REMOTE SENSING IN PHYTOSOCIOLOGY: THE MAP OF VEGETATION OF THE PROVINCIA OF ROME

G. FANELLI*, M. P. BIANCO****, P. CAZZAGON**, D. D'ANGELI**, S. DE CORSO***, M. DE SANCTIS*, P. GIOIA***, A. RAMELLO**, G. RINIERI**, A. SERAFINI SAULI*, P. TESCAROLLO**, A. TESTI*, S. PIGNATTI*

**Dipartimento di Biologia Vegetale, Orto Botanico, Università di Roma "La Sapienza"*
***Cooperativa Pineto 2000*
****IPT Informatica per il Territorio e l'ambiente*
*****Università del Molise, Dip. Scienze e tecnologie dell'ambiente e del territorio, Isernia*

ABSTRACT - Remote sensing is rapidly spreading in monitoring ecological systems: it has been currently used to derive maps of ecological formations, primary productivity, geological maps, urban sprawl etc. Vegetation mapping examples are still relatively scarce. In Italy we can remember the computer-assisted vegetation map of Castel Porziano, the map of monti Sibillini and the cooperative project "Cartanatura" that mapped a large fraction of the Italian territory at the scale 1:50.000. Vegetation mapping heavily depends on the quality of satellite images and of phytosociological information. The map of vegetation of the Rome Provincia is a project funded by local authorities that aims at the phytosociological mapping of the vegetation of the Provincia of Rome, an area large about 5000 km^2. Rocks, soils, geomorphology, vegetation are very diverse, from beech woodlands on limestone on a few mountain ranges above 1000 m, to interesting dune and salt marshes vegetation. The landscape is moreover highly fragmented, due both to complex geomorphology (intricate network of small rivers, valleys and hills) and extensive human impact. We relied on SPOT images, with a resolution of 10 m and 4 spectral bands. We adopted an operator-assisted approach, relying on algorithms that interpret the spectral bands on the base of supplied phytosociological information. Preliminary results are promising. We could map a relatively large sector of the Provincia, and it was possible to prepare partial maps with very fine detail.

- SPOT images seem superior in determining phytosociological units, probably due to high resolution, whereas LANDSAT images are suited to emphasizing structural characters of plant cover;
- There is a very high percentage of correctly classified vegetation units (about 90%) and in many cases it was possible to present a phytosociologically detailed map (up to the level of association);
- Algorithms used in classifying satellite images can be useful in helping phytosoiological interpretation. Often it was possible to recognize affinities and distinctions among vegetation types that are not at all obvious with the usual floristic tabulation.

KEYWORDS - Satellite images; supervised classification, SPOT.
Nomenclature follows Anzalone (1994, 1996).

INTRODUCTION

Remote sensing is mainly concerned with ecosystem-level properties of vegetation, for instance biomass, productivity and LAI (Jasinski, 1990; Todd & Hoffer, 1998; Tucker & Sellers, 1986, Tucker *et al.*, 1985; Huete, 1998, Weiser *et al.*, 1986, Friedl *et al.* 1994), or deals with preparing physiognomic maps of plant cover used principally in assessing landscape change (e.g. Huete, 1998; Harvey & Hill, 2001; Borfecchia *et al.*, 2001). Although examples of remotely sensed phytosociological maps are not very numerous, supervised phytosociological interpretation of satellite images is nonetheless an already grown-up field of research (e.g Della Rocca *et al.*, 2001). Many attempts in Italy and elsewhere allowed to assess the possibility to prepare phytosociological maps of more or less extensive areas of vegetation by means of remote sensing. Nonetheless, in most cases only a coarse classification of vegetation has been thus far obtained, often relying heavily on structural characters of vegetation. Moreover, it has been little explored if remote sensing can help phytosociologists not only in recognizing vegetation units in the field, but also in the definition of vegetation units.

The map of vegetation covers the territory of the Provincia of Rome, a local administrative unit that interests the town of Rome and surrouding areas. The project is funded by local authorities; it begun in 2004 and is currently in progress. The work is based on a large phytosociological database of about 2000 relevés and a long field experience of the working group.

The plant cover of this area is extremely diverse, due to varied geomorphology, lithology and climate, and highly fragmented and often heavily impacted, although also many spots of semi-natural vegetation still exists. The phytosociological analysis of this territory is therefore a difficult challenge, and many topics hereabout are debated (e.g. Lucchese & Pignatti, 1990). This area represents therefore an ideal test for the efficiency and the resolution of currently used methods in the interpretation of remotely sensed images.

The project is still in an initial phase. Nonetheless we could map about 40% of the area, and a few interesting results appeared. The aim of this study is:

- to test at which level of detail it is possible to push the analysis of satellite images;
- to test the efficiency of SPOT images;
- to ask if semi-automatic classification of spectral signatures can help in the definition of vegetation types.

MATHERIAL AND METHODS

Study site

The Rome Provincia covers an area of 538,181 ha around the town of Rome (FIGURE 1). There are two main rivers, the Tiber and its influent the Aniene. Other

FIGURE 1 - Black and white satellite image of the Provincia of Rome.

smaller rivers are the Arrone, from lake of Bracciano, Mignone, and Treja, all in the NW sector of the Provincia. An intricate network of small rivers and ditches is present. In the Provincia five relatively large lakes of volcanic origin are present: Bracciano, Martignano, Albano, Nemi, Giulianello. Morphology is rather varied. The following main units can be recognized:

- the coastal dune belt;
- the plain of the Tiber and the surrounding low hills, with their intricate network of small fluvial valleys (Campagna Romana);
- a hilly volcanic district 300-600 m high in the North-West (Monti della Tolfa and Monti Sabatini);
- the Vulcano Laziale, an extinct Volcano that reaches 950 m a.s.l.;
- the limestone massif of Monti Lepini in the SE (with the peak of M.te Semprevisa 1368 m) and the isolated Mount Soratte in the N;
- the area of the Antiappennino, a series of limestone mountains about 1000 m high (Monti Ruffi, Tiburtini, Prenestini, Lucretili);
- the mountains of Central Appennines (monti Simbruini), where the highest peaks of the Provincia are present (m.te Taurinio 1959 m, M.te Autore 1853 m).

Geology is diverse (Bigi *et al.*, 1988). In the Appennines (in the eastern sector of the Provincia) mainly Jurassic-Cretaceous limestones and marls are present. Two large extinct volcanoes are present, and pyroclastites and lavas outcrop in most of the lowlands of the Provincia. Sedimentary alluvial rocks are present mainly along the Tiber, in a layer underlying the pyroclastites. Small Pliocene clays outcrops are present in the surroundings of Rome. After Blasi (1994) two phytoclimatic regions can be recognized, with two transitional belts (TABLE 1):

- Temperate region: without a period of summer drought, abundant summer rains and winter minimum temperatures around 0 °C. This region includes the mountain areas;
- Transitional temperate region: with 2 months of summer drought and summer rains about 110 mm. The Valley of Tiber is mostly comprised in this region;
- Transitional Mediterranean region: with 2-3 months of summer drought. Most of the Provincia below 1000 m a.s.l. is comprised in this region;
- Mediterranean region: with 3-4 months of summer drought. This region interests the coastal belt.

The Provincia of Rome counts 4,000,000 inhabitans, with a density of 719 people/km^2. Main towns are Rome, Civitavecchia, Guidonia, Tivoli. Most of the territory of the Provincia is cultivated (TABLE 2); nonetheless about 30% of the area is occupied by natural vegetation, in particular coppices. In the Provincia 56 areas protected by European Union (ZPS and SIC) and 38 parks and reserves are present.

Due to complex climate, geology and morphology, the vegetation of the area is very diverse. Schematically, the following main types can be recognized (Lucchese & Pignatti, 1990; Blasi *et al.*, 1995):

Dune vegetation: along the coast a relatively narrow strip of dune vegetation (*Ammophiletea* Br.-Bl. et Tx ex Westhoff *et al.* 1946) is present, often with important examples.

Evergreen Mediterranean woodland (*Quercetea ilicis* Br.-Bl. in Br.-Bl. *et al.* 1952): Evergreen woodlands are present mainly along the coast, on sands, and on steep slopes in the low mountains (Bianco *et al.*, 2002).

Deciduous mixed woodlands (*Quercetalia pubescentis* Klika 1933): deciduous woodlands occur in most of the area of the Provincia below 1000 m a.s.l. The main tree species are *Quercus cerris* and *Ostrya carpinifolia. Quercus frainetto*, *Quercus petraea*, *Quercus pubescens*, *Acer campestre*, *Acer obtusatum*, *Carpinus betulus*, *Carpinus orientalis*, *Fraxinus ornus* are frequently associated. Most woodlands are treated as coppices, but also a few older woodlands are present. The syntaxonomy of this vegetation is difficult, due to high variability and anthropical impoverishment.

Hygrophilous woodlands: along the rivers and in ponds and lakes woodlands with *Populus* ssp, *Fraxinus angustifolia* subsp. *oxycarpa*, *Quercus robur* occur. These woodlands are fragmented and greatly reduced due to anthropical pressure.

Mountain beech woodlands (*Fagetalia sylvaticae* Pawl. 1928): *Fagus sylvatica* woodlands occur in a belt above 1000 m a.s.l.

Grasslands: the main types are grasslands dominated by annuals (*Thero-Brachypodietea* Br.-Bl. *et al.* 1952) in the lowlands and perennial grasslands (*Festuco-Brometea* Br.-Bl. et Tx. 1943) in the mountains. These vegetation types are very rich in species (Fanelli, 1998) and diverse, but extensive stands are present only in Rome and in the limestone mountains.

Supervised classification of satellite images

The vegetation classes have been obtained by supervised classification, applied to a multispectral image of satellite SPOT5 (21 july 2002), employing the PCI

Geomatica software (Harvey & Hill, 2001). Main characteristics of SPOT5 images are pixel size of 10 m and 4 spectral bands:

Green	0.50-0.59 µm
Red	0.61-0,68 µm
Near infrared	0.78-0.89 µm
Short-wave infrared	1.58-1.75 µm

The classification phase has concerned the collection of training areas in the PCI Geomatica Platform, of representative areas and their statistical elaboration. The algorithm, used for the classification has been the Maximum Likelihood (with null class). The statistical analysis and elaboration followed the steps below:

- PCA Analysis of training sites; correlation among spectral bands and estimate of unimodality of the relative histogram;
- scatter plot analysis to determine the quality of training areas;
- coincident spectral plot analysis in order to define the spectral signatures and to evaluate the overlap amongs the classis on different bands;
- analysis of confusion matrix to estimate the signature separability between the classes;
- preliminary classification of training areas to find the useless ones and to control their coherence;
- final classification of the classes;
- photointerpretation and feature extraction of areas larger then 2500 m^2;
- field control of feature results.

RESULTS

The supervised classification could distinguish 64 vegetation or land use classes, in many cases at the level of association. The vegetation types are well separated after their spectral signature, with only about 5-10% overlap. Average accuracy is 95.50, overall accuracy 98.23. Field control could retrieve about 80-90% of classes recognised by supervised classification when the area occupied by a patch was larger than 200-300 m^2.

Problems arose with grasslands; pioneer stages and mosaics with shrubs are often misclassified; moreover, the algorithm often cannot distinguish between permanent grasslands and temporarily uncultivated crops.

In an exploration of potentialities of LANDSAT images, these could recognize most but not all of the types recognized with SPOT images; moreover LANDSAT emphasizes structural differences, to which SPOT images are relatively insensitive.

We present below three examples of actual mapping attempts and we discuss strength and limitations of our approach.

Quercus cerris deciduous woodlands

In the study area, two main types of deciduous *Quercus cerris* woodlands can be recognized: a thermophilous type, and a mesophilous type.

The thermophilous deciduous woodland occurs in the coastal belt (Fanelli, 2002). It represents a deciduous woodland in a Mediterranean climatic belt, and is differentiated in particular by the presence of species such as *Quercus frainetto* (that rarely occurs also in the mesophilous type), *Cytisus villosus*, *Phillyrea latifolia*, *Echinops siculus*, *Ornithogalum pyraenaicum*, *Melica arrecta*, *Luzula forsteri*, *Carex olbiensis*, *Cornus sanguinea*. This community has been referred to *Echinopo-Quercetum cerridis* Blasi et Paura 1993, *Lathyro-Quercetum cerridis* Bonin et Gamisans 1976, *Quercetum frainetto-cerridis* Horvat 1959 or to *Quercetum frainetto-suberis* Blasi *et al.* 1997 (Lucchese & Pignatti 1990, Pignatti 1998, Filesi 2001).

The mesophilous type occurs far from the coast, and is more diverse. Different variants are present, that could even be referred to different associations. These types can be differentiated by species such as *Carpinus orientalis* (which less frequently occurs also in the thermophilous type), *Cornus mas*, *Platanthera bifolia*, *Lathyrus venetus*, *Bromus ramosus*. On steeper slopes *Celtis australis*, *Hippocrepis emerus* subsp. *emeroides*, *Orchis purpurea*, *Orchis provincialis* are present (i.e. *Coronillo emeri-Quercetum cerridis*). Coppices are poor in diagnostic species and a few of the species distinctive of thermophilous deciduous woodlands occur. The variants have been variously referred to *Coronillo emeri-Quercetum cerridis* Blasi 1984, *Carpino orientalis-Quercetum cerridis* Blasi 1984, *Rubio peregrinae-Quercetum cerridis* Pigntti E. et Pignatti S. 1968 (Blasi, 1984; Biondi *et al.*; 2001; Pignatti, 1998). These associations are usually referred to an alliance endemic to Central Italy, *Teucrio siculi-Quercion cerridis* Ubaldi 1988, or to *Carpinion* Issler 1931. These vegetation types are nonetheless difficult to distinguish and debate is still on going about *Quercus cerris-frainetto* woodlands of central Latium (Biondi *et al.*, 2001).

The semi-automatic elaboration of the spot image clearly distinguishes the two vegetation types. On the elaboration of the SPOT5 image (Figure 2) two belts could be distinguished. In the coastal belt, belonging to Mediterranean climate, only the thermophilous type occurs, whereas in the inner, transitional Mediterranean belt, mesophilous and thermophilous types are present, with a prevalence of the latter. Here coppices, with poor undergrowth, are usually referred to the thermophilous type (Figure 3).

The two types are largely overlapping on spectral band 1 and 2, whereas they are particularly well separated on band 3 (NIR) and in part on band 4 (SWIR). The eleboration probably thus relies on water and thermal status of the woodland types. A differentiation related to the structure of the woodlands should be excluded, because structure is independent of classification; both coppices and older woodlands of thermophilous and mesophilous types are represented, whereas thermophilous and mesophilous woodlands are present with both coppices and older woodlands.

In summary, the elaboration distinguishes well two closely related types; impoverished, possibly ecotonal stands in the inner belt are referred to different types from more mature stands.

FIGURE 2 - The SPOT image centered on the town of Rome after supervised elaboration. The picture represents only the Quercus cerris woodlands. Thick black lines represent main roads. Ligth grey: thermophilous Quercus cerris deciduous woodlands. Dark grey: thermophilous Quercus cerris-frainetto deciduous woodlands. The thick grey line separates the coastal belt from the inner belt. In the coastal belt only the thermophilous type is present, in the inner belt the mesophilous type prevails.

Castel di Guido

Castel di Guido is an area about 500 ha sited SW of Rome. Due to its diverse geomorphology and lithology, it hosts a number of different vegetation types. The morphology of the area is that of a fluvial terrace about 40 m a.s.l., with a plateau cut by a network of rivers. On the plateau the potential vegetation is represented by thermophilous *Quercus cerris* woodland; because of degradation *Quercus suber* woodlands, bushes and small stands of dry annual grasslands are present. In the valley, where the environmental conditions are fresher due to shading, *Carpinus betulus* woodlands occurs.

The elaboration of the SPOT image portraits the different vegetation types with fine detail (FIGURE 4). Only mosaics of bush and dry grassland cannot be classified by the semi-automatic elaboration, i.e., mosaics with patch size smaller than pixels of SPOT image cannot be referred to the types input in the elaboration.

Castelli Romani

The main vegetation type of Castelli Romani, a volcano in the SE of Rome, are plantations of *Castanea sativa*. The classification distinguishes nonetheless two types of woodlands. The first, prevailing type are coppices, where the herb layer is usually very poor, with few thermophilous species; the second type cannot be easily distinguished from the tree layer, but in the herb layer microthermous species occur, such as *Lathyrus vernus*, *Anemone ranunculoides*, *Corydalis cava* etc. The latter type usually occurs higher above sea level. This result was unexpected, and has been recognized only in the phase of verification of the elaboration. In a preliminary classification, chestnut woodlands were classified in the same class as

FIGURE 3 - A particular of Figure 2. Light grey, thermophilous *Quercus cerris* woodland, dark grey, thermophilous *Quercus cerris* deciduous woodlands. Coppices, which mainly occur in small stands, are referred to the thermophilous type, whereas larger, more natural stands are referred to the thermophilous type.

thermophilous beech woodlands, which is probably correct, although difficult to assess due to impoverished herb layer.

DISCUSSION

It was relatively easy to obtain a detailed classification of vegetation of the area, notwithstanding noteworthy syntaxonomical difficulties in the phytosociology of vegetation types occurring in the Rome Provincia. These results concerns mainly woody vegetation; grasslands are less efficiently classified. Problems arise mainly where the mosaic of vegetation has finer grain than the pixel size of SPOT images; in this case the spectral signature is intermediate between different types, and the algorithm cannot interpret well the vegetation. These problems arose in particular in mosaics of grasslands and shrubs.

In many examples of algorithmic classification of remotely sensed images, it is not possible to test the phytosociological detail of classification, because only very different types are present, for instance decidouous and evergreen woodlands (e.g. Della Rocca *et al.* 2001; Harvery & Hill, 2001). A notable exception is the map of Monti Sibillini, where closely related grassland could be distinguished (Borfecchia *et al.*, 2001). In the Rome Provincia, closely related associations, possibly belonging to the same alliance, that sometimes have not even been distinguished at the level of association, could be recognized. The potentialities of remote sensing in mapping vegetation seem therefore very promising and further research should be rewarding.

It is interesting that in a few cases unexpected results of classification fitted the phytosociology of vegetation types. For instance, many coppices in the inner sector

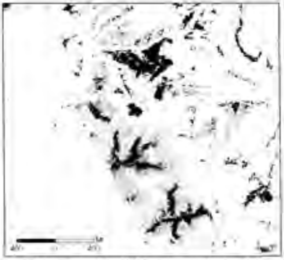

Figure 4 - Semi-automatic elaboration of the SPOT image, particular of the area of Castel di Guido. Black: *Carpinus betulus* woodlands, dark grey: *Quercus cerris* woodlands; light grey *Quercus suber* woodlands and bushes, white: unclassified. In unclassified areas mainly roads, paths, and mosaic of dry grassland and bushes occur.

of the Provincia are closer to coastal thermophilous woodlands than to mesophilous woodlands farther from the sea, according to the semi-authomatic elaboration. This was suspected, but was difficult to demonstrate due to impoverished floristic composition of these coppices. In fact, coppices are transitional between the thermophilous and the mesophilous type; they present a few indicator species of the thermophilous type and a few thermophilous species, that enter in the impoverished floristic composition due to drying following cuttings. The classification of these stands is therefore puzzling. Chestnut woodlands were nicely distinguished into a fresher and a warmer type, that were previously unrecognised in the analysis, again because of impoverishment of coppices. In other cases, affinities recognizable with floristic tabulation of relevés were supported and confirmed by the semi-automatic classification. Chestnut coppices resulted allied to beech woodlands, an affinity quite obvious in typical stands, much more difficult to recognize in impoverished coppices. In summary, the spectral signature is an ancillary help to phytosociological classification, in particular where tables of relevés are unsaturated due to anthropical impact.

Interpretation of satellite images has often relied on a large number of bands; nonetheless, in our study it seems that resolution is much more important than the number of spectral channels in determining vegetation types. SPOT images are relatively unexpensive satellite images. Their main characteristics are a finer pixel size with respect to more broadly used LANDSAT images and a smaller number of spectral bands (only four). These characteristics seem perfectly suited to prepare detailed vegetation mapping of relatively large areas up to the level of association.

CONCLUSIONS

SPOT images can map effectively, accurately and with great phytosociological detail the vegetation of this complex area. It would be interesting to compare these results with analogous elaboration of other images, for instance hyperspectral images. Nonetheless, SPOT images are relatively unexpensive and easily available, and they should be recommended for phytosociological surveys. More sensitive images could be used in particular researches.

The analysis of spectral signatures of vegetation helps phytosociological interpretation. This doesn't mean that we can automatically define vegetation units on the base of spectral bands; interpretation of results of elaboration of satellite images requires a firm knowledge of the floristic variability of vegetation. Nonetheless, it can be very useful in many cases were the classification is difficult and debated.

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TABLE 1 - Main properties of a few climatic stations in the Provincia of Rome.

	M a.s.l.	Average yearly reainfall (mm)	Average yearly temperature (°C)
Temperate region			
M.te Guadagnolo	1203	103	9.0
Subiaco	800	104	12.4
Segni	666	117	12.5
Transitional temperate region			
Palombara Sabina	372	97	14.0
Riano Flaminio	102	96	15.7
Valmontone	306	102	14.4
Transitional mediterranean region			
Guidonia	83	69	15.6
Roma M.te Mario	130	69	15.3
Allumiere	609	87	14.3
Mediterranean region			
Civitavecchia	23	57	16.3
Fiumicino	2	60	15.5
Pomezia	37	71	15.3

TABLE 2 - CORINE Land cover types and percentage cover in the Pronvincia of Rome.

Urbanized	2.84	**Natural vegetation**	34.22
Airports	0.09	Sparse vegetation	0.07
Mines	0.06	Margins and fringes	0.86
Developing areas	0.09	Brunt areas	0.12
Habrours	0.04	Continental wetlands	0.00
Continuous build up areas	0.44	Green urban areas	0.07
Discontinuous build up areas	1.72	Broadleaved woodlands	31.62
Roads and neighbour areas	0.03	Mixed woodlands	0.22
Rcereational sites	0.13	Heaths	0.11
Factories and stores	0.24	Conifer woodlands	0.11
		Grasslands	0.34
Cultivated	61.86	Lawns and meadows	0.36
		Sclerophyllous vegetation	0.34
Mixed cultivations	2.68		
Orchards	0.23	**Water bodies**	0.28
Olive groves	2.69		
Crops	0.03	**Rivers**	0.72
Fields with plantations	2.53		
Fields	52.50	**Bare rock**	0.05
Vineyards	1.19		
		Beaches and dunes	0.03