Landcover degradation analysis of Mediterranean forest by means of hyperplanes obtained from mixture linear algorithms (MLA)

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ABSTRACT: The percentage alteration of the Mediterranean forest landscape is one of the primary indicators for its degradation. In this sense, the land cover abundances change analysis by using mixture linear algorithms (MLA), is presented like a good alternative to study this degradation. This research analyzes the use of two information sources like Remote Sensing (Landsat-ETM+) and Field Radiometry (GER 1500) to obtain mixture hyperplanes. These are calculated by models based on *least square estimations*, assuming that each pure land cover (*endmember*) belonging to any geographic area, behaves as a random variable which distribution function is known. The mixture hyperplanes provide spectral signatures with a suitable correlation level with regard to the supplied from remote satellite sensors once corrected, for the same geographical zone. These established hyperplanes can be used in future researches about Mediterranean forest landscape changes, because they can represent the different levels of its degradation. In this sense, it is proposed that they will feed a land cover spectral library with free accessibility.

1 INTRODUCTION

The uncontrolled urban development brings about not expected and not wished environmental changes. Particularly, the Mediterranean landscape is a good example because it has been under serious and continuous anthropogenic pressure since historical times. Severe degradation of soil and vegetation resources can be observed as a result of such pressure. An analysis of the “observed” changes of the development of vegetation cover may hence serve as a key indicator of its degradation. In this sense, we addressed the problem researching jointly remote (Remote Sensing) and near (Field Radiometry) sensing data. We feel that both techniques can offer us an adequate source of information about land cover degradation.

In remotely sensed data, pixels containing mixed spectral information about the objects under study are commonly found. This is due to the limitations of the spatial resolution of the remote sensor and the heterogeneity of features on the ground. As a result, most detected surfaces within the instantaneous field of view (IFOV) of the remote sensing instrument are spectrally complex and therefore create a heterogeneous spectral mixture rather than one spectrally “pure” signal within the pixel. In spectral mixture theory, the spectral signal of a pixel can be represented as a mixture of signals contributed by all spectrally “pure” features, or *endmembers* (Lillesand 2000), within the IFOV of the sensor at a given time (Chen 2006).

The identification of the pure pixel value is often difficult (Olthof 2007). Nevertheless, the register of land cover spectral response by measurements *in situ* by Field Radiometry can be a good alternative for this task. This technique is able to provide a good set of *endmembers* and in addition refers to spectroscopic measurements made outdoors, with the sun as the primary source of illumination, and allows to the detection and analysis of the spectral characteristics of the land covers in its natural surroundings.

Previous studies exist, related to the sampling method in the spectral register processes (Vazquez 2004, 2007), specifying exhaustively the directives of sampling *in situ* (Field Radiometry). These researches solve a very important aspect, that is the determination of the minimum and optimal number of spectral samples (so large sample) that it is necessary to register for each land cover *endmember*.

In this paper, we have hence employed a mixture linear approach to cope with the different levels of forest landscape degradation. We show an approach to analyze the question above: the use of mixture linear algorithms (MLA) obtained from mixed models based on *least square estimations*. It is assumed that each of the pure existing cover (*endmember*) belonging to any geographic area behaves as a random variable which distribution function is known (Vazquez 2007). Later, the zone at issue can be subdivided in smaller territorial units until its intrinsic behavior be homogeneous from a spectral point of view. These units will be the basic elements to build different "ad-hoc" statistics that can bear in mind the characteristics and variability of real existent land covers. In the limit, the values of these statistics will be the "observations" that will be needed for the *least squared estimation* method. The obtained mixture hyperplanes (Vazquez 2008) will provide spectral signatures with a suitable correlation level with regard to the supplied data from remote sensor ETM+ with a atmospheric correction (Vermote 1997), for the same geographical zone.

The results of applying this approach to a Mediterranean forest zone with different degradation levels are shown and the different mixed hyperplanes considered are able to represent efficiently the different levels of degradation.

2 DATA SET DESCRIPTION

For the present work there has been chosen one of the most typical places of the Madrid Community (Spain), which corresponds to a Mediterranean ecosystem forest principally composed by oaks, bushes and meadows. The study zone is situated in the Mountgancedo near of Madrid City. This site is located to the south-west of the Community, and it has a surface of 125 hectares. The study area selected is located at 40º 24´30´´ N, and 3º49´50´´ W (4473/4474 N, 429/430 W UTM) (Fig. 1). Several Mediterranean species of vegetation coexist besides natural meadows, rocky outcrops, bare soils and a set of generated covers by anthropogenic effects like asphalted paths of some new little cities with commercial buildings and sports center.

The land cover spectral samples have been obtained in the summer by Field Radiometry (GER 1500), in accordance with Landsat ETM+ remote data register. Even though the remote sensor (ETM+) has six bands with the same spatial resolution, only the first four ones can be considered according to the spectral register interval of field radiometer; in order to correlate both sources of information. Sampling *in situ* has been carried out according to a methodology (Vazquez 2007) that optimizes the number of samples to pick-up.

Since the data registered *in situ*, provides a continuous spectral response, a previous reduction methodology based on the integration of the radiance values (Arquero 2003) into the spectral bands interval selected, was carried out. Thus, the field spectral data had been reduced to field spectral signatures, with four values named R-ETM+1, R-ETM+2, R-ETM+3 y R-ETM+4, compatibles with the first four bands of the remote sensor.

3 METHODOLOGY

The used sampling methodology starts with the identification of the landscape unit to be analysed. We select geographical units that represent mixed pixels with different levels of Mediterranean forest degradation. With the aim of doing correlation studies between near and remote sensing data, the selected units have equal dimension that the remote sensor spatial resolution and will be called

Global Unit (**G_u**). This one will be submitted to a process of successive subdivisions, with the purpose of get smaller units or *Intermediate Units*, **I_u**, composed, in turn, by indivisible ones called *Elemental Units*, **E_u**. These smaller units have a spectral response corresponding to a land cover *endmember*. This methodology has been proposed and justified in a previous research (Vazquez 2008) and a small summary appears later.

Figure 1. Visualization of coloured (RGB) aerial image of Mountgancedo area. The zone of study is marked with a square.

As selected **G_u**, it has been chosen five squares that represent five levels of degradation, belonging to a Mediterranean forest placed in the surroundings of Madrid (Spain). They have 30x30 meters of side and fit with the spatial resolution of the remote sensor (Landsat 7 ETM+). Each one of them is subdivided in 64 **E_u** (4x4 meters). In this way it is possible to assure their good spectral representation. Usually the size of the **E_u** is small compared with **G_u**, especially in the fairly common case when landscapes with great covers variability are analyzed. To assure the management of an optimum number of samples it is necessary to create a new unit, called **I_u**, whose dimension will be between the Global and the Elementary Units. In our case its dimension will be equal to 20x20 meters that corresponds to 25 **E_u** (Fig.1). The criteria to design the more representative statistics for **I_u** could be based on a strategy of "considering" more or less the information belonging to the different Elementary Units. In this sense, we propose the “balanced statistic” that consists of assigning to each **E_u**, identical "weight”. So, each of them equally will contribute to the total spectral response of the **I_u**. This idea is showed in the next expression:

$$R_{I_u} = \frac{\sum_{i=1}^{i=5} \sum_{j=1}^{j=5} x_{ij}}{5^2} \quad (1)$$

For the representation of the Global Unit in the sampling process, it is proposed the accomplishment of a diagonal double sampling to obtain 8 point estimations corresponding to each of the **I_u** included in it (Fig.2).

As for the estimation procedure for the Global Unit reflectance there has been chosen the *least squares method* since this one does not need the previous knowledge of the joint density probability function to the analyzed area. It has been used the *least squares method* with abundance constraints. The constraint considered is the full additivity. This requires that the abundance for a mixed pixel must be one. Otherwise if we suppose that the land cover samples come from normal populations and, in addition, it is possible to demonstrate that the mistakes random variable that represent to them has null average and identical variance, the previous method of adjustment acquires a new perspective from inferential-statistic viewpoint.

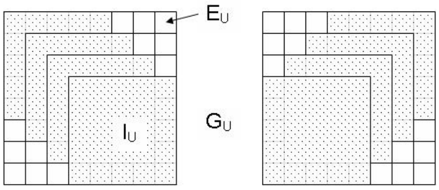


Figure 2. Sampling Units: Global Unit (G_u), Intermediate Unit (I_u) and Elemental Unit (E_u).

This methodology is applied to simulate spectral signatures for the selected geographical $\mathbf{G_u}$ and a set of mixed hyperplanes are been obtained. Once obtained linear mixture results, it is made a correlation between this information and the provided by the remote sensor (once corrected from atmospheric point of view) in the same period of time. The study area basically contains three natural covers: oak, meadow and shrub; and two anthropogenic cover: sport court and fallow.

4 RESULTS

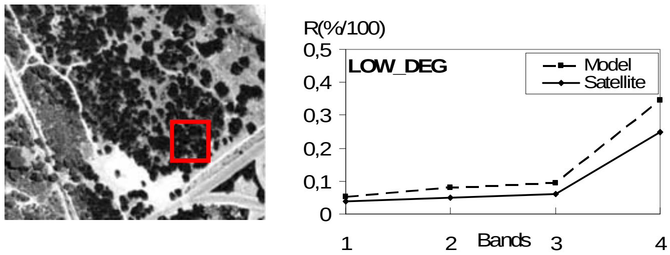
The regression models for each band (mixed hyperplanes) obtained by *linear least squares techniques* through balanced statistics applied on $\mathbf{I_u}$ double diagonal sampling in $\mathbf{G_u}$, and are shown in the next table (Table1):

Table 1. Obtained mixed hyperplanes to Global Unit for the five choose levels of degradation

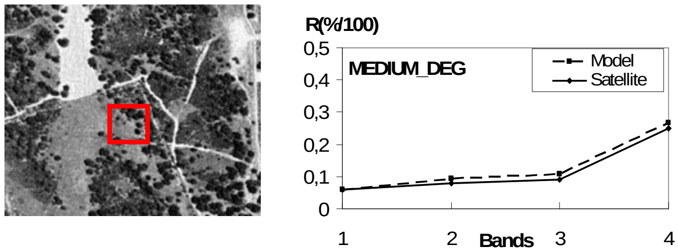
Lower Degrad.	
$R_{R\text{-}ETM+1} = 0.0266\ p_1 + 0.0364\ p_2 + 0.0802\ p_3$	***Endmembers***
$R_{R\text{-}ETM+2} = 0.0281\ p_1 + 0.1333\ p_2 + 0.1831\ p_3$	p_1 : oak
$R_{R\text{-}ETM+3} = 0.0153\ p_1 + 0.1717\ p_2 + 0.2301\ p_3$	p_2 : meadow
$R_{R\text{-}ETM+4} = 0.2204\ p_1 + 0.3320\ p_2 + 0.9263\ p_3$	p_3 : shrub
Medium Degrad.	
$R_{R\text{-}ETM+1} = 0.0441\ p_1 + 0.1037\ p_2 + 0.0519\ p_3$	***Endmembers***
$R_{R\text{-}ETM+2} = 0.0714\ p_1 + 0.1516\ p_2 + 0.0843\ p_3$	p_1 : oak
$R_{R\text{-}ETM+3} = 0.0822\ p_1 + 0.1911\ p_2 + 0.0897\ p_3$	p_2 : meadow
$R_{R\text{-}ETM+4} = 0.3765\ p_1 + 0.2877\ p_2 + 0.2155\ p_3$	p_3 : shrub
Higher Degrad.	
$R_{R\text{-}ETM+1} = 0.1672\ p_1 + 0.0304\ p_2 + 0.3493\ p_3$	***Endmembers***
$R_{R\text{-}ETM+2} = 0.3342\ p_1 + 0.0522\ p_2 + 0.4047\ p_3$	p_1 : oak
$R_{R\text{-}ETM+3} = 0.4996\ p_1 + 0.0778\ p_2 + 0.4987\ p_3$	p_2 : meadow
$R_{R\text{-}ETM+4} = 0.9845\ p_1 + 0.1471\ p_2 + 0.7114\ p_3$	p_3 : shrub
With Sport Court	
$R_{R\text{-}ETM+1} = 0.1119\ p_1 + 0.1671\ p_2 + 0.0416\ p_3$	***Endmembers***
$R_{R\text{-}ETM+2} = 0.1507\ p_1 + 0.2350\ p_2 + 0.0790\ p_3$	p_1 : oak
$R_{R\text{-}ETM+3} = 0.1691\ p_1 + 0.2797\ p_2 + 0.1214\ p_3$	p_2 : meadow
$R_{R\text{-}ETM+4} = 0.4350\ p_1 + 0.4087\ p_2 + 0.2108\ p_3$	p_3 : sport court
With Fallow	
$R_{R\text{-}ETM+1} = 0.0283\ p_1 + 0.1717\ p_2 + 0.0607\ p_3$	***Endmembers***
$R_{R\text{-}ETM+2} = 0.0355\ p_1 + 0.1954\ p_2 + 0.1348\ p_3$	p_1 : oak
$R_{R\text{-}ETM+3} = 0.0270\ p_1 + 0.2338\ p_2 + 0.1913\ p_3$	p_2 : meadow
$R_{R\text{-}ETM+4} = 0.2769\ p_1 + 0.2406\ p_2 + 0.3324\ p_3$	p_3 : fallow

R_i is reflectance and p_i is abundance of *endmember*: oak, meadow, shrub, sport court and fallow.

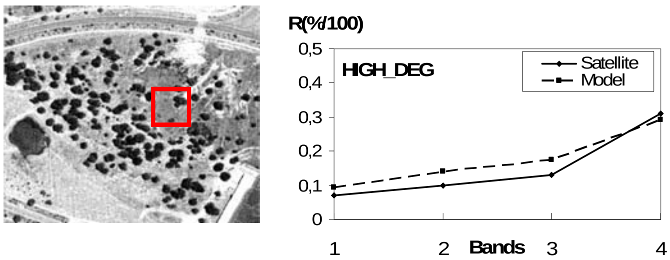
Endmembers	**Low degrad. %**
p_1 : oak	75.6
p_2 : meadow	10
p_3 : shrub	14.4



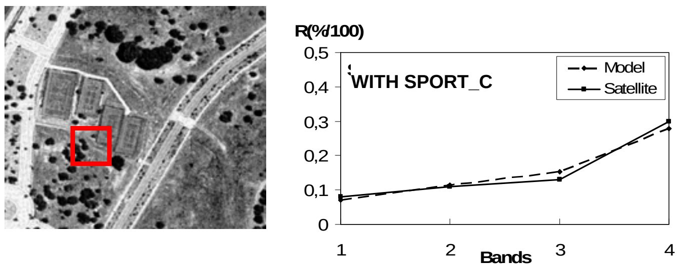
Endmembers	**Med. degrad. %**
p_1 : oak	18.7
p_2 : meadow	78.1
p_3 : shrub	3.2



Endmembers	**High degrad. %**
p_1 : oak	9.4
p_2 : meadow	84.3
p_3 : shrub	6.3



Endmembers	**With sport court %**
p_1 : oak	18
p_2 : meadow	68
p_3 : sport court	14



Endmembers	**With fallow %**
p_1 : oak	25
p_2 : meadow	20
p_3 : fallow	55

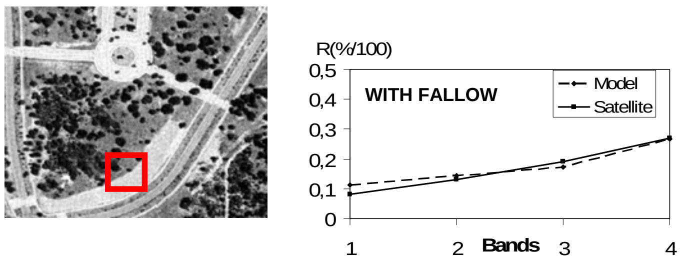


Figure 3. Comparison results between spectral signature values of simulated models and satellite atmospheric corrected data for the five selected Global Units.

The Figure 3 presents comparative results between the signature values (reflectance) obtained from simulated models and those obtained through remote sensor ETM+, for the five Global Units.

The spectral signature modeled has been obtained through the estimated percentage of abundances and are showed in the same figure.

A global analysis of the results showed in the Fig. 3, denote that the spectral signatures modeled are very similar that ones provided by the sensor satellite once atmospheric corrected. Particularly, in the case of Global Units of Lower and Higher Degradation, the simulation predicts signatures values slightly higher than those provided by the satellite sensor but in the other cases it is observed highly correlation. We suggest that the atmospheric correction method of the satellite images, produces an overcorrection in the fourth band (ETM+4), in the cases of high percentage of vegetation, land cover that presents a maximum value in this spectral interval. In the case of Higher Degradation with the higher abundance of class meadow that presents certain spectral variability makes some slightly differences.

5 CONCLUSIONS

The procedure to modelling the spectral response in areas composed by mixed land covers through the successive subdivision of the study area, presents satisfactory results. For that, it turns out indispensable to handle spectral reliable values for each of the present *endmembers*. In consequence it is crucial to have information with a great statistical solidity extracted from adequate multispectral information libraries. With this basic information it is possible to conform signature models to a reasonable adjustment degree to their provided by the satellite images previously corrected atmospherically. Different sets of mixed hyperplanes had been obtained for the different examples. In this work the case of the Mediterranean forest with different levels of degradation and areas deeply transformed by the human action are showed.

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