Remote Sensing for a Changing Europe
D. Maktav (Ed.)
IOS Press, 2009

doi:10.3233/978-1-58603-986-8-102

Remote sensing monitoring to preserve ancestral semi-natural mountain meadows landscapes

I. Pôças[1], M. Cunha[2], A.R.S. Marçal[3] & L.S. Pereira[4]
[1]*Faculdade de Ciências, Universidade do Porto and Agricultural Engineering Research Center, Portugal,* ipocas@mail.icav.up.pt
[2]*Faculdade de Ciências, Universidade do Porto and Centro de Investigação em Ciências Geo espaciais,* mcunha@mail.icav.up.pt
[3]*Faculdade de Ciências, Universidade do Porto, DAM and Centro de Investigação em Ciências Geo espaciais* andré.marcal@fc.up.pt
[4]*Institute of Agronomy, Technical University of Lisbon and Agricultural Engineering Research Center, Portugal,* lspereira@isa.utl.pt

Keywords: Ancestral Landscapes, Mountain meadows, Vegetation indices, remote sensing, SPOT, Landsat

ABSTRACT:

"Lameiros" are ancestral semi-natural meadows, essential elements of mountain landscapes in Northern Portugal. In the "lameiros" a traditional irrigation system is used and water is applied all year around. They are mainly used for forage production for autochthonous bovine feeding, but they are also important for the water and nutrients cycle regulation, erosion control and as barrier to forest fires propagation. Although recognized for their economical, environmental, landscaping, cultural and genetic value, the perpetuation of these "lameiros" could be at risk, at medium term, due to human desertification in the mountain regions and to the announced constraints in use of water resources. To preserve these landscapes it is essential to know them better and to better characterize them. Therefore a monitoring program using remote sensing tools is now being developed to evaluate different patterns of "lameiros", and their spatial extent and evolution. Two important questions are determinant in this program: the selection of the most appropriate spatial resolution for monitoring "lameiros", and the availability of satellite historical data. In this context, NDVI were compared in two selected test sites, with and without full irrigation. Data were derived from several field campaigns with a spectroradiometer and using different sensors: i) Landsat 5 and Landsat 7 (30m pixel), ii) SPOT 4 and SPOT 2 (20m pixel), iii) SPOT 5 (10m pixel). The NDVI temporal series produced were evaluated considering "lameiros" management and weather data. Results obtained so far indicate that the SPOT images provide data at the most adequate scale.

1 INTRODUCTION

The landscape of North of Portugal is characterized by several elements typical of the mountains traditional agriculture, in which "lameiros" present an important role. The "lameiros" are permanent semi-natural meadows originated several hundred years ago (Moreira et al., 2001; Pires et al., 1994). They mainly occur above 700m elevation, in regions with high water availability. "Lameiros" are irrigated all year around, depending upon the water availability: i) in winter and early spring the irrigation aims at promoting a thermal regulation at the soil and vegetation level, to avoid or minimize the freezing risks for the vegetation (Gonçalves, 1985) and then irrigation is called "lima" irrigation; ii) in summer, which is a dry season, the irrigation aims to satisfy the crop water requirements.

In this context, these meadows can be classified as irrigated meadows, imperfect or deficit irrigated meadows and non-irrigated meadows, according to their proximity to water streams and springs and consequently to water availability all over the year (Pires et al., 1994; Pôças et al., 2008a; 2008b; Teles, 1970). The traditional irrigation system is constituted by a network of earth channels and small contour ditches that allows the water to spread over the pasture after being derived from water courses or springs. This ingenious system increases the infiltration opportunity time and reduces the runoff time of concentration, consequently favouring a more efficient use of water in the mountain fields and decreasing the peak flows downstream.

These semi-natural meadows represent the main forage resource for the autochthones bovine races produced in the mountain regions of the north of the country. This livestock production constitutes the first economical input for the local farmers and is a fundamental key for the rural development of regions dealing with an increasing human desertification and aging of population. Besides its economical, rural development and water regulation functions, several other benefits are attributed to "lameiros": i) prevention of erosion risks in sloping areas because the soil is permanently and full covered and runoff flow is slow down when spreading over the forage crop; ii) conservation of the biodiversity related to a variety of plant and animal species; iii) preservation of landscape values, creating an integration of several elements as forest, agricultural fields, communitarian pastures; iv) prevention of the propagation of forest fires because acting as buffer zones.

Despite their multifunctionality, the sustainability of "lameiros" may be compromised by the human desertification and the population aging in the mountain regions and by restrictions in water use. To prevent this situation, a monitoring program is being developed by remote sensing in order to better know and understand the ecological behaviour of these semi-natural meadows, their dynamics in the traditional agriculture and in featuring the mountain landscapes of North of Portugal. The information derived from this monitoring program might help improving the "lameiros" management, mainly water and irrigation management, and support the definition of economical, agricultural and ecological strategies and water and land use policies in the region.

The remote sensing applicability is recognized for biotope monitoring (Bock, 2003), land use monitoring (Marçal and Wright, 1997; Marçal et al., 2005; Sawaya et al., 2003), evapotranspiration mapping (Allen et al., 2007), and crop yield forecasting (Salazar et al., 2008), among others. Vegetation indices computed from red and near infra-red bands are often used to quantify canopy attributes, considering their relationships with various plant biophysical parameters. The Normalized Difference Vegetation Index (NDVI), one of the most used vegetation indices, is a sensitive indicator of the vegetation cover and condition (Rouse *et al.* 1973).

The success on using remote sensing data for monitoring "lameiros" dynamics is, however, conditioned by the spatial resolution adequacy due to the small size of the "lameiros" fields and the limited availability of satellite historical data to study the evolution of these meadows in the mountain landscape during the last decades, including in periods of water scarcity. This study is focused on these two issues.

2 MATERIAL AND METHODS

Test sites

The study area was selected among the mountainous regions of north Portugal, in Salto (Montalegre), where the principal agricultural activity – livestock production – is sustained by "lameiros". Two agricultural fields were selected in this site, having different water regimes, an irrigated

meadow (IM) and a non-irrigated one (NIM). Each selected field was divided in three plots, thus a total of six plots are considered: IM1, IM2, IM3 and NIM1, NIM2, NIM3.
For the evaluation of the most appropriate spatial resolution for "lameiros" monitoring, the following data were used: i) reflectance measurements obtained at field level using a spectroradiometer and ii) satellite image data, from SPOT and Landsat sensors.

Ground field radiometric measurements

To obtain reflectance measurements at field level, a portable spectroradiometer FieldSpec UV/VNIR was used, with a conic IFOV around 25º and a reflectance data capture between 325 nm and 1075 nm of the electromagnetic spectrum.

In each plot, measurement points representative of the field conditions were established: i) four measurement points in the IM1; ii) three measurement points in NIM1, NIM3 and IM2; iii) 2 measurement points in NIM2 and IM3. At each measurement point, the spectroradiometer was set to an integration time of 136 ms and ten reflectance files were saved. These reflectance files were automatically compared with a white reference measurement taken over a reference panel (in which the reflectance all over the electromagnetic spectrum is close to 100%).

Seven campaigns of reflectance measurements were carried out in the period July-December 2007, sampling different vegetation stages – maximum vegetation development, vegetation cut (hay cut), and the initial development after cut, and vegetation dormancy. All measurements were performed in sunny days – 10 July 2007, 20 July 2007, 8 August 2007, 11 September 2007, 20 October 2007, 23 November 2007 and 27 December 2007 – between 11-13 hours.

Satellite data

For the evaluation of the spatial resolution adequacy for the "lameiros" monitoring, images from SPOT and Landsat sensors were used. Data relative to the images used are presented in Table 1.

Table 1 – Satellite images used: sensors, spatial resolution and acquiring dates

Sensors	Spatial Resolution	Red band	Infrared band	Acquiring Dates
SPOT 2	20m	0,61 - 0,68µm	0,78 – 0,89µm	4 July 2005
				8 August 1991
SPOT 4	20m	0,61 - 0,68µm	0,78 – 0,89µm	8 July 1998
SPOT 5	10m	0,61 - 0,68µm	0,78 – 0,89µm	31 July 2002
				20 August 2003
				6 September 2006
Landsat 5	30m	0,63 - 0,69µm	0,76 – 0,90µm	15 September 1998
				20 October 1997
				25 December 1994
Landsat 7	30m	0,63 - 0,69µm	0,78 – 0,90µm	24 June 2000
				21 November 2001

The satellite images were processed with the PCI Geomatica v8.2 software. The processing included geometric correction, calibration and radiometric correction, and atmospheric correction. The geometric correction was based on the manual identification of Ground control points (GCP). The GCP were identified in each satellite image using a 0.5 m spatial resolution georeferenced database (ortophotomap 1/10000). Georeferenced satellite images with 5x5m pixels were created for the study area, using a first order polynomial transformation and bilinear resampling

The meadows fields of interest were identified in the ortophotomap and then converted to 5m pixel resolution, in order to match the georeferenced satellite images.

The digital numbers of the georeferenced Landsat images were converted to spectral radiance using the following equation (Chander and Markham, 2003):

$$L_\lambda = G_{rescale} \times Q_{cal} + B_{rescale} \tag{1}$$

where L_λ is the spectral radiance at the sensor's aperture (W/(m^2 sr μm)), $G_{rescale}$ and $B_{rescale}$ (W/(m^2 sr μm)/DN) are band specific rescaling factors (sensor gain and offset, respectively), and Q_{cal} is the quantized calibrated pixel value in digital numbers.

The digital numbers of the georeferenced SPOT images were converted into spectral radiance, according to

$$L_\lambda = (DN - offset)/Gain \tag{2}$$

where L_λ is the spectral radiance at the sensor's aperture (W/(m^2*sr*μm)), DN is the digital number, Gain represents the sensor gain and Offset is the sensor offset (equal to zero).

The spectral radiance data were then converted into reflectance at the top of the atmosphere through the following equation (Chander and Markham, 2003):

$$\rho = (\pi \cdot L_\lambda \cdot d^2)/(ESUN_\lambda \cdot \cos\theta_s) \tag{3}$$

where ρ is the planetary reflectance (dimensionless), d is the earth-sun distance in astronomical units, $ESUN_\lambda$ is the mean solar exoatmospheric irradiance, and θ_s is the solar zenith angle (degrees). The assumption that the water reflectance at the near infrared (NIR) band should be around zero was used to establish a simplified atmospheric correction process. The reflectance values over a water surface measured in the NIR band were assumed to be the contribution of atmosphere, and subtracted from the reflectance values of all image bands.

Data analysis

NDVI data were computed with the reflectance data obtained in field measurements, considering the red and near infrared band widths of the sensors SPOT2, SPOT4, SPOT5, Landsat5 and Landsat7 (Table1). The NDVI is computed as

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \tag{4}$$

where ρ_{NIR} is the reflectance at the near infrared wavelength band and ρ_{red} is the reflectance at the red wavelength band. The mean NDVI values calculated for each measurement point were therefore obtained, and a mean NDVI value was computed for each agricultural field (IM and NIM) and each plot (IM1, IM2, IM3, NIM1, NIM2 and NIM3)

A one-way ANOVA was applied to the NDVI data in order to evaluate the potential of the different sensors to distinguish between irrigated and non-irrigated meadows. Results are expressed as F values and significance level (p value).

The Pearson correlation was applied to evaluate the correlation between the NDVI results obtained through satellite images and spectroradiometer. However, since the NDVI data obtained through the different sensors represent different years, with variable weather conditions, it was necessary to correct the NDVI values to eliminate the weather variation effect. In order to set that correction a NDVI corrected was defined (NDVIcorr $sensor_x$) as

$$NDVI_{corr\ sensor\ 1} = NDVI_{sensor\ 2} \cdot \frac{ETr_2}{ETr_1} \tag{5}$$

where ETr_x is the relative evapotranspiration, for the spectroradiometer measurements and satellite image dates (1 and 2, respectively). The relative evapotranspiration was calculated using the ratio between the reference evapotranspiration at a 10-days period covering the dates of satellite image or the spectroradiometer measurements (five days before and five days after the date of the spectroradiometer measurement and satellite image) and the 17 years (1991-2007) mean reference evapotranspiration for the same dates. The reference evapotranspiration, which represents the climate effect over a crop, was computed using the FAO56 methodology (Allen et al., 1998).

3 RESULTS AND DISCUSSION

In each satellite image 787 pixels in the irrigated meadow and 690 in the non irrigated meadow were used, distributed for each plot according to field conditions of vegetation development, water distribution and slope and aspect variation – 285 pixels in IM1, 329 in IM2 and 173 in IM3, and 176 pixels in NIM1, 297 in NIM2 and 217 in NIM3.

The mean NDVI values were set for each pair "satellite image – spectroradiometer measurement" – and analysed, as presented in Table 2.

In the three first months of the period considered (July - September) all the satellite sensors used in this study were able to distinguish between irrigated and non-irrigated meadows. The results of the October-December period did not distinguish meadows with different water regimes. These results on the last 3 months reflect the generalized water availability due to precipitation, over both study fields.

Table 2 – Comparison of mean NDVI values (n=3), obtained by different satellite sensors and spectroradiometer (Sp), in irrigated (IM) and non irrigated meadows (NIM).

		Sensors									
			SPOT(10m)			SPOT20m			Landsat5		Landsat7
Month		Sp	D1	D2	Sp	D1	D2	Sp	D1	Sp	D1
Jul	IM				0,82	0,84	0,76			0,83	0,71
	NIM				0,64	0,61	0,56			0,59	0,50
	Sig				*0,000*	*0,000*	*0,000*			*0,001*	*0,004*
Aug	IM	0,65	0,68	0,63	0,65	0,61					
	NIM	0,27	0,37	0,45	0,27	0,38					
	Sig	*0,003*	*0,015*	*0,001*	*0,003*	*0,001*					
Sep	IM	0,70	0,72					0,71	0,77		
	NIM	0,49	0,49					0,48	0,43		
	Sig	*0,001*	*0,000*					*0,008*	*0,000*		
Oct	IM							0,77	0,69	0,77	0,73
	NIM							0,60	0,66	0,59	0,64
	Sig							*0,046*	*0,173*	*0,008*	*0,021*
Nov	IM									0,44	0,59
	NIM									0,50	0,65
sig	Sig									0,542	0,180
Dec	IM	0,43	0,62	0,65				0,66	0,42		
	NIM	0,43	0,63	0,60				0,64	0,41		
	sig	*0,928*	*0,818*	*0,313*				*0,748*	*0,942*		

Sig. - significance of F test performed by ANOVA

The Pearson correlation was computed for each pair “satellite image – spectroradiometer measurement”, considering the corrected and non-corrected NDVI values over the “lameiros”, as presented in Table 3. When compared with the results at field level (represented by the spectroradiometer), both SPOT and Landsat images showed a very interesting behaviour for the monitoring of the studied “lameiros”, as reflected by the correlation values. The results for November and December were less consistent than those from the other months, probably reflecting the unfavourable light conditions during this period, which affect the NDVI measurements.

Although SPOT images with higher spatial resolution (10m) presented better results, it seems that the 20m and 30m spatial resolution images are also relevant for “lameiros” monitoring. This is of particular interest because it allows the use of a broader historical archive of satellite images to characterize the spatial evolution and distribution of these meadows since 1977.

Table 3 – Pearson correlation (r) between spectroradiometer and different satellite sensors for NDVI and NDVIcorr values for each month.

Month		SPOT (10m)	SPOT (20m)	Landsat5 (30m)	Landsat7 (30m)
Jul	NDVI		0,74***		0,94***
	NDVIcorr		0,83***		0,73*
	Obs. number		12		12
Aug	NDVI	0,95***	0,95***		
	NDVIcorr	0,96***	0,79*		
	Obs. number	12	6		
Sept	NDVI	0,79*		0,77*	
	NDVIcorr	0,77*		0,60	
	Obs. number	6		6	
Oct	NDVI			0,60	0,78*
	NDVIcorr			0,78*	0,90**
	Obs. number			6	6
Nov	NDVI				0,04
	NDVIcorr				-0,62
	Obs. number				6
Dec	NDVI	-0,64**		-0,15	
	NDVIcorr	-0,40		0,73*	
	Obs. number	12		6	

Correlation coefficients significance: *$p<0.10$; ** $p<0.05$; ***$p<0.01$

4 CONCLUSIONS

The results revealed very interesting perspectives for the use of SPOT and Landsat sensors for monitoring the “lameiros” dynamics, particularly for the July-September period. However, the study was not conclusive about the potential of both sensors to distinguish between irrigated and non-irrigated meadows all year around. The study described is to be continued, with spectroradiometer measurements performed during 2008, and with satellite image acquisitions planned.

An important aspect of this investigation was the fact that the 30m resolution Landsat images are adequate to monitor “lameiros”, which opens good perspectives in terms of historic coverage using the Landsat thermal band, which might be useful for evapotranspiration mapping to support assessing water management issues for these semi-natural mountain meadows.

ACNOWLEDGEMENTS

The first author wishes to acknowledge the "Fundação para a Ciência e a Tecnologia" for the PhD grant. The authors acknowledge the OASIS European Program for making available the SPOT image data used in this study through the project, ref. 307 and the "Fundação para a Ciência e a Tecnologia" for funding of the PTDC/AGR-AAM/67182/2006 scientific project.

REFERENCES

Allen, R.G., Tasumi, M., Morse, A., Trezza, R., Wright, J.L., Bastiaanssen, W., Kramber, W., Lorite, I. 6 Robinson, C.W. 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) – Aplications. *Jounal of Irrigation and Drainage Engineering.* July/August 2007: 395-406

Allen R.G., Pereira L.S., Raes D. & Smith M., 1998. Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements. *FAO Irrig. and Drain. Paper 56*, FAO, Rome, 300p.

Bock, M. 2003. Remote sensing and GIS-based techniques for the classification and monitoring biotopes. Case examples for a wet grass and moor land area in Northern Germany. *Journal for Nature Conservation* (11) 145-155

Chander, G. & Markham, B. 2003. Revised Landsat-5 TM radiometric calibration procedures and postcalibration dynamic ranges. *IEEE Transaction on Geosciences and Remote Sensing* 41

Gonçalves, D. A. 1985. A rega de lima no interior de Trás-os-Montes. Instituto Universitário de Trás-os-Montes e Alto Douro. Vila Real.

Marçal, A.R.S. & Wright, C.G. 1997. The use of 'overlapping' NOAA-AVHRR NDVI maximum value composites for Scotland and initial comparisons with the land cover census on a Scottish Regional and District basis. *International Journal of Remote Sensing* (18) 491-503

Marçal, A.R.S; Borges, J.S.; Gomes, J.A. & Pinto da Costa, J.F. 2005. Land cover update by supervsed classification of segmented ASTER images. *International Journal of Remote Sensing* (26) 1347-1362

Moreira, N.; Aguiar, C. & Pires, J.M. 2001. Lameiros e outros prados e pastagens de elevado valor florístico. Pastagens de Montanha. *Direcção Geral de Desenvolvimento Rural*. LIsboa

Pires, J.M.; Pinto, P.A. & Moreira, N.T. 1994. Lameiros de Trás-os-Montes. Perspectivas de futuro para estas pastagens de montanha. Série Estudos Escola Superior Agrária. Edição do Instituto Superior de Agronomia.

Poças, I.; Pereira, L.S.& Cunha, M. 2008a. Pastagens como factor de conservação da água em zonas de montanha, os Lameiros. *Pastagens e Forragens.* (28) (In press)

Poças, I.; Cunha, M. & Pereira, L.S. 2008b. Los lameiros, pastizales seminaturales de regadio de montaña: sistemas ancestrales en el paisaje rural portugués del siglo XXI. In: J. Palerm, T. Martinéz, M. Castro, L.S. Pereira (eds.) El pequeño riego y herencias de culturas hídricas en Iberoamérica. COLPOS, Montecillo, México (In press).

Rousse, W.; Haas, R.; Scheel, J. & Deering, W. 1973. Monitoring vegetation systems in great plain with ERST. In *Proceedings of the Third ERST Symposium, NASA SP-3511*, US Government printing office, Washington DC, 309-317

Sawaya, K.E.; Olmanson, L.G.; Heinert, N.J.; Brezonik, P.L. & Bauer, M.E. 2003. Extending satellite remote sensing to local scales: land and water resources monitoring using high-resolution imagery. *Remote Sensing of Environment* (88) 144-156

Teles, A.N. 1970. Os lameiros de montanha do norte de Portugal. Subsídios para a sua caracterização fitossociológica e química. *Separata da Agronomia Lusitana – Vol. XXXI.* Tomo I – II