Teledetección y Desarrollo Regional. X Congreso de Teledetección. Cáceres, España, 2003. pp. 451-456.
Coordinadores: Rosa Pérez Utrero y Pablo Martínez Cobo.

APPLICATION OF HYPERSPECTRAL DATA TO STUDY SALINE WETLAND AREAS IN SEMIARID ENVIRONMENTS

Thomas Schmid (*), Magaly Koch (**), Santos Cirujano (***) and José Gumuzzio (****)
thomas.schmid@ciemat.es

(*) CIEMAT – Research Centre for Energy, Environment and Technology, Madrid, Spain
(**) Center for Remote Sensing, Boston University, Boston, MA, USA
(***) Real Jardín Botánico de Madrid, C.S.I.C., Spain
(****) Universidad Autónoma de Madrid, Facultad de Ciencias C-VI, Madrid, Spain

ABSTRACT

Wetlands in Mediterranean environments represent semiarid ecosystems of importance for maintaining and controlling the environmental quality and biodiversity. Frequently, these ecosystems are affected by salinity and are exposed to intense human induced activities. The high demand for agricultural production in the region of Central Spain (La Mancha Alta) has led to large-scale irrigation schemes with intensive exploitation of water resources. The aim of this work is to compile a spectral library containing wetland components from semiarid areas and to evaluate the capacity of hyperspectral data obtained with the Digital Airborne Imaging Spectrometer (DAIS 7915) to discriminate wetland components related to salinity. Results show that differences between the wetland and surrounding upland soils can be well distinguished by the hyperspectral sensor. In this case, the influence of soil moisture is a dominant factor that influences the spectral characteristics of the soils. Within the wetland areas, soils with different salinity levels are identified. However, the capacity to discriminate vegetation types associated to salinity is less efficient, due to the sparse vegetation cover and homogeneity in semiarid wetlands. In certain wetland areas with a homogeneous and more dense vegetation cover a characteristic spectral curve is obtained relating the soil salinity and vegetation.

RESUMEN

En el entorno mediterráneo los humedales representan ecosistemas semiáridos de gran interés para el mantenimiento y control de la calidad ambiental y biodiversidad. Con frecuencia, estos ecosistemas están afectados por salinidad y sometidos a una intensa presión resultante de la actividad humana. La fuerte demanda en el incremento en la producción agrícola en la zona de La Mancha Alta (Comunidad Autónoma de Castilla la Mancha) ha conducido a la implementación de sistemas de regadío a gran escala con la consecuente explotación intensiva de los recursos hídricos. El objetivo de este trabajo es compilar una librería espectral de componentes de humedales en áreas semiáridas y evaluar la capacidad de datos hiperespectrales obtenidos con el Digital Airborne Imaging Sepectrometer (DAIS, 7915) para discriminar componentes relacionados con la salinidad. Los resultados obtenidos muestran que los datos de DAIS permiten distinguir los suelos asociados a los humedales de los del entorno, siendo la humedad del suelo un factor determinante en las características espectrales. Dentro de los humedales, los datos hiperespectrales de DAIS permiten diferenciar áreas con suelos afectados por diferentes niveles de salinidad; sin embargo, la capacidad para discriminar tipos de vegetación asociada a niveles de salinidad es menos eficaz debido a limitaciones relacionadas con la escasa cobertura y homogeneidad de la vegetación en los humedales semiáridos. En contraste, áreas con suficiente cobertura y homogeneidad muestran respuestas espectrales que permiten ser asociadas a la salinidad del suelo y a la vegetación.

Key words: semiarid, wetland, hyperspectral data, salinity.

INTRODUCTION

Salinity is a common problem in Mediterranean environments and the resulting effects on land cover are expanding (Szabolcs, 1989). Soil salinity problems are frequently associated to changes in land use, especially in fragile ecosystems of semi-arid environments. The demand for increased agricultural production in the Central Spain region (La Mancha Alta) has led to a relative decline of traditional rain fed crops (cereals, vineyard and olive grove), and this, in turn, has led to an increase in large-scale irrigation schemes with intensive exploitation of water resources. The combination of these factors is considered as one important cause for increasing levels of salinity in this area. The wetland areas are especially important ecosystems, because of their role in maintaining and controlling the environmental quality and biodiversity. These land areas are considered as one of the most significant for the migrating and wintering waterfowl in Spain (Oliver and Florín, 1995).

Many wetland areas in central Spain are saline or sub-saline and are subject to natural (seasonal) as well as man-induced changes. Factors causing changes that significantly alter or annul the ecological function of these wetlands can be considered as degradation processes. Some of these factors are due to land use changes, such as drying (drainage) of wetlands and/or their use as waste disposal sites. In addition, the development of large irrigation systems in Central Spain has caused a significant reduction of the ground water resources with a subsequent increment in soil salinity levels (Casado and Montes, 1995). The area is exposed to growing pressures associated with land use changes (agricultural practises) and the possible effects of climate change. The combination of these factors is considered the major cause of wetland losses in this region. It has been estimated that 60 % of the wetland areas have disappeared in the last four decades and only 2.8 % are relatively well preserved (Casado and Montes 1995, Cirujano 2000, Oliver and Florín 1995).

At present, there is an important effort taking place in order to identify salt-affected areas as a result of land degradation and salinization processes (Dehaan and Taylor, 2003; Koch, 2000; Koch *et al.*, 2001 and Metternicht and Zinck, 2003; Schmid *et al., In review*).

The objectives of this work is to compile a spectral library containing wetland components from semiarid areas and to evaluate the capacity of hyperspectral data obtained with the Digital Airborne Imaging Spectrometer (DAIS 7915) to discriminate wetland components related to salinity.

STUDY AREA

The study area is situated in central Spain in the region of La Mancha Alta, a plateau with an average altitude of 650 m.a.s.l. The landscape is dominated by an undulating topography with wetlands located in depressions. The river Cigüela meanders in a north south direction forming a floodplain within the upper Guadiana river basin. The climate is characterised by strong summer drought and a continental character. The mean annual temperature is 14.8º C and the annual precipitation lies at 387.4 mm.

The lithological materials in the wetlands are Quaternary sediments frequently rich in gypsum and calcium carbonates. Tertiary materials with sandstone and limestone surround the wetlands (Peinado 2000). The main wetland soils in the area are salt-affected with gypsic, salic and/or calcic horizons (Salic Fluvisol; Gypsic Solonchak; Gypsic Kastanozems; and Calcic Gypsisol according to FAO, 1998). The upland soils, representative in the more elevated areas around the wetlands are not salt-affected (Haplic and Petric Calcisol; Calcaric, Cromic and Rhodic Cambisol; and Calcaric Leptosol).

The natural vegetation associated to the wetlands is classified into hygrophytic (*Phragmites australis* and *Typha domingensis*) and halophytic (*Salicornia europaea*, *Suaeda vera*, *Puccinellia fasciculata, Limonium carpetanicum, Lygeum spartum,* and *Elymus curvifolius*) species. The distribution of aquatic and marginal vegetation is determined by the presence of soluble salt concentrations (Cirujano, 2000).

The wetlands studies in this work (Figure 1) are classified as (Oliver and Florín, 1995): *Seasonal hypersaline lagoon* (Lagunilla de la Sal); and *anthropogenic affected floodplain* (Cigüela alluvial plain in Finca Pastrana). Other wetland type not considered in this work is *riverine permanent subsaline* (Laguna Grande of Villafranca).

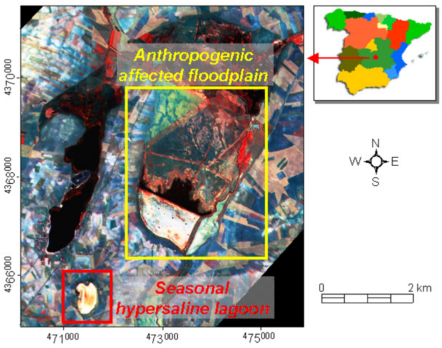

Figure 1.- Study area (Colour composite DAIS 7915 bands 23, 40 and 56 displayed in the red, green and blue channels).

In many areas the salinity encountered in these wetland types is influenced by land use and soil management practises. S*easonal hypersaline* wetlands are better conserved because of their unsuitability for agricultural use; whereas the *anthropogenic affected floodplain* wetlands are most affected by human induced activities as a result of lower soil salinity.

DATA ACQUISITION AND METHODOLOGY

A field campaign was conducted in June 2001 within the framework of the Natural Environment Research Council Equipment Pool for Field Spectroscopy (NERC EPFS) project "Development of a spectral library for wetland degradation indicators in Spain" (Mather *et al.*, 2001). The objective was to obtain field spectral measurements for semi-arid wetland components.

An ASD FieldSpec Pro VNIR-SWIR spectroradiometer was loaned from the NERC EPFS. Apart from the spectral data; surface samples of soil, vegetation, sediment and salt crusts were obtained, and observations and photographs of field conditions were acquired. The location of the spectral measurements and sampling points were referenced using GPS.

At each test site, five representative elements of each component (soil or vegetation type) were selected and three spectral measurements were taken for each element. In this way we considered different states of each representative component. At the location of at least one of the elements a corresponding sample was taken. Additionally, a transect of ten radiometric measurement points with a spacing of two metres between the individual points was obtained with the aim of representing the spectral variability within the DAIS 7915 spatial resolution (5 m) in the test site.

Pre-processing of the spectral curves included converting the spectra files from raw binary format to absolute reflectance curves, using processing software (Kerr, 1998;). Where necessary, the effects of sun-angle and atmospheric absorption were accounted for.

Physical and chemical soil and sediment analyses were carried out on the soil surface samples. Properties measured included: soil texture, soil colour, pH, electrical conductivity, and organic matter, carbonate, iron oxide and soil mineral content. The soil samples were prepared for analysis according to standard laboratory procedures (Klute, A. 1999). and a study of the soil mineral fraction was made using X-ray diffraction analysis.

Hyperspectral data were acquired by the airborne DAIS 7915 sensor as part of the German Aerospace Centre (DLR) HySens program on behalf of the Autonomous University of Madrid on the 29 June 2000 (Gumuzzio *et al*. 2000). At the time of the over flight, a field spectroradiometer (GER3700), operated by a group of DLR experts, was used to obtain spectral curves of specific targets for the purpose of radiometric calibration of the hyperspectral data. The spatial ground resolution of the sensor was approximately 5 m and the swath width 3 km when the aircraft was at an altitude of 3000 m above ground level. The hyperspectral data uptake covered an area of 7.5 by 15 km.

Pre-processing of the hyperspectral data included atmospheric, radiometric and geometric correction and was carried out by the DLR facilities. Image processing was performed on the data using a minimum noise fraction transformation (MNF) for noise removal and by applying the inverse MNF to transform the MNF spectra back to the original data space. This is to improve the spectral processing results and a first step is to obtain the spectral characteristics from the 72 bands of DAIS 7915 at any given location. The aim is to compare and match the spectral characteristics for a wetland component obtained with the hyperspectral data to that from the field spectrometer.

IDENTIFICATION OF SALINE WETLAND CHARACTERISTICS

The wetland areas can be separated into different components such as soil, vegetation and water. The moisture content in the wetland area will define its extension and strongly influences the spectral characteristics of the different components. The spectral curves obtained for different soil and salt crust surfaces (Figure 2) in and around the *seasonal hypersaline lagoon* are influenced by the water moisture content in the soil.

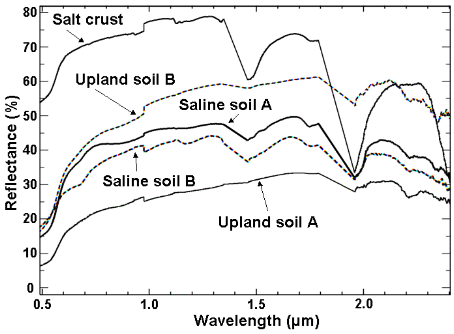

Figure 2.- Spectral characteristics of soils obtained with the field spectrometer.

The salt crust shows a high reflectance in the visible and infra red range, but is strongly affected by the moisture content below the surface and therefore dampens the overall reflectance with important reduction in the response signal within the water absorption ranges (1.3 to 1.46 µm and 1.76 to 1.95 µm). This is further observed in Saline soil A and B, where the signal reduction is less pronounced. The spectral curves of the upland soils show that these soils are significantly less affected by moisture.

The spectral characteristics (Figure 3) from the DAIS 7915 sensor are taken from the same locations as the field spectral curves. The spatial resolution as well as the location precision influences the spectral curve. This is taken into account by selecting homogenous areas with a coverage of 15 by 15 m. As mentioned above, the water absorption dominates the difference between the wetland and upland soils and is well identified with the DAIS 7915 sensor although there is no spectral data between 1.038 and 1.544 µm available for this sensor.

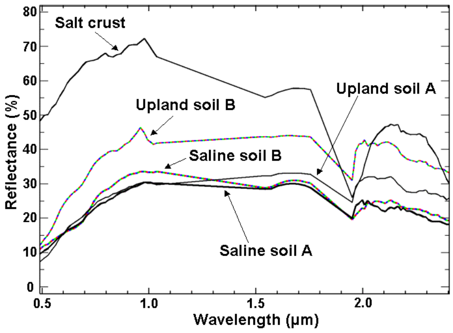

Figure 3.- Spectral characteristics of soils obtained with DAIS 7915.

A comparison of the spectral curves for various soils (Figure 4), obtained with the field spectrometer, is carried out from the *anthropogenic affected floodplain*.

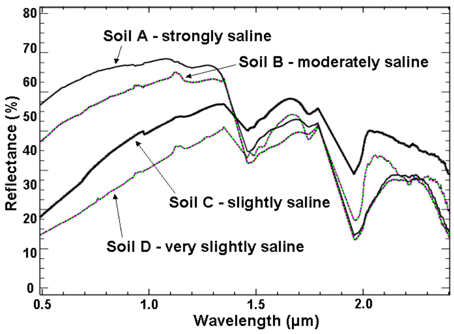

Figure 4.- Soils affected by salinity from the *anthropogenic affected floodplain*.

These soils represent various salinity classes with their respective electrical conductivity (Table 1) according to Schoeneberger *et al.,* (1998).

Table 1. Salinity classes for different soils.

Soil	Salinity class	Electrical Conductivity (dSm^{-1})
A	Very slightly saline	4
B	Slightly saline	6
C	Moderately saline	12
D	Strongly saline	17

The strongly saline soil has the highest reflectance in the visible and near infra red spectrum due to salt efflorescence on the soil surface. Again the moisture content in the soil lowers the signal response as the wavelength increases. In this case the remaining soils show a steady decrease in spectral response as the salinity decreases. However, it is to note that the spectral response in the visible and near infrared spectrum can vary considerably and the difference between the soil salinity is not so obvious.

The natural halophytic vegetation of these wetlands cover a large extent of these areas and could be a good indicator of the salinity levels found in the different soils. Therefore, it is important to determine the spectral characteristics of the different vegetation types as shown in Figure 5, obtained with the field spectrometer. There are certain vegetation species, such as *Salicornia europaea*, which are able to survive strongly saline soils and cover a corresponding area without the competition of other vegetation. The spectral characteristic of this vegetation type could indicate saline properties which are deposited by the plant as well as by wind on the surface of the scale-like leaves. As soils become less saline, other vegetation species start to compete. A steppe vegetation with *Lygeum spartum* indicate a well conserved wetland and degraded areas become colonised by *Suaeda vera* and *Limonium carpetanicum*. The *Tamarix canariensis* is a tree well adapted to saline conditions and is normally found on the edges of wetland areas.

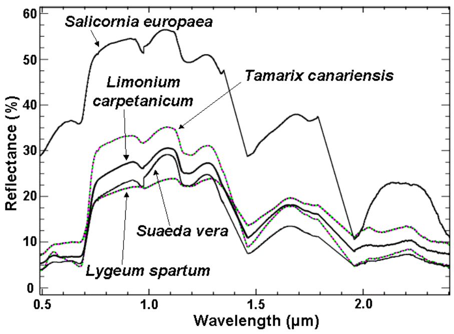

Figure 5.- Spectral characteristics of halophytic vegetation obtained with the field spectrometer the *anthropogenic affected floodplain*.

The spatial resolution of the DAIS 7915 sensor makes it difficult to present spectral characteristics of individual plant species. In this case a spatial resolution of 5 m by 5 m will seldom be dominated by one type of vegetation. An example (Figure 6) is taken from an intact saline area with a sparse steppe vegetation (Albardinal) dominated by *Lygeum spartum*.

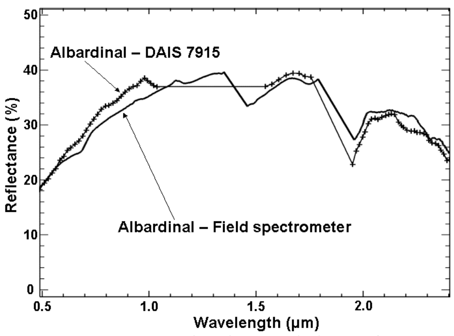

Figure 6.- Spectral characteristics of steppe vegetation (Albardinal) from the *anthropogenic affected floodplain* obtained with a Field spectrometer and DAIS 7915.

In the case of the Field spectrometer, an average radiometric curve is obtained from a transect of 10 individual points which include bare soil and the vegetation. The spectral characteristics obtained from the hyperspectral DAIS 7915 sensor is obtained as an average over the specific area where the transect was taken with the field spectrometer.

A further case (Figure 7) is taken from an area strongly degraded due to agricultural activities. As a result of salinity, these activities where abandoned and the natural vegetation has been invading the area forming a initial steppe vegetation (Limonietum) with mainly *Limonium carpetanicum*.

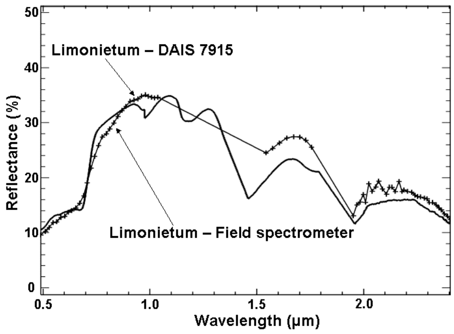

Figure 7.- Spectral characteristics of steppe vegetation (Limonietum) from the *anthropogenic affected floodplain* obtained with a Field spectrometer and DAIS 7915.

As mentioned above, the spectral curves have been obtained from a transect for the two different sensors. The vegetation cover is more dense and therefore the characteristic increase in reflectance from the red to the near infra red is well indicated.

The result of the spectral curves obtained with the DAIS sensor clearly indicates a mixture of the soil and vegetation components and the resulting curve matches to the radiometric curve obtained with the field spectrometer. This shows that the different wetland components can be identified with the DAIS sensor.

CONCLUSIONS

Spectral characteristics obtained with the field spectrometer and the hyperspectral DAIS 7915 sensor show that it is possible to differentiate semiarid wetland components associated to salinity levels.

The spectral characteristics between wetland and upland soils can be particularly well identified as well as the differences associated to salinity levels within the wetland areas.

A discrimination of vegetation types associated to salinity levels is possible with the DAIS sensor when there is sufficient extension of a dominant vegetation type.

In summary, the spectral data from the DAIS sensor can discriminate to an acceptable degree the salinity levels and moisture conditions of the semiarid wetland soils and certain spatial limitations are encountered to differentiate vegetation species associated to salinity gradients.

REFERENCES

Casado de Otaola, S. and Montes Del Olmo, C. 1995. Guía de los lagos y humedales de España, J.M. Reyero (Ed.), Madrid, 255 pp.

Cirujano, S. 2000. Humedales de La Mancha - Flora y vegetación. En Humedales de Ciudad Real, Esfagnos (Ed.), Talavera de la Reina, España, pp. 124-131.

Dehaan, R. And Taylor, G. R. 2003. Image-derived spectral endmembers as indicators of salinisation. Int. J. Remote Sensing, Vol. 24, No. 4, 775-794.

FAO. 1998. World reference base for soil resources. World Soil Resources, Report 84. Food and Agricultural Organization of the United Nations, Rome.

Gumuzzio, J., Koch, M., Schmid, T. 2000. Synergetic use of multispectral and hyperspectral data in characterising change in semi-arid wetlands in Spain. Hysens Project HS-2000ES2: "Hyperspectral Sensors (DAIS 7915, ROSIS)", DLR - German Remote Sensing Data Centre.

Klute, A. 1999. Methods of soil analysis. ASA. SSSA., pt. 1 and 2. Wisconsin, USA.

Kerr, C, H. 1998. Primary Processing software – REFSPEC.EXE v1.3. Equipment Pool for Field Spectroscopy, Natural Environment Research Council.

Koch, M. 2000. Geological controls of land degradation as detected by remote sensing: A case study in Los Monegros, NE Spain. Int. J. Remote Sensing 21(3), pp. 457-473.

Koch, M., Schmid, T. and Gumuzzio, J. 2001. The study of anthropogenic affected wetlands in semi-arid environments applying airborne hyperspectral data. In: J. Rosell Urrutia and J. Martínez-Casanovas (Editors), Teledetección Medio Ambiente y Cambio Global. Universitat de Lleida - Editorial Milenio, pp 297-301.

Mather, P., Shafri, H., Schmid, T., Gumuzzio, J. and Koch, M. 2001. Development of a spectral library for wetland degradation indicators in Spain, Natural Environment Research Council, Equipment Pool for Field Spectroscopy.

Metternicht, G. I. and Zinck, J. A. 2003. Remote sensing of soil salinity : Potentials and constraints. Remote Sens. Environ. 85, pp 1-20.

Oliver, G. and Florin, M. 1995. The wetlands of La Mancha, Central Spain: Opportunities and problems concerning restoration. In: G. Oliver, F. Moline and J. Cobos (Editors), Bases ecológicas para la restauración de humedales en la Cuenca Mediterránea. Consejería de Medioambiente, Junta de Andalucía, España.

Peinado Martín, M. 2000. Geología y Geomorfología. En Humedales de Ciudad Real, Esfagnos (Ed.), Talavera de la Reina, España, pp. 104-111.

Schmid, T., Koch, M., Gumuzzio, J., Mather, P. M. and Shafri, H. (*In Review*). A spectral library for a semi-arid wetland and its application to studies of wetland degradation using hyperspectral and multispectral data. International Journal of Remote Sensing.

Schoeneberger, P.J., Wysocki, D. A., Benham, E. C. and Broderson, W D. 1998. Field book for describing and sampling soils. Natural Resources Conservation Service, USDA, National Soil Survey Center, Lincoln, NE.

Szabolcs, I. 1989. Salt-Affected Soils. CRC Press, Inc. Boca Raton, Florida.

ACKNOWLEDGMENTS

The authors acknowledge the support of the UK Natural Environment Research Council Equipment Pool for Field Spectroscopy (NERC EPFS), for the loan of the ASD FieldSpec Pro spectroradiometer used in this research. The authors express their gratitude to the German Aerospace Centre (DLR) for provision with the DAIS 7915 data, collected during the HySens Project.