Studying Land Use Patterns in Crete Island, Greece, Through a Time Sequence of Landsat Images and Mapping Vegetation Patterns

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Abstract: - The discrete character of the islands of the Mediterranean Sea, in terms of their rough anaglyph and their climatic differentiation creates a number of difficulties in the detection of the changes of land use patterns and vegetation pattern through satellite images. The internal complexity of the terrain and the land surface provide obstacles in the clear discrimination of land uses and habitat types. The spatial coherence of the land uses is very helpful for a more complete description of the spectral properties of the satellite images contributing significantly to the detection of the possible coexistence of classes. Apart of the linear methods, differential topological methods were used to detect the spatial complexity of the land uses, such as the fractal dimensions of the perimeters of the polygons constructed through classification techniques. Object oriented classification was applied for the vegetation classification. The above mentioned techniques were employed for a better understanding of the temporal changes of land use and the production of a vegetation map in the island of Crete.

Key-Words: - Land Use, Satellite Remote Sensing, Landsat, Classification, Temporal changes, Crete.

1. Introduction

In an effort to develop a multidimensional expert system which could to be used for monitoring the landscape changes and for the management of the natural resources, a consortium of research institutes undertook the task of creating a number of thematic maps through the collection of environmental data and the processing of satellite images and topographic maps. The project aimed to combine a number of digital geographically based information layers of the whole island of Crete, linked to other statistical and environmental databases.

Land-use and habitat characterization is critical in government planning and definition of policy strategies. The definition of the land-use categories and the study of their temporal change are of specific importance in modelling the environmental parameters and providing the background layout for the rest of GIS analyses aiming towards the presentation of potential risk areas. Moreover, the vegetation mapping via habitat characterization is a primary approach and a basic tool for the implementation of conservation and management practises concerning natural ecosystems [1].

Satellite remote sensing imagery has the ability to provide a wide spectrum of information of the land cover, land use and vegetation patterns covering a wide area of interest with a sufficiently adequate resolution [2, 3, 4]. Nevertheless, due to the rough anaglyph the high spatial differentiation of land cover, the high heterogeneity of the landscape and the high spatial differentiation of environmental variables in dry Mediterranean environment, processing of the satellite imagery needs further refinement.

In the current study a further processing of satellite imagery was attempted in order to present land use pattern in the island of Crete, to reveal the temporal change of land uses during the last two decades, to assess the related parameters of the analysis as well as to produce a mesoscale vegetation map of Crete based on habitat characterization. Several similar studies have been conducted in the area of Crete having a different degree of coverage, focusing in specific aspects of land-use changes (such as desertification) and lacking a detailed degree of sampling and ground verification [5, 6, 7, 8, 9].

2. Materials and Methods

2.1. Study area

The study area is Crete, a Greek island of south-eastern Europe, with an area of 8729 km^2 and an extremely mountainous terrain of several massifs, with the highest summits of similar altitude to the majority of those in the Greek mainland. These massifs are separated by lowlands, which are sometimes extended flat areas close to the sea level.

Various calcareous rocks (limestone and dolomites) dominate the mountain terrain, whereas Neogene sediments including limestones, sandstones and marls, cover large areas of the lowlands. In the island there are also ortho-quartzites, phyllites, flyschs, Quaternary rocks and alluvian deposites [10].

The climate of Crete is typically Mediterranean where mean annual rainfall decreases from west to east and from north to south, but increases with altitude. There is also a slight increase in mean annual temperature from northwest to southeast and a decrease with altitude.

2.2. Satellite Imagery

In order to study the recent temporal changes of land–use in the island of Crete, 9 Landsat-5 TM and Landsat-7 ETM images were used, spanning from 1985 to 2003. All images were acquired in April and May seasons.

Images were georeferenced to the Greek Reference System (EGSA'87) based on an Ortho SPOT PAN image with 10m spatial resolution. As the images did not cover the whole island of Crete, mosaiking processes were carried out, maintaining the original spectral values of the image components (Fig. 1).

Figure 1. Real colour composite of the mosaic of the island of Crete.

Enhancement of the images was based on the modification of their histogram through image equalization techniques. High-pass and edge-enhancement filters were also applied in order to investigate the complexity of the data. Reclassification methods considering a resulting pixel size of 210x210m were also applied to decrease the complexity of the images and detect areas of dominant land covers.

2.3. Complexity

The terrain profile of the island territories of the Mediterranean is well known for the high degree of land-use mixture existing all over their extent. Land-parcels are narrowly separated, making the study of their attributes through medium resolution imagery, a difficult task. The complexity of the definition of land-uses becomes even fuzzier due to the rough anaglyph of the islands, which promotes the parallel development of micro-environments favoring different degrees of evolution of the natural and agricultural vegetation species.

The fractal dimension of the polygon perimeters of land uses, which has been used, is an invariant measure of the complexity of a spatial feature. In the case of spatial data, fractal dimension is calculated by the formula D=2-A, where A is the slope of the linear regression of the logarithmic semi-variogram of the phenomenon under examination [11, 12, 13]

Another, linear, estimation of complexity is the one given by the ratio of the logarithm of the sums of areas of polygons to the logarithm of the sums of the corresponding perimeters, per use. The output of the above approaches is similar and comparable.

COMPLEXITY PER USE (LINEARLY ESTIMATED)				
classnames	**1988**	**1994**	**1999**	**2003**
VINEYARD	1,376	1,343	1,348	1,068
URBAN AREAS	1,347	1,344	1,356	1,347
WOLD	1,349	1,352	1,360	1,331
SYLVAN	1,357	1,334	1,343	1,334
OLIVE GROVE	1,342	1,349	1,343	1,348
CITRUS	1,406	1,355	1,366	1,358
CULTIVATION	1,399	1,372	1,361	1,368
MINERAL	1,422	1,339	1,340	1,338
MIXED FLORA	1,352	1,348	1,366	1,362
FAVITY	1,347	1,337	1,337	1,312
ALLOUVIANS	1,342	1,349	1,372	1,369
RIFT	1,344	1,326	1,350	1,342
SHRUBBY	1,410	1,335	1,348	1,357
GARRIGUE (PHRYGANA)	1,444	1,354	1,376	1,373
SNOW	1,379	1,419	1,433	1,384
LANDFILLS	1,454	1,395	1,403	1,395
WATER	1,427	1,429	1,493	1,472

Table 1. Generalized estimate of spatial complexity of land-uses for the periods of 1988, 1994, 1999 and 2003.

The calculated fractal dimension was equal to 1.6, approaching the value of 1.85 in more complex plain areas. In fact, the complexity in micro-level analysis is shown to be increasing since 1988. On the other hand, the more generalized image of 210x210m pixel size (44100 m^2 groupings), which was used to detect the zones of dominating land-uses, indicate a more or less steady (or slightly decreasing) trend of dominant land-uses (Table 1).

2.4. Classification of Data for Land-uses

Usually, when a spatial phenomenon has a high degree of complexity, the use of ISODATA or K-means Cluster Analysis algorithms are inappropriate in the classification of the features [14]

Supervised classification for land-use was performed by taking in account all the spectral bands of each image. Training data were collected through field surveys using GPS and in some specific cases from ortho-rectified aerial photographs in order to create a more definite separation of adjacent categories. Thus, the data collected consisted of polygons of unmixed land-uses and lines through which land-uses were clearly separated, so that the discrimination ability of the algorithm could be enhanced.

More than 450 training areas were specified, corresponding to about 17 different categories (Fig. 2).

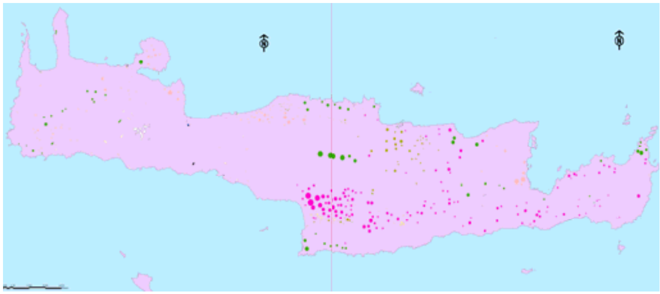

Figure 2. Distribution of the training sites selected and mapped through GPS survey and aerial recognition.

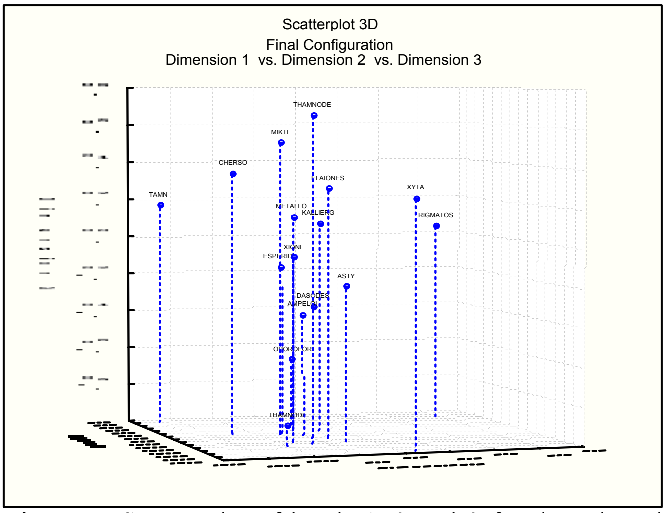

Figure 3. Scatter plot of bands 1, 2 and 3 for the selected land-use classes.

Based on the statistical evaluation of the training sites, it was decided to reduce the classification analysis to 16 classes (see Table 1). These categories, apart of describing the spatial variation and evolution of land-uses, they can be also used as an index of monitoring the convolving phenomena of urbanization and desertification in Crete.

The discrimination of the spectral signatures is better defined by using the Euclidean Distance and the Percentage Disagreement in seven dimensions (proportional to the bands of Landsat TM). This analysis reconstructed the land-use space with the method of multidimensional scaling and the resulting scatter plots indicated the degree of separation among the different categories (Fig. 3).

2.5. Classification of Data for Vegetation Mapping

Object oriented classification [15] has been applied in order to produce a digital image of the vegetation in the island of Crete. The basic feature of this approach is that no single pixels are classified but rather image objects, which are extracted in a previous image segmentation step [16]. The classification was performed using a standard nearest neighbour classifier, with user-selected samples similar to a supervised classification in a pixel-based image analysis system. The classification process was based on fuzzy logic, to allow the integration of a broad spectrum of different object features such as spectral values, shape, or texture for classification.

The task of the vegetation classification was more complicated as a result of the highly heterogeneous vegetation mosaic of the study area. Using object oriented classification; polygons were represented as the actual objects of interest depending on the scale that has been used for the processing.

Figure 4. Distribution of the training sites selected and mapped through GPS survey and aerial recognition.

At the beginning, more that 1000 training areas (Fig. 4) were specified corresponding to 24 habitat categories, according to NATURA 2000 [17] plus the categories of agriculture, urban and water. Taking into consideration that, a) in the mesoscale approach several of the above habitats were not the representative parts of the actual objects due to their relatively small area in relation to the total area of the polygon, as well as that, b) despite of the high number of training sites any further attempt to map vegetation in a fine scale could result to higher patchiness and a much higher number of unconfirmed patches [18], it was decided to reduce the classification analysis to 14 classes of NATURA 2000 habitats, plus the habitats of agriculture, urban and water.

2.6. Land-Use Changes

The temporal detection and evaluation of the land-use patterns was carried out after normalization of the original satellite images, in order to minimize radiometric, atmospheric and seasonal variability. A step by step algorithm was employed for studying the temporal changes in the spectral profiles through the calculation of the first and second derivatives for subsequent years. Thus, the first derivatives were calculated as the differences between subsequent years, such as between t & t+1, t+1 & t+2, etc. All the rest temporal change estimates were calculated in reference to the latest satellite image, namely 2003 image.

The spatial detection of the spectral changes was examined by calculating the second order differences of the images. This type of Laplacian approach responds well to the generalization of more or less homogeneous polygons exhibiting relative small changes. Furthermore, the examination of the results of the 2nd derivatives indicated that the temporal changes of band 7 could describe synthetically the corresponding changes in bands 1, 2 and 6. Similarly, changes in bands 3 and 4 could be represented by those of band 5. These results empower the differential development of land use dominance in plain or coastal areas in compartment to the mountainous Land.

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2.7. Participation

In a number of cases, the usual classification by using indexes, such us vegetation indeces, is inappropriate due to the internal complexity and co participation in value ranges of the different land uses. The necessity for the use of multi-value logic is imposed by the fact that these land uses have an over-coverage property. The high complexity of the plain and coastal areas in the higher resolution image classification in accordance of the homogenization of land uses politics and the dominance of certain land uses depending on the time period, indicate that the "pocks" of intensive use and high credit tend to cover a larger portion of land (for example urban, tourist or intensive cultivation activities with the parallel depreciation of a part of agricultural areas, etc). In the mountainous land instead, because of the inelasticity toward such changes and the less complex presence of such "cell - pocks", these uses tend to be eliminated.

The participation polynomials of land-uses to the corresponding spectral bands were produced through normalization of their values in each band. Ranges of the participation probabilities to the percentiles of the whole spectrum were also estimated (Fig. 5). A more generalized set of participation rules was produced by the previous one by setting a value of 1 in cases where the criterion coverage of more than 5% per land-use was satisfied.

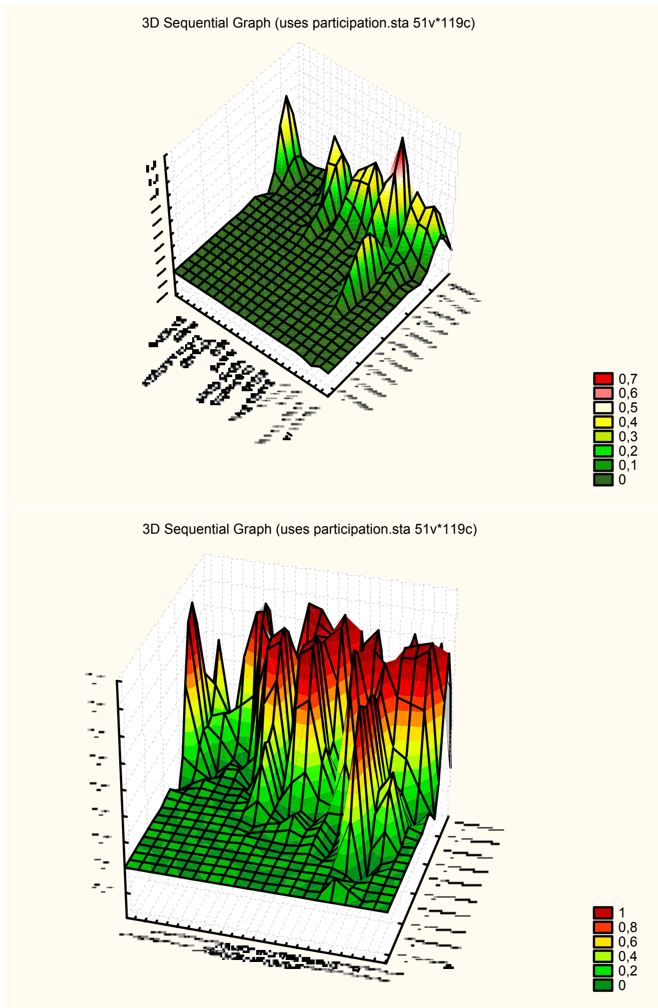

Figure 5. The probabilistic map is shown to the top and the "sharp" participation map is shown to the bottom.

2.8. Coherence

Spatial spectral coherence is based on analyzing the common “firing” or “suppression” of different components in Fourier coefficients. This handling is not biased by the time delays or the spatial framework of the images and it provides information about the trend of the possibility of co-existence and co-evolution of the different land-uses [19].

Figure 6 shows an example of the above procedure for the region of N. Malevizi and E. Temenous, in east Crete. The above map indicates the result of the union of the spectral values per land-use. 2D FFT produced the coherence matrix which indicates the percentage agreement of each Fourier spectral frequency to the land-use, providing a measure of the coherence.

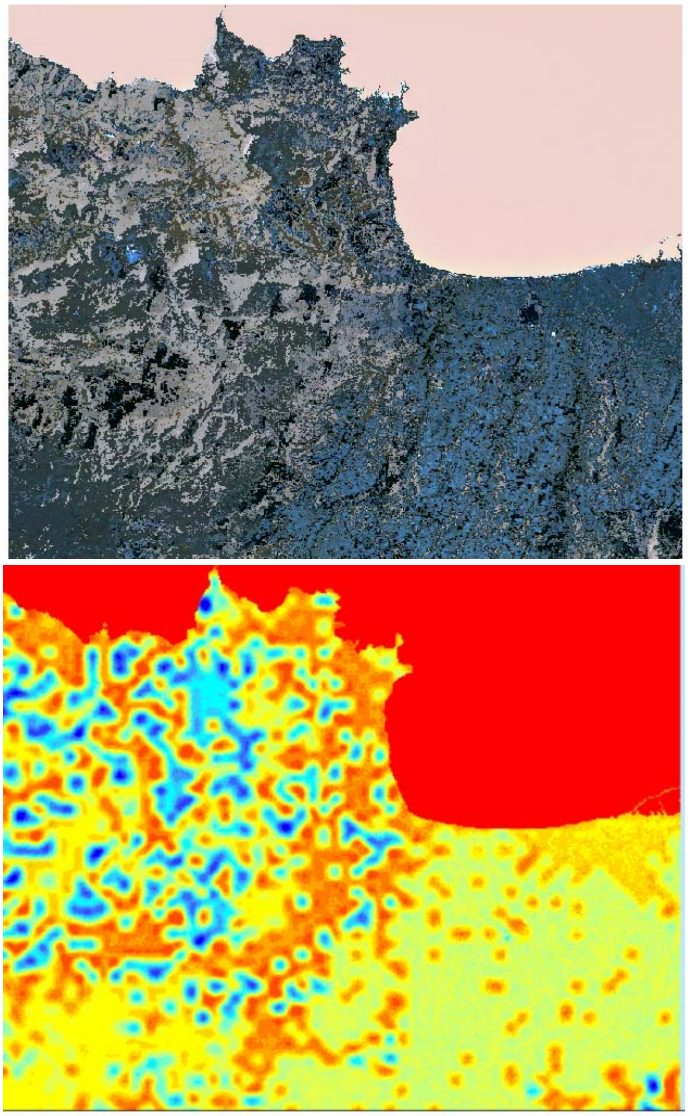

Figure 6. Spatial Spectral Coherence analysis for the area of N. Malevizi and E. Temenous in central Crete. Above is the map of the classification of the union of the spectral values per land-use and below is the result of the spectral coherence.

The results of such analysis indicate the homogeneous, widespread common spectral firing of land uses in plain areas with high complexity and of intensive land activities. The question arisen is which part of the non homogeneous firing of mountainous lands is due to the less linear complexity of pixel population. However, the vast difference of this coherent spectral behavior, in accordance with the usual classification methods and techniques, denotes a differentiating compact development of these two kinds of areas.

3. Results and discussion

3.1. Land use changes

The spectral signature of the urbanized environment also indicates a shift of the population moving from the agricultural mainland towards the more tourist-attractive north (and even south) coast. This trend is well correlated with the decreasing of vegetation cover within the urban and suburban areas. Similar decrease is noticed in the forest and wild flora areas, together with the simultaneous decrease of water reservoirs.

Figure 7 indicates the spectral signatures of the selected land-uses. Temporal variations of the spectral signatures of the land-uses are shown in Fig. 8

Temporal changes show a larger complexity in the low level plains and the urban areas. The changing patterns of land-use seem to have been triggered by political policies, such as the 1988-1994 EE agricultural land-use change directives, which led towards the abandonment of the traditional cultivations (olives and grapes) and the adoption of more complex cultivations.

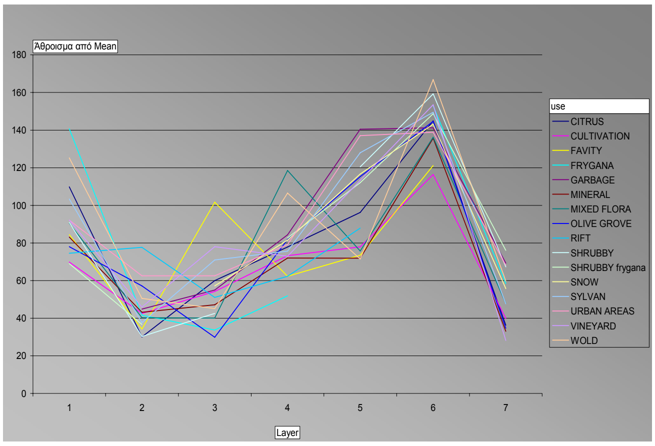

Figure 7. Normalized spectral signatures for the major classes selected.

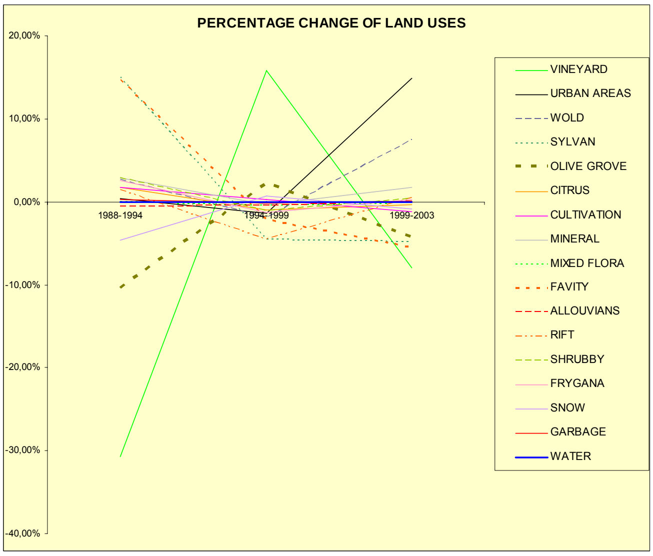

Figure 8. Percentage changes of land-use categories for the period 1988-2003.

Finally, the edges of the homogeneous areas in the plains and in the urban areas become fuzzier in the recent years, in contrast to the corresponding ones at the mountain regions. This is also an index of the environmental and/or anthropogenic pressures imposed in the specific regions.

3.2. Vegetation

The spectral signatures of the habitats resulted by the object oriented classification of the LANDSAT image for the year 1999 is presented in Figure 9. Due to the presence of snow in parts of the habitat of the Oro-mediterranean phrygana, this habitat has been excluded from the spectral signatures diagram.

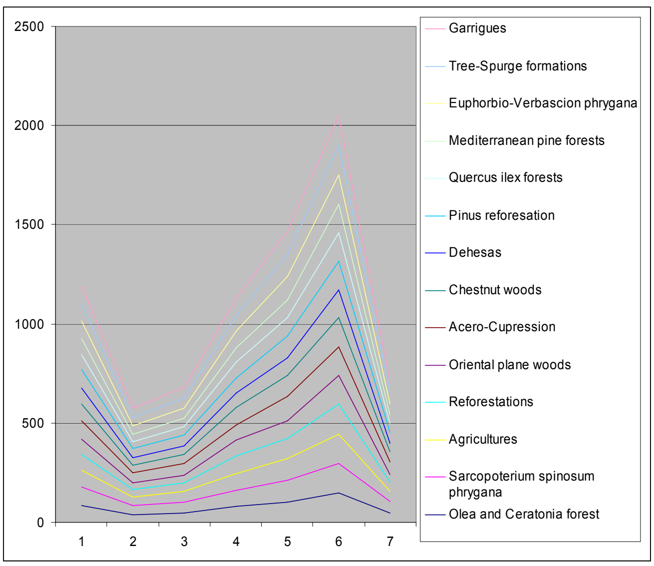

Figure 9. Spectral signatures for the studied habitat types of Crete.

As is obvious regarding Figure 9, the spectral signatures of the habitats follow a very similar pattern and a differentiation of the habitats occurs (based on spectral signatures), giving a reasonable value to the results of the habitat mapping at a mesoscale approach. Nevertheless, taking into consideration our field observations, the habitat patches of the mesoscale approach are not homogenous in nature, as smaller patches of other habitats are included. Therefore, a more fine scale approach is required in order to reach a more detailed mapping and more accurate levels of spectral signature differentiation.

The obtained draft mesoscale map of the habitat patches of Crete is presented in Figure 10 and the relative cover of each habitat in the total area of habitats of the island is presented in Table 2.

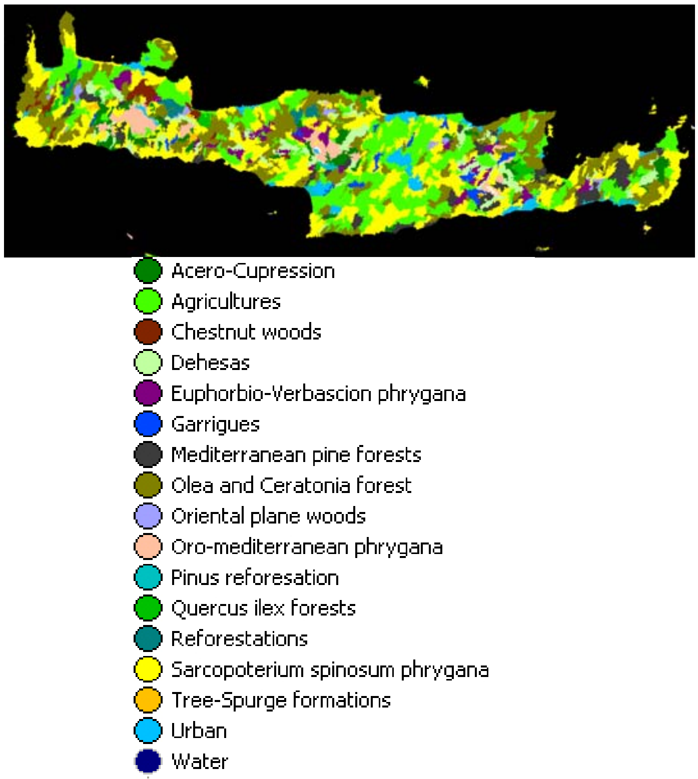

Figure 10. Mesoscale map of the habitat vegetation of Crete

According to the results the dominant habitat type in the area seems to be the *Sarcopoterium spinosum* phrygana, followed by the habitats of Agricultures, *Olea* and *Ceratonia* forests, Dehesas, Mediterranean pine forests, Acero Cupression and Oro-mediterranean phrygana.

The relative cover of each habitat type for the areas of NATURA 2000 of the phytogeographical region of Crete and Karpathos (KK) has been attempted in the past [20]. According to these results *Sarcopoterium spinosum* phrygana are the dominant habitat type of the NATURA 2000 areas followed by the habitats Oro-mediterranean phrygana, Dehesas, *Olea* and *Ceratonia* forests and Mediterranean pine forests.

Comparing the rank order of the relative cover of habitats in both, our results and the results of NATURA 2000, the representation of each habitat type in the NATURA 2000 areas of Crete could be resulted.

More specifically, the *Sarcopoterium spinosum* phrygana seems to be the dominant habitat type in both studies indicating an analogous relative representation of this habitat type in the areas of NATURA 2000, while the Oro-mediterranean phrygana seems to be relatively over represented in the NATURA 2000 areas, compared to their relative participation in the total habitat area of Crete. This over representation could be explained by the spatial distribution of NATURA 2000 areas in the landscape of the phytogeographical region. The high mountain areas of the island, where the Oro-mediterranean phrygana dominate are well represented in the NATURA 2000 system as a result of their high number of endemic species.

Habitat	Area percentage (%)
Olea and Ceratonia forest	20.69
Sarcopoterium spinosum phrygana	27.32
Agricultures	23.69
Cupressus reforestation	1.12
Oriental plane woods	0.80
Acero-Cupression	4.02
Oro-mediterranean phrygana	3.52
Chestnut woods	1.31
Dehesas	5.38
Pinus reforesation	0.81
Quercus ilex forests	1.40
Mediterranean pine forest	4.84
Euphorbio-Verbascion phrygana	3.20
Tree-Spurge formations	0.50
Garrigues	1.40

Table 2. Percentage contribution of each habitat in the island of Crete.

4. Conclusions

Taking into consideration the up to now results of habitat mapping at a mesoscale approach in the island of Crete, it could be concluded that a) a further discriminative analysis is required at a final scale, in order to incorporate the total amount of habitat types of the area, and achieve a better result and b) any over or under representation of habitats in the over all NATURA 2000 area is related to the spatial distribution of those areas in the landscape of the island.

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