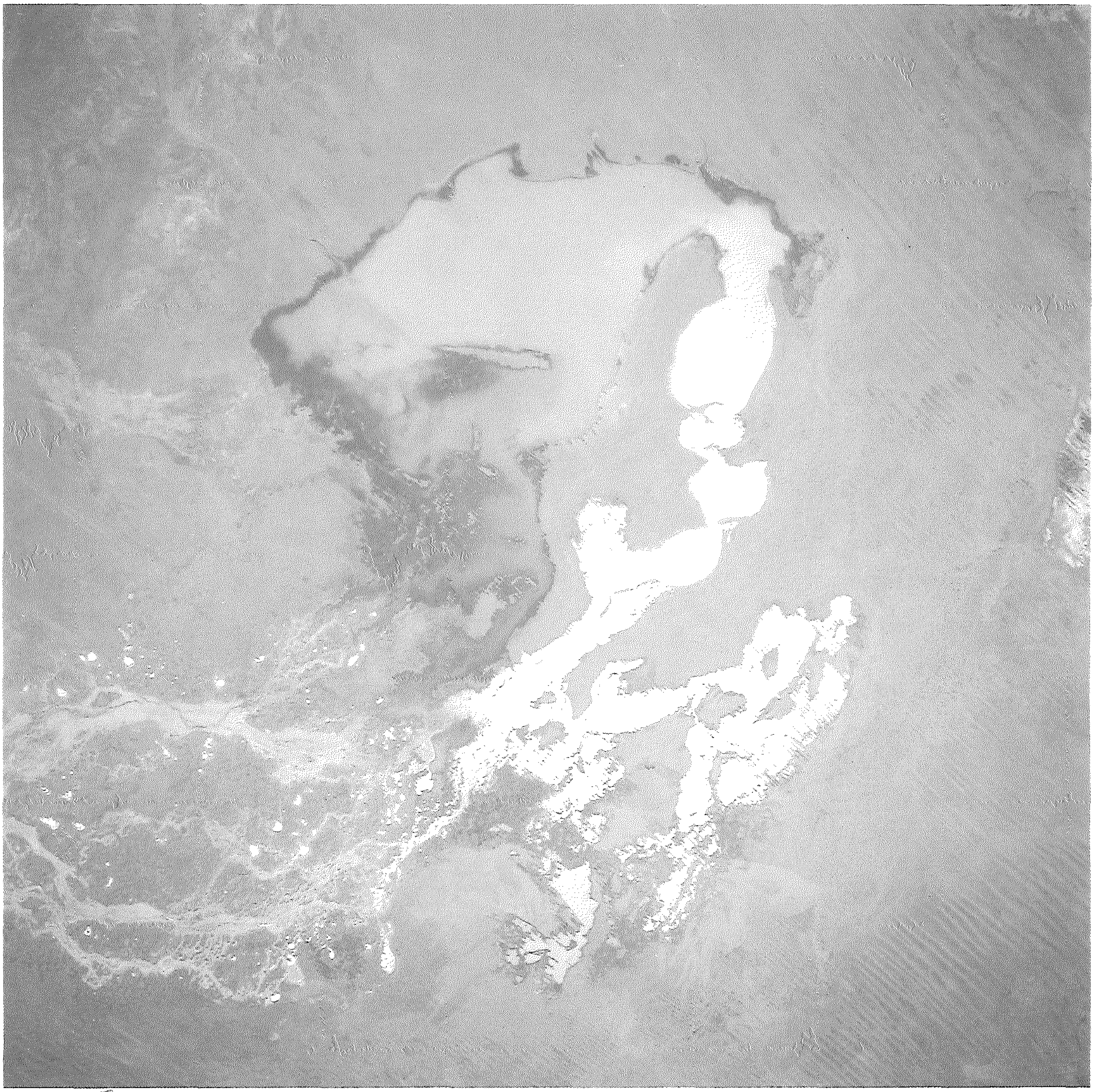
Reprint from

GEOCARTO International

Vol.10
2
1995

A Multi-disciplinary Journal of Remote Sensing & GIS



Australia: Gregory Salt Lake showing seasonal water level on 16 September, 1993 (S51-76-94)
Courtesy of Earth Science Branch, NASA Johnson Space Center, Houston, Texas, USA.

Vegetation Mapping in Sierra Juarez (Baja California, Mexico) from SPOT Data

Marie-Francoise Passini
Laboratoire de Botanique Tropicale
Université Paris-VI
Paris, France

Bernard Lacaze
CNRS - Centre d'Ecologie Fonctionnelle et Evolutive
B.P. 5051, 34033 Montpellier Cedex 1
France

Abstract

SPOT data were digitally analyzed for vegetation type identification in Sierra Juarez mountains, Mexico. From the analysis of spectral responses of dominant vegetation species, it has been concluded that a simplified typology of vegetation units should be used. Thus 5 vegetation classes have been defined and a supervised classification applied to SPOT data. Results of classification obtained on training areas indicate a 95% level of correct identification.

Introduction

The use of high spatial resolution satellites (Landsat-TM, SPOT) allows vegetation mapping and monitoring in ecologically complex areas. Regarding this objective, visual analysis of SPOT color composite imagery appears almost as effective as medium scale color infrared photo-interpretation (Buttner and Csillag 1989, Chuvieco and Vega 1990). However, digital data processing is generally assumed to be the most efficient method for land-use/land-cover mapping at a regional level (Lacaze 1990; Baker *et al.* 1991), or for characterizing structure and composition of vegetation cover (Franklin, 1986).

Applying this approach to mountainous areas may give rise to methodological problems and limitations (Megier *et al.* 1991). The use of remote sensing data is still necessary in the areas with limited access and often insufficient vegetation mapping. This is the case in Baja California, Mexico, where thematic maps are only available at large scales (1/1,000,000 to 1/250,000). In this study, we used SPOT monotemporal data for obtaining a preliminary vegetation map at a detailed level (scale 1/50,000) in a test area of Baja California.

Study area

The studied area is located at the west side of Sierra Juarez (Fig. 1). This range of mountains, with a general North-West/South-East orientation, is the prolongation of mounts Cuyamaca and Palomar (California). Sierra Juarez is formed basically by plutonic rocks and has a relatively mild topography; altitudes are lower than 1,900 m.

Main vegetation units are distributed along a West-East humidity gradient, and may be described as follows:

(i) cropland (altitudes < 750 m);
(ii) "chaparral" : shrubland with *Adenostoma sparsifolium* and/or *Adenostoma fasciculatum*, *Rhus* sp. pl., *Ceanothus cuneatus* and *Quercus* sp. pl.;
(iii) coniferous woodland, with 3 main types (Passini *et al.* 1989):
open to sparse woodland with *Pinus monophylla* (mean height = 8 m);
mid-dense to open woodland with *Pinus quadrifolia* (mean height = 12 m);
dense to mid-dense woodland with *Pinus jeffreyi* (mean height > 15 m) and, locally, near La Oliva, one facies with *Calocedrus decurrens*.

Low shrubland with *Artemisia tridentata*, often occupies clearcut areas or tree-fall gaps in coniferous woodland, inducing a spatially complex mosaic.

Data acquisition

Satellite data were extracted from SPOT scene 547-286 recorded on January 8th 1987 in the multiband

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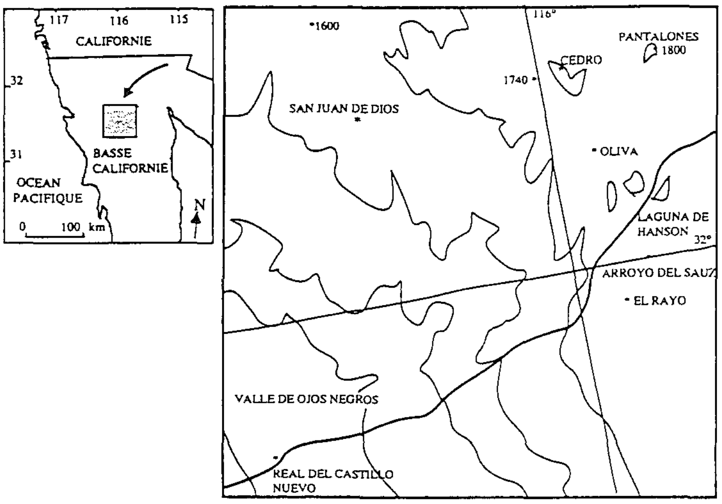

Figure 1 Location of the study area

mode (3 channels, spatial resolution 20 m). These were system-corrected data ("level 1B"); no further radiometric or geometric corrections have been applied. Data have been obtained during winter, with a low solar elevation angle (33°).

Ancillary data used in the study were the following:

- aerial photographs at the scale of 1/50,000 (from CENTENAL, México, 1967);
- topographical maps at the scale of 1/50,000;
- thematic maps (land-use, geology) at the scale of 1/1,000,000);
- phyto-ecological relevés obtained during 1986, 1987 and 1988 along 2 perpendicular transects (North-South and West-East directions).

Methods

Digital data processing was performed at *Centre National Universitaire Sud de Calcul*, using the following software packages : HLIPS (High Level Image Processing System, cf. NIBLACK 1985) and STIMDI (*Système de Traitement des IMages Digitalisées*, cf. CHAUME 1990).

Our classification approach was a supervised one, using training areas located on color-composite imagery at the scale of 1/50,000 with help of topographical maps at the same scale. Color composition has been obtained with the Intensity - Hue - Saturation technique : intensity attributed to channel XS2, hue to a ratio vegetation index and saturation maintained constant at the maximum level. This kind of visualization allows the visual characterization of main vegetation types in the studied area (Passini and Lacaze 1990). Thus 74 zones have been defined, 51 of which concerning dominant natural vegetation types and 23 other land-cover units or less represented classes.

From the analysis of spectral responses of training areas, a simplified typology of natural vegetation classes has been established. Then classification was performed using the maximum likelihood algorithm, with equiprobability of classes and no reject class. Visualization of results has been obtained with a Versatec color printer through STIMDI or UNIRAS software packages.

Results

Spectral responses of thematic classes

From the analysis of training areas, it is possible to derive spectral responses of thematic classes. These classes are defined here as land-cover units (water, bare soil, ...) and/or from dominant vegetation species. Results concerning mean spectral responses and standard deviations in the 3 SPOT channels are given at Table 1.

An evaluation of separability of thematic classes can be obtained from computation of an inter-class distances matrix (Table 2) displaying Euclidean distances between class mean values in the 3-dimensional SPOT feature space. Results indicate that broad land cover units (water, vegetation, bare soil, snow) are well separated. Discrimination between vegetation types or between dominant species appears more difficult; this confirms previous studies on vegetation characterization with SPOT data in semi-arid areas (Lacaze and Lahraoui 1987). Consequently, it is necessary to define new simplified thematic classes more suited to SPOT capabilities.

Definition of simplified thematic classes

From the analysis of spectral responses of training areas, several conclusions have been obtained:

Table 1 Spectral responses of thematic classes from training areas: mean values and standard deviations (*italics*) in the 3 SPOT channels

Class	Nb. of pixels	XS1	XS2	XS3
Snow	1476	138.3 *(15.9)*	95.2 *(8.3)*	110.5 *(12.0)*
Bare rock	287	58.0 *(10.0)*	53.1 *(9.8)*	62.3 *(7.4)*
Sand	2027	45.8 *(3.6)*	45.6 *(4.2)*	46.9 *(4.0)*
Bare soil	4678	33.0 *(1.6)*	28.0 *(2.3)*	31.1 *(2.1)*
Shadow	297	19.2 *(2.1)*	13.3 *(2.1)*	12.1 *(3.3)*
Water	787	25.5 *(0.5)*	18.1 *(0.4)*	13.3 *(0.5)*
Burnt area	834	25.5 *(2.8)*	17.7 *(3.0)*	19.1 *(3.7)*
Alfalfa	1758	29.4 *(2.1)*	21.0 *(2.7)*	49.3 *(5.8)*
Meadow	1594	29.9 *(1.2)*	20.7 *(1.6)*	54.8 *(7.0)*
Rangeland	6961	37.1 *(1.7)*	34.0 *(1.9)*	36.5 *(2.4)*
Jojoba	517	29.4 *(1.0)*	23.0 *(1.3)*	26.5 *(1.6)*
Zimondsia sp.	895	27.6 *(2.1)*	22.0 *(2.8)*	30.4 *(4.8)*
Salsola	1270	34.0 *(1.2)*	29.0 *(1.4)*	32.4 *(1.6)*
Cyperus	176	28.2 *(1.7)*	23.1 *(1.6)*	41.6 *(3.1)*
Chaparral	708	30.7 *(3.4)*	23.6 *(3.6)*	27.7 *(3.5)*
Arctostaphyl.	188	25.9 *(1.8)*	18.6 *(1.4)*	26.7 *(2.2)*
Adenostoma	970	21.4 *(2.2)*	14.5 *(2.2)*	24.1 *(2.6)*
Pinus	903	26.2 *(3.5)*	19.5 *(3.6)*	34.8 *(5.9)*
Quercus	252	28.4 *(2.2)*	16.1 *(1.7)*	29.9 *(3.0)*

i) some areas are spectrally heterogeneous (high coefficient of variation) : this corresponds to spatial heterogeneities that were noticed in the field;

ii) if definition of vegetation classes is based on dominant species, some of such classes are spectrally heterogeneous; this is the case for the *Pinus* sp. pl. class, as the resulting histograms of SPOT data are highly multimodal;

iii) some vegetation classes are very close in the spectral feature space: for example, *Quercus* class and part of *Pinus* class.

It became then necessary to eliminate some heterogeneous training areas and to redefine some classes. From 51 training areas representing natural vegetation, we selected 30, according to the lowest values of coefficient of variation. A simplified typology

Table 2 Matrix of distances between thematic classes

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Snow	1	1																		
Bare rock	2	104	0																	
Sand	3	123	21	0																
Bare soil	4	148	47	27	0															
Shadow	5	175	75	54	28	0														
Water	6	167	68	48	22	8	0													
Burnt area	7	165	65	44	18	10	6	0												
Alfalfa	8	148	45	30	20	39	36	31	0											
Meadow	9	146	43	31	25	45	42	36	6	0										
Rangeland	10	140	38	18	9	37	30	27	20	24	0									
Jojoba	11	156	55	35	8	20	15	10	23	28	17	0								
Zimondsia	12	156	54	34	8	22	18	12	19	25	16	5	0							
Salsola	13	146	45	25	2	30	24	19	19	24	7	10	10	0						
Cyperus	14	150	47	29	13	32	29	23	8	13	15	15	11	12	0					
Chaparral	15	154	53	33	6	22	16	12	22	27	15	2	4	8	14	0				
Arctos.	16	160	59	39	13	17	13	8	23	28	21	6	5	14	16	7	0			
Adenos.	17	167	65	46	19	12	12	7	27	32	28	12	12	21	21	13	7	0		
Pinus	18	156	54	35	12	24	22	16	15	20	18	10	5	12	8	9	8	13	0	
Quercus	19	162	60	41	15	18	17	11	21	26	23	10	7	17	15	11	5	6	7	0

Table 3 Typology of vegetation classes, defined from dominant species in the upper canopy layer.

LABEL	DOMINANT SPECIES	FREQUENT CO-DOMINANT SPECIES
PINUS	*Pinus jeffreyi*	*Pinus quadrifolia* *Pinus monophylla* *Quercus turbinella*
	Pinus quadrifolia	*Pinus jeffreyi* *Quercus turbinella* *Quercus dunnii* *Arctostaphylos glandulosa* *Ceanothus cuneathus* *Adenostoma pl. sp.*
	Pinus monophylla	*Pinus quadrifolia* *Arctostaphylos glandulosa* *Ceanothus cuneathus* *Adenostoma pl. sp.*
QUERCUS	*Quercus turbinella*	*Pinus jeffreyi*
	Quercus dunnii	*Pinus quadrifolia*
ARCTOS	*Arctostaphylos glandulosa*	*Quercus dunnii* *Ceanothus cuneathus* *Pinus monophylla* *Pinus quadrifolia*
ADENOS	*Adenostoma sparsifolium* *Adenostoma fasciculatum*	*Rhus triloba* *Ceanothus cuneathus* *Quercus dunnii*
ARTEMI	*Artemisia tridentata*	*Baccharis emoryi* *Quercus ajoensis*

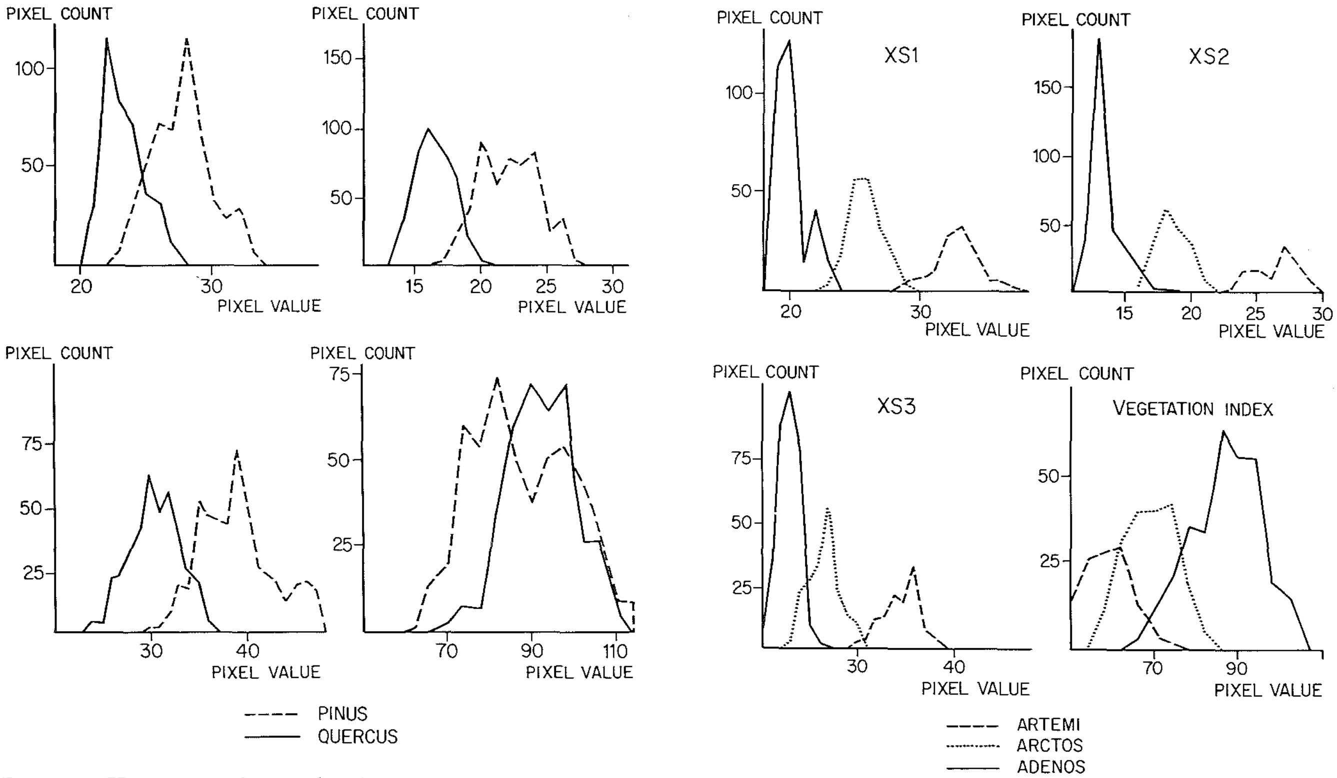

Figure 2 Histograms of SPOT data (CCT counts) for 5 vegetation classes.

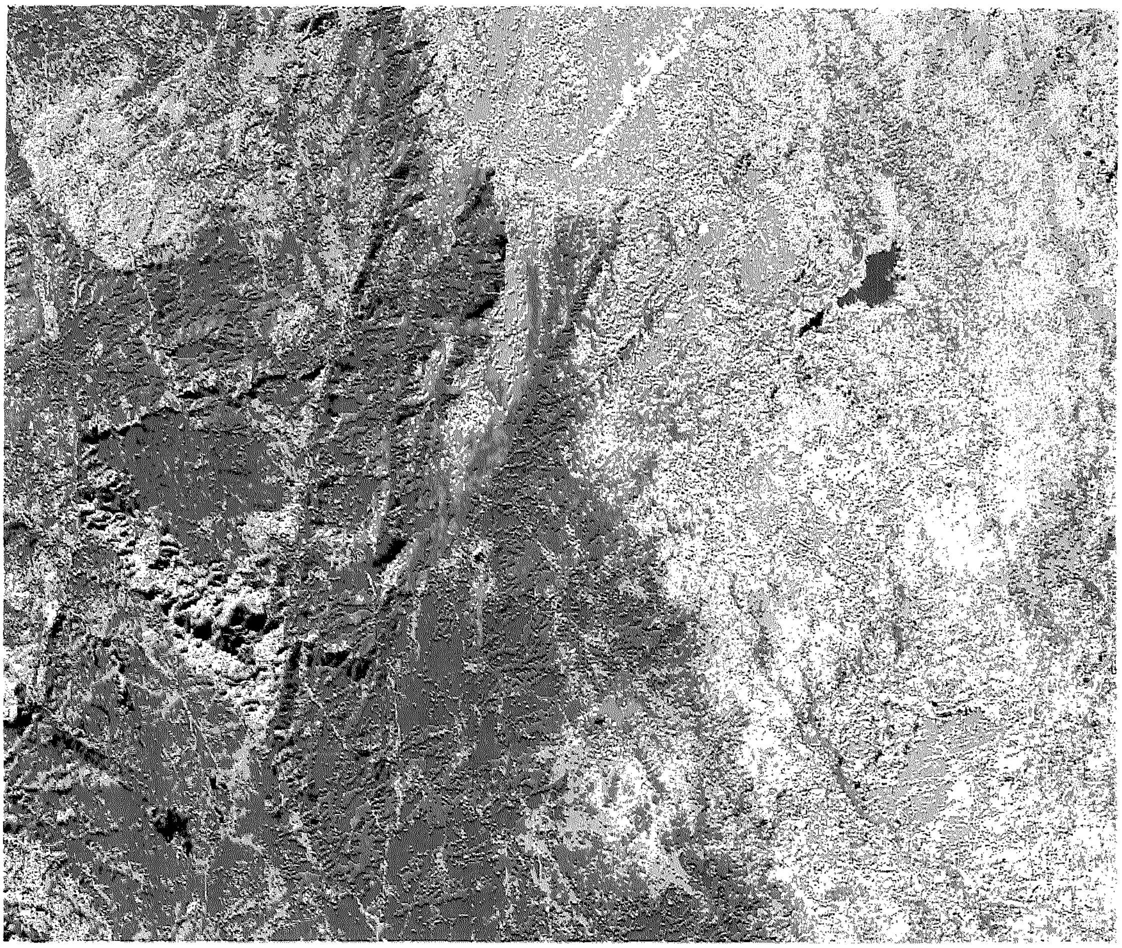

Figure 3
Result of classification of SPOT data.

Color key:
White: Snow,
Light blue: Bare rock,
Orange: Bare soil,
Black: Shadow,
Purple: Water,
Pink: PINUS,
Red: QUERCUS,
Light green: ARCTOS,
Blue: ADENOS,
Yellow: ARTEMI

(Original scale = 1:100,000)

of classes is given at Table 3. Here PINUS class is restricted to *Pinus* sp. pl. as dominant species, but QUERCUS class indicates *Quercus* sp. pl. dominance or *Pinus* and *Quercus* co-dominance. Other classes (water, snow, bare rock, bare soil, shadows) remained unchanged.

Spectral responses obtained for each class are indicated at Table 4. The analysis of histograms of SPOT data for 3 channels and a ratio vegetation index (Figure 2) confirms the relative homogeneity and separability of the simplified classes.

Classification

Classification was performed using the maximum likelihood algorithm using 3 SPOT channels. Results obtained on the training sites are expressed as an inter-class confusion matrix (Table 5). These results indicate a very good recognition level of vegetation classes (mean value 95%). The addition of a vegetation ratio in the classification scheme does not give significant improvement of classification accuracy.

Classification has then been applied to the study area. Results are given in Figure 3, for one part of the

Table 4 Spectral responses of vegetation classes: mean values in the 3 SPOT channels and ratio vegetation index.

Label	XS1	XS2	XS3	Vegetation index
PINUS	27.7 *(2.2)*	22.0 *(2.2)*	38.8 *(3.8)*	87.2 *(11.0)*
QUERCUS	23.3 *(1.5)*	16.4 *(1.4)*	30.5 *(2.6)*	90.4 *(7.7)*
ARCTOS	25.9 *(1.2)*	18.6 *(1.2)*	26.6 *(1.7)*	70.7 *(4.2)*
ADENOS	20.1 *(1.3)*	13.4 *(1.0)*	22.8 *(1.1)*	83.2 *(6.6)*
ARTEMI	32.7 *(1.8)*	26.6 *(1.8)*	34.7 *(1.9)*	64.9 *(3.7)*

Table 5 Confusion matrix between classes obtained on training areas.

		1	2	3	4	5	6	7	8	9	10
Snow	1	100									
Bare rock	2		100								
Bare soil	3			99							1
Shadow	4				99					1	
Water	5					100					
PINUS	6						93	3	1		3
QUERCUS	7						1	93	5	1	
ARCTOS	8						1	1	98		
ADENOS	9								1	99	
ARTEMI	10						1		5	1	94

area representing 1200 x 1000 pixels (approximatively 48,000 hectares). These results confirm the altitudinal distribution of main vegetation units. The patchy nature of forested ecosystems at higher altitude ranges appears clearly. This fragmentation results from several factors: micro-climatology (windfallen trees), human influence (wood cutting, grazing in clearcut areas), tree pathology.

Conclusions

Results estimated from training areas classification are quite good when using a simplified typology of vegetation units. Spatial generalization of results appears satisfactory on a qualitative basis, but a quantitative assessment of results based on the analysis of a set of test areas distinct from the training ones is still needed. Althouh some misclassifications may occur with monotemporal SPOT data, it appears that this kind of approach gives a valuable assesment of the spatial distribution of woodland, dense shrubland and sparse vegetation in the studied mountainous area. Further improvements should be achieved through corrections of atmospheric and topographical effects, and use of multitemporal data.

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