AUTOMATIC LAND USE/LAND COVER CLASSIFICATION SYSTEM WITH RULES BASED BOTH ON OBJECTS ATTRIBUTES AND LANDSCAPE INDICATORS

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Commission IV, WG IV/4

KEY WORDS: hybrid classification, landscape pattern analysis, object oriented thematic map, remote sensing high resolution image.

ABSTRACT:

Recently, there is an increasing demand for information on actual land use/land cover (LU/LC) from planning, administration and scientific institutions. Remote sensing combined with GIS tools can give quick reply providing timely information products in different geometric and thematic scales. Anyway the effort to make the land use map by visual interpretation is still very high and cannot keep up with the development pace. On the other side automatic procedures do not assure to follow detailed and well-structured land use nomenclature if it is not performed by a customized learnig system. This new approach is required to incorporate automated image classification to human image understanding.
In this context the here proposed T-MAP application combines segmentation tools with an hybrid classification technique (a rather new trend in image classification) and a rule-based thematic categorization depending on information both at pixel and object level. Its rule-based system lets the user define thematic assignments by building rules based on feature attributes (i.e. membership cover class percentage, confusion index, etc.) and on landscape analysis (spatial metrics and pattern indicators), taking, in this way, also advantage of the human land use understanding. The output is a thematic map characterized by a custom-designed legend and a reasonable performance in terms of accuracy, number of extractable classes and legend detail.

1. INTRODUCTION

The land use map is an useful resource to support the decisions of the city planners, economist, ecologist and for every decision-makers involved in the sustainable development of the territory. The recent availability of remote sensing imagery with high spatial resolution and the land-use thematic characterization performed in automatic way bring to derive spatial dataset with good accuracy. Furthermore recent researches showed the advantages to adopt an object based classification instead of a classical per pixel solution. For this reason we present an application based on an hybrid classification implemented in the object rule based software named T-MAP. The classification is performed on a set of multi-spectral images combined with pseudo bands (filters and textures) to improve the identification of particular patterns (i.e. permanent crops). Following the cover assignment to the polygon entities is realized applying some fuzzy rules based on membership class percentage and spatial metrics to infer more land use categories.
Generally the identification of specific land use classes by remote sensing data is very problematic. In fact some areas are spatially heterogeneous and with similar spectral response (i.e. artificial landscape). The artificial cover consists of several different structures like buildings, roads, gardens or other vegetation areas, which make complex to analyze the urban and suburban landscape. Some studies describe the possibility to use the information coming from the landscape metric analysis to put in evidence some urban land use structures and changes in the urban growth (Herold et al., 2002(a), Herold et al, 2002(b)). In fact the landscape metrics applied to urban segmented areas can help to perform an useful separation between high and low-density residential class.
The landscape metric investigation applies the basic concepts of the conventional visual interpretation that defines the photomorfic regions in term of “homogeneous structures” characterized by similar size, density and spatial pattern. The environmental indicator related to the pattern of the landscape are quantitative indices based on the fractal geometry focused on the structural analysis of patches, defined as homogeneous entities with similar attribute. This quantitative analysis can be adopted to analyze the structural complexity and the fragmentation of the urban environment in contrast to the natural areas. These are good information to apply in a rule based system to describe the urban morphology. However it is necessary to have image with very high spatial resolution, as those coming from the new satellite sensors systems or digital airborne camera (IKONOS, Quickbird, Leica ADS40, and so on).

2. METHODOLOGY

2.1 The landscape structural analysis: an useful tool to analyze the spatial patterns

The landscapes is a mosaic of patches and the structural analysis of the patch cover composition is suitable for a variety of mapping objectives. In literature the field of landscape ecology has provided strong conceptual and theoretical basis for understanding landscape structure, function, and change (Forman and Godron 1986). The landscape ecology involves the study of landscape patterns, the interactions among patches within a landscape mosaic, and how these patterns and interactions change over time (O’Neill et al., 1988). A prerequisite to study the landscape characteristics is the ability to quantify landscape structures. Customized analytical methods were developed in open source environment and linked to commercially GIS with graphics capabilities. The well-known useful tool, for spatial pattern analysis, is FRAGSTATS, a public domain software developed by the Oregon State University (McGarigal et al, 2002). FRAGSTATS offers a comprehensive choice of landscape metrics and works both on vector and raster images. It is also available a modified version distributed in the Patch Analyst package that calculates spatial statistics on shape files and grid files directly in GIS environment (Elkie et al, 1999).

2.2 An overview on the class and patch metrics used in this study

To determine the nature of patches in a landscape it is important to analyze the shape. Shape is a difficult parameter to quantify in good manner in a metric. FRAGSTATS computes two types of shape indices, both based on perimeter-area relations. The Shape Index (SI) measures the complexity of patch shape compared to a circular standard shape and it is minimum for circular patches while it increases when the patches become more and more noncircular. The index can be applied also at class level: Mean Shape Index (MSI) measures the average patch shape, or the average perimeter-to-area ratio, for all the patches in each class type, while the Area-Weighted Mean Shape Index (AWMSI) weights the patches according to their size. The degree of complexity of a polygon is characterized by the Fractal Dimension (FD) such that the perimeter of a patch is related to the area of the same patch (McGarigal et al, 1995). As the perimeter increases the polygons become more complex. The value of the fractal dimension depends on the patch size or the units used, or both. At the same manner we can also compute an Area-Weighted Mean Patch Fractal Dimension (AWMPFD) at the class level by weighting patches according to their size.

At class level Patch Density (PD) is a fundamental aspect of landscape structure in relation with the number of patches, facilitating comparisons among classes of various type. The PD could serve as a good fragmentation index; then a class with a greater density of patches could be considered more fragmented than a class with a lower density of patches, maintaining the same class area. Also the Mean Perimeter Area Ratio (MPAR) index, that is the sum of each patch perimeter/area ratio divided by number of patches, shows the fragmentation of the class when it assumes high values. Patch Size Standard Deviation (PSSD) is a measure of absolute variation; it gives information about patch size variability, in relation with Mean Patch Size (MPS).

Furthermore there are several edge statistics representing landscape configuration. Edge Density (ED) facilitates the comparisons among landscapes of various sizes. This index is affected by the resolution of the image. Generally, at coarse resolutions the edges can be straight lines, on the contrary, at finer resolutions, the edges may appear as highly convoluted lines and they have the greatest edge length.

The choice of the resolution it is a very important factor. The technical capabilities of the GIS instruments and the high resolution of images suggest to choose a finer Minimum Mapping Unit (MMU) that specify the minimum patch size to be represented in a landscape. The information at several scales can improve the complex representations of the landscape and to help to perform accurate analysis, but at the same time the landscape metrics are qualitative and quantitative sensitive to changes in scale (Turner et al. 1989).

2.3 Interaction among patches within a landscape can be useful to discover detailed cover classes

Some metrics previously described are more interesting if referred to the class level. In fact at this level they help to understand the different characteristics of the covers, their homogeneity or their excessive fragmentation. But if it is necessary to distinguish in detail certain classes, the study must go in deep analyzing the single patch characteristics. In this case it is better to have an object based classification instead of a grid solutions, because the size of the polygons and their shape complexity can allow to make better a distinction inside each cover class. The comparison between some patch indices related to built up structures can generates a series of rules to characterize different artificial land use classes. Analyzing the size of the patches or the density, it is possible to distinguish the commercial from the urban cover, or to identify the dense urban environment from the sparse one.

In our research we produced an object based thematic characterization by means of an hybrid classification directly in a GIS environment. Setting different Minimum Mapping Unit (MMU) of segmentation and combining different spatial metrics and other parameters, it was possible to develop a rule system to map in detail land cover classes.

3. TEST SITE

The data used in this study are high resolution multi-spectral Leica ADS40 strips (ground resolution 1 meters) acquired on July, 2007 and related to a south-eastern part of the Ancona Province in Italy. They cover an area of approximately 16 km2, comprising urban and rural landscape and natural Mediterranean environment, which includes the Natural Park of the Conero Mountain (Figure 1).

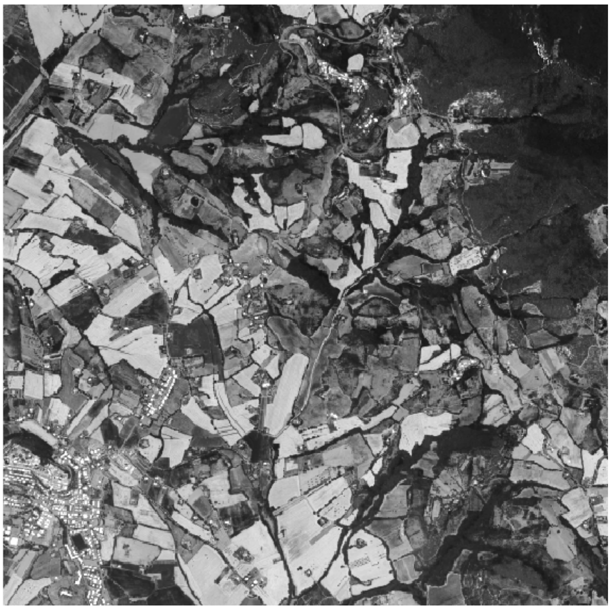

Figure 1. The test area

4. DATA PROCESSING AND RESULTS

The fractal analysis it was performed in grid and in vector format, first of all at class level and successively at patch level.

4.1 Structural analysis at class level applied to a per pixel classification.

The first application of the landscape metrics at class level was performed on the grid coming from a per pixel texture augmented classification (Figure 2). In fact to augment the information related to some agricultural covers (i.e., arable lands and permanent crops) we added to the original bands texture features generated by different filters. The set of feature bands was used by an AdaBoost classifier algorithm (Zingaretti et al., 2009, Frontoni et al, 2009).

To perform the landscape structural analysis we clumped the pixel of the grid by means the solution at 8 neighbours. Analyzing in detail the different cover classes the metrics which put the accent on the characteristics of the clusters and on the data distribution inside the landscape are the Number of Patches (NUMP) and Area Weighted Mean Patch Fractal Dimension (AWMPFD). In fact for the class “urban fabric” we have an high number of patches which indicate an high number of sparse cells of this class (NUMP=13795), on the contrary a low value (NUMP=5444) represents the homogeneous agricultural cover. Furthermore the presence of classes with few and sparse pixels suggest the inclusion in similar classes, because they will be not a dominant class in the successive hybrid classification.

The shape complexity is confirmed by the AWMPFD, that for the urban class is higher (AWMPFD=132) than the other vegetation covers (AWMPFD=123). Also the Patch Density (PD, number/100 ha), at class level, can allow to distinguish the artificial presence from the other ones because the high value shows the fragmentation: “urban fabric” PD=822, “arable land” PD=324.

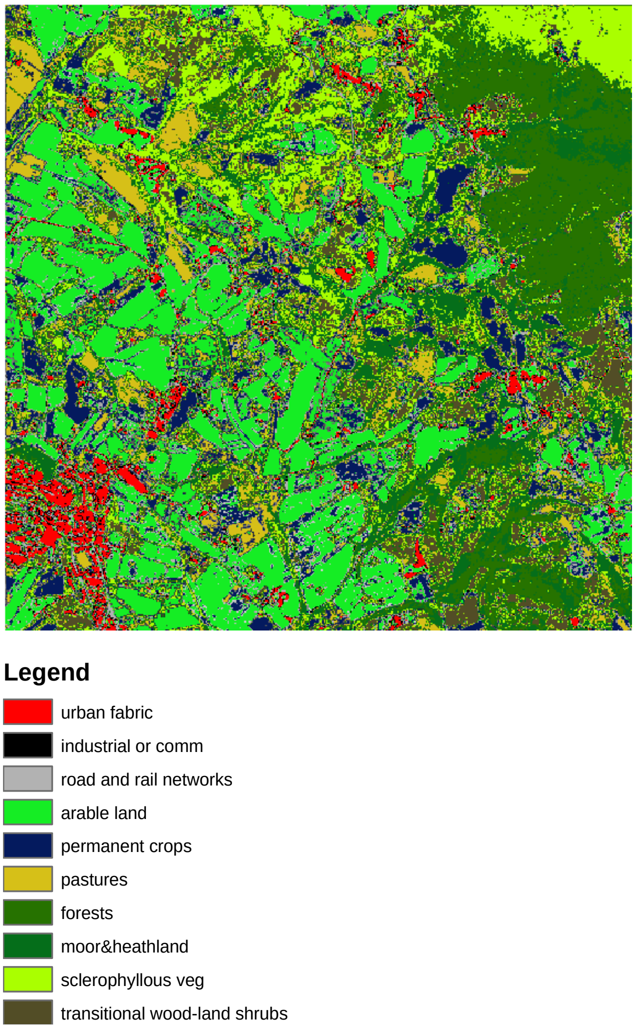

Figure 2. The per pixel AdaBoost classification

4.2 Structural analysis at class level applied to an hybrid classification.

The second stage of this structural analysis was performed on an hybrid classification based on object segmentation which assigns the dominant class inside each polygon (Tassetti et al., 2010). In the software T-MAP we developed a segmentation tool, based on an approach that combines edge-detection with region-growing techniques (RGED algorithm). In order to verify the landscape pattern analysis at different resolutions three segmentations are carried-out with different MMU (2.89 ha, 0.36 ha, 0.03 ha) (Figures 3, 4, 5).

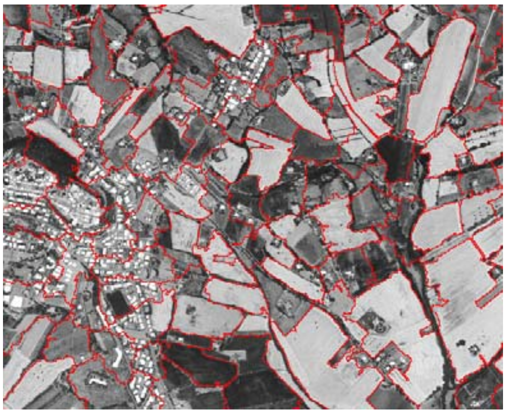

Figure 3. The segmentation with MMU 2.89 ha

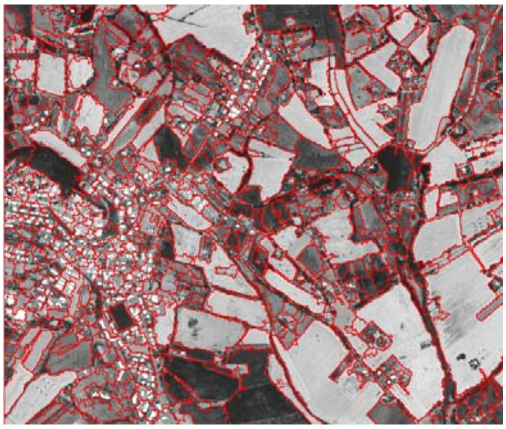

Figure 4. The segmentation with MMU 0.36 ha

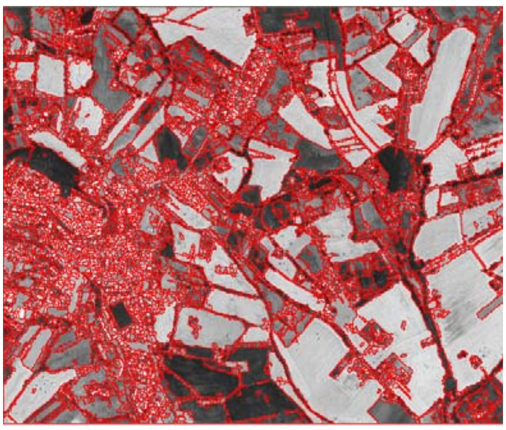

Figure 5. The segmentation with MMU 0.03 ha

We obtain an accurate and precise segmentation, which extracts a set of meaningful objects, such as regions with closed contours (polygons), useful for thematic mapping. This last phase was performed by means of a customized Winner Takes All (WTA) approach which uses the dominant class percentage to assign the land cover attribute (Figure 6).

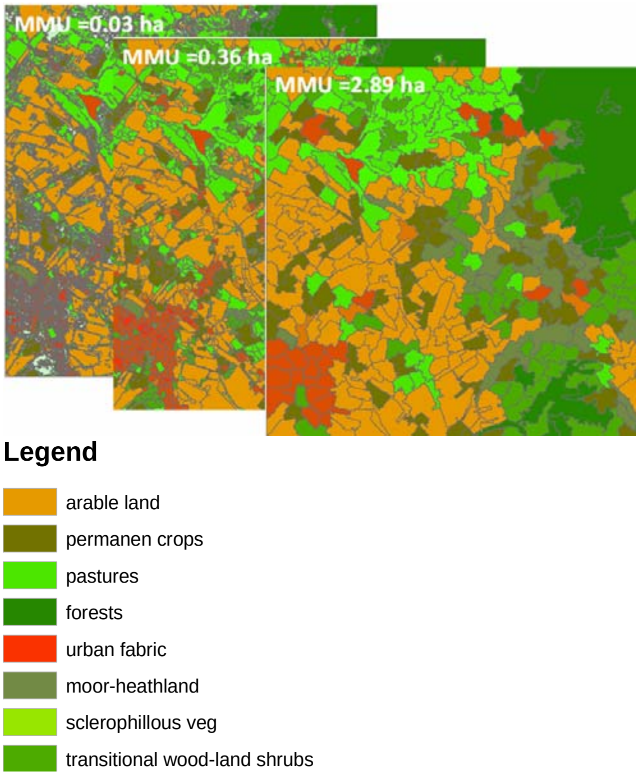

Figure 6. The hybrid classification applied to different MMU segmentations

The choice of a correct resolutions improves the measure of the metrics because the structures of the patches are often determined by the characteristics of natural or manmade features present in the landscape (Table 1).

Urban fabric	*MPAR (m/ha)*	*MPS (ha)*	*PSSD (ha)*	*AWMSI*
MMU 0.03 ha	3490.38	0.03	0.07	1.64
MMU 0.36 ha	1217.61	0.38	0.11	1.94
MMU 2.89 ha	399.81	3.85	0.85	2.16
Arable land	*MPAR (m/ha)*	*MPS (ha)*	*PSSD (ha)*	*AWMSI*
MMU 0.03 ha	2986.78	0.26	0.97	2.28
MMU 0.36 ha	930.84	1.29	1.89	2.17
MMU 2.89 ha	417.20	4.44	2.31	2.36

Table 1. Landscape metrics comparison between natural and manmade features

Analyzing some parameters it is evident as the selected MMU is quite similar to the Mean Patch Size (MPS) of the urban patch resulting in this manner suitable for a detailed urban analysis. Furthermore the fragmentation is underlined by high values of MPAR and low values of PSSD. For the arable land the parameters underline the presence of areas more homogeneous.

4.3 Structural analysis at patch level applied to an hybrid classification.

The importance of the segmentation process is showed at patch level. In fact, the RGED algorithm gives a series of specific spectral and spatial parameter related to the shape of each polygon. Some of them are: the *compactness* which gives information related to a particular form of the region; the *convexity* which gives indications about the correctness of the contours, because it compares the perimeter of the region with that of the convex hull; the *solidity* which gives information about the regularity of the shape as the *roundness*; last but not least also the *form-factor*, which is conceptual similar to the Shape Index (SI) and it is good to verify the congruence with the attribute assignment to the object. These parameters compared with the landscape metrics demonstrated which are also useful information to analyze the spatial characteristics of a cover.
The objective of this work was the separation between different artificial land use classes on the basis of the spatial structure. The high density residential areas consist on in single family residences with neighborhood gardens and regular street pattern. The low density residential cover has large structures surrounded by extensive vegetated areas, which presents single parcels not spatially aggregated and independent patches.
Consequently our analysis was focused on the different dimensions of urban land-use structure and the fragmentation of each built-up patch (Figure 7).

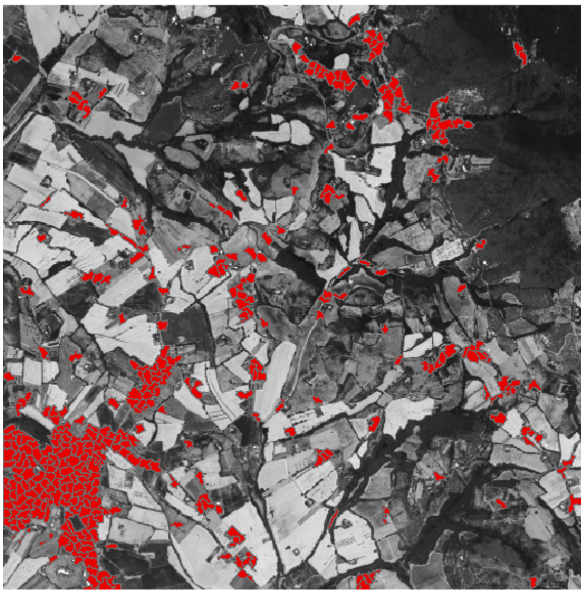

Figure 7. The distribution of the artificial areas in the test site

The urban fabric class, related to the segmentation with MMU 0.36 ha presents the lowest Mean Shape Index value (MSI=1.94) and on the contrary the highest Mean Perimeter Area Ratio (MPAR=1217). These are good indications to begin a detailed study to distinguish sub classes inside this land cover.
The first analysis compares the Shape Index (SI) values for each polygon coming from Patch Analyst and the Form-Factor index obtained by the segmentation process in T-MAP. In every case both are suitable to put in evidence patch with different characteristics which could be associated to different cover areas: urban and suburban. Moreover they give spatially the distribution of these structures in the landscape (Figures 8, 9).

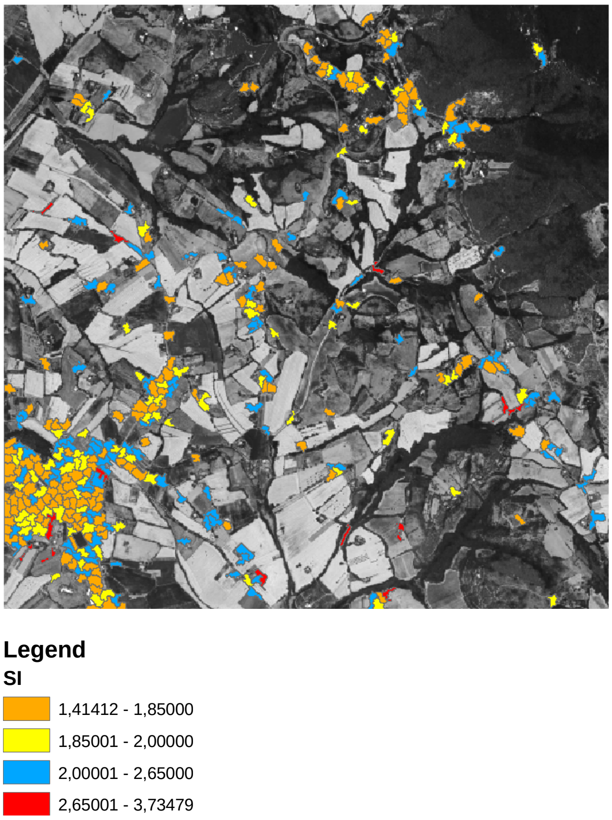

Figure 8. The importance of the shape index (SI) to differentiate the urban and suburban areas

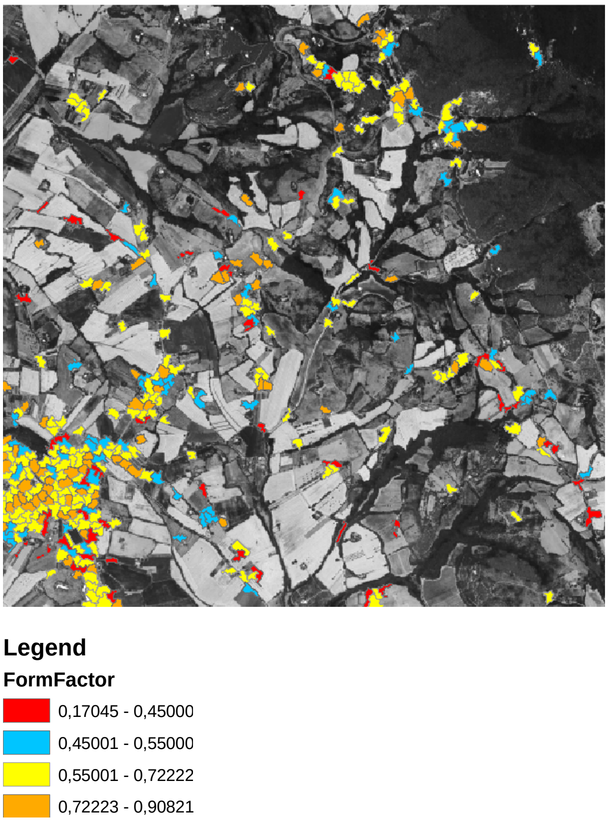

Figure 9. The importance of the Form-factor index coming from T-MAP segmentation to differentiate the urban and suburban areas

4.4 Rules based system to define a detailed land cover map.

The process to assign detailed cover classes depending on complex patterns requires necessarily a new learning system. It combines additional spatial and contextual attributes related to the object with the presence percentage of cover classes inside it. Moreover the rule-based classification performance is strongly related to the segments' quality and the consequently MMU selected. The experimental results show that the developed approach fits to extract relevant classes previously ignored.

In particular the aim of this phase was to establish different rules to recognize heterogeneous agricultural areas and to differentiate the urban fabric class according to its density in continuous and discontinuous urban fabric. These areas are difficult to classify especially because they forecast the concurrent presence of different cover signatures.

In dense urban areas, the land cover class confusion is low. The continuous urban fabric class is assigned when urban structures and roads occupy more than 80 % of the surface area. Misunderstandings can arise only in case of bare soil with similar spectral responses, but they can be limited by checking the patch dimensions: the segmentation procedure over urban fabrics gives in fact only small regions.

The discrimination between continuous and discontinuous urban fabric is performed computing houses' and roads' area percentages and setting a threshold (between 40 % and 80 %) to underline a green areas' presence. At the same time to complete the rules we take into account the structural measures calculated at the previously stage.

After the production of the LC/LU thematic map (Figure 10) we calculated for each new class the landscape parameters shown in Table 2, whose values confirm the correct thematic assignment.

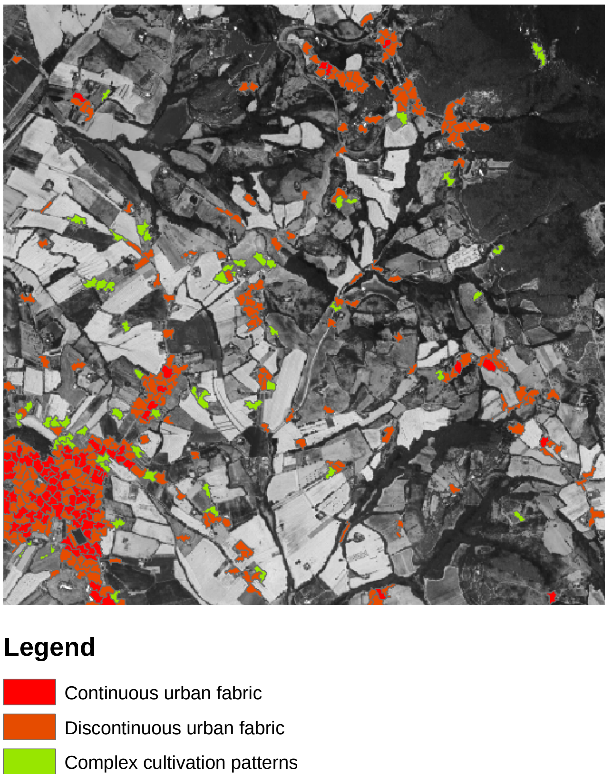

Fig. 10. The artificial areas in the detailed Land Use Map

	MSI	*MPAR*	*NUMP*
Continuous urban fabric	1.84	1431	83
Discontinuous urban fabric	1.96	1149	217
Complex cultivation patterns	2.03	1183	54

Table 2. Landscape metrics for the detailed artificial areas

CONCLUSIONS

This approach performed on an object based segmentation is better than other type of spatial structure investigation as the filter based on quadratic kernel and only per pixel data, because provided the best thematic characterization on irregular areas.
The variables that play an important part in this investigation are: the domination of a land cover class, the density of the built up and the spatial texture, the spatial aggregation, the scale of the images and the MMU selected.
In order to improve the detail of the land cover classification the spatial metrics seems to be and appropriate way to describe better the urban landscape in combination with new classification methodology.

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