INTEGRATION OF REMOTE SENSING AND GIS FOR MAPPING AND SPATIAL MODELING VEGETATION IN THE *SUPRAMONTE* MOUNTAIN AREA (CENTRAL EAST SARDINIA)

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ABSTRACT - An application of an integrated approach for mapping the vegetation of *Supramonte di Orgosolo*, a Sardinian mountain area on limestone and siliceous substrata, is presented herewith. The spectral unmixing on satellite data has given reliable quantitative information over the vegetation cover and distribution pattern over the whole study area. The digital image processing on color air photographs has been a good quantitative measure of soil cover density, ranging from values 5% to 100%. The main result has been the semi-automatic production of the physiognomic-structural vegetation map of the study area, distinguishing nine classes over the 15 assessed in the field surveys. This is due to the limitations and constrains of the used dataset and to the reasons discussed in the paper, with some suggestions about future improvement of the methodology.

KEYWORDS - Sardinia, Vegetation mapping, GIS, Remote Sensing, Spectral Mixture Analysis.

INTRODUCTION

Traditional field methods of vegetation mapping, supported by phytosological releves, provide plenty of possibilities to describe vegetation in a large detail but are time and labour intensive, might be biased by the subjectivity of the interpreter (Congalton, 1991; Müllerová, 2004) and therefore not always possible to replicate (Carmel and Kadmon, 1998), compare and update. Geomatic tools and remote sensing (RS) offer well-documented advantages in several applications of vegetation science, including synoptic view on large or unacessible areas, multispectral data availability, multitemporal coverage and increasing geometrical resolution (Kovacs *et al.*, 2005). RS can partly eliminate some of the problems implicit in traditional techniques but the nature of resulting information differs (Mosbech and Hansen, 1994). Instead of focusing on community structure and floristic composition, RS relies on dominant species, their biomass i.e., chlorophyll content and leaf traits, water content, physiognomy, phenology (Dennison and Roberts, 2003), canopy structure, pattern and soil conditions (Graetz, 1989; Franklin *et al.*, 1994; Müllerová, 2004). RS, now widely applied on collecting and processing data, provides a wide range of sensor systems including aerial photographs, airborne multi-spectral scanners, satellite imagery, low and high spatial, temporal and spectral resolution data and ground based spectrometer measurements. Landsat TM satellite images have been proved to be a good tool for mapping vegetation (e.g. Jensen, 1996; Cingolani *et al.*, 2004; Cohen and Goward, 2004), although conventional supervised classification techniques have some inherent problems, due to differences in type and scale of information acquired by field methods and satellites (Cherrill *et al.*, 1994; Keuchel *et al.*, 2003; Wilkie and Finn, 1996). When the mapping area is complex and heterogeneous, as frequently occurs in the Mediterranean, these problems are intensified, leading to mapping attempts of limited success (Budd, 1996). Communities or structural types may be arranged in the landscape as patches smaller than the pixel size and thus attempts to map them are hampered (Clark *et al.*, 2001). Therefore, a more realistic and integrated approach for mapping this type of landscape is needed, such as the definition of informational units (e.g. digital terrain model, land-use classes) at a higher hierarchical level, i.e. as combinations (mosaics) of communities or structural types (Davis *et al.*, 1994).

However, for regional monitoring applications relying on temporal data sets, Landsat has several advantages. First, with more than 30 years of Earth imaging, it offers the longest-running time series of systematically collected remote sensing data (Cohen and Goward, 2004; Röeder *et al.*, 2005). Second, the spatial resolution facilitates characterization of land cover and cover change associated with the grain of land management. (Cohen and Goward, 2004).

Digital image analysis techniques have progressively improved as well, as in the case of spectral mixture analysis (Hostert *et al.*, 2003; Dennison *et al.*, 2004). Integrated GIS and remote sensing have already successfully been applied to map the distribution of several plant species, their ecosystems, landscape, bio-climatic conditions, and factors such as land change, facilitating range expansion or erosion of certain species, biological invasions. A more integrated approach, i.e. botanical field surveys, location of DGPS ground control points, retrospective analysis with historical aerial photos, satellite remote sensing and GIS analysis (e.g. analysis of DEM and derived thematic layers), have resulted to fuel mapping and spatial modeling of vegetation in Mediterranean mountain areas. This applies also in highly fragmented system, where geometric resolution of remotely sensed data may become a limitation.

An application of this integrated approach for the *Supramonte di Orgosolo*, a Sardinian mountain area on limestone and surrounding siliceous substrata, is presented herewith. A first application of this methodology was presented in 1998 (Brundu *et al.*, 1998). More recently, additional ground control plots have been individuated to extend the methodology over siliceous areas, aiming to producing vegetation maps for a larger area with semi-automatic procedures.

FIGURE 1 - Overview of Campu su Murdecu, inside the study area, where soil analysis and detailed vegetation field surveys have been performed.

MATHERIAL AND METHODS

Study area

The *Supramonte di Orgosolo*, a Sardinian mountain limestone system and the surrounding siliceous substrata, have been accurately studied in the past by several Authors (e.g. Susmel *et al.*, 1976; Camarda, 1977; Arrigoni *et al.*, 1990; Arrigoni and Di Tommaso, 1991; Arrigoni, 1996). It's a very peculiar mountain system with important biodiversity and landscape values, hosting one of the best preserved climacic *Quercus ilex* L. forest in the Mediterranean basin. The study area covers a square surface of 20x20 km (central UTM ED_{50} coordinates, 32 T 530000, 4448700). Arrigoni (1996) produced a vegetation map of this area (1:50,000) distinguishing the following eight vegetation classes: (1) mountain Holm oak forest (*Aceri monspessulani-Quercetum ilicis* Arrigoni, Di Tommaso et Mele, 1990); (2) degraded wood and macchia (*Cisto cretici-Genistion corsicae* Arrigoni et Di Tommaso, 1991); (3) macchia on siliceous substrata (*Erico arboreae-Arbutetum unedi* Allier et Lacoste, 1980); (4) mountain garigue on limestone pavements (*Cerastio supramontani-Helianthemetum crocei* Arrigoni et Di Tommaso, 1991); (5) mountain garigue of dolinas (*Nepeto foliosae-Santolinetum insularis* Arrigoni et Di Tommaso, 1991); (6) mountain garigue on decarbonated soils (*Thymo herba-baronae-Santolinetum insularis* Arrigoni et Di Tommaso, 1991); (7) casmophilous formations of limestone falesias (*Laserpitio garaganicae-Asperuletum pumilae* Arrigoni et Di Tommaso, 1991); (8) casmophilous-mesoxerophytic formations (*Helichryso saxatili-Cephalarietum mediterraneae* Arrigoni et Di Tommaso, 1991).

In the present study we assessed the presence of 15 main vegetation types in the study area, with field surveys and locating ground control points, using code-differential positioning by GPS (DGPS). This selection has been restricted and oriented toward the possibility of using and integrating remotely sensed data (aerial and satellite imagery) and GIS tools for semi-automatic detection and mapping.

The main vegetation units are as follows: (1) *Quercus ilex* L. forest; (2) *Q. ilex*, *Phillyrea latifolia* L. and *Arbutus unedo* L. forest; (3) *Juniperus phoenicea* L. and *J. oxycedrus* L. mixed formations; (4) *J. oxycedrus* formations; (5) Garigues with *Santolina insularis* (Genn. ex Fiori) Arrigoni and dwarf shrubs; (6) Garigues with *Ephedra major* Host.; (7) Discontinuous vegetation of limestone pavements; (8) *Erica arborea* L. and *Arbutus unedo* shrublands; (9) *Erica scoparia* L. shurblands; (10) Garigues with *Genista corsica* (Loisel.) DC and *Thymus catharinae* Camarda (syn. *T. herba-barona* Loisel.); (11) Herbaceous communities with *Asphodelus microcarpus* Saltz. et Viv.; (12) Herbaceous communities on hydromorphic soils; (13) Riparian formations with *Alnus glutinosa* (L.) Gaertn.; (14) Burned areas and recovering of vegetation; (15) Afforestation areas with exotic conifers.

Each typology is characterised by peculiar features (with a variation range) concerning floristic composition, physiognomy, structure, spatial pattern and soil cover, phenology, response to disturbance (fire, grazing, cutting etc.) and probability of occurrence along environmental gradients (altitude, slope and aspect, soil types etc.).

Geomatic tools

A dedicated GIS was implemented for the study site, containing location of ground control plots, and the available thematic layers, such as the digital elevation model (derived for the Regional Topographic map, CTR, 1:10.000) soil map, riparian network, Corine Land Cover, and it was used to integrate and analyse the information derived from remotely sensed imagery.

Historical b/w aerial photographs are available since 1950s, and the more recent imagery *Volo Italia IT 2000*, taken during the "Terraitaly 1998-99" flight, represent a valuable data-set of digital colour orthophotographs (orthorectified and georeferenced) which cover all the Italian territory with a nominal scale of 1:10.000 and one meter resolution on the ground.

The available Landsat TM satellite imagery has been a set of two images dated respectively 1987 and 1995 (respectively summer and spring season). Traditional multi-spectral classification approaches, as well as most vegetation indices are not ideally suited as information extraction methods providing largely unbiased estimates for green vegetation cover (Sommer *et al.*, 1998). Therefore satellite data have been geometrically-radiometrically corrected and processed with Spectral Mixture Analysis, SMA (Adams *et al.*, 1989; Dennison *et al.*, 2003; 2004; Hostert *et al.*, 2003; Röder *et al.*, 2005; Smith *et al.*, 1990) at JRC, Ispra (Varese). SMA assumes that most of the spectral variation in multi-spectral images is caused by mixtures of a limited number of surface materials, and it attempts to model the multispectral reflectance as a mixture of representatives types called "spectral end members" (i.e. vegetation, soil and bedrock components, shade). Linear mixing within the footprint of a multichannel spectrometer or imaging sensor further assumes that the surface components are large and/or opaque enough to allow photons to interact with only one component, i.e. the radiative transfer process are additive. Spectra can then be unmixed by inverting the linear mixing equation. The mix-

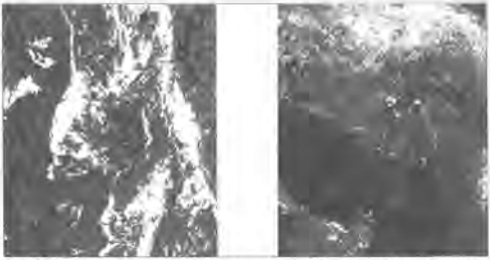

FIGURE 2 - Left: vegetation cover density (fraction map) by spectral unmixing of the study area; right: vegetation cover obtained by spectral angle mapper on digital aerial orthophoto for the area of Su Disterru, in the centre of the whole study area.

ing paradigm provides a type of image enhancement which is not only intense but also physically meaningful (Craig, 1994). It's objective is to isolate spectral contributions of important surface materials (end member abundance, fraction maps) before these are edited and recombined to produce thematic maps.

As a simple and robust semi-automated approach to estimate vegetation cover density Spectral Angle Mapper (SAM) has been applied to the color orthophographs available for the study area. SAM is originally a spectral classification method that matches image reflectance spectra to reference spectra, which are described as vectors defined by a common origin and the respective coordinates of the pixel in the n-dimensional feature space. The match between the reference end member signature and the pixel signature is determined by the angle between the vectors. As a consequence SAM is not influenced by brightness differences e.g. due to different illumination conditions. Although the orthophographs are no reflectance images, they fulfill two fundamental conditions of SAM. They can be explained as three independent RGB channels, each of which can take the value 0 as lowest intensity and finally "with vegetation" and "without vegetation" pixels have clearly different coordinates in the three RGB channels.

RESULTS

The photo-interpretation of Landsat-TM 543 and 321 RGB-composites dated 1987 and 1995, lead to a good correspondence between the image (colour, pattern, seasonal change) and the vegetation typologies previously assessed by field surveys. The spectral unmixing on satellite data (FIGURE 2) gives reliable quantitative information over the vegetation cover and distribution pattern over the whole study area. The digital image processing on colour air photographs gives a good quanti-

TABLE 1 - The nine classes detected with spectral unmixing of Landsat TM imagery in the study area.

(1) *Quercus ilex* forest and *Quercus ilex*, *Phillyrea latifolia* and *Arbutus unedo* forest;
(2) *Juniperus phoenicea* and *J. oxycedrus* mixed formations; and *J. oxycedrus* formations; and *Erica scoparia* shurblands; and *Erica arborea* and *Arbutus unedo* shrublands;
(3) Garigues with *Santolina insularis* and dwarf shrubs; and Garigues with *Ephedra major*; and Garigues with *Genista corsica* and *Thymus catharinae*;
(4) Herbaceous communities with *Asphodelus microcarpus*; and Herbaceous communities on hydromorphic soils;
(5) Discontinuous vegetation of limestone pavements;
(6) Discontinuous vegetation of limestone falesias
(7) Riparian formations with *Alnus glutinosa*;
(8) Burned areas and recovering of vegetation;
(9) Afforestation areas with exotic conifers.

tative measure of soil cover density, ranging from values 5% to 100%. The covering classes should be defined taking into account a well-known classification system, which may be related to vegetation field surveys. These results can be enhanced by mean of appropriate filtering and topographic correction. From an ecological point of view, an increase in the slope determines a more open wood formation, e.g. in *Q. ilex* forest on limestone. Thus the coverage that is commonly measured as vertical projection of the crowns can be corrected by an opportune coefficient related to the slope taken from the digital terrain model. The value of the coefficient must be different on granite and schist substrates, where the floristic and structural patterns of plant community change to a great extent. Multitemporal available imagery highlights the general stability of the system in the limestone area during the time interval taken into account, while wild fires are a common disturb factor in the area on siliceous substrata. It has been possible to detect and map the nine classes reported in TABLE 1.

DISCUSSION

The result of the applied integrated methodology has been the semi-automatic production of the physiognomic-structural vegetation map of the study area, distinguishing nine classes over the 15 assessed in the field surveys. This is due to the limitations and constrains of the used dataset and to the reasons discussed in the following, with some suggestions about future improvement of the methodology.

The *Quercus ilex* forest of *Supramonte di Orgosolo* can be easily detected but has not been distinguishable by mixed formations with *Q. ilex*, *Phillyrea latifolia* and *Arbutus unedo*, and they are therefore treated as a whole in the produced vegetation map. This is determinated by their similar spectral signature also in multitemporal imagery, which is more or less stable in the different seasons. In fact, they present a different floristic composition and are found on different soils, but their spatial distribution can not be automatically detected and expert knowledge is required by photo-interpretation. Accurate field surveys or more geometrically refined thematic layers (e.g. soil maps) are required for improving mapping results.

The second resulting mapping class is made of the following four: *Juniperus phoenicea* and *J. oxycedrus* mixed formations; *J. oxycedrus* formations; *Erica sco-*

paria shurblands; *Erica arborea* and *Arbutus unedo* shrublands. They are greatly different from a floristic and structural point of view, but, nevertheless, they exhibit a similar spectral signature. *J. phoenicea* formations are found on limestone, while *J. oxycedrus* grows both on limestone and on siliceous substrata, thus discrimination by thematic GIS layer, classification trees or other methods are problematic to apply. *Erica scoparia* shurblands are typical of hydromorphyc (at least temporarily) clay soils, and therefore, they can be detected if this information is available and if its formations are large enough in comparison to imagery geometric resolution; when these conditions do not occur, they are ranked as the surroundings shrublands, without further information. *Erica arborea* and *Arbutus unedo* shrublands are exclusively found on siliceous substrata, from lower quotes to over 1,000 m a.s.l., and this distribution may help the semi-automatic detection.

Also the three types of garigues that are present in the study area have been mapped in a single class, although some possibility of discrimination might be addressed in future studies. The garigues with *Ephedra major* are found only on limestone debris; garigues with *Santolina insularis* and other dwarf shrubs are found mainly on limestone; finally, garigues with *Genista corsica* and *Thymus catharinae* are present mainly, if not exclusively, on siliceous substrata. These three types of garigue are easy recognizable in field surveys for their physiognomy and their peculiar floristic composition, but it has not been possible to distinguish between them on Landsat imagery. The signature is highly characterized by rock outcrops, bare soil and dry phytomass. These formations are very reach in therophitic species, with a phenology that strongly influences multitemporal spectral signature. They have a great phytodiversity value, being very reach in endemic species. Sardinian formation with *Ephedra major* are recorded as ones of the more large formation in Italy.

The two main herbaceous communities detected by field surveys (i.e. herbaceous communities with *Asphodelus microcarpus*; herbaceous communities on hydromorphic soils) have been mapped using a single class. These formations are characterized by a high prevalence of therophitic and perennial herbal species, both with a marked seasonal pattern. *Leucojum aestivum* L. subsp. *pulchellum* (Salisb.) Briq. is a beautiful bulbous plant that characterises some of these herbaceous communities on hydromorphic soils found in the study area. Herbaceous communities with *A. microcarpus* have originated after fire events and are constrained to this status by grazing pressure.

The discontinuous vegetation of limestone pavements has been clearly detected with satellite imagery and the SMA analysis on aerial photographs can give further quantitative information on the total cover.

The detection of the discontinuous vegetation of limestone falesias has been greatly improved by the availability of the digital terrain model (DTM). Traditional mapping and maps usually give an under-estimation of these formations, being their topographical projected surface often below the mapping resolution even at detailed scales. For the same reasons they are under-estimated in the remotely sensed imagery and only the availability of a detailed DTM, in a geo-database framework, can give a good possibility to quantify with more precision their real surface extent and store the information therewith. Limestone falesias are very reach in exclusive associations which are plenty of endemic species.

The riparian formations with *Alnus glutinosa* are normally located between the two main lithologic substrata of the study site and they are topologically discontinuous. The geometric resolution and the shadow effect are serious constrains for the detection of these typologies in this kind of topography. Thus field surveys are required and the probability of occurrence can be modeled with GIS tools (e.g. digital terrain model analysis).

The resulting map highlights also the presence of burned areas and processes of vegetation recovering. Although burned areas are easily detectable with RS this is normally possible only soon after the event, after one year they are included in garigues or in the herbaceous communities, and semi-automatic detection is not any more possible (other indirect methods should be applied). On limestone areas the recovering is more difficult for local aridity or highly delayed by grazing pressure, as is remarkably observed in the Campu su Murdecu, inside the study area.

Finally, the afforestation areas with exotic conifers, i.e. plantations with *Cedrus atlantica* (Endl.) Carrière, *Pinus nigra* Arnold, *Castanea sativa* Miller and native *Q. ilex* are easily detectable also in relation to their pattern and shape. Furthermore, they are mainly located on the siliceous substrata.

Conclusions

The described and utilised integrated methodology has thus given the possibility to produce a vegetation map that describes vegetation physiognomy and structure, main floristic traits and human impacts at different scales. Implementing and refining semi-automatic procedures gives the possibility to update maps more frequently as requested for management purposes. Geomatic tools have highly improved mapping outcomes, but the expert knowledge of site conditions and oriented GPS field surveys are the fundamental requirements of the whole methodology.

This methodology, applied in this study to mountain areas, can be extended also to other Sardinian and Mediterranean areas, for producing thematic maps suitable for land management over large areas.

The SMA analysis on aerial photographs have given further information, at a more detailed scale, on a quantitative aspect of vegetation in a broad sense, that is phytomass, and helped to integrate the information derived from satellite derived vegetation cover density in comparison with vegetation indices, correcting thus some of the bias of the "traditional" vegetation indices and improving geometric resolution of Landsat imagery.

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Riassunto

L'integrazione di diverse metodologie geomatiche, segnatamente telerilevamento, rilievo GPS e modellizzazione GIS, con i tradizionali e fondamentali rilievi di campo ha consentito la produzione di una mappa fisionomico-strutturale della vegetazione dell'area di studio (20 x 20 km), nella Sardegna centro-orientale, comprendente il Supramonte di Orgosolo di natura calcarea, e le circostanti zone su substrati silicei. L'elaborazione delle immagini satellitari (SMA) e delle foto aeree (SAM) ha permesso di identificare, in maniera semi-automatica, 9 diverse tipologie, rispetto alle 15 osservabili in campo. I vantaggi ed limiti della metodologia sono descritti nel presente studio, assieme ad alcune proposte operative per il raffinamento della metodologia.

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