleaved forest (the forest is met only in third zone). These rules are summarized below**:**

Zone 1: broadleaved forest reclassified to maquis (similar spectral signatures)
over 500m olive trees reclassified as garrigue
Zone 2: broadleaved forest reclassified to maquis (similar spectral signatures)
over 600m olive trees reclassified as maquis
Zone 3: over 350m olive trees reclassified as maquis
Zone 4: broadleaved forest reclassified to maquis (similar spectral signatures)
over 280m olive trees reclassified as garrigue
Zone 5: under 450m broadleaved forest reclassified to olive trees
over 600m olive trees reclassified as maquis

Besides the above corrections, some additional corrections to the classes of natural vegetation, olive cultivations, urban areas, other crops, marsh and saltworks were applied based on the interpretation of aerial orthophotographs/Quickbird imagery and manual editing. Specifically, the main urban areas and villages (with a significant extent compared to the spatial resolution of the classified maps – 59m) were digitized and overlaid to the classified map. All pixels erroneously classified as "urban areas" were reclassified to bare land. Also, the main "other crops" areas (with a significant extent) and all the marshes and saltworks were digitized, and overlaid to the classified map. Similar overlays were made in specific areas for olive trees and natural vegetation.

The same corrections were applied for the Landsat TM classified image. The topographic effect was less pronounced in this image and the areas affected were significantly less.

3.2 Identifying impossible/false changes

In this section a method for improving the classifications of both dates is presented. This method is based on the comparison of multi-temporal changes and the identification of false changes based on set of rules. These rules are summarized in Table 1 where the main cases of possible and impossible changes from one land cover type to another are shown. Areas falling under the second category were re-examined with the help of orthorectified aerial photographs and Quickbird imagery, and the classified images were revised.

Table 1. Possible and false land cover/use changes

1975 (from)	**1999 (to)**	
bare land	garrigue	possible
other crops	urban areas	possible
other crops	olive trees	possible
other crops	garrigue	possible
other crops	maquis	possible
maquis	olive trees	possible - re-examined
maquis	garrigue	possible - re-examined
maquis	pine forest	possible
water	all classes except water	false
urban areas	all classes except urban areas	false
olive trees	urban areas	possible
olive trees	garrigue	false
olive trees	pine forest	false
olive trees	bare land	false
olive trees	other crops	possible - re-examined
olive trees	maquis	possible - re-examined
garrigue	olive trees	possible
garrigue	pine forest	possible
garrigue	bare land	possible – re-examined
garrigue	maquis	possible
pine forest	olive trees	possible – re-examined
pine forest	garrigue	possible
pine forest	maquis	possible

Finally, scattered “changed” pixels were also removed from the “change” maps as they most probably identified erroneous changes due to random errors.

3.3 Accuracy assessment of the produced land cover/use maps

In order to evaluate the classified maps before and after their post classification processing established accuracy assessment procedures were employed. The most common technique is to use an error matrix to determine the percentage of pixels, which are correctly classified for all classes, the percentage correct for each class, plus errors of omission and errors of commission per class. The Kappa statistic introduced by Cohen (1960), is also a widely used index which measures the difference between the observed agreement and the chance agreement between two maps.

Ground truth data were provided by the interpretation of aerial photographs (1960) for the classified map of 1975 and Quickbird imagery (2001) for the map of 1999. Also, selected field checks were carried out in order to estimate the accuracy of the classification results (for the 1999 map).

A few other methods have been developed in recent years for accuracy assessment of classified images. Notably, the Classification Success Index (CSI) developed by Koukoulas & Blackburn (2001) would be useful for quantifying land cover accuracies in the context of a land use change study since it accounts for both commission and omission errors. This technique will be applied in the future in order to improve the change detection process.

4 Results

Two thematic maps of high accuracy were produced (Figure 2, 3) for the identification of land cover/use changes (both in 59m resolution). The total accuracy in both land cover/use thematic maps was considerably improved (1975: from 58% to 94%, 1999: from 53% to 96%). Also, all the individual producer's and user's accuracies were improved especially for those classes that were not used in the initial scheme of classification due to the high spectral confusion.

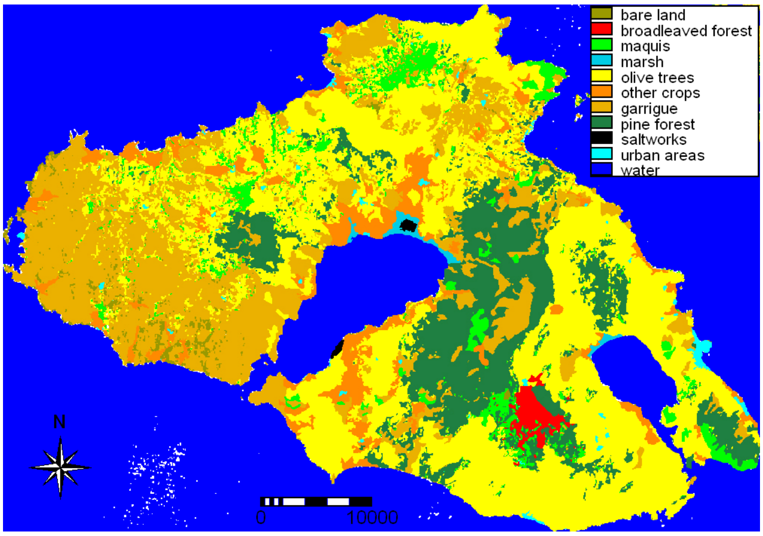

Figure 2. Land cover/use map produced from LANDSAT MSS image classification (1975)

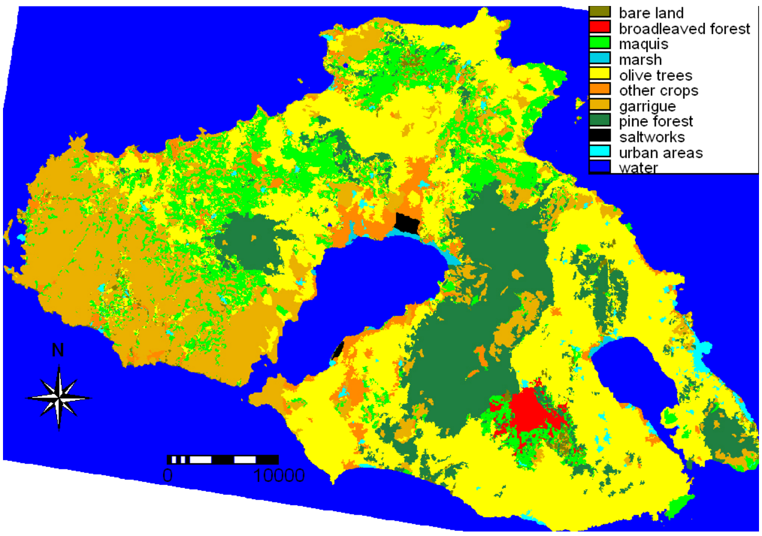

Figure 3. Land cover/use map produced from LANDSAT-5 TM image classification (1999)

The two thematic maps were overlaid with the cross operation (post-classification comparison), comparing pixels at the same positions, in order to detect and map land cover/use changes. Post - classification comparison constitutes the most frequently applied method for the mapping of land cover/use changes and presents the advantage of the identification and mapping, not only of the location and the extent of changes, but also of the nature of changes, i.e. the replacement of specific land cover/use class from another class (Foody 2002, Chen 2002, Hung and Wu 2005). However, it is possible to include false change detection due to map inaccuracies (Jensen et al. 1993, Rutchey and Vilcheck 1994, Foody and Boyd 1999).

The area covered by each land cover/use class (in %) is shown in Table 2. The larger and more significant changes that have taken place in Lesvos island are shown in Figure 4.

Table 2. Statistical data of land cover/use changes

Land cover/use	**Area (%) 1975**	**Area (%) 1999**
Bare land	1.4	1.3
Broadleaved forest	0.9	1.0
Maquis	5.2	13.7
Marsh	0.5	0.4
Olive trees	43.0	40.4
Other crops	6.7	4.2
Garrigue	26.2	21.4
Pine forest	15.3	16.1
Saltworks	0.1	0.2
Urban areas	0.7	1.3

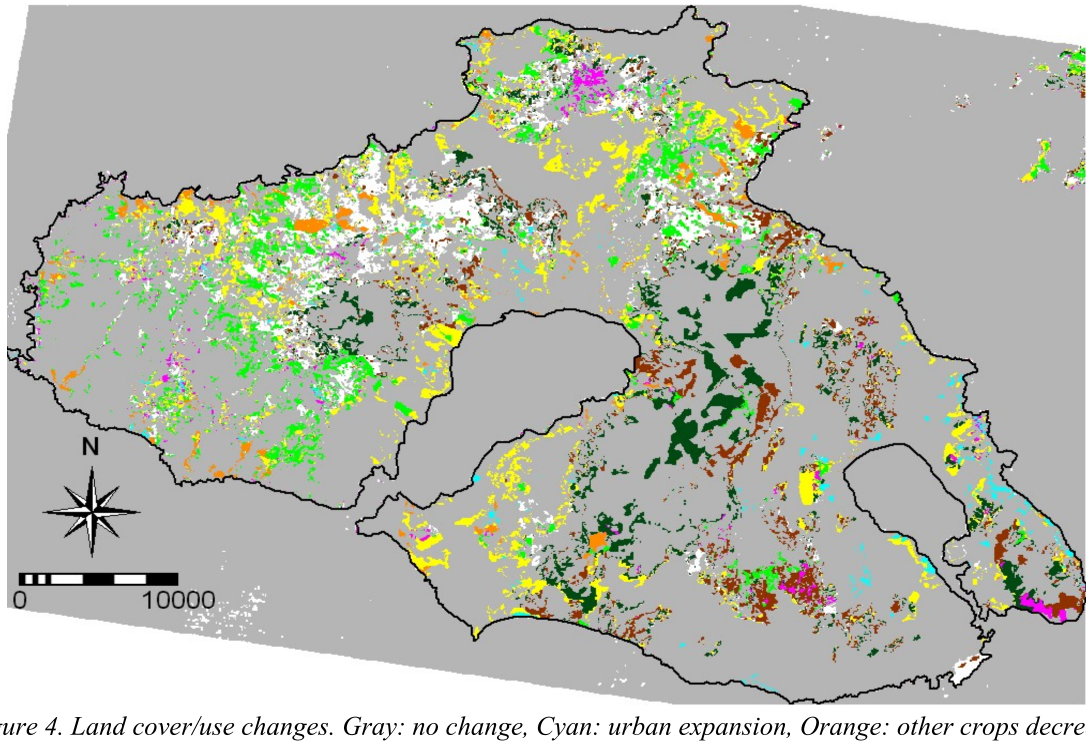

Figure 4. Land cover/use changes. Gray: no change, Cyan: urban expansion, Orange: other crops decrease, Yellow: olive groves expansion, White: olive groves abandonment, Dark Green: regeneration of pine, Dark Brown: deforestation of pine, Green: maquis vegetation increase, Magenta: degradation of bush vegetation

Human intervention and pressure manifested through certain practices, in the urban, agricultural and natural environment of the study area, have resulted in the following main changes:

A) A considerable urban expansion can be observed (the urban area almost doubled), mainly in the coastal plain, tourist areas and the large villages. This expansion is recorded in the perimeter of the existed urban areas, with a radial arrangement, and at both sides of the main road axes.

B) A notable decrease of other crops (mainly arable crops and citrus trees) was observed in many sites. In a few cases, an increase of arable crops, mainly near to coastal villages and plain areas, was recorded, reducing the rate of total decrease of other crops.

C) Although the change in the distribution of pine forest is uneven, a small increase of total area of pine forest is recorded. There are four main pine forests in the island. The larger forest is located in the central part of Lesvos (between Kalloni saltworks and Agiasos village), the second is in the west part of the island (near Parakoila village), and the other two are near the town of Mytilene (NW and SSE). The last two have suffered higher pressure. In the largest forest of the island, the regeneration of pine forest seems to prevail and the newly forested areas are larger than the areas that were burned or replaced by crops. Finally, the forest of Parakoila appears to increase its area, suffering less human pressure. The total balance of pine forest is positive.

D) The olive trees sprawl was observed mainly in coastal and plain areas, while the abandonment of olive trees occurred primarily in mountainous and semi-mountainous areas. The increase of olive groves was observed to have taken place at the expense of natural vegetation (mostly garrigue and maquis rather than pine forest) and other crops (arable cultivations). On the other hand, several sites were detected, where the abandonment of olive trees has allowed the regeneration of bushes vegetation (mainly maquis). These sites are located in mountainous and semi-mountainous areas.

E) The expansion of maquis vegetation in the north and north-west parts of the island (replacing olive trees) and the decrease of garrigue vegetation and bare lands were observed (bare soils, bare rocks), as shown in Table 2.

For the accuracy assessment of land cover/use changes a significant number of pixels were selected randomly, with a uniform distribution in the entire region of study. A comparison between the satellite images, the individual produced thematic maps, the aerial photographs (1960) and Quickbird imagery (2001) was made, in order to conclude about the plausibility or not of changes (small extent changes it is possible to provoke by misregistration or false classification) and create a simplified statistical table (Table 3), that describes quantitatively the precision of map of changes (Macleod and Congalton 1998, Foody 2002). During the pixel sampling a greater emphasis was given in the regions where the changes of land cover/use have been recorded.

Table 3: accuracy assessment of map of land cover/use changes

		Ground truth data	
		Change	**No change**
Classification data	**Change**	**2257**	292
	No change	323	**1348**

Total accuracy: **0,85**

5 Discussion – Conclusions

Using the MSS imagery for 1975, with four bands (two in the visible and two in the infrared) and a nominal spatial resolution of 59m, the identification of important land cover types was difficult to perform. Land cover types that are similar in their appearance and their spatial distribution on the landscape, are very difficult to identify with imagery of poor spectral and spatial resolution. For instance, olive trees demonstrated a similar spectral response to the maquis vegetation (mainly the Quercus family). Using a Landsat TM image of higher spectral and spatial resolution proved equally problematic in distinguishing these two land cover types. However, these land cover types were the most significant to identify since the abandonment of olive cultivations (in terms of their importance for the island's economy) is successed by *Quercus Ilex* in the first stage (Giourga et al., 1994). Bare land and low vegetation (garrigue) are also difficult to discriminate using Landsat imagery due to their homogeneous and smooth appearance. Using the rule-based approach that was presented in the previous sections we were able to improve upon the accuracy of the results. Indeed the improvement was significant raising the accuracy of each land cover map to over 90% and consequently the change detection accuracy to 85%. The results confirm that change detection using satellite data alone is a difficult task with many inaccuracies.

Accuracy is of course a function of the thematic and spatial resolution used. While updating land cover maps derived from classified satellite imagery using manual interpretation of aerial photographs, the analyst needs to be aware of the scale of the update patches. One of the difficulties is the requirement that the scale of digitised patches should match the scale of the original or generalised classified image. In any case one should avoid producing a map with varying scales across its area. This would lead to severe misunderstandings of the nature and scale of changes and any further spatial analysis would be compromised.

The land cover/use changes detected in the study area, during the time span 1975-1999, are significant and interesting. The complexity of the relief is a limiting factor for the agriculture, and often results in the abandonment of olive cultivations. Most changes in the olive cultivations were on high slopes and altitudes. Significant urban and crop expansion at the expense of vegetation zones were also detected. The latter together with cultivating practices that are applied, such as the destruction of older terraces in combination with more frequent appearance of adverse weather conditions (intense rainstorms), seem to intensify the erosion of landscape and favor the appearance of recent flood phenomena (Eresos and Kalloni villages).

For the improvement of the reliability of the results additional work will be carried out in the near future, concerning especially the mapping of olive trees, bush vegetation (maquis, garrigue) and the bare lands (bare soil, bare rocks). Manual interpretation and rules based on ancillary data are unavoidable in mapping these landscapes. Further work will involve fusion of images from different sensors and different resolution. Automation of the rule part of the methodological framework will also be considered.

Appropriate management of land use and the conservation and protection of natural environment require accurate and adequate information. The production of two land cover/use thematic maps, at a scale of 1:150.000 (approximately), in a region which is characterized by the absence of accurate old or recently updated maps is a significant contribution to this field. The two thematic maps can be used as a reference base, in the future, on a similar study of future changes.

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