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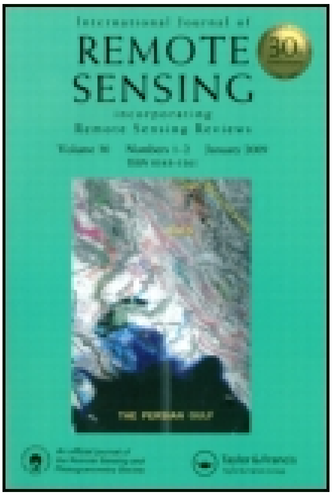

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A spectral library for a semi-arid wetland and its application to studies of wetland degradation using hyperspectral and multispectral data

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Abstract. Semi-arid wetland areas in Central Spain are especially sensitive ecosystems and are considered to be one of the most important areas for the migration and wintering of waterfowl in Europe. Many of these wetland areas are saline or sub saline and are subjected to natural (seasonal) as well as human induced changes. Factors causing changes that significantly alter or modify the ecological function of these wetlands are considered to be degradation processes. The use of hyperspectral and multispectral data together with ground spectra and field studies has a great potential for monitoring wetland conditions. In this work spectral and analytical information concerning soil, vegetation and land use, contained in a site specific spectral library, is linked with the spectral characteristics of components from an anthropogenic influenced wetland area in La Mancha Alta. This information forms the basis for determining and selecting end members from hyperspectral data (DAIS 7915), which are then extrapolated to lower spatial and spectral resolution multispectral Landsat ETM+ and TM data. A spectral unmixing is carried out to obtain a multitemporal analysis for evaluating wetland degradation. Results show that the approach is successful in determining rapid surface change due to anthropogenic influences. Spectral unmixing results present an increase of salt-affected soil and a redistribution of saline pasture. This is further supported with a post classification change detection assessment and ground data confirm that principal causes are changes in wetland use together with water regulation of the Cigüela river.

1. Introduction

The region of La Mancha Alta in central Spain contains numerous semi-arid wetland areas with small extensions, which are of great importance with respect to their influence on biodiversity and on the migratory movements and wintering of waterfowl (Moral 2000). These environments are especially sensitive to degradation

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processes. Several functional types of wetland exist in this area, in particular saline and sub saline wetlands. Frequently, these wetlands undergo important human-induced changes that tend to alter or modify their ecological function. The area is exposed to growing pressures associated with land use changes (agricultural practices) and the possible effects of climate change. The combination of these factors is considered the major cause of wetland losses in this area. 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).

The monitoring and control of the degradation processes in the semi-arid wetlands often present practical difficulties. The challenge is to detect, with adequate precision and at different temporal and spatial scales, any rapid changes in the composition of the surface land cover (soil, vegetation and water).

The main objective of this work is to evaluate the use of a site specific spectral library in conjunction with hyperspectral and multispectral data to detect spatial and temporal induced changes in semi-arid wetlands of La Mancha. This work includes measurement of the spectral characteristics of land cover components such as soils, halophytic and hydrophytic vegetation, salt crusts, upland soils surrounding the wetland areas and the land use surrounding these wetland areas using a spectroradiometer in the field. A detailed physical and chemical soil analysis on the corresponding soil samples, as well as a classification of the vegetation and land use, is also required. This approach is intended to provide information for a georeferenced data base *La Mancha Wetland Spectral Library*, which was designed to include site-specific spectral curves and additional information on different wetlands and their components. This database is the support for identifying end members of wetland components to be employed in the spectral unmixing of the DAIS 7915 hyperspectral data. The spectra of these end members is derived from the hyperspectral data and then extrapolated to the multispectral Landsat ETM+ and TM data, which are then used in a multitemporal analysis of land cover changes in the wetlands.

2. 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 the depressions. The river Cigüela meanders in a north–south direction forming a floodplain within the upper Guadiana river basin. The climate is characterized by strong summer drought and a continental character. The mean annual temperature is 14.8°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 1994, 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 with the wetlands is classified into hydrophytic (*Phragmites australis* and *Typha domingensis*) and halophytic (*Salicornia europea*, *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 in La Mancha Alta are classed (Oliver and Florín 1995) into the following types: seasonal hypersaline (Lagunilla de la Sal and Laguna Grande de Quero); riverine permanent subsaline (Laguna Grande of Villafranca) and anthropogenic affected floodplain (Cigüela alluvial plain). In many areas the level of salinization of these wetland types is influenced by land use and soil management practices. Seasonal 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. Our study site, which has an area of approximately 500 ha, is situated at Finca Pastrana in the floodplain of the Cigüela river (figure 1).

3. Methodological procedure and data acquisition

The correct identification of wetland components forms an essential part of the methodological procedure to determine wetland degradation. A preliminary characterization of the flood plain wetland in the Finca Pastrana was carried out and 16 test sites were selected to represent various conditions and components in the wetland.

A field campaign was conducted in June 2001 within the framework of the NERC project 'Development of a spectral library for wetland degradation

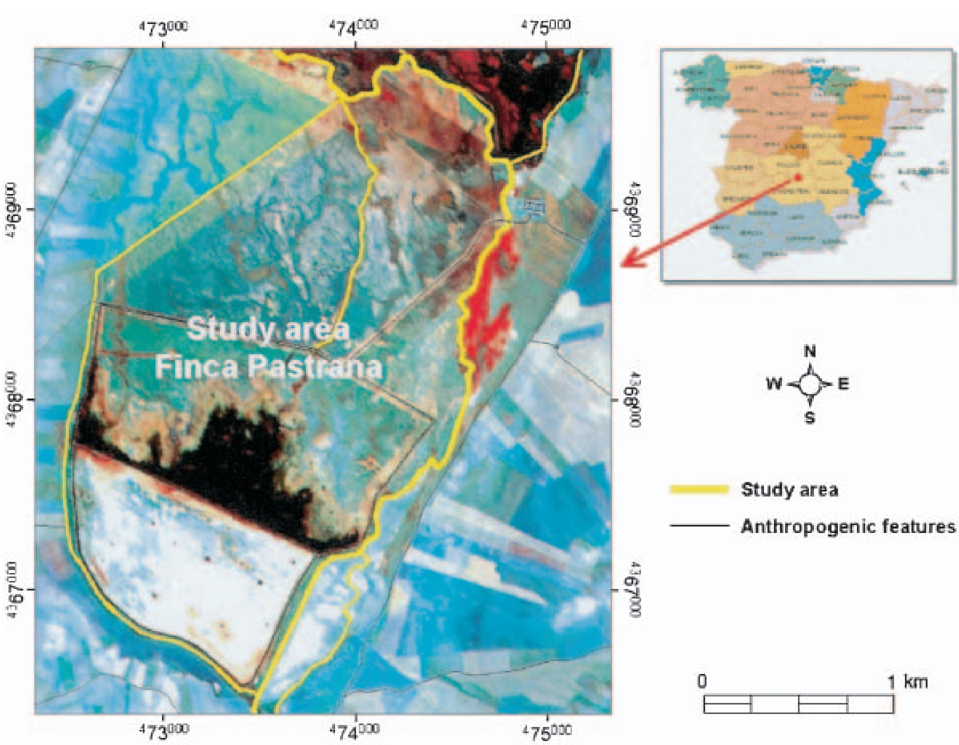

Figure 1. Study area (colour composite using DAIS 7915 bands 23, 40 and 56 displayed in the red, green and blue channels).

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 for a period of 20 days. 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 locations of the spectral measurements and sampling points were measured 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. At the location of at least one of the elements a corresponding sample was taken. Additionally, a transect of 10 radiometric measurement points with a spacing of 2 m between the individual points was obtained with the aim of representing the spectral variability within the test site.

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 (Rowell 1993). A study of the soil mineral fraction was made using X-ray diffraction analysis.

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

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, 29 June 2000 (Gumuzzio *et al*. 2000). At the time of the over flight, a field spectroradiometer, 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. In addition, multispectral data (Landsat ETM+ for 28 June 2000 and TM for 17 June 1987) were purchased for use in temporal change detection.

The minimum noise fraction transformation (MNF) and the pixel purity index (PPI) were applied to the DAIS data for noise removal and end member identification. Multi dimensional scatter plots were used to examine the selected image end members. Analysis of the image data is performed with linear spectral unmixing using an unconstrained model. Further processing includes an unsupervised classification (ISODATA) with post-classified field assessment in order to implement a change detection matrix.

4. Identification and application of wetland components

An identification of the image end members was carried out by matching field spectra from the spectral library with the image end member spectra (figure 2).

The spectral curve matching allows soil properties and ancillary data to be associated with the final identification of a wetland component. The saline soil labelled 'C' in table 1 is classified as a Salic Fluvisol (FAO 1998).

A pool of image end members was generated and identified in this manner. Five of these end members, which best describe the wetland area, were selected for use in subsequent analyses. In order to apply these end members to multispectral data, the ETM+ and TM images were co-registered and resampled to a spatial resolution of 5 m. The pixel locations of the five selected hyperspectral end members were used to

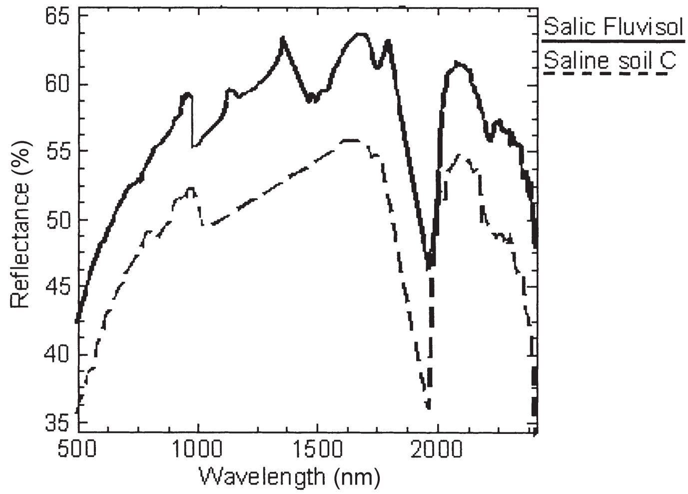

Figure 2. Spectral matching of field (solid) and image derived spectra (dashed).

Table 1. Soil surface properties of the saline soil 'C'.

Properties	Soil surface depth 0–1 cm	
General	Area	Finca Pastrana
	Date of sampling	18 June 2001
	UTM coordinates	Easting: 30 473690
		Northing: 4367128
Physical	Texture	Clay loam
	Munsell colour	Dry: 10YR7/2 (light grey)
		Wet: 2.5Y5/2 (greyish brown)
	Organic matter (%)	3.0
Chemical	pH	8.6
	Electric conductivity (dSm^{-1})	5.3
	Carbonates (%)	40.0
	Free iron oxides - Fe_2O_3 (%)	0.1
Minearology (%)	Gypsum	32.9
X-ray diffraction	Calcite	47.4
	Phyllosilicates	18.6
	Quarz	1.1

extract the pixel vectors from the same locations in the ETM+ and TM images. Figure 3 shows the Salic Fluvisol end member derived from the DAIS hyperspectral data. The corresponding pixel vector in the ETM+ image is shown in figure 4.

Spectral unmixing was carried out using a linear unconstrained model on both the ETM+ and the TM images. Fraction maps were obtained for the five end members. The results for two end members (saline soil with accumulation of salt efflorescence on the surface, and a saline pasture) are shown in figures 5 and 6.

The distribution of the Salic Fluvisol is mainly restricted to the southern part of the Finca Pastrana study area on both dates. However the fraction map for 2000 shows a higher concentration of the end member on the floodplain area, whereas in

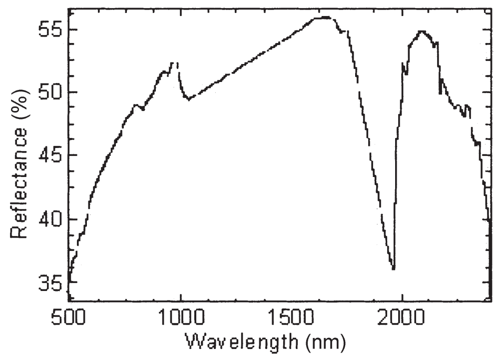

Figure 3. Hyperspectral end member.

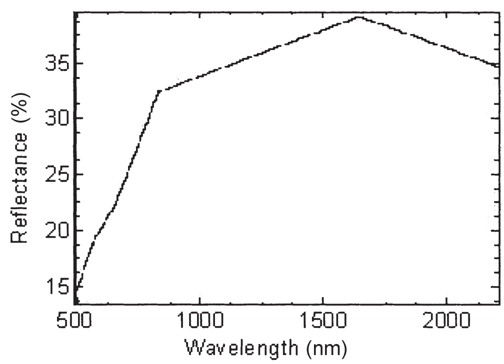

Figure 4. Multispectral end member.

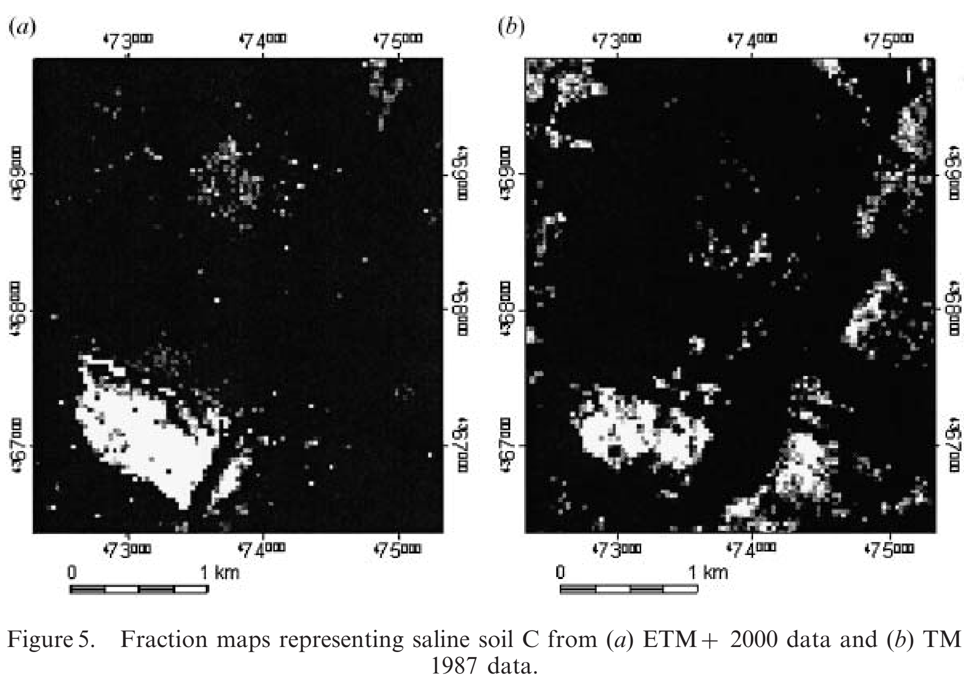

Figure 5. Fraction maps representing saline soil C from (*a*) ETM+ 2000 data and (*b*) TM 1987 data.

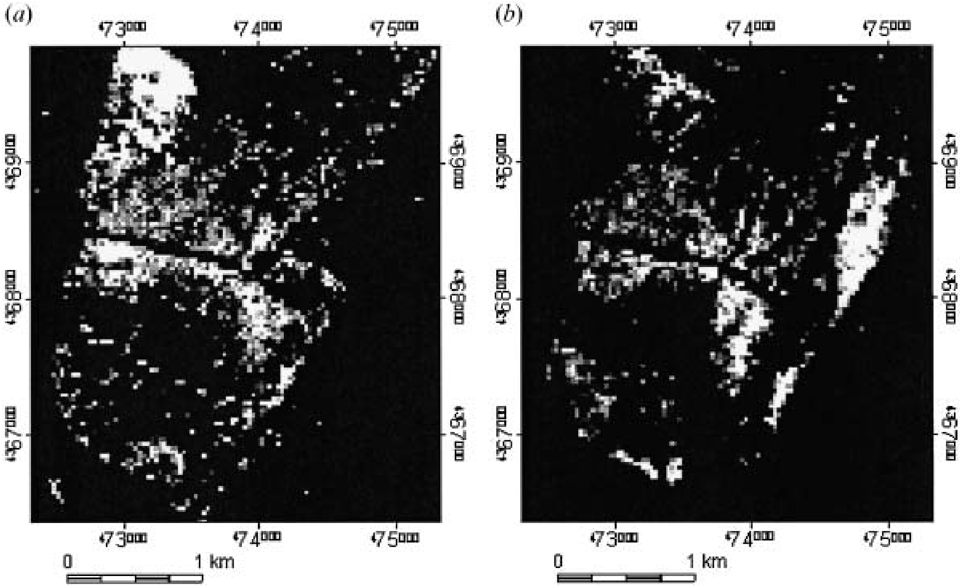

Figure 6. Fraction maps representing saline pasture A from (*a*) ETM+ and (*b*) TM data.

1987 a significant proportion was located in the periphery area surrounding the floodplain wetland. This spatial distribution pattern is related to variations in hydric soil conditions and agricultural practices, respectively.

The saline pasture end member is characterized by mixed halophytic vegetation and its occurrence is related to the amounts of soluble salts in the soil. The soil component is exposed throughout the area and contributes to the overall spectral response of this end member (figure 6). The fraction maps of both dates show similar distributions within the central wetland zone, but differences are found in the outer parts of the Finca Pastrana area. This distribution is related to land use changes, where these areas are affected by agricultural activities. The area to the east has changed from saline pasture to fallow land between 1987 and 2000. The opposite can be observed for the zone in the north-west.

In order to visualize changes in the spatial patterns of the end member distribution between 1987 and 2000, a change detection analysis for the Finca Pastrana area was carried out, using the Landsat ETM+ and TM images. The aim was to detect changes in land use/cover between the two dates and to relate this information to the results obtained from spectrally unmixing both data sets using the wetland spectral library. An unsupervised classification based on the ISODATA algorithm with post-classification field assessment is used for this purpose. The ISODATA method produces a more generalized classification of the wetland components than does the spectral unmixing method, since the former procedure is largely unsupervised.

Three images are used in the ISODATA classification procedure: DAIS (2000), ETM+ (2000) and TM (1987). The classified DAIS image serves as a reference for labelling spectral classes in the ISODATA output for the ETM+ image, since both images were taken at approximately the same time (28 and 29 June 2000). The same set of ISODATA parameters is used in all three classifications to ensure consistency. The mean spectral curve for each of the 10 resulting classes was obtained and compared across the different data sets. Classes were labelled by comparing the classification results and the corresponding spectra taken from the DAIS and ETM data sets (figures 7, 8, 9). In addition, field observations assisted in the labelling task.

Once the DAIS and ETM+ 2000 isodata classes had been matched, it was relatively easy to label the TM 1987 classes, again based on a comparison of the mean spectral curves of corresponding classes and visual interpretation. The results obtained for DAIS and ETM+ have a similar distribution of the classes within the Finca Pastrana area. This is expected, as the acquisition of the images is one day apart. The class distribution obtained with the TM image shows a clear difference in the southern part of the study area. Saline soil C covers a much greater area in the year 2000 and this coincides with the results obtained with the spectral unmixing. In the case of the saline pasture A, the changes obtained applying the spectral unmixing and the unsupervised classification is not as well distinguished. Field verification has shown that vegetation density is a key factor influencing the classification.

A post-classification comparison was performed on the ETM+ and TM classification maps using a change detection matrix. This method compares the 1987 and 2000 classification maps on a pixel-by-pixel basis and summarizes land cover change classes in a change matrix (table 2). Off-diagonal classes represent change classes and values along columns show from–to land cover changes in percentage. The change matrix shows how individual classes are transformed into another land use class. The saline soil C shows 16.29% of this class remains unchanged between the two dates. The remaining area occupied in 1987 has

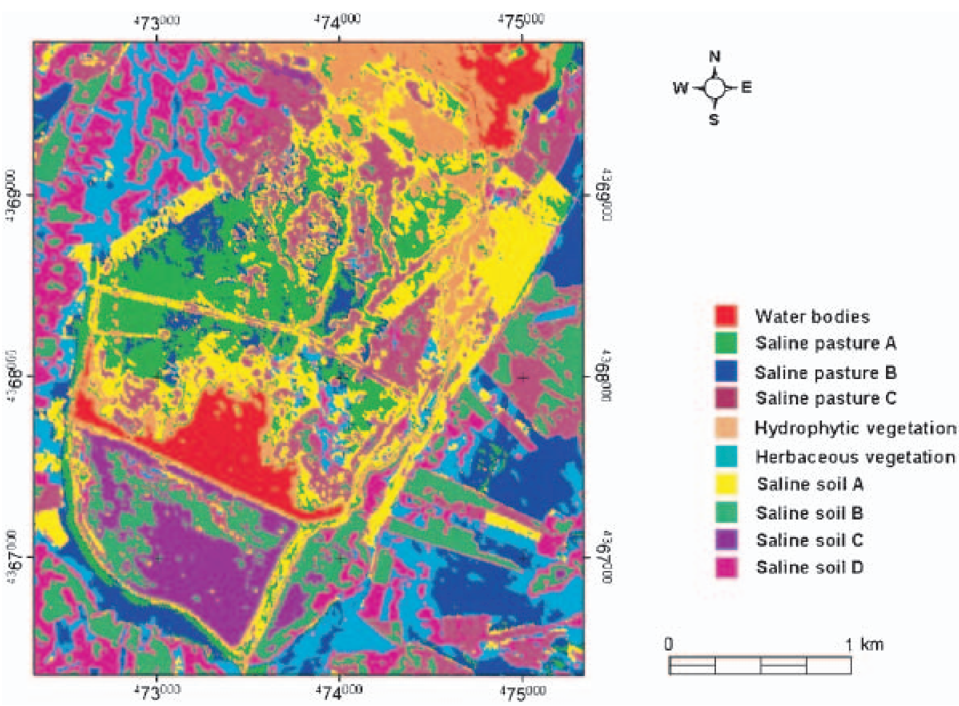

Figure 7. ISODATA classification result: DAIS image.

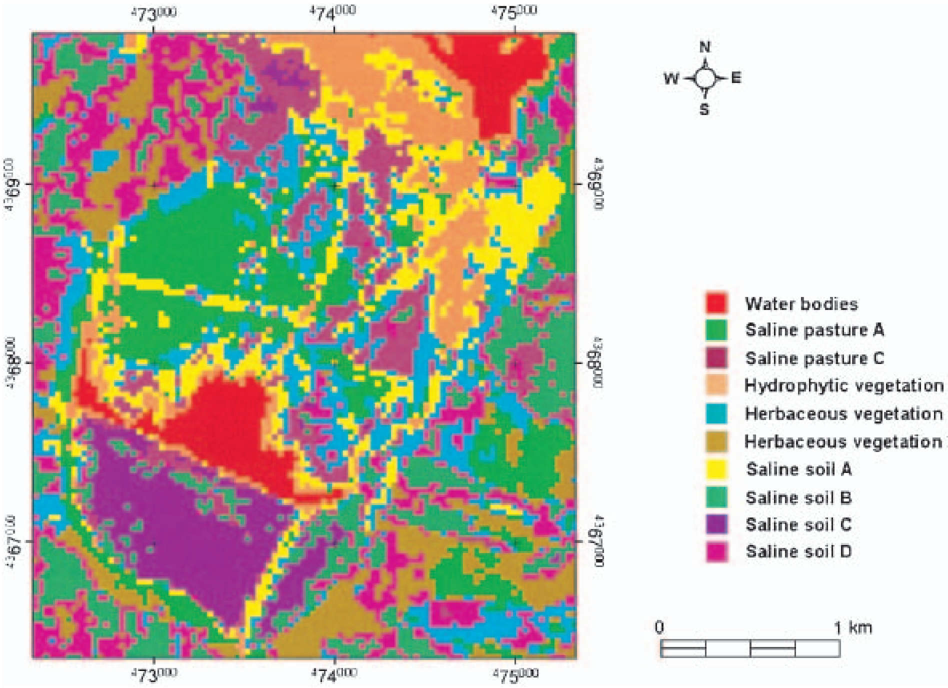

Figure 8. ISODATA classification result: ETM+ image.

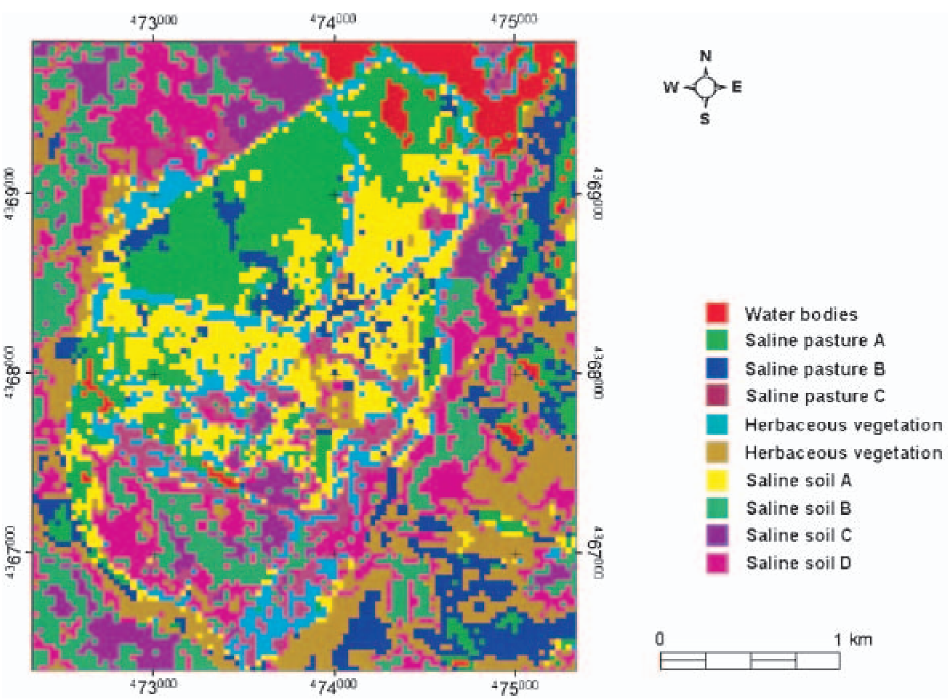

Figure 9. ISODATA classification result: TM image.

Table 2. Change matrix derived from isodata classification of the TM 1987 and ETM+ 2000 images, showing 'from–to' changes in land use and cover (in percentage).

		ISODATA 1987									
	Class %	Water bodies	Saline pasture A	Saline soil A	Herbaceous vegetation 1	Herbaceous vegetation 2	Saline soil D	Saline pasture C	Saline soil B	Saline soil C	Saline pasture B
ISODATA 2000	Water bodies	39.41	4.45	4.55	8.81	0.57	2.05	15.61	1.34	8.60	0.10
	Saline pasture A	8.52	31.30	23.81	5.30	21.36	3.79	1.84	0.73	0.14	27.18
	Saline soil A	6.65	15.50	19.07	24.42	3.75	4.64	10.70	2.92	6.19	9.46
	Herbaceous vegetation 1	1.42	17.91	19.83	10.63	14.45	10.94	10.76	8.25	3.78	21.49
	Herbaceous vegetation 2	0.47	1.11	1.74	2.77	25.93	18.68	1.10	8.18	0.41	11.90
	Saline soil D	0.47	2.71	2.65	7.21	14.65	22.28	7.54	33.30	15.12	13.51
	Saline pasture C	1.66	12.53	15.74	11.87	5.93	3.77	19.20	1.92	16.87	3.95
	Saline soil B	0.71	2.29	2.25	5.42	10.52	16.71	6.07	22.58	28.47	11.92
	Saline soil C	0.00	0.33	1.35	5.23	1.76	14.11	17.57	17.96	16.29	0.10
	Saline pasture B	40.67	11.86	9.01	18.34	1.09	3.04	9.60	2.82	4.13	0.39
	Total %	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

changed to the other classes, where the most has been converted to Saline soil B with 28.47% in 2000. Furthermore, 31.3% of the saline pasture A remains unchanged and 17.91% is converted to herbaceous vegetation 1.

The results obtained from the post-classification comparison of the 1987 and 2000 images confirms the view that the Finca Pastrana area underwent a substantial change in wetland usage due to changes in water regulation through the channelling of the Cigüela river, and the use of a dam to seasonally inundate the area. Differences in the fraction map and the classification results show that inundation occurred in the year 2000 whereas in 1987 the area was drier. This can be confirmed by the precipitation record.

5. Conclusions

The methodology outlined in this paper shows that the incorporation of site-specific data provides a basis for successful classification. Improved identification and characterization of wetland components is achieved by the use of the spectral library and is fundamental for the selection of end members.

Association of the properties of the land cover/land use types in the study area and the spectral field data further enhances the interpretation of the spectral and spatial variations observed in high spatial and spectral resolution imagery. This is especially important in wetland degradation studies, because surface cover variations are often associated with subtle changes in salinity levels, moisture content and anthropogenic influences.

The implementation of the methodology described in this paper has proven successful in determining the spatial distribution of areas of rapid change in surface cover that are produced by anthropogenic influences. Agricultural and land use changes in the study area have been driven by new environmental law policies at a European level, so that intensive cultivation and irrigation schemes have replaced traditional agricultural practices.

Acknowledgments

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