Comparative Landscape Pattern Analysis Using Remotely-Sensed and Statistical Data to Evaluate Regional Diversity

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Abstract
In this study we use classified Landsat Thematic Mapper (LTM) satellite imagery of the years 1990 and 2000 in order to calculate some relatively simple landscape metrics and to quantify the landscape pattern of the Hellenic rural island of Crete. The metrics fall into both categories; those that quantify the composition of the map without reference to spatial attributes, requiring integration over all patch types, and those that quantify the spatial configuration of the map, requiring spatial information for their calculation. Then, we compare the appropriate landscape diversity indices of the above landscape in different times (1990 and 2000). As it appears, the evaluation of changes in landscape structure requires measuring a variety of indices in addition to the diversity. We conclude that, at least in the studied region, the effects of landscape changes can be monitored and predicted on large scale and over long periods of time using combined land cover, statistical and other auxiliary data. The research shows the need to establish a standardized approach, which can be used for analysis to track and quantify the undergoing changes in the landscape over a period.

Keywords
Spatial Pattern, Landscape Indices, Agricultural Landscapes, Geo-statistical Nomenclature.

Introduction
A necessary step in the assessment of agricultural policies and of their impact on the countryside and landscapes is the study of spatial units that constitute the underlying structure of these areas. Therefore, there is a strong need for statistical data on rural populations, and particularly, on landscapes and land use, which are by their nature, spatial in form. In this respect, the management, the processing and the display of such statistical data is, largely, a spatial process. However, to produce environmental indicators requires delineation of the land use data according to natural attributes, beyond that of administrative function. As a result, NUTS (Nomenclature for Statistical Territorial Units) system cannot be applied in its present form to units that are more relevant from a geographical point of view, such as drainage areas, landscape units and bio-topes. In the simplest form of a landscape the number of land cover types is limited. The landscape can be characterised (Patil *et al.*, 1998) by the proportion of each land cover type, by the aggregation into patches (shape), by the distribution of patch size and by the spatial distribution of patches (clustered or dispersed). Such characterizations exclude several aspects that can be quantified and may be integrated in the future, including topographic roughness indicators from Digital Terrain Models (DTM) indications on the open/closed landscape type, and the impact of the human presence, such as sparse buildings in rural areas.

Remote sensing provides valuable information on land cover. Landscape indicators can be computed on classified satellite images (Patil and Taillie, 1999). However the choice of the classification algorithm or the application of filters can substantially modify the values of landscape indicators. Comparisons between diversity indicators can be considered objective when the area under study is small enough to fit in a single satellite image and the same automatic procedure is used for different areas or the same area in different dates (Chuvieco, 1999). Photo-interpretation of satellite images from different dates on the same area can provide valuable information on land use changes to analyze the impact of spatial policies (Smits and Annoni, 1999). Note, that preliminary results of the investigation concerning temporal changes show that changes in landscape structures can be traced and interpreted by means of landscape metrics. However, monitoring changes require a high quality standard of input data in order to avoid any data related distortion of the results.

The aim of this paper is to quantify landscape patterns in the Hellenic region of Crete, during the two periods of 1990 and 2000, to quantify changes in the agricultural landscape pattern and to interpret these changes in relation to differential land use. Some relatively simple landscape patch metrics, have been calculated. The analysis is based on digitized maps of land cover derived from Landsat Thematic Mapper (LTM) satellite imagery of the years 1990 and 2000. For the year 1990 the CORINE Land Cover (CLC) raster dataset is reclassified from the original 44 classes into 16 classes that meet the needs of the Land Use/Cover statistics in Hellas and analyzed using an aggregate function. For the year 2000 the analysis is based on comparative optical photo-interpretation of satellite images, gathered in 1998-1999 which is the same as the census reference period (1998 to 1999), to produce thematic maps of land use/cover at a scale of 1:100.000. The geographical database uses the same 16 classes, as in the case of the modified CLC1990, and provides better acquisition period (LTM 1998 to 1999).

Materials and Methods

The CLC geographical database

Landscape data were ultimately derived from satellite imagery of the years 1990 and 2000. CLC raster dataset (100m x 100m pixels) is a geographic land cover/land use database encompassing most of the countries of the European Community, aiming of gathering information associated with the environment on certain priority topics. The CLC nomenclature is hierarchical and distinguishes 44 classes at the third level, 16 classes at the second level and five classes at the first level. The use of CLC nomenclature with 44 classes at three hierarchical levels is mandatory. Additional national levels can be mapped but should be aggregated to NUTS III level for the European data integration. No unclassified areas should appear in the final version of the data set.

CLC is now recognised by decision-makers as a key reference data set for spatial and territorial analysis at different territorial levels. The CLC inventory and its updates are key reference data sets, which will provide the basis for the development of spatial analysis and integrated environmental assessment. CLC1990 has been carried out in many European Countries over the period 1985 - 1995, whereas its upgrade, the CLC2000, which is based on Image 2000 data set, has been carried out during 1999 -2001. Note that I&CLC2000 (Image 2000 and CLC 2000) project consists of two main components which are interconnected (Pertigão and Annoni, 1997). Image 2000 covers all activities related to satellite image acquisition, ortho-rectification and production of European and national mosaic, whereas, CLC2000 covers all activities related to detection and interpretation of land cover changes. Thus, the overall aim of updating is to produce the CLC2000 database and the CLC changes database between 1990s and 2000.

The geo-statistical database

In the light of recent developments concerning land use statistics the National Statistical Service of Greece (NSSG) is testing an up-to-date methodology, in order to produce a detailed land cover map for the Hellenic territory. The data sources for this land cover map include aerial ortho-photographs, satellite images as well as agricultural census (FSS), whereas the minimum mapping unit is the same as with the CLC. The new geo-statistical database aims to cover the needs of land use/cover statistics as far as the distribution of the Hellenic total area into basic categories of land use is concerned. The new database is properly generalized as reference data and harmonized with the FSS nomenclature, by means of characteristics and definitions. As a result, the distribution of the main land uses in Hellas has been organized into sixteen classes. For the year 1990, the CLC1990 database is used. The correspondence between the two nomenclatures appears in Benaki and Tsiligiridis, 2001. Interesting to note that using the 44 CLC classes one may capture the total land cover diversity i.e. that linked to urban and natural areas. Nevertheless, our interest is to shed light on the relationship between agriculture and the landscape in rural areas and therefore the pre-mentioned reduction in the number of CLC classes is obvious.

Spatial analysis of the information to be recorded is realized by determining the area of the minimum recorded surface, which is taken according to the proposed nomenclature of sixteen classes, the methodology of use/cover definition, the requirements of 1:100.000 scale and the user needs. The method, by which the theme information is drawn up, is a comparative photo-interpretation of new satellite data collected in 1998-99 in relation to those used for the creation of the Hellenic CLC database. The digital photo-interpretation of the new satellite data is made using image processing software and other data such as those from land recordings. The recording, planning and the use of the data from the field work also define the reliability of the specific photo-interpretation.

The new geographical database for the country's area has numerous advantages. It provides a land use/cover map covering all the Hellenic territory using 16 classes, it takes into account the FSS nomenclature and definitions, it allows a comparison between different periods, using the same source of information, namely census or photo-interpretation, as well as, it allows a comparison between the two sources of information, namely census versus photo-interpretation. In the case of Hellenic Republic, the acquisition period of the data is spread over 2 years for both, the LTM 1998 to1999 and the FSS 1999/2000 (reference year the 1998-1999 crop year). Finally, it enables the integration of the chrono-geographical co-ordinates of the satellite images sources of CLC. This helps in the identification of districts for which image interpretation is one year apart (minus or plus) from the census year (1990 or 2000, respectively). In addition, using the intermediate FSS data that correspond closely to the date of the satellite image, it will be possible to mitigate the effect of time. As it appears, the new geo-statistical database is in principle more accurate than CLC. It can be used to calibrate diversity measurements computed from CLC, although there are some problems because the reference dates may not coincide.

Data processing

To explore the results of the combined polygon and grid based information there is a need to tackle the limitations inherent in the NUTS system. For this, a recently developed interface (Sambrakos *et al.*, 2001) between statistical and geographical data is used, which provides a comparison between them. The integration process of statistical data with georeferenced land cover results in a map allowing the crossing of existing data from different sources at a more precise level than the one used until now, and providing an efficient and user-friendlier dissemination. In this sense, agricultural as well as other statistical data, such as environmental, social, economical, etc., can be crossed with geographical information, namely, soil, human population, etc., making indicators easily readable and pointing out the main differences between aggregates of classes.

For example, geographical spatial units that correspond to arable land, as indicated in FSS, must be located. The details of the steps which aim to relocate the surfaces of the FSS are as follows. The first step is to match the geographical classes and the FSS nomenclature. Thus, for each district the share of each FSS class within the polygons can be defined. Clearly, each polygon has to be allotted a probability of containing a given type of FSS land use. In the next step it is possible to define some rules so that quantitative FSS data, other than land use can be redistributed. Finally, the geographical database could be combined with other layers of geographical information, such as climate, topography, pedology, and socio-economic data in order to refine the location rules to be applied to the variables that one may whishes to spatialize (Sambrakos *et al.*, 2003). These operations should provide a well stocked database able to deal with the problems of sustainable agriculture at an appropriate geographical level.

The analysis which has been carried out, presented and discussed in Benaki and Tsiligiridis, 2001 include the differences (%) in arable areas, areas under permanent crops, and cultivated areas, as they were recorded in the districts (NUTS III) and prefectures (NUTS II) level between the two nomenclatures. The available data from the 2000 FSS is based at the Municipality/Commune level (NUTS IV), whereas the data drawn from the new geo-statistical nomenclature is at the district level (NUTS III) of four pilot regions (island of Crete, Central, West, and East Macedonia and Thrace). The comparison shows large difference between in the agricultural areas. Generally, the examined agricultural areas in the geo-statistical nomenclature are greater than the corresponding agricultural areas in the 2000 FSS. The differences are because of the difficulties in correlating the pastures areas between the two databases, whereas the differences in the arable areas and the areas under permanent crops are related to the different methodologies.

Landscape diversity indices

Landscape metrics serve as a useful tool to describe the landscape structure in its various aspects (e.g. landscape diversity, fragmentation). So far, a large set of measures for landscape structure analysis has been developed (McGarical, 2000). They have been classified as patch diversity and distribution indices, patch shape indices, fragmentation and isolation indices and land use indices. A critical review of the most important published metrics may be found in (Glezakos and Tsiligiridis, 2003). However, a single indicator, which describes all aspects of landscape structure, does not exist. To avoid misinterpretations multiple metrics should always be used and the interpretation of these indicators should refer to each other. To limit the number of indices to a reasonable amount eight different metrics describing the structure of an entire landscape were applied. These indices are the Patch Density (*PD*), the Edge Density (ED) or Perimeter/Area Ratio (*PAR*), the Number of Classes (*NC*), the Shannon's Diversity Index (*SHDI*), the Shannon's Evenness Diversity Index (*SHEI*), the Dominance index (*D*), the Interspersion and Juxtaposition Index (*IJI*), and finally the Similarity Index (*SI*).

Nevertheless, the calculation of structural metrics requires a pre-defined spatial reference unit. Due to the fact that there is no unique naming for such a spatial unit, various terms may also be found in the literature (restitution unit, landscape units etc.) The choice of an adequate reference unit has a substantial influence on the results, because it determines to a great extent the interpretability and the significance of the metrics. Three approaches concerning reference units may be applied: administrative/statistical units (NUTS Regions), landscape units and a grid approach (moving window). In official statistical systems regional statistics relate to administrative units. At the EU level the NUTS is based on representing such units, where statistical figures are spatially related. NUTS is a hierarchical classification at five levels. In our study, administrative unit at NUTS II (region) and NUTS III (nomos or district) levels are used as spatial reference units and the metrics are calculated. The reason for this choice is to be able to analyze spatial units of similar or comparable size.

Results

In this preliminary study, we used polygon based analysis in order derive the area estimates of land use of the Crete region in 1990 and 2000 as well as the percentage of change. Note that based on grid analysis and testing two base units of 3x3 km^2 and 1x1 km^2 grid cell size more detailed results (NUTS II/III level) of the area estimates of land cover classes (in %) are produced which we present in Table 1. The figures, as presented in Table 2, indicate that substantial change occur only in class 12 (shrub and/or herbaceous vegetation associations -areas with mixed shrub / grassy vegetation) with an increase of +3.4%, class 11 (transitional woodland / shrub) with a decrease of -2.6%, and class 8 (pastures -areas under meadows or pastures) with an increase of +2 %). In all other classes only minor changes in land use were detected. The grid cell square of 3x3 km^2 is determined empirically, whereas the grid cell square of 1x1 km^2 is taken for comparison.

Next, we extend the grid analysis by calculating the predetermined landscape metrics based on the 20m x 20m land use pixels within each grid cell. The number of land cover classes within each grid cell is counted for each NUTS III region (Chania, Iraklio, Rethimno and Lasithi). The results are presented in Table 3, and as it may be observed they are consistent, whereas the change in structural metrics is not significant. For example, in the case of 3x3 km^2 (the same results are obtained using grid cell square of 1x1 km^2), comparison in a regional level between 1990 and 2000 shows that the patch density (per 100 ha) remains almost the same as well as the edge density, where a small decrease is observed. Shannon index, Shannon evenness index and Dominance index increased slightly, whereas the most significant change is observed in the increase of Interspersion and Juxtaposition index. Note the Shannon index indicates no change in the diversity of the land use classes in terms of number of classes and area distribution. This result is consistent with the high value of Similarity index between the 1990 and 2000, which shows there is no change between the tested sites.

Conclusions

In this work we compared landscape diversity in the rural area of Crete for the periods 1990 and 2000. We focused on factors affecting landscape diversity, on the relationship between changes, as well as, on the spatial distribution of elements. Note that the evaluation of changes in landscape structure requires measuring a variety of indices in addition to the diversity. From the results obtained we were not able to identify, at a regional context, patterns that lead to an important change the landscape diversity in the study area. The structural metrics indicate no advance in fragmentation and split of the land use classes. The Shannon index indicates an insignificant raise in the diversity of the land use classes and area distribution. Finally, the similarity index showed no significant change in the tested region. Before we close this final section the following concluding remarks need to be pointed out:

- The Minimum Mapping Unit size is 25 ha. Under this threshold landscape units may be included in surrounding categories. For example a few plots of woodland in the middle of arable fields will be included in an arable land polygon if the woodland is a small proportion. If the proportion is large, the polygon will be labeled as *heterogeneous agriculture*.
- The minimum size of 25 ha of the geographical mapping units presents the difficulty of identifying parcels of smaller size. Thus, a number of non-agricultural areas are classified as agricultural whereas they are only partially agriculture. This is a common problem in areas with forest and olive-trees. Besides, areas classified as non-agricultural areas in geo-statistical nomenclature may include part of an agricultural area. This explains a number of differences within the agricultural classes. For example, part of meadows or permanent crops can be included in areas with arable crops and conversely.
- In the case of CLC, the existence of heterogeneous classes suggests directly using their area percentage as an additional type of diversity index. Although quantitative calibration has not been performed, areas coded as *heterogeneous agriculture* have been visually identified as the most complex areas (high diversity).
- There is no information in CLC about the size of the agricultural plot. For example an agricultural plain of 1000 ha divided into 5000 plots of 0.2 ha will be a single polygon for CLC, the same as if it were a single plot of 1000 ha.

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TABLES

Table 1: Area estimates of land use in the region of Crete in 1990 and 2000.

Code	***Land cover classes Geo-statistical database***	***Crete (ha) 1990***	***Crete (ha) 2000***	***Change***	
				ha	***%***
1	Urban fabric • Build-up areas • Urban agglomerations	3,713.575	8,616.031	-4,902.456	-0.593
2	Industrial, commercial units. (Industrial or commercial zones)	224.180	596.793	-372.613	-0.045
3	Transport units (Communication networks)	1,115.804	1,267.373	-151.569	-0.018
4	Mine. Dump and construction sites. (Mines, waste disposal sites and construction sites)	395.804	571.249	-175.445	-0.021
5	Artificial, non-agricultural vegetated areas, sport and cultural activity sites (artificial or non-agricultural green areas)	0.000	69.238	-69.238	-0.008
6	Arable land	8,909.367	9,141.513	-232.146	-0.028
7	Permanent crops	188,985.234	193,732.887	-4,747.653	-0.574
8	Pastures (Areas under meadow or pasture)	240,703.259	224,109.624	16,593.635	2.007
9	Heterogeneous agricultural areas (Areas with mixed uses (mixed farmland))	156,318.966	154,564.228	1,754.738	0.212
10	Forests (Forested areas)	22,332.011	25,654.819	-3,322.808	-0.402
11	Transitional woodland /shrub	19,629.957	41,176.419	-21,546.462	-2.606
12	Shrub and/or herbaceous vegetation associations (Areas with mixed shrub/grassy vegetation)	152,098.731	124,325.482	27,773.249	3.359
13	Open spaces with little or no vegetation (Areas with little or no vegetation)	37,194.166	42,626.033	-5,431.867	-0.657
14	Inland waters	164.103	293.823	-129.720	-0.016
15	Inland wetlands	0.000	0.000	0.000	0.000
16	Coastal wetlands	0.000	0.000	0.000	0.000

Table 2: Estimate of area in different land cover classes (in %) of the island of Crete (Nuts II/III)

NUTS II/III		**Land Cover Classes (in %) - grid-based analysis (3x3 km^2**															
Code/Name	**Year**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Chania	**1990**	0.38		0.38			0.38	14.66	25.19	17.29	5.64	3.01	25.94	7.14			
	2000	0.38					0.76	19.01	18.25	13.31	4.18	10.27	23.95	9.89			
Rethimno	**1990**	0.65		0.11	0.22		1.51	23.65	27.21	17.28	2.38	2.59	19.76	4.64			
	2000	0.61					1.21	16.97	39.39	20.00	0.61	2.42	12.73	5.45	0.61		
Iraklio	**1990**	0.69		0.69			0.69	31.62	26.46	24.40	0.69	1.37	12.03	1.36			
	2000	1.04		0.35			1.04	35.07	28.12	21.53	0.35	4.51	4.86	3.13			
Lasithi	**1990**	0.48			0.49		2.90	14.01	35.75	17.87	2.42	3.86	14.49	7.73			
	2000				0.49		1.96	14.71	37.25	16.67	3.43	4.90	15.69	4.90			
Crete	**1990**	0.65		0.11	0.22		1.51	23.65	27.21	17.28	2.38	2.59	19.76	4.64			
	2000	0.87	0.11	0.11	0.11		1.08	23.21	27.65	17.25	2.93	4.23	16.48	5.97			

Table 3: Structural indices of the region of Crete (Nuts II/III)

		Grid based (cell: 1 km x 1 km)								**Grid based (cell: 3 km x 3 km)**							
Code	**Year**	**NP**	**PD**	**ED**	**SHDI**	**SHEI**	**D**	**IJI**	**SI**	**NP**	**PD**	**ED**	**SHDI**	**SHEI**	**D**	**IJI**	**SI**
Chania	**1990**	354	0.149	11.75	1.790	0.768	4.092	68.300		82	0.039	5.61	1.802	0.773	4.104	69.790	
	2000	343	0.147	10.92	1.910	0.750	4.395	70.000	0.885	89	0.038	5.44	1.890	0.851	4.088	79.850	0.826
Rethimno	**1990**	238	0.159	12.08	1.594	0.717	3.791	63.920		55	0.037	5.78	1.762	0.721	4.160	74.010	
	2000	226	0.152	11.19	1.647	0.644	4,132	61.020	0.899	55	0.037	5.49	1.648	0.702	3.950	67.010	0.911
Iraklio	**1990**	306	0.116	10.09	1.571	0.616	4.056	53.750		67	0.026	4.95	1.569	0.667	3.872	55.160	
	2000	296	0.112	9.24	1.630	0.615	4.195	56.810	0.876	51	0.020	4.47	1.565	0.659	3.867	57.330	0.832
Lasithi	**1990**	400	0.219	13.15	1.767	0.737	4.165	69.450		89	0.048	6.18	1.799	0.781	4.101	73.060	
	2000	383	0.210	12.80	1.763	0.709	4.248	68.870	0.934	77	0.042	5.72	1.753	0.798	3.951	76.130	0.912
Crete	**1990**	1231	0.148	11.13	1.733	0.676	4.298	59.360		274	0.030	5.16	1.749	0.704	4.233	66.290	
	2000	1160	0.140	10.50	1.806	0.685	4.446	62.850	0.934	270	0.033	5.07	1.805	0.727	4.290	67.150	0.924