**Mediterranean habitats: a multi-variate analysis of VEGETATION data.**

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## Abstract
We have analyzed the annual cycles of normalized difference of near-infrared and red reflectance from selected VEGETATION pixels (1 $km^2$). Pixels were selected according to a set of very detailed maps of habitat types in the NW Mediterranean basin. We run a principal component analysis on the set of time series and projected the observations on the plane defined by the first two principal components. We found that individual time series tended to cluster by habitat type, with a clear segregation of Mediterranean and Mid-European types. The main axes of variation of the multi-temporal data set are proportional to the total annual light interception and to the time of the year whence the maximum value occurs. As both traits are of primary importance for the fitness of plants under different bio-climatic regimes, the time series provide a substantial discrimination among types of vegetation. Nevertheless, the phenology of light interception on its own cannot account for many structural differences, which implies that additional information is required to discriminate some habitats.

## Introduction
Annual cycles of greenness, as observed from satellite imagery at resolutions ranging from 1 to 8 km, have proven to be a useful proxy of the phenology of light interception. Such data are calculated as temporal sequences of the contrast between near-infrared and red reflectance values and have been applied, among other purposes, to produce digital land cover charts at continental and global scales (Loveland and Belward 1997, Tucker *et al*. 1985, Lobo *et al*. 1997). VEGETATION imagery has superior radiometric and geometric specifications (Spot Image 1998) than the commonly used NOAA-AVHRR images, which should result into a more accurate description of phenology.

An important problem for the analysis of regional and global multi-temporal imagery with 1 $km^2$ resolution such as VEGETATION is the difficulty of linking image information to landscape structure as it is conceived by field ecologists. For many regions on Earth, classification schemes that are used for environmental management, forestry and wildlife and biodiversity conservation imply that most 1 $km^2$ pixels are a mixture of different categories. This problem is exacerbated in the Mediterranean basin, because complexities of topography, micro-climatology and an old human occupation result into intricate spatial patterns, where few 1 $km^2$ homogeneous quadrats exist, even with regard to crude legends.

Although sub-pixel analytical techniques are increasingly common, the fact is that information from well-known and sufficiently homogeneous targets is as critical for the understanding of the imagery as a network of instrumentally-equipped validation sites. Our goal is to advance on the ecological understanding of the seasonal spectral response of homogeneous pixels, as a previous step to understand mixed pixels. We identify the homogeneous VEGETATION pixels on ecological maps that have been produced using very high-resolution imagery and field inspection, and then analyze the annual signal of their spectral response. In the following, we present initial results on this type of analysis for the NW Mediterranean.

**Methods**

We have analyzed the 1998 annual cycles of a spectral vegetation index for a number of very detailed habitat types in the NW Mediterranean basin using VEGETATION imagery. The index is the normalized difference of reflectance in the near-infrared and red spectral bands:

$$ND(NIR,R) = (r_{nir} - r_{red}) / (r_{nir} + r_{red})$$

where $r_r$, $r_{nir}$ stand for reflectance values as provided by standard S10 VEGETATION images in bands B2(0.61 - 0.68 cm) and B3(0.78 - 0.89 cm).

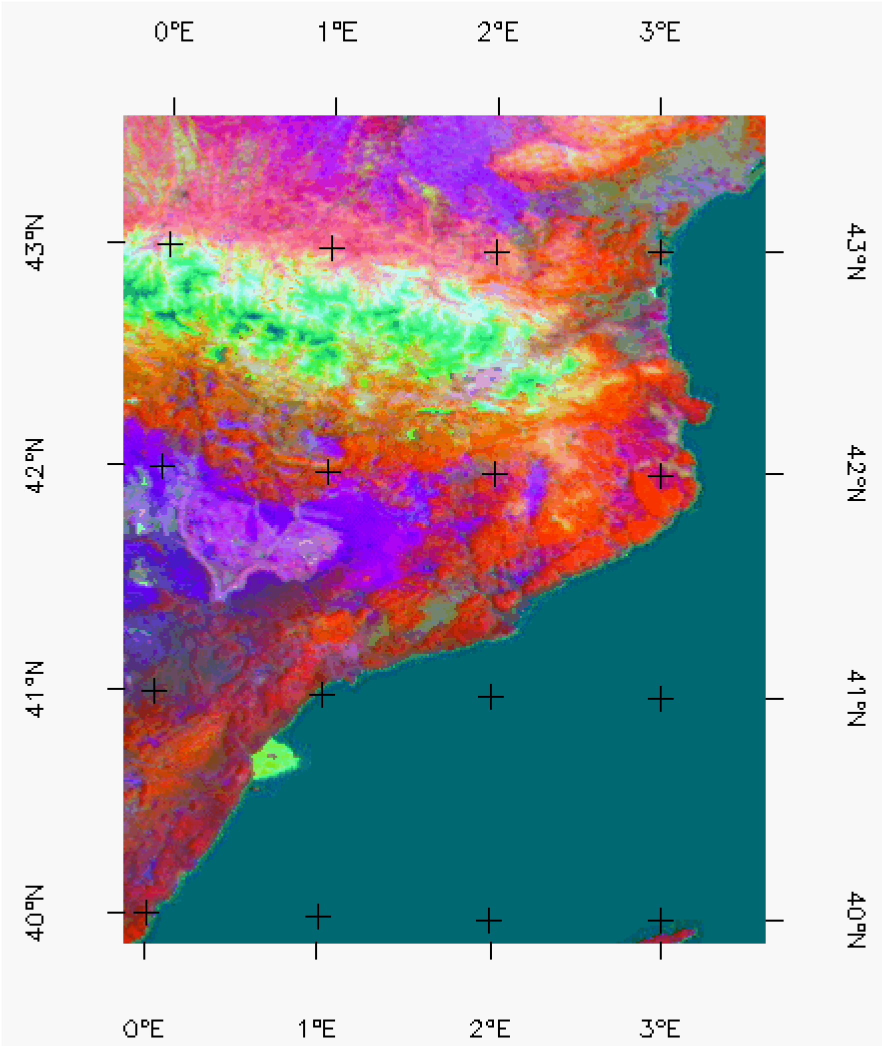


**Figure 1.** Color composite of the first three Principal Components of the multi-temporal ND(nir, red) series of the area of study.

We have processed 36 S10-VEGETATION images and 18 digital maps of habitats at scale 1:50,000. The legend of these maps is based on the Corine Biotopes Manual (Devillers *et al*., 1991) and the Directive 92/43 of the European Union with specific improvements for Catalonia (NE Spain) (Carreras & Vigo 1997). We selected all VEGETATION pixels (1 $km^2$) that were included (at least in a 90%) within one single habitat patch, and extracted the time series of reflectance data and ancillary information for these pixels. We calculated the time series of the ND index for each selected pixel and organized these values as the rows of a data set. We run a principal component analysis on the data set of time series, projected the observations on the plane defined by the first two principal components, and discussed the relative positions of the projected pixels according to their vegetation class.

**Results**

The first two Principal Components (PC) of the ND(nir, red) data set account for a 54% and 24% of the total variance of the time series, which facilitates the representation of the pixels on a reduced plane (Fig. 2).

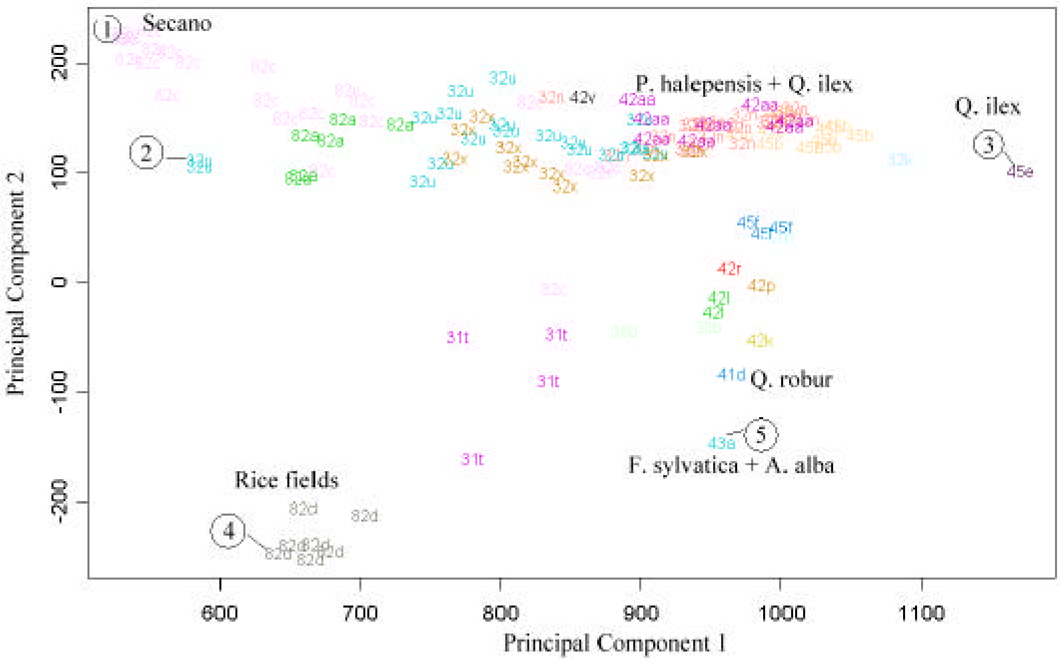


**Figure 2**. Projections of the time series of ND(nir, red) of selected VEGETATION pixels on the Principal Component plane. Labels stand for classes of the Habitats map (see Appendix). Time series of ND(nir,red) for circled numbers are reproduced in Figure 3.

The time series of pixels located at extreme positions on the PC plane let us identify the major sources of variation in the data set (Fig. 3). The first PC orders the time series according to their average level, and is thus proportional to annual light interception. The second PC is related to the time of occurrence of the maximum ND(nir,red): series with their maximum in early Spring are projected on the upper part of the plane, while those with their maximum at mid-summer are projected on the bottom and series of evergreen habitats are projected on the middle.

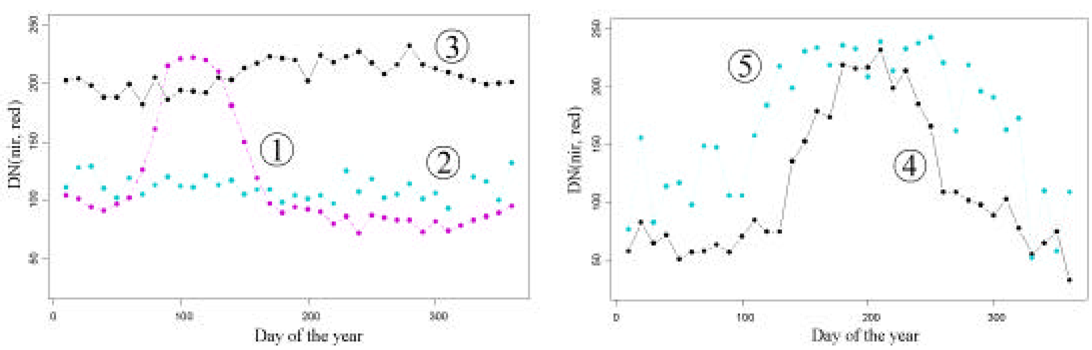


**Figure 3.** Time series of ND(nir,red) for some relevant positions on the PC plane (Fig 1).

Figure 2 also shows that Mediterranean and Mid-Atlantic classes are well segregated, except for the *Q. rotundifolia* (45f) class. After inspection of the area covered by these particular VEGETATION pixels on the color ortho-imagery, we could observe that they correspond to a montane region in the Pyrenees and that include a notorious cover of deciduous *Q. faginea*. This fact explains the intermediate position of this habitat.

In general, the selected VEGETATION pixels tend to be projected on the PC plane by clusters according to habitat class, but some pixels are outlaying from their cluster. We were able to explain these cases by tracing back the position of the given VEGETATION pixel to the 1:25,000 ortho-image that had been used to produce the map and, eventually, consult site information. This is the case of two pixels of rosemary garrigue (32u) that are located to the left of the main cluster. These two pixels are included in an area that was burned in 1994 and the consequences are still present in the 1999 VEGETATION imagery.

Other interesting observations in Fig. 2 include the ordination of the montane pine forests (42m, 42r, 42p, 42l and 42k) according to a gradient that is coincident with increasing moisture, and the ordering of the "secano" fields (non-irrigated cereal crops in seasonally-dry lands, 82c), which responds to the inclusion of an increasingly higher fraction of fallow land.

**Conclusions**

Considering the ordination of the Habitat classes on the PC plane, the main axes of variation of the multi-temporal ND(nir,red) data set are proportional to the total annual light interception and to the time of the year whence the maximum value occurs. As both traits are of primary importance for the fitness of plants under different bio-climatic regimes, the time series of ND(nir, red) provide a substantial discrimination among types of vegetation. Nevertheless, the phenology of light interception on its own cannot account for many structural differences, which implies that additional information is required to discriminate some Habitats.

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## Appendix. Simplified legend of the Map of Habitats (Carreras and Vigo 1997)

| Legend code | Corine code[1] | Legend unit | Description | Altitude zone | Biogeographic zone |
|---|---|---|---|---|---|
| 82c | 82.3 | "Secano" (Extensive cultivation) | Unirrigated fields, mainly of cereals, under seasonally-dry climates | Basal, Submontane | Mediterranean |
| 82d | 82.41 | Rice fields | Flooded paddies | Basal | Mediterranean |
| 32u | 32.42, 32.431, 32.433, 32.45, 32.4B+32.2121, 32.4C-F, 32.4H+32.274 | Rosemary garrigues, including *Cistus albidus, Globularia alypum*, etc. | Low, calcicolous, dry shrubland dominated by *Rosmarinus officinalis* | Basal | Mediterranean |
| 32x | 32.432+32.4J | *Cistus clusii* and *Anthyllis cytisoides* garrigues | Low, calcicolous, dry, thermophilous shrubland | Basal | Mediterranean |
| 32n | 32.341, 32.342, 32.348, 32.36, 32.374*, 32.375*, 32.378*, 32.379* | *Cistus monspeliensis, C. Salvifolius* and broom garrigues | Low, silicicolous, dry shrubland | Basal | Mediterranean |
| 32k | 32.321* | *Erica scoparia* garrigues | Shrubland on siliceous, deep soils | Basal, Submontane | Mediterranean |
| 31t | 31.84221* | Pyrenean, montane shrubland of *Genista balansae* | Open shrubland on siliceous, south facing slopes | Submontane,Montane | Medio-European |
| 45b | 45.2162* | Open woodland of *Quercus suber* | *Quercus suber* forest with heliophilous,, acidophilous understorey | Basal | Mediterranean |
| 45e | 32.1121*, 32.1131*, 32.11611*, 45.3131*, 45.3132*, 45.321 | Montane forests or maquis *of Quercus ilex* | Dense sclerophyllous formations of *Quercus ilex* with shruby understorey | Submontane, Montane | Mediterranean |
| 45f | 32.1124*, 32.1134*, 32.11614*, 45.3411, 45.3415*, 45.345 | *Quercus rotundifolia* forest or maquis | Sclerophyllous formations, somewhere including shruby understorey | Submontane | Mediterranean |
| 42aa | 42.8412* | Pine forests of *Pinus halepensis* with sclerophyllous understorey | Secondary *Pinus halepensis* forests with holm-oak related understorey | Basal | Mediterranean |
| 42v | 42.67 | *Pinus nigra* reforestation | Secondary forest of *Pinus nigra* subsp. *salzmannii* with ligth herbaceous understorey | Submontane | Submediterranean |
| 42m | 42.5921* | Pyrenean box *Pinus sylvestris* forests | Calcicolous, xerophilous *Pinus sylvestris* forests with *Buxus sempervirens* | Montane | Submediterranean |
| 42r | 42.5E | *Pinus sylvestris* reforestation | Secondary forests of *Pinus sylvestris* with herbaceous understorey | Submontane,Montane | Submediterranean |
| 42p | 42.5B11* | Pyrenean xerophilous *Pinus sylvestris* forests | Silicicolous *Pinus sylvestris* forests with open understorey | Montane | Submediterranean |
| 42l | 42.562 | Pyrenaean silicicolous mesophile forests of *Pinus sylvestris* | *Pinus sylvestris* forests with dense, moss understorey | Montane | Medio-European |
| 42k | 42.561 | Pyrenean calcicolous mesophile forests of *Pinus sylvestris* | *Pinus sylvestris* forests with dense understorey | Montane | Medio-European |
| 41d | 41.291*, 41.292* | Pyreneo-Cantabrian oak-ash forests | Mixed, deciduous forests of *Quercus robur, Tilia, Fraxinus excelsior,* etc., of humid soils | Submontane,Montane | Medio-European |
| 43a | 43.141 | Mixed forests of *Fagus sylvatica* and *Abies alba* | Mesophilous forests of humid soils | Montane | Medio-European |

[1]Codes according to Corine Biotopes Manual (Devillers *et al*., 1991); (∗) refer to new specific units for Catalonia