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Relationships between morphological units and vegetation categories of Soratte Mount (Italy) as inferred by processing elevation and MIVIS hyperspectral data

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ABSTRACT: The relationships between vegetation typologies and morpho-units have been investigated to determine the percentage occurrence of land cover types within detected landform classes. The land cover map has been obtained by applying a standard parametric supervised classification procedure to VIS-NIR bands of the airborne MIVIS data collected over the Soratte Mount (central Italy) site. The morphometric data, set up by processing a DEM (Digital Elevation Model) as elevation differences between every pixel and its eight neighbours, have been analyzed by means of a new geomorphometric quantitative analysis, based on ISODATA classification method, thus permitting the definition of homogeneous morphometric classes of the study area. The results of the two classifications have been then compared by using a correspondence analysis method; by this way, peculiar tables have been set up, facilitating the interpretation of the interrelationships between the two data sets.

1 INTRODUCTION

Two classification procedures categories have been applied to a medium-high relief area of the Italian Latium region, 40 Km north of Rome. The selected area, the Soratte Mount, is a natural reserve of Rome Province interest, where mainly carbonate outcrops and peculiar vegetation covers are present, reaching elevations as high as almost 700 m.

The study attempts at defining mutual relationships between plant categories and landform types, highlighting peculiar morphological characteristics of detected land cover categories.

The vegetation typologies have been derived by applying the *ML* (Maximum Likelihood) method to the first 28 of 102 hyperspectral channels of the airborne *MIVIS* (Multispectral Infrared Visible Imaging System, Bianchi et al., 1994) data collected within an extensive survey campaign over the Rome Province. The MIVIS spectral characteristics are summarized in the table shown beside.

Spectrometer	Spectral region	Bands Number	Spectral Range (µm)	Band width (µm)
I	Visible	20	0.43-0.83	0.02
II	Near Infrared	8	1.15-1.55	0.05
III	Medium Infrared	64	2.0-2.5	0.009
IV	Thermal Infrared	10	8.2-12.7	0.34-0.54

The morphometric data have been instead gathered from a raster DEM created by interpolating topographic map isolines. These data have been processed through a new geomorphometric method (Adedirian et al., submitted; Negroni et al., 2000; Parcharidis et al., 2001) based on the statistical multivariate investigation of local topographic gradients, calculated along the 8 directions of each pixel neighbourhood. This approach allows to quickly estimate the spatial distribution of different types of slope steepness and, in the meanwhile, emphasizes the impact of erosional and tectonic processes on the overall relief.

2 MOUNT SORATTE NATURAL RESERVE

The natural reserve of Soratte Mount**,** located to the North of Rome, covers a territory of 410 *ha* including most of the homonymous carbonate ridge. It exhibits NNW-SSE orientation with a peculiar elliptic shape and reaches a summit of 692 m a.s.l., steeply raising above the neighbouring landscape. This mountain is mainly made up of Mesozoic limestone rocks, emplaced during the Apennines orogenesis (Miocene) and later affected by extensive faulting, related to the Tyrrhenian Sea's opening (dated to the Upper Miocene). These geomorphological characteristics strongly influence the spatial distribution and differentiation of vegetation, well diversifying from those of the neighbouring areas.

In the NE side of Soratte Mount deciduous and evergreen sclerophyll woods prevail, while in its SW side, where thermophilic conditions markedly occur, there are mainly shrubs and woodlands with sclerophylls prevalence, somehow similar to the Mediterranean scrub, even though with its own characteristics. Where dryness conditions take place and the rocky substratum crops out, grassy prairies and garigues, suitable for more extreme environments, predominate. At the foot of the mountain, the lower slant of slopes and a more developed soil favour the occurrence of deciduous oak-tree woods.

3 DATA PROCESSING

3.1 *Mivis Data Processing*

The hyperspectral MIVIS data were collected during an airborne campaign carried out on June 20 1998 at an absolute altitude of 1500 m a.s.l.; the variability of the underlying morphology led to a 1.6 to 2.7 m range of pixel ground resolution. Recorded data were radiometrically calibrated to radiance and brightness temperatures and geometrically corrected at the CNR ground station seated in Pomezia (Rome, Italy). An existing DEM and other ancillary digital data were employed for a correct production of thematic maps; the DEM, an ESA-ESRIN's courtesy, was obtained by means of SAR interferometric techniques. For the geometric correction re-sampling tables, set up by integrating airplane's position and attitude data recorded by MIVIS position and attitude system sensors, were used.

MIVIS corrected data were employed as input to the image processing step, based on a mixed procedure of photo-interpretation and supervised classification. The photo-interpretation was supported and integrated by *FCC* (False Colour Composite) of the following two MIVIS band triplets:
(i)Ch.13 ($0,6\mu m<\lambda<0.69\mu m$), Ch.7 ($0.53\mu m<\lambda<0.57\mu m$),Ch.1 ($0.43\mu m<\lambda<0.45\mu m$); (ii) Ch.19 ($0.79\mu m<\lambda<0.81\mu m$), Ch. 28 ($1.50\mu m<\lambda<1.55\mu m$), Ch.13 ($0.67\mu m<\lambda<0.69\mu m$); and by separate visualization of Ch. 28 ($1.50\mu m<\lambda<1.55\mu m$) and Ch. 93 ($8.21\mu m<\lambda<8.56\mu m$).

The FCC (False Colour Composite) of MIVIS bands 13, 7 and 1 reflects the higher absorption bands on Red and Blue shades and the major reflectivity peak of Green in vegetation: this hue mixture better approaches the natural colour representation. Bands 19, 28 and 13, included in the second FCC, correspond instead respectively to the maximum reflectance plateau in the Near-Infrared, the H_2O absorption peak and chlorophyll peak; hence, this FCC highlights vegetation covers, discriminating between agricultural cultivations and spontaneous vegetation. The single bands 28 and 93 allow to emphasize covers less discernible, i.e. bare soils, vegetation sparse or in relative dryness conditions.

The following land use classes were identified and their boundaries outlined: *natural environments* (woods, brushwoods, prairies, rock outcrops); *agricultural lands* (seeded lands, olive-trees, orchards); *urban areas* (built-up centres, buildings); *quarries* and *water bodies.*

The study area appears mostly characterized by agricultural land use patches with evident occurrence of olive-trees; however, large territories exhibit relatively intact natural environment where high tree woods are associated with re-naturalization areas. On the basis of this land use classes partitioning, only areas defined as "*natural environments*" were taken into account in the next processing by applying appropriate masking procedures.

Moreover, naturalists of Rome Province Administration performed surveys *in situ*, to define the interpretation keys and the flower associations of botanic interest. The results of these surveys were compared and integrated with information extracted from the pre-existing "Vegetation Map of Soratte Mount" (Abbate et al., 1981).

By considering all gathered data, many spectrally uniform areas were delimited so defining an exhaustive number of *ROI* (Regions of Interest) that were used as input data to the *ML* (Maximum Likelihood) supervised classification method. This procedure was applied only to the first MIVIS 28 bands and to the Thermal-Infrared channel 93, being the third spectrometer ($2.0\ \mu m$ to $2.5\ \mu m$) not completely significant for the classification of green vegetation.

The list of the botanic and land use classes as located in Soratte Mount area are reported here below (Fig. 1):

1. Mixed woods of deciduous trees and evergreen sclerophylls with predominance of *Quercus ilex*;
2. Mixed woods of deciduous trees and evergreen sclerophylls (*Quercus ilex, Ostrya carpinifolia, Fraxinus ornus, Acer monspessulanum*);

3. Brushwoods with prevailing Mediterranean sclerophylls (*Broadleaf Phillyrea, Quercus ilex, Acer monspessulanum, Pistacia terebinthus*);
4. Deciduous broadleaf woods with clear predominance of *Quercus cerris*;
5. Deciduous broadleaf woods with prevailing presence of *Quercus cerris*, and subordinately *Quercus frainetto, Carpinus orientalis, Fraxinus ornus, Acer campestre, Ostrya carpinifolia, Cornus mas, Ligustrum vulgaris*;
6. *Ostrya carpinifolia* communities;
7. *Carpinus orientalis* communities;
8. *Spartium junceum* shrubs (subordinate presence of *Helychrysum italicum, Pistacia terebinthus*);
9. Grassy vegetation in non arid environments (*Solanum nigrum, Chenopodium album, Pteridium aquilinum*);
10. Graminaceous and camephytes garigues (*Helychrysum italicum, Dactylis glomerata, Dasypyrum villosum, Spartium junceum*);
11. Grassy vegetation in arid environments with clusters of *Euphorbia characias* and *Helicrysum italicum*;
12. Prevailing rock outcrops with reduced and/or absent vegetation;
13. Seeded lands;
14. Agricultural wooden plants (olive groves, vineyards, orchards);
15. Urban areas (build-up centres, buildings)
16. Quarries

All identified classes, both land use and of botanic interest ones, were then assembled into a unique thematic map at 1:10,000 scale.

SORATTE MOUNT NATURAL RESERVE

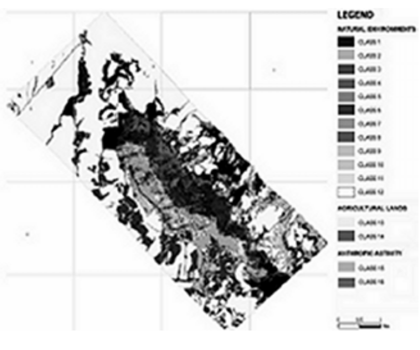

Figure 1. Thematic map of Soratte Mount as derived by processing airborne spectrometer data (16 land use classes displayed with a BW class shading)

3.2 *Dem Data Processing*

A new quantitative geomorphometric procedure, based on a multi-band classification technique to local geomorphic gradients, has been applied to a DEM covering the study area and provided by the Rome Province administration by digitising topographic sheets. The proposed analysis process permits to define areas characterized by similar local geomorphological setting and to illustrate the relationships between relief and geo-structural scenario (Adediran et al., submitted; Negroni et al., 2000; Parcharidis et al., 2001).

Geomorphometry (Nogami, 1995; Pike, 1995), in general, can be considered as a bridge between the results of the studies based on field analysis and the physical modelling of geomorphic processes: it allows to define a measure of the landscape shape. Quantitative geomorphology represents an helpful tool to investigate the imprint of the balance between rock formations emplacement and the subsequent erosion and sculpturing processes of the topographic surface.

In geomorphometry the digital representation of the elevation setting of a given region (DEM) is usually processed to obtain the so-called *Spatial Models* (Onorati and Poscolieri, 1988; Onorati et al., 1992; Poscolieri et al., 1996), such as *slope*, *aspect*, *shaded relief*, the first being a measure of the sloping angle module, the second a measure of the slope azimuth direction with respect to North, and the third a simulation of the lighting conditions of a landscape under different light source positions above the horizon, useful for correcting the topographic effects onto remotely sensed images. The applied approach follows the methods of unsupervised classification of multispectral bands images and, somehow, the spectrum shape analysis, if for each raster DEM's pixel the 8 neighbourhood cells values are considered as following a trend resembling that of contiguous spectral bands. Thus, a geomorphometric map, showing the spatial distribution of peculiar physiographic units, is obtained and corresponding geomorphologic setting are being estimated with respect to vegetation distribution. As regards of Soratte Mount area, the DEM under study has been geocoded taking into account the WGS84 ellipsoid and achieving a pixel resolution of about 20 m in x and in *y* coordinates.

For quantitatively defining the geomorphologic characteristics, the topographic gradient of each pixel of this DEM along the 8 main azimuth directions has been checked up: starting from the NW corner and moving clockwise, elevation differences between the central pixel and every neighbour have been processed.

NW		N		NE
	-1	0	0	
W	0	1	0	E
	0	0	0	
SW		S		SE

The eight resulting values characterize, on the whole for any pixel, local topographic variations that reveal changes in shape, orientation and steepness, and explode from one to eight layers the possible input data set for the application of multispectral classification techniques: in this case an unsupervised cluster analysis technique, such as ISODATA, has been applied. It is a flexible, iterative partitioning method used extensively in engineering (Hall and Khanna, 1977) and based upon estimating some reasonable assignment of the pixel vectors into candidate and then moving them from one cluster to another in such a way that the sum of squared error (SSE) measure of the preceding section is reduced. ISODATA stands for “Iterative Self-Organizing Data Analysis Technique” and “Self-Organizing” refers to the way in which it locates the clusters that are inherent in the data. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. The ISODATA utility repeats the clustering of the image until either a maximum number of iterations has been performed, or a maximum percentage of unchanged pixels has been reached between two iterations. The output of the classification is presented as a digital thematic map showing the spatial distribution of the class membership across the study area, where each class exhibits similar geomorphological setting. For the Soratte Mount the following parameters have been chosen: a number of 10 classes, a change threshold percent of 95 and a maximum iterations number of 8. The resulting classification map has been presented attributing a given shading (figs. 2 and 2a) to each class to facilitate the interpretation. So to compute mean and st.dev. of the eight layers, represented by the elevation differences with respect to central pixel, the classes have been statistically analyzed. For a correct morphostructural interpretation of the classification results and for verifying the accurateness of the classified map statistical information, slope and aspect maps of the Soratte Mount area have been taken out from the same DEM. From each derived data set main statistical values, relatively to all ten ISODATA classes, have been processed and then compared with the statistics earlier obtained directly

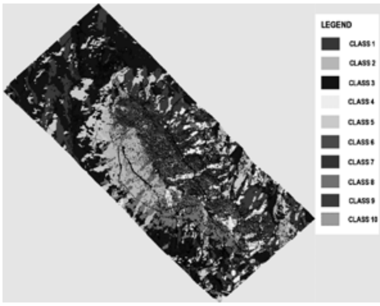

Figure 2. ISODATA classification map with the 10 geomorphometric classes displayed with a BW class shading

Figure 2a. 3D representation of the map shown in fig. 2

from the classified thematic layer. The mean statistics of the derived data have been compared with the corresponding class on the classified map (see table 1).

4 CORRELATION BETWEEN THE LAND COVER TYPES AND THE MORPHOLOGICAL UNITS

The spatial distribution of the different ISODATA classes and their correlation to the local land cover types have been examined and equally presented in the tables 1 and 2.

Table 1. Mean geomorphometric parameters of the ISODATA morphometric classes

ISODATA CLASSES	ELEVATION (mean values)	SLOPE (mean values)	ASPECT (mean values)
1	357.5m	29.3°	51.9°
2	320.9m	20.4°	255.7°
3	187.6m	3.0°	216.9°
4	247.5m	18.8°	112.5°
5	185.4m	7.8°	271.8°
6	293.5m	24.5°	246.6°
7	246.2m	15.9°	47.4°
8	314.8m	16.0°	195.8°
9	181.4m	5.9°	72.9°
10	379.8m	30.0°	45.8°

The classification differentiated features based on elevation, aspect and slope and class centroid means of these component terrain derivatives have been further analyzed to study similarities and differences between classes. For example class 6, with mean elevation value of 293.5 m a.s.l. and a mean slope of 24.5°, is higher and steeper than class 9 with a gently slope of 5.9° and a relatively lower mean elevation of about 181.4 m a.s.l.

Table 2. Correlation between the geomorphometric units and the relatively prevailing land cover types

GEOMORPHOMETRIC UNITS INTERPRETATION	LAND COVER TYPES
1. Steeply sloping areas facing NE-E	*Ostrya carpinifolia* (6)+*Quercus ilex* (1)
2. Averagely sloping areas facing W-SW	Grassy vegetation in arid environments (11)
3. Gently sloping areas facing S-SW	Agricultural wooden plants (14)+quarries (16)
4. Averagely sloping areas facing E-SE	Prevailing rock outcrops with reduced vegetation (12)
5. Gently sloping areas facing W	Brushwoods with prevailing Mediterranean sclerophylls (3)
6. Steeply sloping aeas facing W-SW	Carpinus orientalis communities (7)
7. Averagely sloping areas facing NE	Mixed woods of deciduous trees and evergreen sclerophylls (2)
8. Averagely sloping areas facing S-SW	Seeded lands (13)+Quarries (16)
9. Gently sloping areas facing E-NE	Agricultural wooden plants (14)+Garigues (10)
10. Steeply sloping areas facing NE	*Ostrya carpinifolia* communities (6)

In order to obtain this relationship between geomorphometric units and land cover types, a correspondence analysis was first performed as presented below in tables 3 and 4.

The analysis reveals the following findings in terms of association between the land cover types and geomorphometric units. A preliminary correspondence table (cross-tabulation) has been calculated, showing the number of cases, otherwise known as pixels in this study, for each class as obtained from both the geomorphometric and land cover maps. The land cover map shows 16 classes while the other one exhibits 10 classes. Next, the relative percentile distribution of each land cover type in relation to geomorphometric units has been computed (see table 3). The table examines the relative change in land cover types abundance as a function of geomorphology. It has been created after a linear transformation of the correspondence table according a standard scale, where the statistical bias was eliminated. Standardization is necessary because it makes possible to significantly compare the original values, since the morphological units are not evenly represented, also observations are often standardized from symmetric distributions to express them in common scale. Afterwards, in order to calculate the distribution of each land cover type within the morpho-units, the number of representative cases of each land cover type has been divided by its total. This turned out in a new cross-tabulation showing the distribution of the land cover types within the geomorphometric units (see table 4).

So, it was possible to depict the variation of the distribution of the land cover types within the morpho-units by two variables: the former being the change in land cover type due to geomorphology and the latter the size of the geomorphometric unit. In order to describe the relative change in land cover abundance as a single function of geomorphology, the effect of the variations in geomorphometric unit size has been eliminated by means of standardization. In this procedure the calculated percentages of land cover types have been divided by their corresponding morpho-unit fraction area. This relationship between the two variables has been investigated: thus, it is evident from table 3 that class 14 (*agricultural wooden plants*) is the prevailing land cover type in the morpho-units; moreover, *deciduous broadleaf woods with predominance of* ***Quercus cerris*** (class 5) and *mixed woods of deciduous trees and evergreen sclerophylls with predominance of* ***Quercus ilex*** (class 1) are also abundant in the geomorphometric units.

5 CONCLUSIONS

The unsupervised classification of a multilayer data set extracted from a DEM has allowed the automated definition of geomorphic units within the natural reserve of Soratte Mount. The application of the applied geomorphometric method for the evaluation of analogous morphological units has assisted in highlighting the spatial distribution of geomorphologic features and their degree of intensity.

Table 3. Relative distribution of each land cover types in relation to geomorphometric units

GEOMORPHOMETRIC UNITS / LAND COVER TYPES	CL.1	CL.2	CL.3	CL.4	CL.5	CL.6	CL.7	CL.8	CL.9	CL.10	TOTAL
CLASS 1	.476466	.065457	.027222	.148299	.021516	.251760	.151761	.032875	.023567	.508785	1,707708
CLASS 2	.199333	.003846	.000760	.011898	.002100	.147269	.092384	.000151	.001973	.198946	0,658660
CLASS 3	.033116	.207877	.013791	.084773	.008538	.030563	.010337	.097348	.011713	.039184	0,537240
CLASS 4	.001812	.000427	.002618	.003736	.017329	.018295	.011995	.000055	.005037	.001757	0,063061
CLASS 5	.064611	.088064	.078870	.144196	.104217	.218743	.098005	.031804	.091299	.058634	0,978443
CLASS 6	.013412	.000000	.000000	.000130	.000000	.002134	.003548	.000000	.000000	.014709	0,033933
CLASS 7	.019736	.009256	.009352	.007644	.011157	.069181	.022746	.001620	.006165	.016998	0,173855
CLASS 8	.002511	.020526	.003353	.006672	.002087	.002400	.007833	.008675	.005310	.002288	0,061655
CLASS 9	.075830	.037126	.038316	.112152	.061437	.116759	.134236	.029883	.062457	.060309	0,728505
CLASS 10	.000985	.053007	.005372	.004319	.001784	.000320	.002887	.027055	.003382	.000490	0,099601
CLASS 11	.016971	.042468	.013596	.078252	.018632	.020909	.047781	.095715	.020766	.012993	0,368083
CLASS 12	.007532	.032492	.006891	.035239	.008437	.006347	.017509	.081865	.007477	.009357	0,213146
CLASS 13	.027491	.270872	.699626	.270859	.678886	.073074	.260379	.254338	.708181	.022759	3,266465
CLASS 14	.017988	.129160	.072082	.036967	.048839	.018829	.118801	.217949	.033677	.012421	0,706713
CLASS 15	.018846	.015116	.026743	.039342	.007893	.009601	.012057	.103429	.017446	.015894	0,266367
CLASS 16	.006928	.020065	.001168	.013970	.006729	.012055	.004684	.016197	.001022	.006701	0,089519

Table 4. Distribution of the land cover types within the geomorphometric units

GEOMORPHOMETRIC CLASSES / LAND COVER TYPES	CL. 1	CL. 2	CL. 3	CL. 4	CL. 5	CL. 6	CL. 7	CL. 8	CL. 9	CL. 10
CLASS 1	5.476188	.752323	.312870	1.704446	.247295	2.893567	1.744241	.377842	.270860	5.847641
CLASS 2	7.292004	.140711	.027792	.435238	.076814	5.387411	3.379584	.005524	.072165	7.277855
CLASS 3	.680418	4.271132	.283346	1.741777	.175430	.627965	.212378	2.000152	.240658	.805099
CLASS 4	.353136	.083313	.510293	.728195	3.378167	3.566437	2.338328	.010703	.981984	.342499
CLASS 5	.738427	1.006456	.901388	1.647977	1.191071	2.499959	1.120072	.363482	1.043432	.670108
CLASS 6	9.912190	.000000	.000000	.095751	.000000	1.576849	2.622140	.000000	.000000	10.871325
CLASS 7	1.724575	.808822	.817187	.667926	.974882	6.045098	1.987615	.141533	.538678	1.485274
CLASS 8	.390207	3.190016	.521058	1.036956	.324373	.373038	1.217375	1.348251	.825326	.355613
CLASS 9	1.271104	.622327	.642275	1.879952	1.029845	1.957173	2.250136	.500905	1.046936	1.010927
CLASS 10	.086186	4.636985	.469911	.377781	.156023	.027996	.252592	2.366729	.295834	.042892
CLASS 11	.513807	1.285741	.411636	2.369089	.564098	.633021	1.446591	2.897777	.628700	.393377
CLASS 12	.382932	1.651899	.350342	1.791546	.428936	.322696	.890154	4.161955	.380121	.475698
CLASS 13	.056857	.560217	1.446969	.560190	1.404073	.151133	.538516	.526022	1.464662	.047070
CLASS 14	.222856	1.600161	.893028	.457979	.605063	.233268	1.471821	2.700163	.417221	.153888
CLASS 15	.678810	.544446	.963230	1.417020	.284296	.345811	.434260	3.725314	.628374	.572487
CLASS 16	.994065	2.878828	.167651	2.004458	.965524	1.729576	.672117	2.323950	.146574	.961446

Conclusively, this study provides a valuable new information source for geomorphological applications. It further demonstrated the ability of the designated landform elements to be overlaid on any digital map and imagery for further applied research. Such geomorphometric techniques using DEMs apart from discrimination of geomorphic units holds great promise for other various applications like identification of landscape unit for soil-landscape, and relationship between land-cover and land-shaping process can be examined. In this context, peculiar correspondences among some vegetation categories and morpho-units within the Soratte Mount area have been shown.

Future research / study should lay more emphasis on the combination of digital techniques with multivariate statistics. This will enable the approach to be well suited in enlarging the areas of investigation of interrelationship between geomorphology and land covers framed within the impact of human activities and natural hazards.

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