APPLICATION OF PROBA-1/CHRIS DATA TO DETERMINE DEGRADATION INDICATORS WITHIN THE SEMI-ARID WETLAND AREA (NATIONAL PARK LAS TABLAS DE DAIMIEL, SPAIN)

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KEY WORDS: Semiarid wetlands, PROBA-1/CHRIS, degradation indicators, endmembers, MTMF

ABSTRACT:

The National Park of Las Tablas de Daimiel in Central Spain is a wetland area of great value regarding biodiversity and wildlife habitat. This type of ecosystem is unique within a semi-arid climate and especially sensitive to degradation processes caused by growing pressure on natural resources (agricultural practices, groundwater depletion and land use change) as well as climatic changes. The objective of this work is to determine semi-arid wetland characteristics that are related to indicators of quality or degradation that represent the wetland state as a result of human-induced activities applying multi-angle Proba-1/CHRIS data. Data acquisitions were taken when the wetland area was under the influence of dry or wet conditions as a result of management practices intended to regulate the ecosystem habitat. The methodology is focused on obtaining wetland information related to wetland indicators (vegetation, water mass, soil and sediments). Endmembers are identified and a partial spectral unmixing is carried out applying a Mixture Tuned Matched Filtering. Results show that image-derived endmembers from the multi-angular Proba-1/CHRIS data identified a series of surface components, which are associated to the conditions and quality of the wetland area. These include important wetland indicators such as palustrine vegetation species (*Pragmites australis* and *Cladium mariscus*) and shallow water bodies. Fractional abundance maps were obtained for endmembers that were well represented within the wetland area. In this case, the identification and spatial distribution of *Phragmites australis* can be used as an indicator that is affecting the emblematic *Cladium mariscus*.

1. INTRODUCTION

Wetland areas in semi-arid regions are very important and vulnerable ecosystems. These complex and fragile ecosystems are especially important in maintaining and controlling the environmental quality and biodiversity and often undergo extreme changes from the wet to the dry season (Millennium Ecosystem Assessment, 2005; Carrasco, 2006). In Central Spain, small wetland areas are spread throughout the region and are mainly threatened by human-induced activities causing rapid processes of degradation with loss of wetland surface and, eventually leading to their disappearance (Cirujano and Medina, 2002). Activities such as intensive irrigation, overexploitation of groundwater, drying and artificial drainage of wetlands as well as altering and channelling of rivers have severely affected the wetlands and their natural functions. This is the case of the semi-arid wetland "Las Tablas de Daimiel", National Park included in the UNESCO Man and Biosphere Reserve, Special Protection Areas for Birds (SPA) and Ramsar Convention. This wetland is a refuge for endemic and threatened species of flora and fauna, but the human-induced changes lead to a loss of characteristic vegetation and large colonies of anatid invernates. Nowadays, degradation processes such as desiccation, salinization, euthrophication and contamination are seriously affecting the wetland area (Sánchez-Carrillo and Álvarez-Cobelas, 2001; Alvarez-Cobelas et al., 2007).

The monitoring of the conditions of wetlands is important in order to manage and preserve these natural ecosystems. 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). These changes can be detected with Earth Observation (EO) data, especially because wetlands are dynamic systems requiring frequent observations to capture seasonal and inter annual dynamics related to hydrological processes and human impact. Wetland areas under semi-arid conditions have been carried out in previous studies applying different types of optical sensors with hyperspectral and multispectral data acquisition capabilities (Koch et al., 2001; Schmid, et al., 2005; Andrew and Ustin, 2008). An integrated approach has been carried out where EO information from different sensors has been applied to these types of wetlands (Schmid et al., 2008a; 2008b).

The objective of this work is to determine semi-arid wetland characteristics related to indicators of quality or degradation that represent the wetland state of the National Park of Daimiel as a result of human-induced activities applying multi-angle Proba-1/CHRIS data. The work is further carried out with field and imaging spectroscopy data, soil and water analyses, field survey observations, topographic information and ancillary data. This includes selecting wetland indicators that are representative for emerging and aquatic vegetation, shallow water bodies, soils and sediments, developing a spectral library containing wetland

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indicators, identifying indicators with multi-angle hyperspectral data from the Proba-1/CHRIS sensor and applying partial spectral unmixing to determine the spatial distribution of palustrine vegetation in relation with changing conditions.

The study area (Figure 1) is located in Central Spain in the Autonomous Community of Castilla La Mancha within the Province of Ciudad Real. The area lies in a depressed basin of Tertiary materials (mainly of limestone and calcareous clays) and Quaternary sediments. The wetland is fed by floodwaters from two rivers, which gives rise to a broad riverine wetland that, in normal conditions is flooded with inputs from the discharge of an aquifer. The flooding area is 1750 ha, with permanent waters as well as shallow and seasonal waters from areas subject to regular flooding. This hydrological system promotes a shallow surface water lamina supporting characteristic vegetation that makes an excellent habitat for fauna associated with the aquatic and palustrine environment (Carrasco, 2006). Quaternary materials are associated with processes resulting from flooding by ground water (sand, mud and clay) and the growth of extensive hygrophilous vegetation, which gives rise to large amounts of accumulated organic matter (peat).

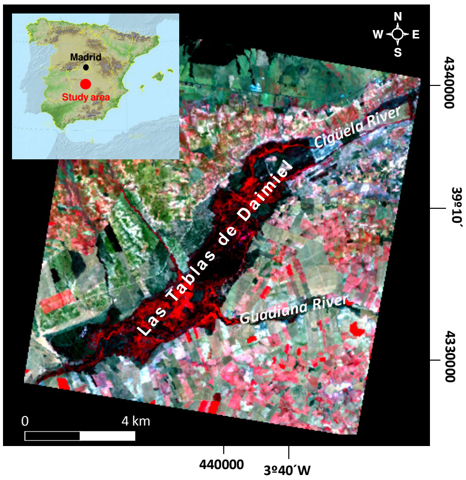

Figure 1. Study area of the Las Tablas de Daimiel wetland National Park. (Proba-1/CHRIS at Nadir from 20 July 2007 false colour composite using bands at wavelengths of 0.745, 0.664 and 0.563 µm in the Red, Green and Blue channels).

A diverse mosaic of vegetation communities include aquatic plants (*Chara hispada*), palustrine vegetation (*Cladium mariscus, Pragmites australis, Typha domingensis*), halophytic plants in areas of temporal flooding (*Salsola vermiculata, Scripus maritimus, Lathyrium salicaria, Althanea oficinales*), halophytic plants in areas rarely flooded (*Limonium carpetanicum*) and wooded areas (*Tamarix gallica, Tamarix canariensis*) within the wetland area. Detailed vegetation mapping has been carried out since the mid 1950s by several authors (Cirujano, 1998; Alvarez-Cobelas et al., 2007) and is carried out through extensive field surveys and supported by aerial photography. The state of the wetland is closely related to indicators of quality such as: 1) a clear and shallow water lamina; 2) the presence of aquatic plants with special attention given to different species of alga of the genus Chara, which live underwater (stoneworts); and 3) emergent helophytic plants such as *Cladium mariscus* (great fen-sedge), which is emblematic of the National Park. Furthermore, degradation indicators include the presence of nitrophilous and invasive species; reduction in the surface area of *Cladium mariscus*; increase of halophytic vegetation and eutrophic conditions in the surface water. Efforts to restore the wetland area by artificially supplying the area with river water have largely failed to achieve their goal.

2. METHODOLOGY

2.1 Data acquisition and pre-processing

The integrated methodology includes data obtained from a field ASD FieldSpec Pro (VNIR-SWIR) spectroradiometer and multi-angle hyperspectral satellite-borne Proba-1/CHRIS sensor. Simultaneously, water and soil samples were collected and analyzed in the laboratory as well as vegetation and terrain features that were classified according to field observations. Field spectroradiometer data was taken during the months of May 2006 and 2007, and July and August of 2007. Proba-1/CHRIS data was acquired under cloud free conditions in mode 1 on 3 July 2006, 20 July and 15 August 2007 through the ESA program providing data for a Category-1 LBR Project. The sensor acquires data at five different nominal viewing angles (+55º, +36º, 0º, -36º and -55º). The sensor in mode 1 contains 62 channels within a spectral range of 406-1003 nm, bandwidth between 8-20 nm and a ground sampling distance of 34 m.

Pre-processing of the hyperspectral data included radiometric, atmospheric and geometric calibration. System and radiometric corrections where done according to the methodology developed for ESA (Gómez-Chova et al., 2008). A geometric correction was applied using Ground Control Points (GCPs) with the corresponding root mean square (RMS) error of less than half a pixel obtained for all the CHRIS images.

2.2 Methodological procedure

A methodological procedure (Figure 2), divided in separate parts (I, II and III) was implemented to determine the capacity of the Proba-1/CHRIS data for the identification of wetland indicators.

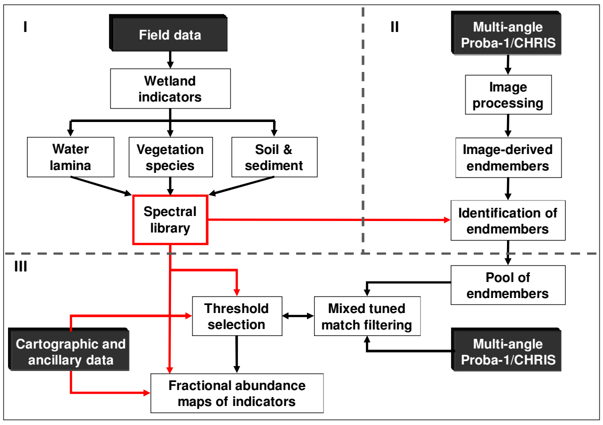

Figure 2. Methodological procedure for determining wetland indicators.

In part I, field data was obtained with the field spectrometer representing spectral properties of selected surface covers. These surface covers were characterised by soil and water studies and analyses and the classification of the vegetation. A spectral library was created containing the different field data and key reference spectra for verification and identification of results obtained in the work.
Part II was the image processing of the Proba-1/CHRIS data to obtain image-derived endmembers applying the ENVI image processing program (Research Systems Inc., 2008). Image processing included the minimum noise fraction (MNF) procedure to transform the original data to a new dataset and thereby reducing interband correlation and data redundancy (Green et al., 1988). The inherent dimensionality of the data was taken to be equal to the number of eigenvalues whose magnitude exceeded 1.0. The corresponding components for each image were input to the pixel purity index (PPI) procedure (Boardman et al., 1995), where the spectrally most pure pixels in the hyperspectral dataset were determined. The MNF and PPI results were then projected into an n-dimensional visualizer (Boardman, 1993) to determine image-derived endmembers. A pool of endmembers representing vegetation, water lamina, soil and sediment was created for each viewing angle for the different dates. The identification and labelling of the endmembers was carried out comparing key field spectra from the spectral library and verifying the location in the field.
In part III, the selected image-derived endmembers corresponding to the different wetland surface covers were introduced into the mixed tuned match filtering (MTMF) algorithm (Boardman, 1998). The MTMF performs a partial unmixing by identifying the abundance of a single, user-defined endmember, by maximizing the response of the endmember of interest and minimizing the response of the composite unknown background. To obtain the most accurate classification of each endmember, a 2-D scatter plot of matched filter (MF) values versus infeasibility was plotted. Pixels identified with a high MF and low infeasibility were likely to contain the purest endmember pixels. The optimum threshold values were determined by comparing the spectral profile of matched pixels against the endmember spectral profile. Cartographic and thematic maps as well as ancillary data were used to further optimize these values. Fractional abundance maps of the wetland indicators were obtained from the corresponding images and sensor angles.

3. RESULTS AND DISCUSSION

The results presented in this study are obtained with data from sensors operating at the field and satellite level. Field spectra and associated field observations and laboratory analyses as well as multi-angle hyperspectral data are implemented to determine the characteristics related to wetland indicators. Compilation of a spectral library played a key role to determine these characteristics (Figure 3). During the period of data acquisition, a large part of the wetland area was dry in 2006 and 2008 due to over exploitation of the aquifer by irrigation. However, in the summer of 2007, water was transferred from another region and flooded an important area of the wetland. This type of contribution is only temporal as the wetland ecosystem is adapting to a severe shortage of water.

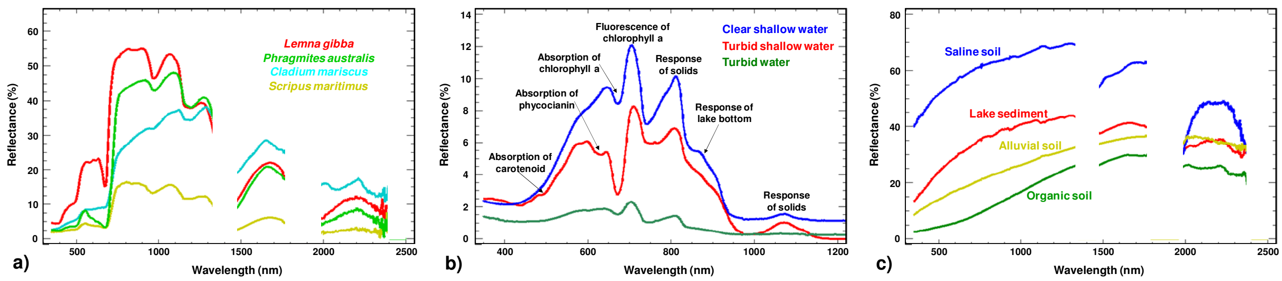

Figure 3. Field spectra obtained with the ASD fieldspec Pro for a) vegetation, b) water lamina and d) soil and sediment.

As expected, the phenological state of the vegetation is closely related to the species type and seasonal conditions (Figure 4a). The emblematic palustrine vegetation, *Cladium mariscus*, is identified with spectral characteristics that show the plant is often with reduced vigour during the summer. This perennial species has been reduced drastically as a result of intensive agricultural practices and its surface area has been reduced to 10% of the original area in the 1950's (Alvarez-Cobelas et al., 2007). *Scripus maritimus* (sea club-rush) has a reduced reflectance due to surrounding water and is found in favourable wet areas. *Phragmites australis* (common

reed) is an invasive species in maximum vigour during the summer and is seen as an invasive vegetation species. However, with increased shortage of water, even this species is being displaced by more terrestrial species (*Cochlearia glastifolia* and *Conyza canadensis*). Due to water availability in 2007, floating aquatic vegetation (*Lemna gibba*) was identified and related to processes such as water eutrophication. As a result of this water availability, different water laminae were identified (Figure 4b). The water column depth was from 30 to 100 cm, but in turbid waters the transparency was a maximum of 34 cm. In the turbid shallow water, suspended solids were of 127 $mg{\cdot}l^{-1}$ and the amount of chlorophyll was 275 $mg{\cdot}m^{-3}$. The spectral curve of this water lamina show two significant spectral features associated with cyanobacteria (phycocyanin at 620 nm) and high contents in suspended solids (1025 nm). Soil and sediment spectral characteristics (Figure 4c) were associated with laboratory analyses with the most outstanding values as follows: Lake sediment with a calcium carbonate content of 67.8 %, organic soil with an organic matter content of 54.1 %, saline soil with an electric conductivity of 38.2 dSm^{-1}, and alluvial soil with a calcium carbonate content of 30 %.
Selected field locations with known wetland components are located in the CHRIS data for the different acquisition angles and compared to the field spectroscopy data available from the spectral library (Figure 4).

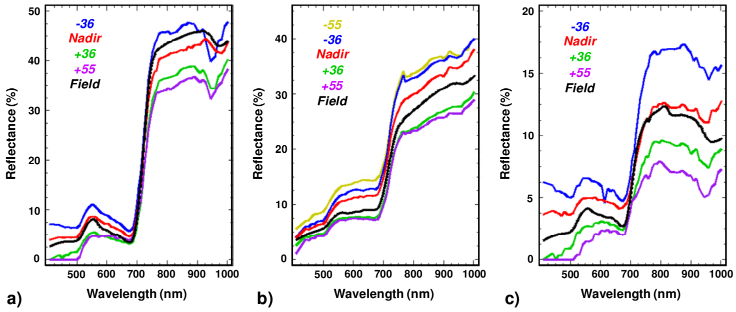

Figure 4. Spectral curves of Proba-1/CHRIS and field spectroscopy for a) *Phragmites australis* (20 July 2007), b) *Cladium mariscus* (3July 2006) and c) *Scripus maritimus* (20 July 2007).

The spectral reflectance for the different vegetation shows that there is a significant difference between the different acquisition angles of CHRIS. Forward-scattering reflectance values are considerably lower than nadir values for all the wavelengths as a result of the increased visibility of shadows cast by vegetation and soil roughness elements. Back-scattering reflectance values are higher than the nadir as there is less shadow. Furthermore, there is a high correlation between the CHRIS nadir data and the field spectra.
Four image-derived endmembers of *Phragmites australis* were selected from the Nadir image of the 20 July 2007. These endmembers were selected from areas within the wetland with different conditions and implemented into the MTMF algorithm to determine their distribution of fractional abundance (Figure 5).

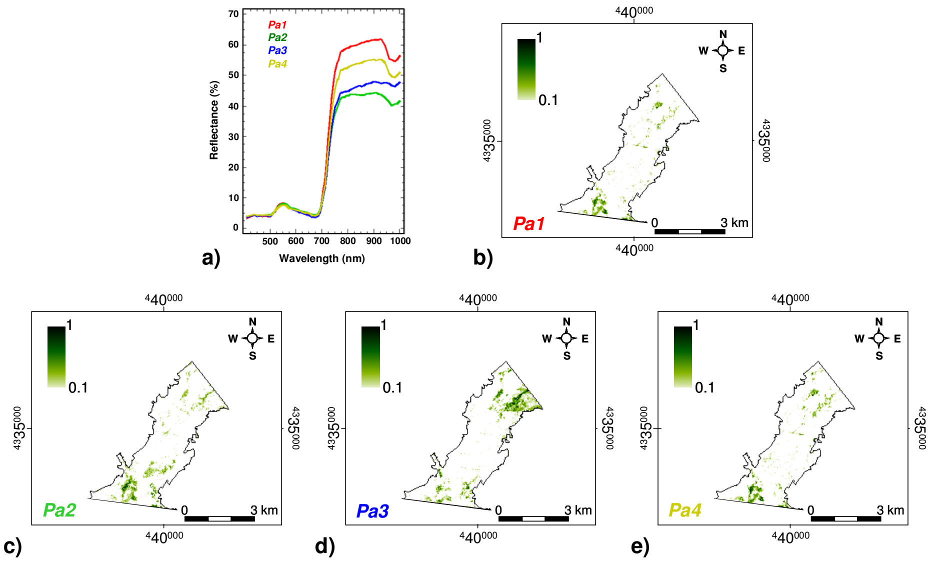

Figure 5. *Phragmites australis* (*Pa*) a) image-derived endmembers and corresponding fractional abundance maps for b) *Pa1*, c) *Pa2*, d) *Pa3* and e) *Pa4*.

The main variation between the endmembers (Figure 5a) is the vigour and cell structure within the NIR range and this is represented by variations in the spatial distribution of the fractional abundance values (Figure 5b to 5e). There is a direct relation with the water absorption value centred at 965 nm and the abundance distribution. The greater the absorption, the higher abundance values are related to *Phragmites australis* stands with a high vigour and optimum growth. Further fractional abundance maps are obtained using the *Pa4* endmember equivalent selected from the same area at the different nominal viewing angles of the 20 July 2007 (Figure 6).

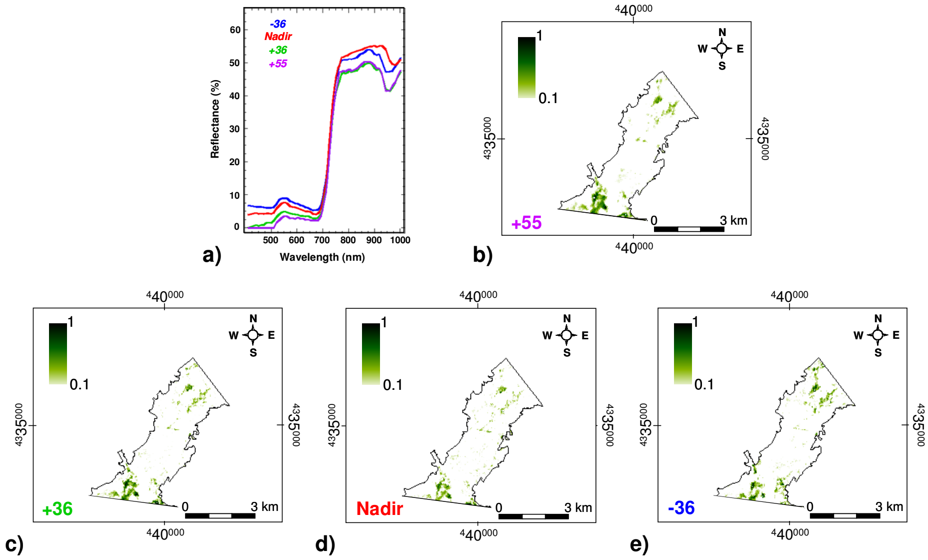

Figure 6. *Phragmites australis* a) image-derived endmembers from the different nominal viewing angles with the fractional abundance maps for b) +55, c) +36, d) Nadir and e) -36.

The spectral characteristics of the endmembers (Figure 6a) for the different nominal viewing angles are similar and the corresponding distribution of the fractional abundance values (Figure 6b to 6e) increase for the angles +55 and +36 and decrease at Nadir and -36. The *Phragmites australis* plant reaches a height of at least 1.5 m and therefore, vegetation structure and the effect of shadow increases the abundance values and distribution. Therefore, the CHRIS data identified both the vegetation properties as well as the physical structure of the palustrine vegetation. Fractional abundance maps were further obtained for the *Phragmites australis*, but using the corresponding endmembers for the different acquisition dates at Nadir (Figure 7).

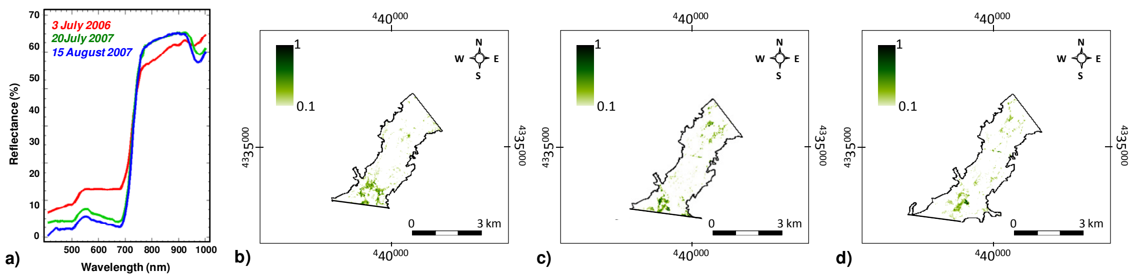

Figure 7. *Phragmites australis* a) endmembers and fractional abundance for a) 3 July 2006, b) 20 July 2007 and c) 15 August 2007.

The corresponding endmembers for each acquisition date was obtained within the same area, however, conditions changed between 2006 and 2007. Spectral characteristics (Figure 7a) showed differences in the chlorophyll and water absorption at 660 nm and 965 nm, respectively, and the vegetation vigour. Therefore, the abundance maps show an important variation between 3 July 2006 (Figure 7ba) and the two remaining dates (Figure 7c and 7d). This is mainly due to the dry conditions in 2006 that influenced the distribution of the *Phragmites australis.* In this case, variations in the wetland conditions are affecting this indicator and rapid changes are observed from one year to the next.

4. CONCLUSIONS

The study of a complex ecosystem such as semi-arid wetlands applies a methodology where there is a great interest to implement data from various sources at different spatial and spectral resolution. In this case the application of multi-angular Proba-1/CHRIS data has shown the following advantages:

- Multi-angular data has the potential to determine complex wetland indicators. In particular, this refers to the wetland vegetation as well as water lamina. However, detailed field spectra played a key role to identify the spectral characteristics obtained with the multi-angle hyperspectral CHRIS data.
- Image-derived endmembers were identified for indicators related to the degradation of the wetland. Fractional abundance maps were obtained for endmembers that were well represented within the wetland area. In this case, identification and spatial distribution of *Phragmites australis* can be used as an indicator that is affecting the emblematic *Cladium mariscus*.
- Results showed that several spectral endmembers for each individual vegetation species has to be accounted for to obtain a reasonable spatial distribution and corresponding abundance.

The identification of these different wetland indicators is an important, but challenging work. Therefore, this work is ongoing and further field campaigns together with data specific acquisition with the Proba-1/CHRIS sensor is planned.

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6. ACKNOWLEDGEMENTS

The authors would like to thank ESA for providing the data through the Category-1 LBR Project (3782) and in particular to Dr. Bianca Höersch and Peter Fletscher involved in the management and data acquisition. Special thanks also go to Dr. Luis Guanter from GeoForschungsZentrum-Potsdam and Dr. Luis Gómez from Valencia University for the system and atmospheric correction. Special thanks go to Dr. Santos Cirujano for identifying the wetland vegetation and providing the information on the distribution. Sincere thanks also go to the Director of the National Park Mr. Carlos Ruiz de la Hermosa for supporting our work and his team for accompanying us in the field work. Finally, the authors acknowledge the funding of the National Project (CGL22005-06458-C02-02/HID) by the Spanish Ministry of Education and Science.