COENOSES 11: 37-44, 1996
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AN INDEX TO EVALUATE LANDSCAPE CONSERVATION STATE BASED ON LAND-USE PATTERN ANALYSIS AND GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES[1]

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Keywords: Carabid beetles, Land use pattern, Landscape conservation, Thematic maps.

Abstract. A numerical index to evaluate the conservation state of the natural landscape has been proposed. The land use map of the study area derived by supervised classification of satellite images has been reclassified on the basis of land use typologies reflecting the degree of environment conservation. The proposed Index of Landscape Conservation state (ILC) has been computed on the basis of the geographic surface covered by each land use typology. The index gives importance to the position of a land use typology along a 'naturalness' degradation gradient. Improvement and limits of the ILC are discussed.

Introduction[1]

The development of a Geographic Information System (GIS) is usually considered to be tied to interpretation of satellite or remote sensing images, from which thematic maps of the territory are obtained. The same can be achieved by manually digitizing the objects under the research aim. Sometimes it is believed that the production of such maps "exhausts" the functions of a GIS, so that simple computer aided design (CAD) operations are passed on as GIS, only because geographic maps have been produced and the perimeter of some municipality has been calculated.

It seems reasonable to think of GIS as a tool that, on the basis of variables surveyed (vegetation, temperature, altitude, etc.) and represented in the form of thematic maps, enables the drawing of "derived maps" picturing the geographical pattern of variables that cannot be surveyed (climatic indices, faunistic value, etc.). In this way a GIS plays an important role in addressing both scientific research and land use policies (see also Aspinal 1993).

To focus the guidelines of a research program it may be useful to obtain synthetic information, in the form of numeric indices, on the environmental situation pictured by the thematic maps. Such indices could help in outlining trends in the studied phenomenon, or the presence of an area of interest on which to concentrate the research effort, or on which to apply particular policies (see e.g., O'Conner et al., 1992, Verlouw et al. 1992).

The present paper comes as part of a research project for the study of desertification in the Mediterranean region, coordinated by the International Centre for Alpine Environments (ICALPE, France). The purpose is to find a quantification method of land use pattern, to be applied at the landscape level, that enables the comparison of zones under different topographical and ecological points of view.

Methods

The study area belongs to a geographical district in the Calabria region of Italy, called Sila Greca (Figure 1). This district is characterized by a group of reliefs sloping towards the Ionian sea from a maximum altitude of around 1600m. The Sila Greca extends over an area of more than 100000 hectares. On the basis of map studies and field observations, an area representing the main bioclimatic belts of the Sila Greca region was outlined, the limits of which were drawn taking into account some river basins, and in particular by including a large river, structured in a mountain torrent part, and in a "fiumara"[2] outlet part; and by including a series of watercourses representing the hilly and coastal landscape of the Sila Greca.

The land use map of the study area was produced by the French society "Geospace" on the basis of multispectral and multitemporal SPOT images interpreted by a supervised classification. The data, formatted as TIFF images, were imported and managed by the IDRISI software package

1 Research carried out for the "Medimont" project (coordinated by Dr. M. Dubost, ICALPE, France), supported by the European Community (ECDG XII); and partly financed by CNR, "Progetto Strategico per l'Ambiente in Calabria (National Coordinator Prof. A. Moroni).

2 A "fiumara" is a large river bed with small permanent islands of vegetation, flooded during the spring, but for the most part of the year characterized by water shortage.

Figure 1. Location of the Sila Greca region in the Italian peninsula.

(Eastman 1992). The map includes information on environmental typologies, and also on their importance in terms of surface. It has also intrinsically included a quantitative estimation that allows us assess the degree of influence of the different land use patterns on the landscape conservation state.

In our starting assumptions (Figure 2) the strong influence in the area of several anthropogenic factors on the landscape (land tenure, agriculture, livestock) was supposed. This influence was documented historically, and its effect was studied by diachronic analysis of land use starting from the XIX century (Appiani, unpublished). The fact that a true desert landscape (such as the Sahara or Gobi desert) was not recognizable in the study area, made it difficult to find an index of desertification at the landscape level that allowed sharp distinction between a desertification against a non-desertification condition. It seemed more reasonable to suggest an index that enables us to find areas in which serious landscape degradation with risk of desertification is expected at some degree of probability.

The Geospace classification is not a classification of landscape degradation or 'naturalness'. In order to evaluate the conservation state of the environment, a degradation scale of reference was needed to re-classify Geospace land use typologies according to their state of conservation. Many investigations carried out on Carabid beetle communities have found that they are sensitive to environmental degradation, and thus can be used as reliable biological indicators (cf., Stork 1990, Desender et al. 1993). On the basis of the authors' research carried out for many years on this group of invertebrates (Brandmayr 1983, Brandmayr & Zetto Brandmayr 1988, Pizzolotto 1994), a group of environmental degradation categories was proposed (Table 1, second column), and the categories were ordered following a degradation/naturalness gradient to which Carabid beetles are sensitive. The choice of these categories was made taking into account also the Corine classification (again, not a classification of landscape 'naturalness'), because it is widely

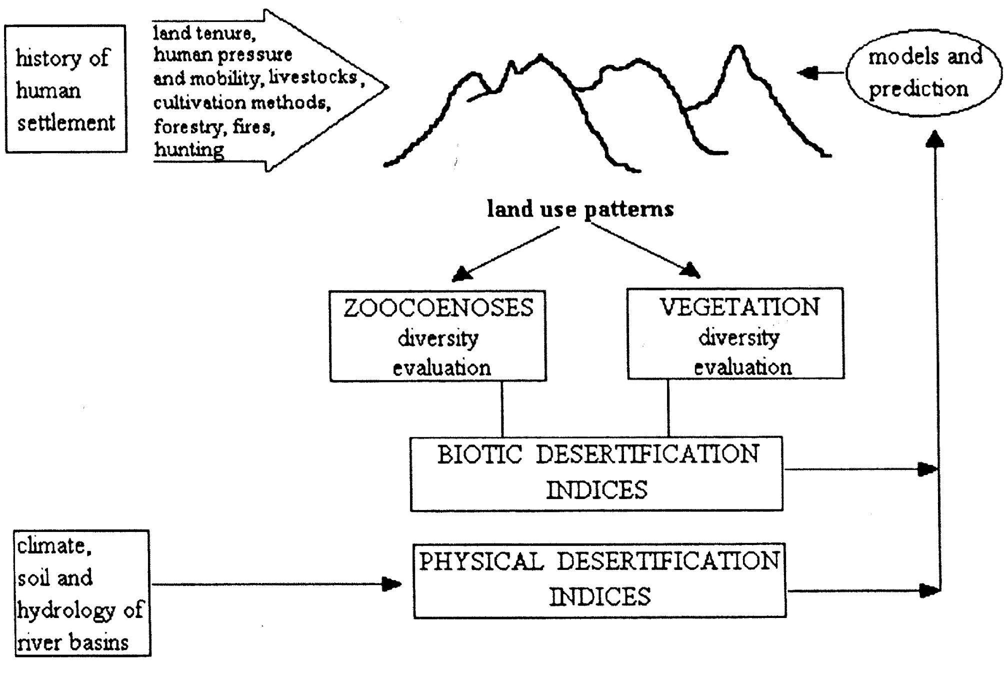

Figure 2. Frame of the main research lines in the Medimont project.

Table 1. Conversion table among Corine land use typologies, Geospace typologies and the categories used to draw the GPLC, and then to compute the ILC. The groups of Geospace typologies enclosed with thin lines were converted into the categories of the middle column. Fruit and olive trees into permanent crops; chestnut and *P.laricio* into paraclimax forests; and so on. The same holds true for Corine typologies. The dashed line between typologies 3.1-3.3 and categories 8, 10, 11 means that this conversion is problematic.

Corine typologies	Categories for the ILC	"Geospace" typologies
1.1 Urban fabric	1. Bare soil	bare soil
1.2 Industry, commercial transport units		
1.3 Mine, dump, construction sites	2. Ruderal	-
1.4 Artificial, nonagric. vegetated areas	3. Artificial green	bare fields
2.1 Arable land	4. Fields	cultivated land
2.2 Permanent crops	5. Permanent crops	fruit trees
		olive trees
2.3 Pastures	6. Pastures	lowland grasslands
		hilly graslands
		mountain grasslands
2.4 Heterogeneous agric. areas	-	
	7. Park landscape	*Quercus ilex* scrubs
		hilly scrubs
3.1 Forests	8. Artificial forests	-
3.2 Scrub and/or herbaceous vegetation	10. Paraclimax forests	chestnut
3.3 Open spaces, little or no vegetation		*Pinus laricio*
	11. Climax forests	*Quercus ilex*
		hilly oaks
		mountain oaks
4.1 Inland wetlands	9. Azonal ecosystems	wetlands
4.2 Maritime wetlands		alluvial

used to classify satellite images. In Table 1 the comparison of Corine typologies, typologies used by Geospace, and categories used in the present work is presented. The same table gives the rules for the conversion of Geospace typologies into degradation categories.

The land use categories classified following the new categories gave the geographical pattern of landscape conservation for the study area (Figure 3). The information held by this new map was synthesized in a graphic model by cumulatively summing the percentage portion of the territory occupied by each category. We called this cumulative graph the "Graphical Pattern of Landscape Conservation state (GPLC)". A synthetic index of the conservation degree of the environment that can be applied at the landscape level was derived from the GPLC and named "Index of Landscape Conservation state (ILC)".

Symbolically x_i is the cumulating percentage value and the area beneath the graph can be expressed as

$$A = \sum_{i=1}^{nc} x_i - 100$$

where nc is the number of categories (the last category will always sum up to 100%).

Table 2. First row: number of pixels by categories in figure 3. Second row: percentage ratio of the total number of pixels for the study area. Third row: cumulative summation of entries in the second row.

	1	2	3	4	5	6	7	8	9	10	11
	bare soil	ruderal	art. green	fields	perm. crops	pastures	park landscape	artificial forest	azonal	paraclimax forests	climax forests
pixels	42083	63949	0	15543	128135	285548	211959	0	5819	296500	393815
%	3	4	0	1	9	20	15	0	0	21	27
% cumul.	3	7	7	8	17	37	52	52	52	73	100
ILC=0.69											

The maximum value of A will be

$A_{max} = 100*(nc-1)$

The Index of Landscape Conservation is now

$ILC = 1-(A/A_{max})$

The index ranges from 0 to 1 and, as can be seen from the graphic model, it is proportional to the importance of the conserved natural environments (the area above the graph). Assuming that the taxiway of an airport is evaluated, the graph will cumulate 100% of the area starting from the first category (bare soil) to the last, giving an ILC equal to 0.

Results

The 17 landcover typologies in the map generated by the remote sensing analysis were grouped into 11 new categories. Then the map was redrawn on the basis of these categories (Figure 3). The cover of each category was calculated (Table 2) as the number of pixels in the raster image. The whole study area extends over 1 443 351 pixels.

It is possible to give a general idea of the conservation state of the study area by the GPLC (Figure 4) drawn on the basis of Table 2 (third row). The ILC tied to this GPLC has a value of 0.69.

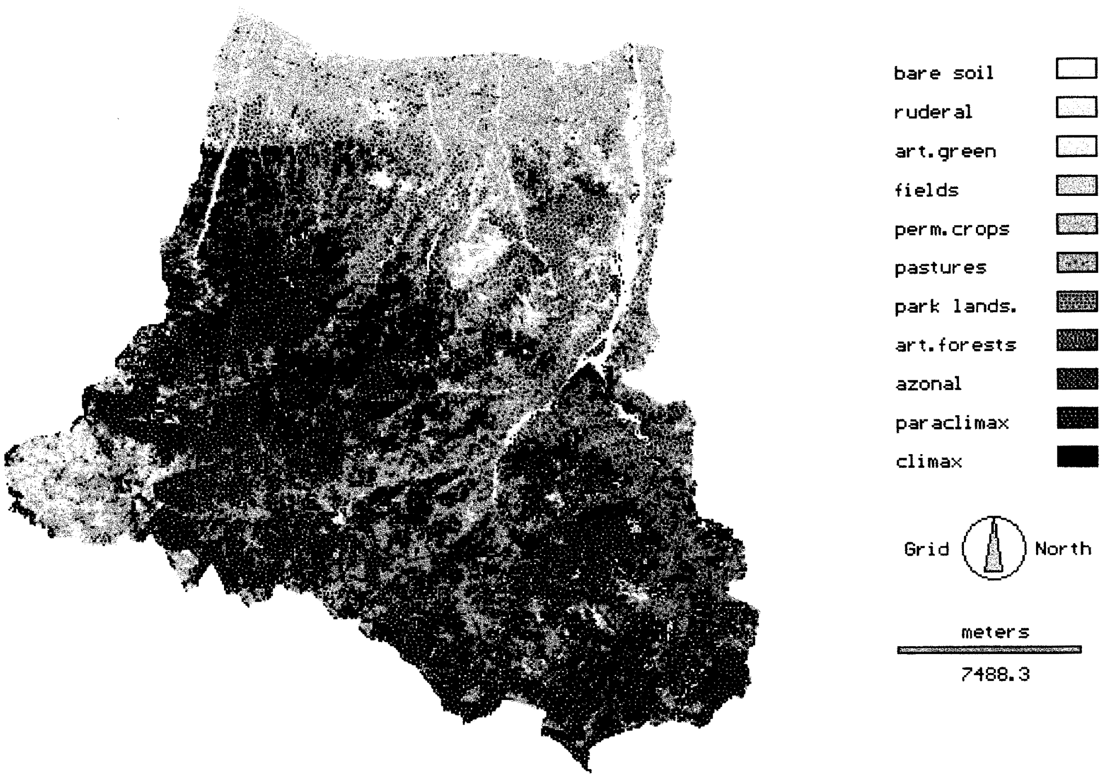

Figure 3. Geographical pattern of the landscape conservation state in the study area, after reclassification of the land use map made by Geospace society.

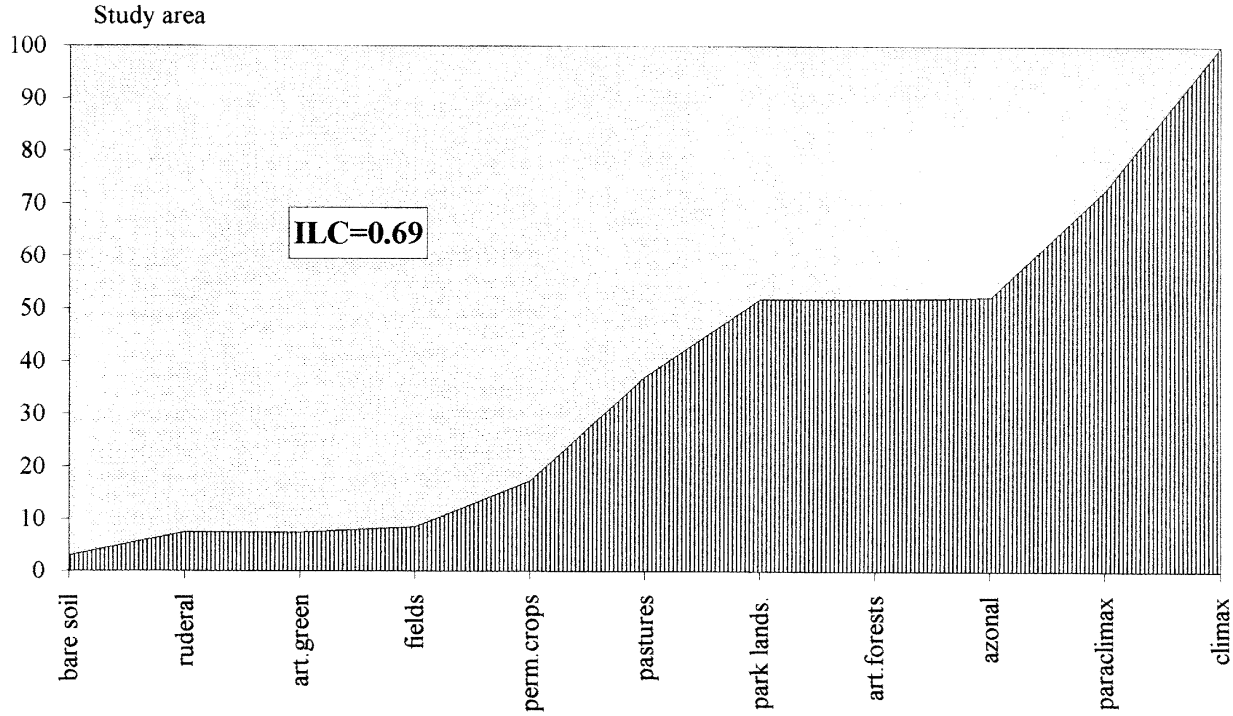

Figure 4. Graphical Pattern of Landscape Conservation state (GPLC) for the whole study area.

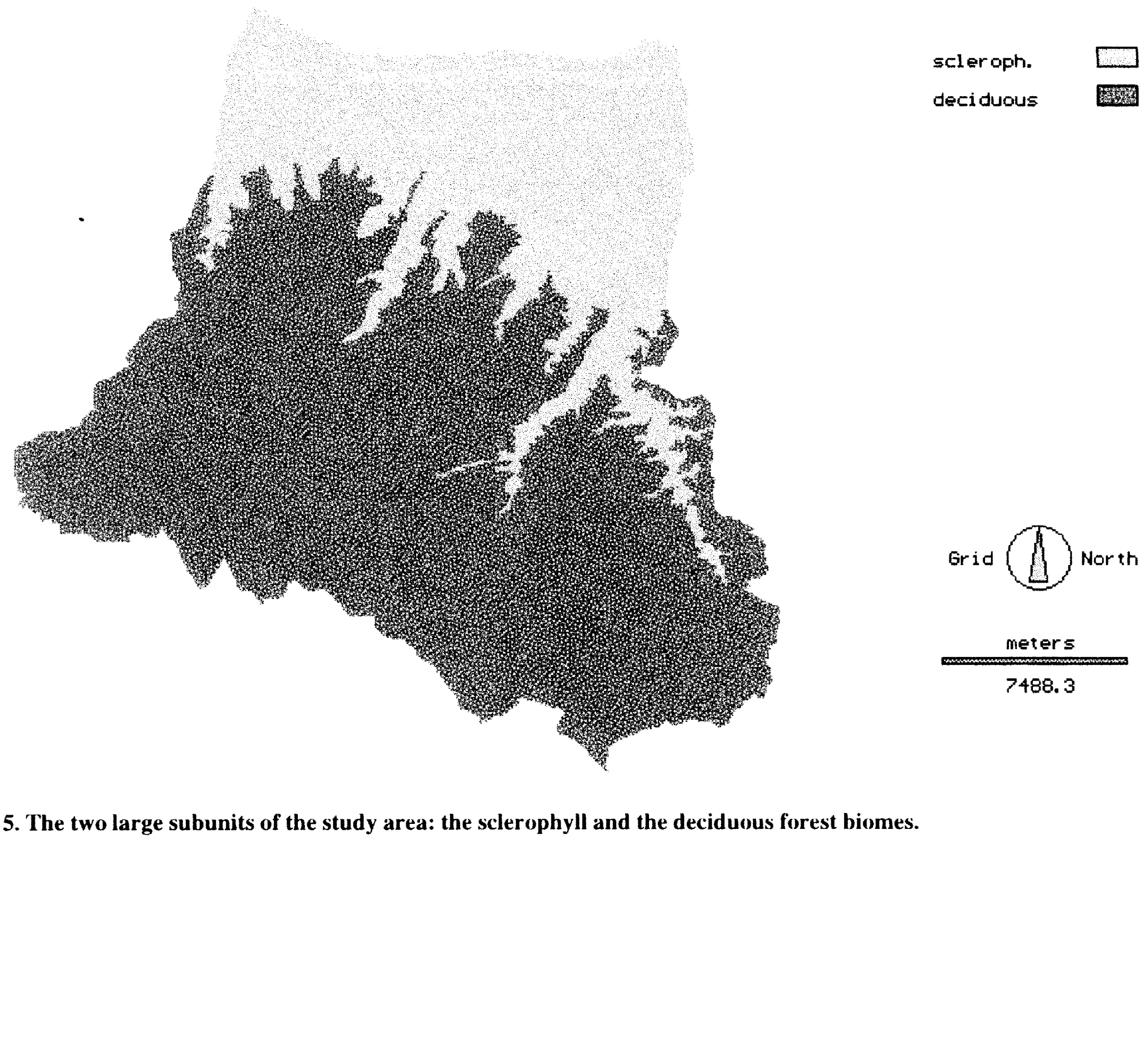

Figure 5. The two large subunits of the study area: the sclerophyll and the deciduous forest biomes.

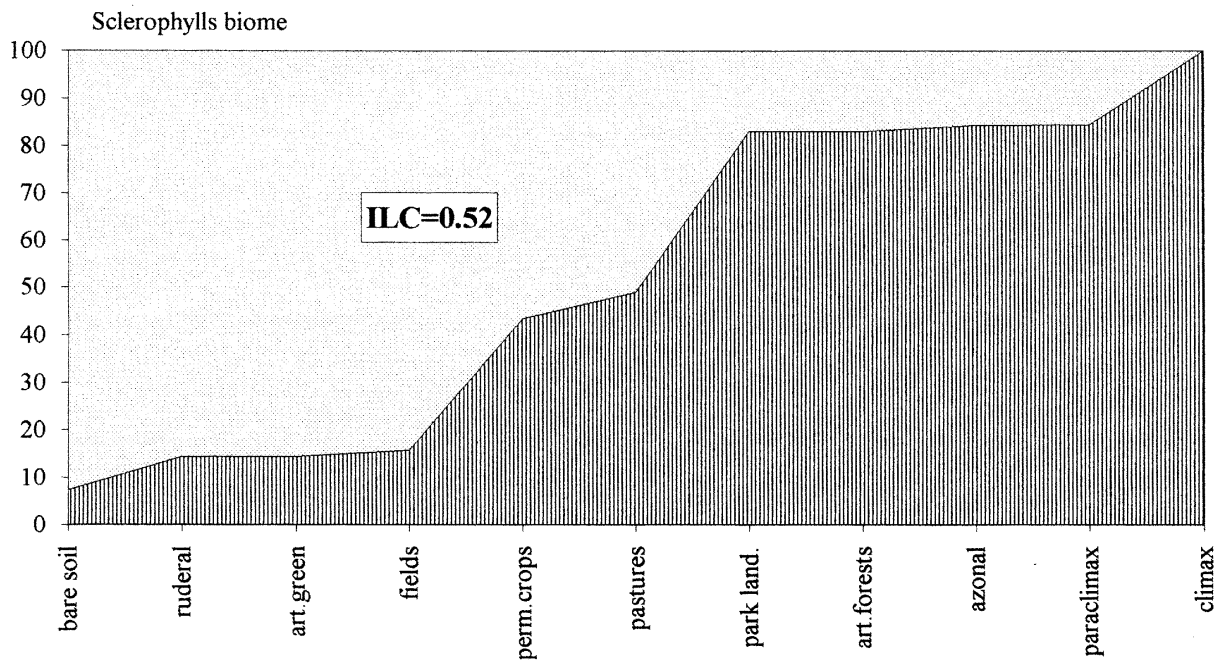

Figure 6. Graphical Pattern of Landscape Conservation state (GPLC) for the sclerophyll biome

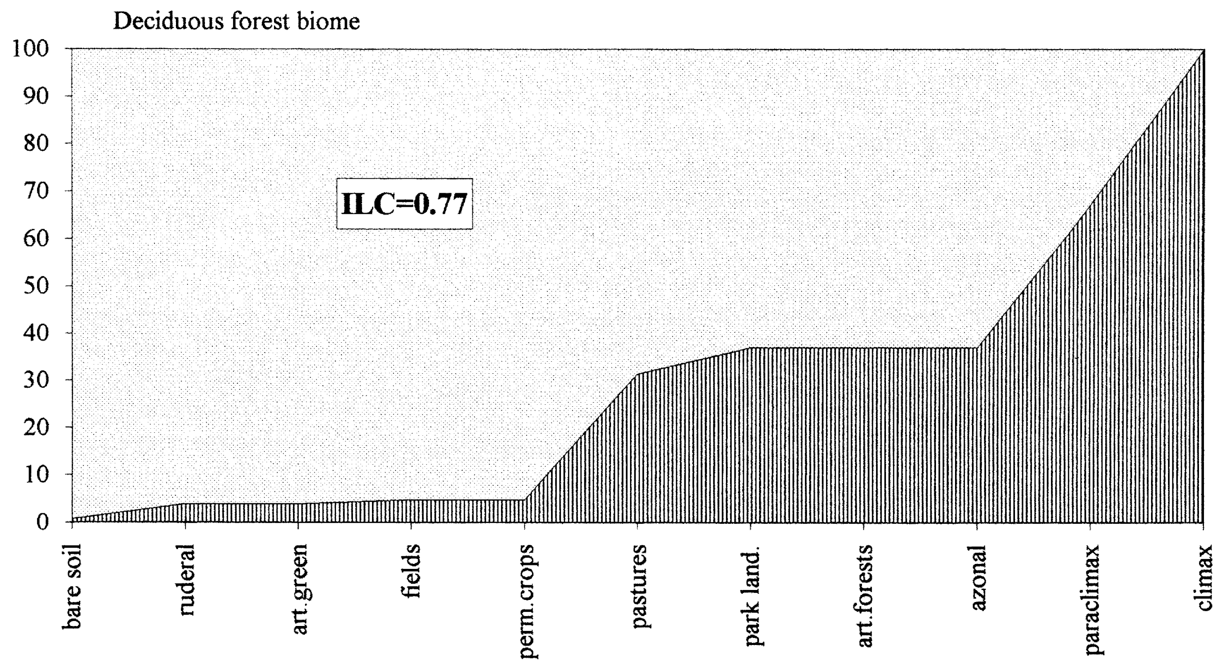

Figure 7. Graphical Pattern of Landscape Conservation state (GPLC) for the deciduous forest biome

The application of the ILC at this geographical scale may be helpful if the study area shows homogeneous conditions with respect to the main ecological trends (altitudinal series, ecological successions), but even in this situation, we cannot exclude that particular features are present at the level of elementary geomorphologic units (a valley, an alluvial lowland, a mountain massif). Actually, one often needed to find "territory unit" that enables one to mark "windows" in the study area to be compared.

For the present work, the study area was dissected by two large subunits (Figure 5), following a bioclimatic criterion, and having as the "dissecting line" the upper limit of *Quercus ilex*. Attention was given to the two biomes that characterize the Sila Greca natural landscape, i.e., the sclerophylls and the

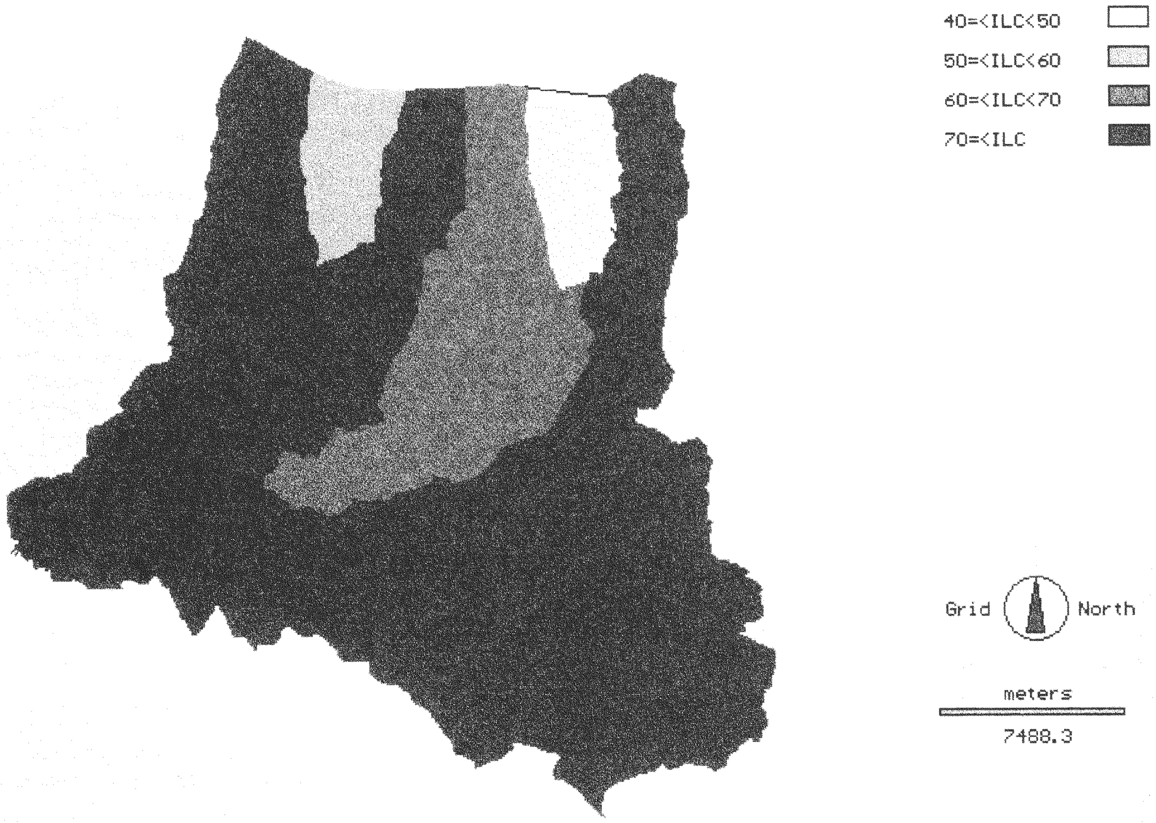

Figure 8. Geographical pattern for the Index of Landscape Conservation state (ILC) evaluated on the river basins of the study area.

deciduous forest biomes. Such a subdivision is consistent with historical diachronic analysis that found that the present human settlement is a consequence of shifting of the population and economic activities from the mountains towards the seaside zone of the study area.

Figures 6 and 7 give the GPLC and ILC for the sclerophylls and deciduous forest biomes. From both a graphical and numeric point of view, the two zones show differences mainly tied to the importance of categories more affected by human activities (bare soil to pastures). It is to be stressed that in the seaside area highly erodible bedrocks are present, which if affected by agricultural overexploitation may lead to the deep erosion phenomena, the "calanchi" badlands. The main historical and modern urban centres were found in the same area.

Orography and climate make the seaside and hilly zones more favourable for agriculture. This is mirrored in Figures 6 and 7, where, for the sclerophylls biome, a significant contribution to the GPLC is given by the categories of permanent crops and park landscape, mainly abandoned fields and unproductive land with scattered trees. For the deciduous forest biome, pastures and paraclimax and climax forests are the most prevalent categories affecting the shape of the GPLC curve.

Discussion

In this paper we discussed the problem of further processing of a classified satellite picture. In many circumstancies (e.g., environmental assessment or decision making) tsuch processing is strongly needed, since a simple interpretation of satellite images is not sufficient to plan environmental policies. The ILC is a means to use knowledge about a taxon, gained after years of field research, for the interpretation of the landscape in a formal way; even if the subjective decision of the researcher plays an obvious, but important, role in determining the rank of the categories. It is not another way to interpret satellite pictures, but a mean to see what the satellite cannot see.

From the graphical point of view, the GPLC gives insight on the environmental (ecosystem) conservation state. The area above the curve is proportional to the ILC, and even in the case of draft pictures (as in Figures 6, 7) it is possible to see which categories are responsible for changes in the slope of the graph.

The ILC does not evaluate the simple dispersion of a number over the series of addenda that generated it (the equitability does), but gives importance to the rank of each addendum (i.e., the cover of each category) along a gradient with ecological meaning. This is easily demonstrated by changing the order of categories in Table 2.

The ILC seems more suitable for comparisons among subunits of the same area, than for comparisons among ecologically very different regions. As far as concepts like ecological succession and climax stage have general value, we still move to verify the meaning of a comparison between, for example, alpic and mediterranean environments based on the ILC. It is a helpful index, if applied at the regional level. It enables us to outline particular landscape conditions for more detailed study by introducing new environmental categories that better fit the outlined phenomena.

The several types of choices that can be made to mark the "window" are tied to the aims of the research to be performed. Two groups of approaches could be outlined. An "administrative" approach, which are of particular interest to policymakers, and an ecological approach, mainly tied to basic research. In the first case administrative (municipality, province) or altitudinal limits could be taken as territory units, while in the second one could refer to river basin limits (geomorphologic approach) or to vegetation belts (bioclimatic approach) as units. Figure 8 gives a map of the ILC for the river basins of the study area as an exemple.

Intuitively, a third type of approach could be suggested, namely the use of polygonal windows which frame portions of the study area following a random or a systematic selection processes ("geometric" or "fractal" approach). However, if there is evidence of the presence of factors that generate clusters or trends in the landscape variables, it would be better to make choices on the basis of the knowledge of clusters and trends (see also Harrison and Dunn, 1993).

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