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LAND DEGRADATION MONITORING: SPECTRAL VARIABILITY IN A SEMI-ARID MEDITERRANEAN ECOSYSTEM (NATURAL PARK CABO DE GATA-NÍJAR, SPAIN)

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ABSTRACT

The overall goal of this study is to develop remote sensing desertification indicators for drylands, in particular using the capabilities of imaging spectroscopy (hyperspectral imagery) to derive soil and vegetation specific properties linked to land degradation status. For this purpose, a hyperspectral (field and remote sensing) monitoring program was established in the Natural Park Cabo de Gata-Níjar in south-eastern Spain to: a- monitor the landscape biological and ecological multitemporal changes; b- identify sources of variability in the spectra, in relation with the ecosystem dynamics; c- develop physiologically and physically meaningful spectral indicators of change adapted to drylands specific reflectance signatures and environment.

The Cabo de Gata-Níjar Natural Park presents a still-preserved semi-arid Mediterranean ecosystem that has undergone several changes in landscape patterns and vegetation cover due to human activity. Traditional land uses, particularly grazing, has favoured in the Park the transition from tall arid brush to tall grass steppe. In the past ~40 years, tall grass steppes and arid garrigues increased while crop field decreased, and tall arid brushes decreased but then recovered after the area was declared a Natural Park in 1987. Presently, major risk is observed from a potential effect of exponential tourism and agricultural growth. This paper presents observations and preliminary results from the spectral monitoring program, both at the field and at the remote sensing scale.

INTRODUCTION

Desertification is a land degradation problem of major importance in the arid regions of the world. Deterioration in soil and plant cover have adversely affected nearly 70 percent of the drylands as mainly the result of human mismanagement of cultivated and range lands. Combating desertification involves having an accurate knowledge on a current land degradation status and the magnitude of the potential hazard. As emphasized in the UN Convention to Combat Desertification, there is a need nowadays for more assessment of land degradation and desertification processes. Maps at the global, local, and regional scale of desertification status and hazards involve ground studies, high data requirements, erosion/desertification modelling, that make them rare and sparse. Current multispectral remote sensing data offer indices based on 2 to 3 band ratios that are used as proxy of the complex processes that take place in a degrading land, but are inherently limited. Thus, the knowledge on the current land degradation status of a land, or the magnitude of the potential hazard, is for the most part incomplete and fragmented[1]. This makes it extremely difficult to design and implement mitigation, reclamation and prevention measures.

In this context, GFZ dryland degradation program (in: Climate Variability and Human Habitat) aims at, with a thorough understanding of the global desertification processes, exploring the capabilities of imaging spectroscopy to derive soil and vegetation specific properties linked with land degradation status[2]. The quantitative parameters to be determined from the hyperspectral data can be incorporated into erosion and dryland degradation models to monitor land degradation processes, assess land degradation status via the use of a globally applicable land degradation index, and gain indicators for characterising specific surface properties related to water cycles, erosion processes, and plant productivity in drylands.

Test sites were established in several vulnerable regions to determine the suitability of the procedures engaged: a- A dry area in north-eastern Germany is being used to explore the relationships in a small catchment between spectral reflectance and rainfall runoff modelling[3]; b- In the frame of the DeSurvey EU-IP (http://www.desurvey.net), advanced information extraction procedures are developed and tested to allow the determination of relevant soil parameters[4] (e.g. organic matter content, soil iron content) from hyperspectral data; c- The Natural Park Cabo de Gata-Níjar in southern Spain (Almeria) encompasses a large range of land degradation processes, and provides an excellent study site to develop a hyperspectral monitoring desertification program. The project in Cabo de Gata is the focus of this paper.

STUDY AREA

The Cabo de Gata-Nijar Natural Park is a marine-terrestrial Park located in the Almeria province, SE Spain. The park covers 37570 ha of land and 12126 ha of marine coastline with altitudes ranging between 562 m high and 60 m under the sea level. The climate is Mediteranean semi-arid. The average annual rainfall between 1973 and 1996 at 43 m elevation was 193.9 mm, and the mean annual temperature was 19.4°C[5]. The park is composed of two big features: the Cabo de Gata massif (Sierra del Gabo de Gata), and the coastal plain (Bahia de Almeria). The Cabo de Gata massif is the emerged section of a huge volcanic region which continues under the sea of Alboran and emerges in North Africa. This volcanic rock of the calco-alcaline type was formed during the Tertiary Era in four periods of hydrothermal activity between ca. 15 and 8 million years ago. Presently, there are about 3500 people living all year round in the park, including all the villages.

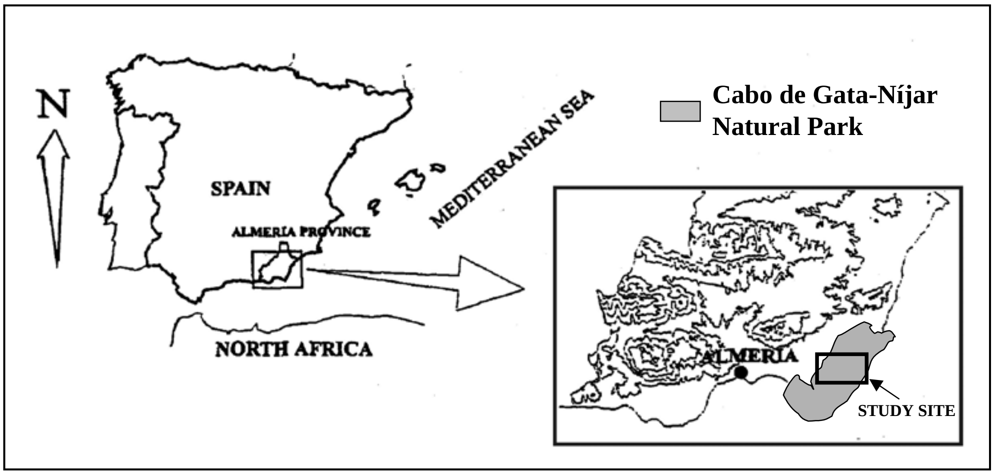

Figure 1: Location of the Cabo de Gata-Nijar Natural Park. The square locates the area covered by HyMap in 2003 and 2004.

The ecological importance of the park is in its volcanic origin, semi-arid climate, and marine-terrestrial character, producing habitats such as Mediterranean steppe, dunes coastal formation, salt mines, cliffs, and marine prairies of fanerogamas. The Natural park biodiversity made it be classified in 1997 by the UNESCO as World Reserve of the biosphere. Soils are of two main types, calcareous or volcanic. Of more than 200,000 catalogues plant species in the Mediterranean area, the Cabo de Gata-Nijar Park contains about a thousand, a surprising number for such a small and fairly low lying area. The vegetal landscape is composed of various types of shrubland, ranging from tall arid brushes with species like the palmito (*chamaerops humilis* L. -considered the only native palm in the European continent), phlomix, to tall grass steppes of *Stipa tenacissima* L., arid garrigues (genista, artemisia), arid scrubs (thymus), opuntia (cactus), and crop fields.

In Cabo de Gata-Nijar, the important social and economic changes in the last 50 years are that ~45% of croplands have been abandoned since 1957, and the area was proclaimed a Natural Park in 1987. A recent study on land cover changes between 1957 and 1994[5] has shown that land cover changes in the park underwent in the last 50 years two major processes. First, croplands and arid garrigues were reduced as a result of land abandonment, and second, there is an evolution towards tall grass steppes as a consequence of vegetation successional dynamics (from garrigue to steppe) and vegetation successional regression (from brushwood to steppe). The regeneration of cropland abandonment appears quite improbable, although vegetation cover is preserved due to the favourable effect of stepped terrain in the brushwood formation. Finally, the increase of tourist infrastructures will increase the habitat fragmentation of the Cabo de Gata-Níjar tall arid brush.

METHODS

In collaboration with the Cabo de Gata-Níjar monitoring program from the university of Almeria, INCAMAR[6] (Oyonarte C., pers. Com.), acquisition of field spectroscopy and hyperspectral images began in 2003 and aims at acquiring and analysing multitemporal spectral data covering dry and wet seasons.

Several land degradation parcels presenting variable levels of soil development and biological activity were defined in summer 2003, covering the Park spatial dynamics and land degradation processes. The parcels are located in agricultural lands and in natural (non-degraded) environments, both for calcareous and volcanic soils. Specific targets associated with dunes and saline areas were added since summer 2005 in order to cover also eolian and salinization processes.

Figure 2: links: Parcel F, natural area-volcanic soils (Photo: Univ. Almeria). Right: Parcel B, agricultural (degraded) area-volcanic soils (Photo: GFZ-Potsdam). Pictured with the FieldSpec Pro® from the GFZ-Potsdam.

Spectral field data were acquired in July 2003, May 2004 and July 2005 with the FieldSpec Pro® (http://www.asdi.com) from the GFZ-Potsdam. The targets measured encompass the whole range of rocks, soils and vegetation that can be observed within the park, associated with natural areas and agricultural areas (both in calcareous and volcanic soils), dunes and saline areas. Measurements for the dry season are concluded, some wet season measurements are yet to be done.

The hyperspectral remote sensing monitoring, summarized in Table 1, includes yearly acquisition of airborne images with the HyMap scanner (http://www.hyvista.com/hymap.html). The image preprocessing for 2003 and May 2004 data was performed by Martin Bachman and Stefanie Holzwarth at DLR (German Aerospace Center, Oberpfaffenhofen, Germany). It included the development of a new DEM at 2m for the Cabo de Gata Natural Park, automatic geocoding (ORTHO) and atmospheric correction (ATCOR4). The different flightlines were further in GFZ mosaicked.

Table 1: HyMap (128 channels, 0.4-2.4 μm, 12-17 nm wide) airborne campaigns in Cabo de Gata.

	Pixel size	Spatial coverage	Flightlines	Spectral coverage	Coord. field
11 July 2003	4 & 6m	Calc+volc+agri+mines	3 E-W, 2 N-S	0.45-1.3, 2-2.45 μm	FieldSpec
18 May 2004	5m	Calc+volc+agri+mines	5 E-W	0.45-2.45 μm	FieldSpec
13 August 2004	5m	Calc+volc+agri+mines	5 E-W	0.45-2.45 μm	
15 June 2005	5m	Calc+volc+agri+mines +dunes+saline areas	6 N-S, 1 dunes	0.45-2.45 μm	GER 3700

RESULTS

Spectral analyses of landscape components

The land degradation parcels presents variable levels of soil development and biological activity, and are named from A to H, A being the most degraded, H the one with the most vegetation diversity. The targets in the Cabo de Gata land degradation parcels can be grouped in four main categories: 1- rocks, 2- soils (bare soils, soils with stones, physical crust), 3- lichens (biological crust on soils and rocks), 4- vegetation (*S. tenacissima* L., *chamaerops humilis* L., opuntia, thymus, periploca, annuals, others).

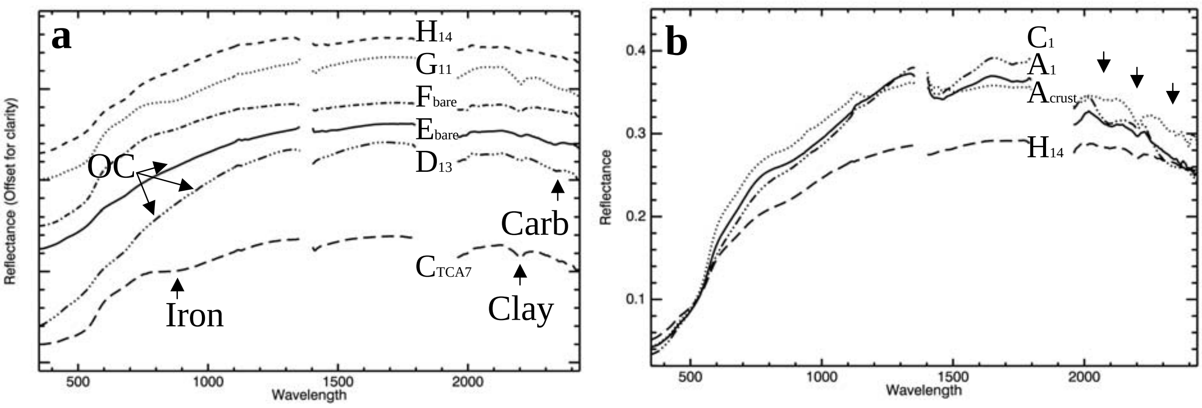

Figure 3: Soils field spectra from July 2003: a- bare soil surfaces, parcels C to H; b- natural soil surfaces, soils with residue (A_1, C_1), soil crust (A_{crust}), soil with gravel (H_{14}).

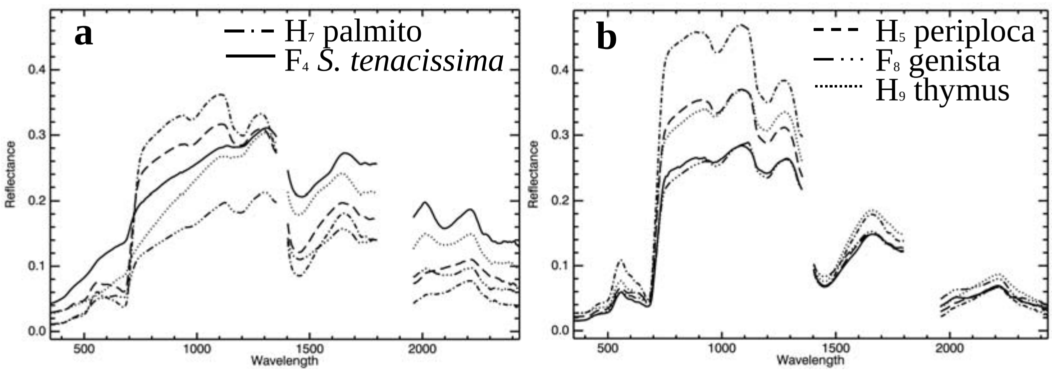

Figure 4: Vegetation field spectra of same targets in a- July 2003; b- May 2004.

The field spectral campaigns showed the high spectral variability within the park. In the rocks and soils spectra, iron (parcels C, F, G, H with strong iron content), clay, carbonate (parcels D, E), OC content can be identified, in association with their location in the park and laboratory soil analyses. In natural soil surfaces, mixture of soils (mainly clays) and vegetation residues can be identified in the spectra. In the vegetation spectra from 2003, both photosynthetic vegetation (PV) (red-edge;

max reflectance ~0.35) and non-photosythetic vegetation (NPV) can be identified. In the vegetation spectra from 2004, mainly PV signatures are observed. NPV signatures were observed for annuals (*Stipa capensis*, already dried out), and a few S tenacissima in agricultural and calcareous areas. Soil crust (biological crust) can be difficult to differentiate from other biological elements.

Remote sensing coverage

Despite the geocoding and atmospheric correction, small discrepancys are observed in the data, for example in the location of the land degradation parcels. The difference can be up to several pixels when compared from one flightline to the next, or from the July 2003 dataset to the May 2004 dataset, and has to be further improved.

Figure 5 compares HyMap spectra at the driest season (July 2003), and at the wet season a few weeks after the spring bloom (May 2004), associated with areas 20x20 m wide at the parcels location. The 20x20m average allows us to consider those spectra as representative of the parcel area, which is homogeneous at this spatial scale. The mixing at the sub-pixel scale in the parcels area is such that in each pixel are present ~all groups defined in the field spectral study: rocks, soils, lichens, PV and NPV. For clarity of the figure, we showed only the spectra from parcels C to H. HyMap spectra are characteristics of drylands spectral signatures, i.e. mixtures of rock, soils, NPV, and some PV at the wet season.

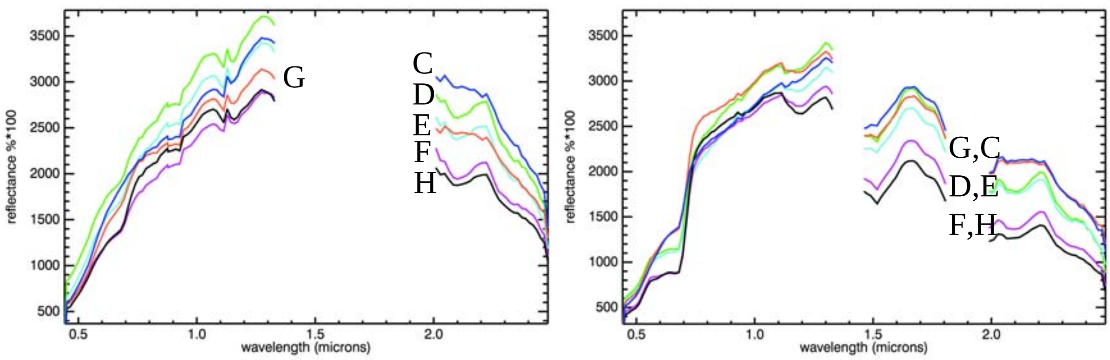

Figure 5: HyMap spectra over the land degradation parcels (C: agricultural-volcanic; D/E: natural-carbonates, opposite slopes; F/G/H: natural-volcanic, up-slope, opposite slopes): a- 11 July 2003; b- 18 May 2004.

CONCLUSIONS

For the important issue of land degradation monitoring, a hyperspectral monitoring program has been established in the Natural Park Cabo de Gata-Níjar in southern Spain (Almeria) since 2003. This program is correlated with field spectral observations and analyses of the main factor of changes in the spectra at the multi-annual and also inter-annual (dry and wet seasons) time scale. The focus of this study is threefold and consists of: a- identifying sources of variability in the spectra in relation with the ecosystem dynamics; b- developing land degradation spectral indices; c- testing and validating the integration/relevance of the remote sensing indices for land degradation and erosion modelling.

The Natural Park Cabo de Gata-Níjar is a preserved semi-arid Mediterranean ecosystem. It encompasses a large range of land degradation processes and provides an excellent study site to develop a field and remote sensing hyperspectral monitoring desertification program. We showed that a high variability and complexity is associated with drylands spectral signatures, mainly associated with the integration in the field-of-view of a mixture of mainly non-photosynthetic biological activity linked with a strong soil component signal. The soil component itself is an intimate mixture of vegetation residue, bare soil, and crust (biological or physical) reflectance signature.

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