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APPLICATION OF AIR-TRANSPORTED MULTISPECTRAL SENSORS FOR THE STUDY OF PROTECTED AREAS. AN EXAMPLE OF THE SPECIAL NATURE RESERVE "DUNAS DE MASPALOMAS" (GRAN CANARIA, CANARY ISLANDS)

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With 4 figures and 4 tables

ABSTRACT. This work wants to show the importance of air-transported multispectral sensors for the planning and managing of protected areas, in relation to environmental aspects, where they are a valuable tool to get additional information which is complementary to information obtained by field work and aerial photography.

INTRODUCTION

The use of multispectral sensors in environmental research is not new. However, they are not widely employed in the Canaries, because the spatial resolution of the sensors currently used in satellites does not allow the production of cartographic material in a more detailed scala than 1:50,000 or 1:25,000, which are not appropriate to show natural events of limited spatial extension but great repercussion in the environment (the best resolution is 10 x 10 meters per pixel of the SPOT-HRV-satellite, in panchromatic mode).

So, air-transported multispectral sensors became an alternative method (ARBIOL, 1994). They are in fact increasingly employed, especially in environmental research, where spatial resolution is equally important to spectral resolution, and have the ability of obtaining information which is impossible to gain with other methods (GUTIÉRREZ, FERNÁNDEZ-RENAU & GOMEZ, 1994).

On 28th october 1993, the sensor Daedalus Multispectral Scanner (DS-1268) flew over the Special Nature Reserve "Dunas de Maspalomas" at an height of 4500 feet, using the "Airborne Thematic Mapper (ATM)" system. It belongs to the Instituto Nacional de

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Técnica Aeroespacial (INTA) and has a spatial resolution of 1.72 m per pixel in nadir (one IFOV of 1.25 Mrad). With this sensor, information of twelve channels of the electro-magnetic spectrum can be obtained (five in the visible spectrum, three in the near infrared, two in the middle infrared and two in the thermic infrared). They are configurated in accordance to the Thematic Mapper sensor of the last LANDSAT satellites, with a line to line sensing. Two parallel longitudinal passings were made, with 20% transversal overlapping (see figure 1, reference map).

TABLE 1 - Spectral configuration of ATM-DS 1268

CHANNEL	CONFIGURATION ATM DS-1268
1	0.42-0.45 μm
2	0.45-0.52 μm (TM1)
3	0.52-0.60 μm (TM2)
4	0.60-0.62 μm
5	0.63-0.69 μm (TM3)
6	0.69-0.75 μm
7	0.76-0.90 μm (TM4)
8	0.91-1.05 μm
9	1.55-1.75 μm (TM5)
10	2.08-2.35 μm (TM7)
11	8.50-13.0 μm (TM6)
12	8.50-13.0 μm

GEOGRAPHIC CHARACTERISTICS OF THE STUDY AREA

The Special Nature Reserve "Dunas de Maspalomas" is situated at the southermost point of Gran Canaria. On an extension of 408 ha, it contains several characteristic canarian ecosystems like a system of dunes (with both mobile dunes and dunes undergoing a fixation process), a humid zone (the "Charco de Maspalomas", a small lagoon with great ornithological importance, where numerous migrating birds find a resting place on its flights between Europe and Africa), and a varied representation of psammophile and xeric plant communities. Among the latter, small *Tamarix canariensis* WILLD. and date-palm groves, found at some places, are the most important. The Special Nature Reserve was established according to the law 12/1994 of the Canarian Govermnent.

In the littoral zone of the reserve two large beaches are found (Playa del Inglés and Maspalomas). During the last 30 years, an important touristic development took place there, and today more than 150,000 beds are offered and the zone is visited annually by more than 2 millon tourists. This leaded to a strong alteration of the natural conditions.

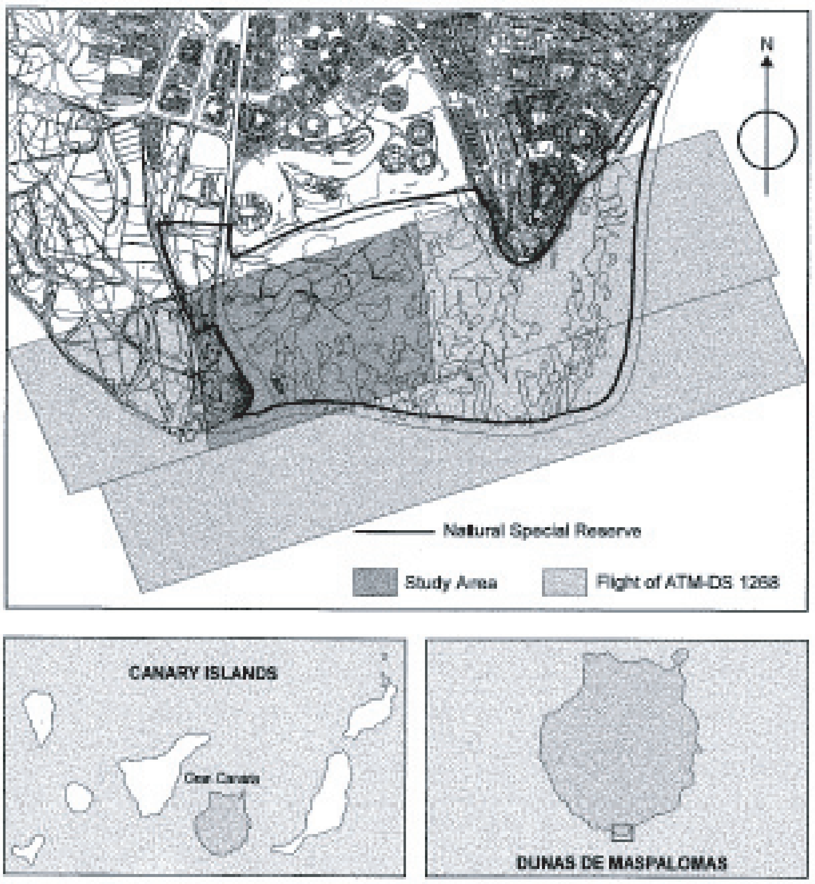

Fig. 1 - Reference Map of Dunas de Maspalomas Reserve.

OBJETIVES OF THE WORK

The objetives of this work followed two major, not mutually excluding lines:

The first had a more methodologic character and consisted in demostrate the utility of this working tool for environmental analysis of natural areas of reduced dimensions, both recognizing multispectrally the natural ressources of it (geology, vegetation, geomorphology, land uses, etc.) and as a preliminary step of management planning.

The second line had a more practical character and consisted in characterizing the different plant communities of the study area according to their spectral signature, with the help of former fieldwork experience and aerial photographies.

We tried to find correlations between vegetation distribution and vigour and environmental factors like presence of fresh water and substrates with high nutrient, organic matter, clay or carbonate content.

MATERIAL AND METHOD

In order to obtain an approximative study of the data obtained at the flight, we used a sample of a sector of one of the passings. Channels 1, 2, 3, 5, 7 and 12 were choosen, two in the blue region of the spectrum, one in the green region, one in the red region, one in the near infrared region and one in the thermic infrared region (see table 1).

The first document realized was a false-colour 753 (RGB) composition, with the aim of realizing a visual analysis which would allow us to get a global view of the area, accentuating the characteristics of the plant cover.

Later, the first digital treatment exercise was done in order to get the Normalized Difference Vegetation Index (NDVI), which can be obtained by the following formula:

$$NDVI = \frac{\mathrm{NIR} - R}{NIR + R} \qquad \textbf{(1)}$$

where NIR means the near infrared band and R the band corresponding to the red channel of the visible spectrum.

The reason for using these channels is, that in the near infrared the vegetation has its greatest reflectivity, while in the red channel this value is very small. The rest of the spectral responses are annulated by this quotient, because they show a similar behaviour in these two bands of the electro-magnetic spectrum. The characteristics of the vegetation state, like stress niveau or vigour (MELIÁ, GANDÍA & CASELLES, 1986), are pointed out. When normalization of the data is done, results are limited between -1 and +1; so, interpretation of the obtained image is easier (CHUVIECO, 1990). The nearer this value is to +1, the better is the condition of the vegetation (see figure 2).

A second analisis done was that of the main components of the image (PCA). This is based upon statistical multivariant analysis. There is some repetition of the information given by the bands of a multispectral image, with a high correlation of the data. With the aid of a lineal combination between original data, new bands are created, which are lineally independent between themselves (PINILLA, 1995).

In this case, bands number 2, 3, 5 and 7 were used. In table 2 and 3, results are exposed, expressed in percent of the original variance associated to each component. The eigenvector matrix of the image is also shown, where we notice the association between the first three components and the original bands.

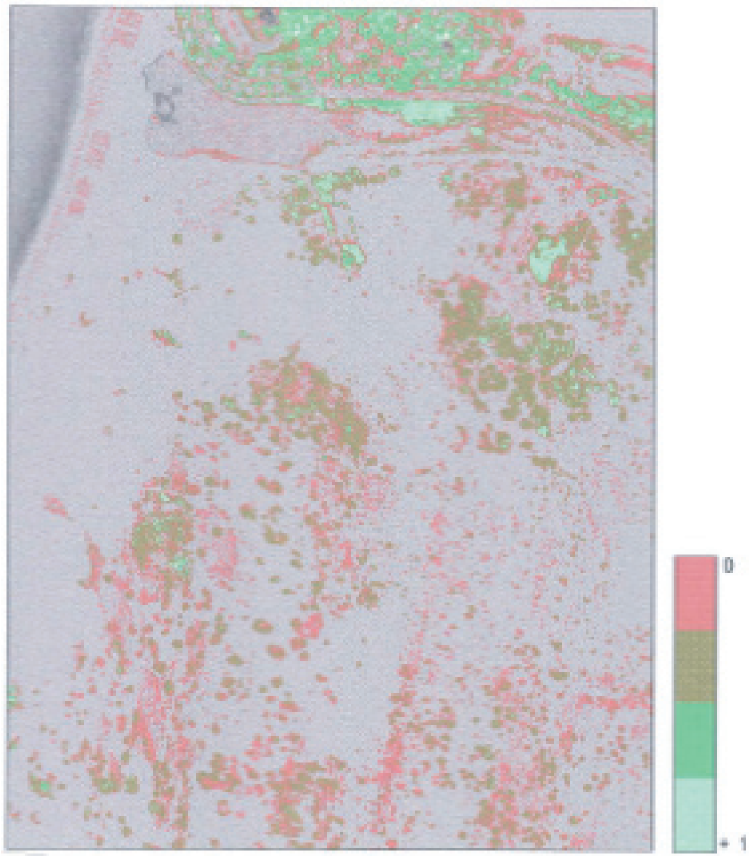

Fig. 2 - Normalized Difference Vegetation Index (NDVI).

TABLE 2 - PCA. % of the original variance

Principal components analysis (% of original variance)				
Component	1	2	3	4
% Variance	95.06	3.87	0.72	0.35

TABLE 3 - PCA. Eigenvector-matrix

Principal components analysis (Eigenvector-matrix)			
Components/Bands	Component 1	Component 2	Component 3
Band 2	0.222	-0.099	0.838
Band 3	0.707	-0.318	0.135
Band 4	0.570	-0.147	-0.526
Band 5	0.356	0.931	0.052

The most significative result obtained of this data is that the first component represents more than 95% of the original variance of the image (see figure 3). This means, that it accumulates nearly all the data of the selected bands. The second component has 78.34% of the rest of the original variance, whilst the third component represents 67.29% of the rest. This means that the three first components occupie more than 99% of the original variance of the image, or of the reflectivity received by the bands analized here. The fourth component receives non-relevant information which is present only in some pixels of some of the bands. Therefore, only the three first components were selected for later analysis.

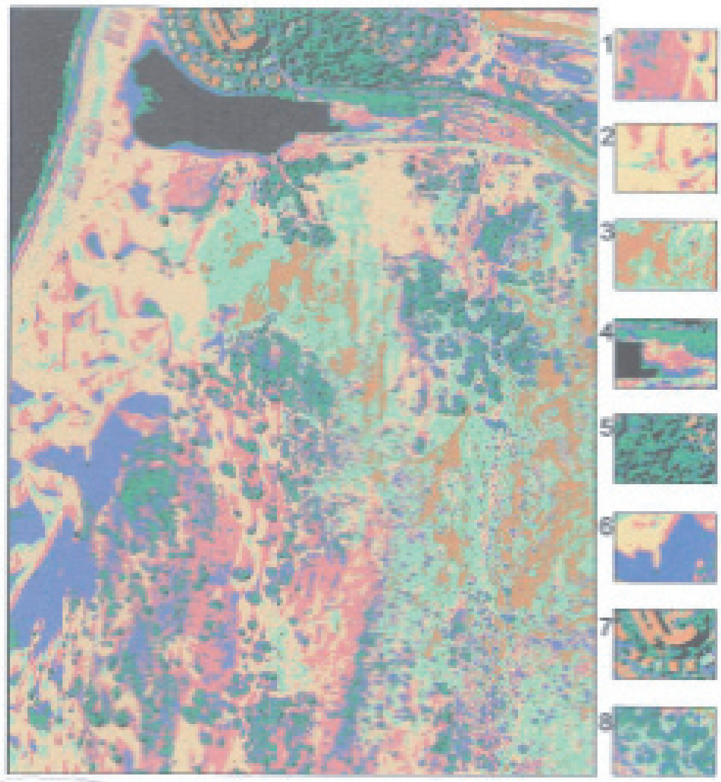

Fig. 3 - First principal component.
Legend: 1- Sedimentary terraces; 2- Mobile dunes system, 3- Fixed dunes system; 4- Wetlands and associated vegetation; 5- Phoenix groves; 6- Salty soil depressions; 7- Urbans site, 8 - Tamarix groves.

The spectral sense of the components is given by the eigenvector-matrix, where the association between each component and the original bands is shown (CHUVIECO, 1990).

So, it is possible to determine that the first component is a ponderated average of the reflectivity of all the bands that compose the image, which allows us to recognize the common features present in all bands. The second component has a more clear spectral explanation, as the features related to the vegetation that are present in the image stand out, because the highest value is found in band 7 (NIR), which is more sensitive to the spectral response of the vegetation. The other values of the visible spectrum are low and negative. The third component seems to correspond to the interaction of the atmosphere, because the highest values are located in the band belonging to the blue sector of the visible spectrum, which is the most sensitive to atmospherical dispersion processes.

Later, the spectral response of each of the elements which were recognizable thanks to our field knowledge of the area was realized, analizing its reflectivity. The digital values (DV) were considered as previous steps for determining in later works if the results of a supervised classification automatically allows to identify and represent in cartography the differentiated elements in relation to their spectral response (see figure 4).

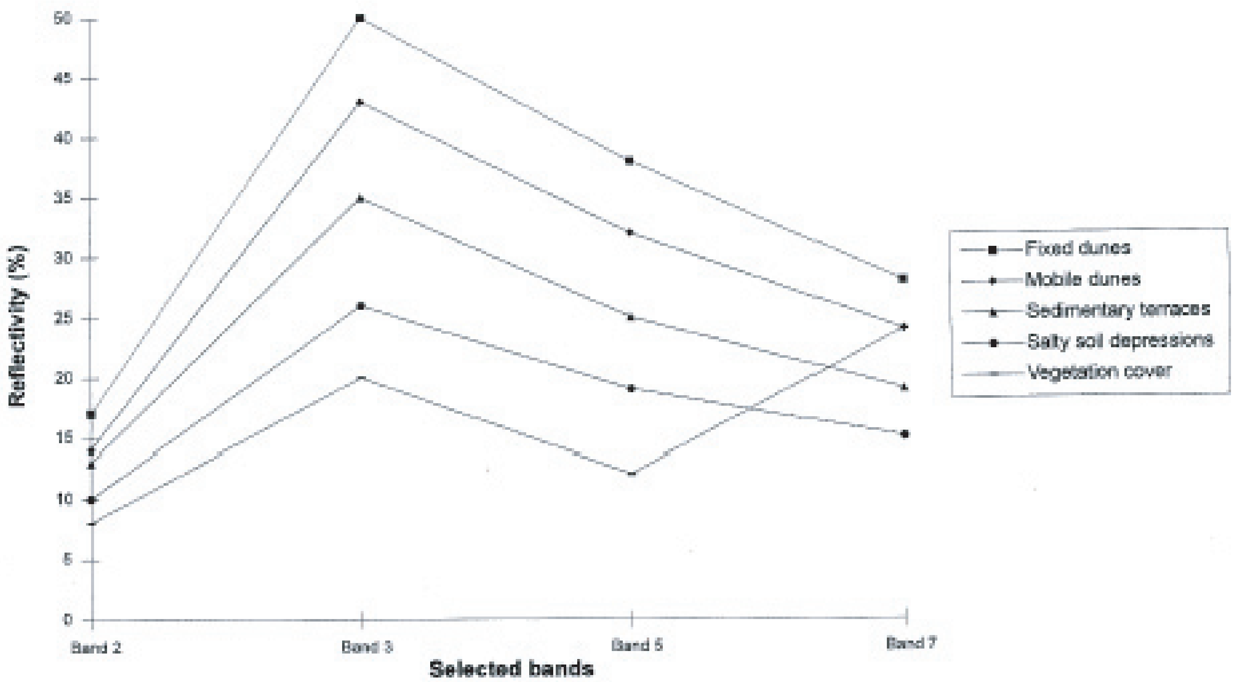

Fig. 4 - Spectral Response of covers.

Several polygons of the cover to identificate were taken for this purpose. In the following table, the numbers of pixels taken as samples for the spectral caracterization of each cover is shown.

TABLE 4 - Spectral analysis of the covers. Samples.

Spectral analysis of the covers	
Covers	Number of pixels
Mobile dunes	2.156
Fixed dunes	7.628
Salty soil depressions	969
Sedimentary terraces	3.348
Vegetation	1.093

ANALYSIS AND INTERPRETATION OF THE RESULTS

1 - Normalized Difference Vegetation Index (NDVI)

This digitalized treatment of the mentioned bands allows us to differentiate very well the *Suaeda vermiculata* FORSSK. ex J.F. GMEL. scrub vegetation. It is located on compacted material of sedimentary terraces and is dispersed and very poorly developed, apparently being in a period of strong water stress, with many death vegetative parts. Its reflectivity level in near infrared is low.

It also allows us to differentiate (characterized by high value in NDVI) the more dense scrub vegetation with *Launaea arborescens* (BATT.) MURB., *Schizogyne glaberrima* DC. and, over all, *Juncus acutus* L.. It is in a good vegetative condition, showing great vigour, and indicates the presence of a high phreatic level of fresh water. This is corroborated by the excellent near infrared reflectivity of the date palms which grow at this places.

The interpretation of this image, complemented with the field work information, permits an evalution of the quality of the *Tamarix canariensis* groves, making it perfectly possible to distinguish vigorous parts and those parts with diminished vitality, possibly due to human interference or to disfavourable water conditions or wind-broken branches. Tamarix groves and isolated individuals in good vegetative condition contrast sharply and can possibly be taken as bio-indicators of zones with good (saline or brackish) water supply.

In relation with the hydrophitic vegetation, groves of *Phragmites australis* (CAV.) TRIN. mixed with *Juncus acutus* can be distinguished very easily. They have the highest NDVI value (near +0.7) and are located at the back side of the lagoon and in other areas with very high phreatic level. They indicate natural wet zones or potential wet zones to be regenerated.

The groves of *Juncus acutus* which grow on compacted sand bordering the sedimentary terrace at the interior of the dune zones are also very well detectable by its great vigour. They are bio-indicators of very high fresh-water phreatic levels.

In salty soil depressions in the zone of mobile dunes, the index allows us to recognize, also due to their great growing vigour, the *Cyperus laevigatus* L. ssp. *laevigatus* "lawns".

2 - Principal Component Analysis (PCA)

Several factors determine the zonation recognizable on the images. First, it is possible to differentiate the mobility of the sandy substrate, which allows us to define one area of mobile dunes and another of dunes undergoing a fixation process. On the other hand, a marine phreatic level, which extends to the interior of the zone of the dunes, can be identified. It has a very low spectral response on all the bands.

As a result of the analysis and interpretation of the images, it is also possible to recognize the presence of a compacted, non-permeable substrate (sedimentary terraces), where there is a greater abundance of clay and carbonates. On the other side, the presence of some fragments of hydrophitic vegetation in some areas close to the lagoon, but situated more to the interior of the dune field, reveals the existence of a superficial phreatic level which may be an indicator of a former lagoon in this zone.

The colour image of the principal components allows us to differentiate clearly the moist, salty soil depressions between the dunes. The mobile dunes move over this depressions which, at high-tide, are covered by seawater which can reach up to 300 m to the interior of the zone of the dunes.

At the most interior zone of the Special Nature Reserve, the difference in reflectivity between mobile dunes, which are increasingly scarcer here, and the dunes undergoing a fixation process, is very conspicuous. The latter type of dunes accumulate a higher concentration of organic matter in its incipient soil, or have a different mineralogical composition.

In this zone, it was not possible to detect the "lawns" of psammophile *Cyperus kalli* (FORSSK.) MURB. and *Ononis serrata* FORSSK., without doubt the most extensive plant cover in this area, because the species mentioned are annual and were not in the vegetative phase when the survey was made.

However, this differentiated spectral response has very much to do with the peculiar behaviour of *Cyperus kalli*, a rhizomatous geophyte which develops an intrincate web of rhizomes and roots from the soil surface to more than 25 cm down in the sandy ground. These rhizomes sprout after good rainfalls, thus forming extense patches of clonal origin (LICHT, 1975).

In this sector, between the soil depressions covered with dense scrub vegetation and the lagoon and the canalized part of the ravine, an area with a greater reflectivity in all the bands can be identified. It coincides with the highest part of the whole dune zone and may represent an area of fossil dunes. At its eastern flank, these ancient dunes are progressively dismantled by aeolic erosion and because no new sand supply is possible due to the presence of the well-vegetated soil depressions that are situated in front of them. In the zone of fossil dunes, only very small extensions of *Cyperus kalli* are found, which is not able to colonize the rest of the dunes. The dynamic of the dune is retarded here and dies at its western face, where *Tamarix*-groves ascend, elevating the height of the dunes which fall backwards, with a difference of more than 10 m in relation to the zone of dense tree vegetation which is found in the vicinity of the former Heliotherapic Center.

Between the mobile dunes and the fixed ones, there is a zone with a sedimentary terrace 2 m in height (KLUG, 1968). It is non-permeable, with great abundance of stones, high clay concentrations and presence of carbonate crusts.

On the images, we can observe the heterogeneous deposits with clayish alluvial material behind the lagoon, above the canalized tract of the ravine. This material was dragged and swept away by the ravine, the Barranco de Maspalomas.

The documents also allow us to detect very clearly former anthropic actions: for instance, in the contact zone of the mobile dunes and the lagoon, deposits of clayish sedimentary material that was excavated out of the lagoon; and in the zone of the fixed dunes, the places where in 1989 the Hotel Dunas and in 1992 the Heliotherapic Center were pulled down.

At last, the analysis of the components, as it ocurred with the NDVI, allows us to distinguish clearly the zones where certain hydrophitic vegetation types concentrate, especially the vegetation dominated by *Juncus acutus,* and the zones with optimal tree (*Tamarix*-groves) and shrub (*Juncus acutus*, *Schizogyne glaberrima* and *Launaea arborescens*) cover. They are excellent bioindicators of a high phreatic level of fresh or brackish water. The field study revealed that in those points, water was found in less than 1 m depth, usually associated with very compact sand masses.

3 - Analysis of the reflectivity of the covers.

In the study of the reflectivity of each of the analized covers, it was significative to observe that the band corresponding to the blue channel of the visible spectrum (band 2) had a very low reflectivity due to interactions with the atmosphere. The highest reflectivity was the one of the green band, except for the vegetation cover, where the highest reflectivity corresponded to the infrared. On the other hand, the data of the standard deviation are very low, of which we can conclude that the samples taken are homogeneous and representative.

Anyway, we have to consider that what is shown here is only a sample. For optimal understanding of the spectral response of the covers, we have to analize the totality of the data obtained in the two passings made by the plane.

DISCUSSION AND CONCLUSIONS

Although we had no field data collected at the same time the sensor fligh was realized, and that we analized only some of the bands from which data were available, the results seem very satisfactory. If we could have disposed of those data, without doubt we would have been able to make some correlations between them and the reflectivity shown by the sensor. This would have been relevant for characterizing the trophic state of the Maspalomas lagoon (LÓPEZ & CASELLES, 1989). In the same way, if we would have worked with some of the other bands from which data were available, as the middle infrared, this would have been helpful for characterizing more precisely the different species which form the plant cover. In this band, which is extremely sensitive to changes in water vapour content, vegetation present most irregularities, depending mainly on the species (MELIÁ, GANDÍA & CASELLES, 1986; CHUVIECO, 1990).

As a conclusion, we confirm the suitability of the methods applied for the caracterization of natural ressources, ecosystems and ecological processes of protected areas of reduced dimensions, as a previous step for plannification and managing.

At one side, air-transported multispectral sensors permits us to identify the plant communities present in a zone, after an analysis of the spectral signatures. This makes it possible to draw a precise cartography, and to evaluate the vigour and health state of the vegetation.

On the other hand, we can delimit environmentally homogeneous units, in relation to certain ecological processes or ecological factors like vegetation, humidity, soil types, etc. The apparent uniformity and monotony of desert territories like the one studied, reveals to be in fact complex when tools like the ATM sensor are applied, and when the field study data are correlated with those obtained by digital treatment of the images. This allows us to detect correlations not described in previous papers which followed more traditional working methods like aerial photography, granulometric analysis, etc. Therefore, the utility of the spectral analysis for detailed and precise carthography of terriories with similar characteristics of the one studied, is very obvious.

With this previous training, precise carthographic documents can now be elaborated of the Special Natural Reserve, appliying the results obtained by conventional digital treatment to the rest of the data obtained by the air-transported sensor.

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