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Remote sensing based indicators of changes in a mountain rural landscape of Northeast Portugal

Isabel Pôças [a,b], Mario Cunha [a,c,*], Luis S. Pereira [b,d]

[a] Faculdade de Ciências da Universidade do Porto, Campus Agrário de Vairão, 4485-661 Vairão, Portugal
[b] Centro de Engenharia dos Biossistemas, Tapada da Ajuda, 1349-017 Lisboa, Portugal
[c] Centro de Investigação em Ciências Geo-espaciais, Rua do Campo Alegre 687, Porto, Portugal
[d] Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal

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A B S T R A C T

Landscape metrics were used to analyze landscape changes and related driving forces in a mountain rural landscape of Northeast Portugal over three decades. This landscape has great heterogeneity, which favors high levels of diversity and provides for a variety of habitats. The landscape metrics were obtained from land cover maps derived from Landsat images of 1979, 1989 and 2002. Results indicate a trend for increased landscape fragmentation, decrease of annual crop fields (−43%) and, mainly, increase of meadows (+60%). Results relate with decline and aging of the rural population, and to several measures and policies of subsidies implemented in the region in application of the Common Agriculture Policy, which contributed to the replacement of annual crops by meadows. Results are potentially useful to base appropriate policies for landscape management and conservation planning.

Introduction

The spatiotemporal dynamics of traditional mountain rural landscapes reflect the centenarian land use evolution resulting from a longstanding interaction between men and environment, and recent changes due to impacts of population migrations and policies influencing land use. That interaction between men and environment led to the development of traditional landscapes whose characteristics are closely linked to many features of local geography, climate, water availability, soils and historical occupation of the region.

The Northern region of Portugal is characterized by traditional mountain rural landscapes with great heterogeneity, complex land cover patterns, and large fragmentation as it often happens for mountain landscapes. These characteristics favor high levels of biodiversity and provide for a variety of habitats, including for rare or even threatened species.

Mountain semi-natural irrigated meadows ("lameiros") are one of the most characteristic elements of the mountain landscapes of Northern Portugal (Pôças, Cunha, Marçal, & Pereira, 2008; Pôças, Cunha, & Pereira, 2009). They present ancestral irrigation systems that originate in the high middle age when mountains were first colonized (Raposo, 1994). In addition to their economic importance for livestock grazing and hay production, these meadows are recognized as a protected habitat (habitat 6510, ICN 2006a) particularly of rare plant species (Moreira, Aguiar, & Pires, 2001) and fauna species (e.g., *Gallinago gallinago*, ICN, 2006a; Rufino & Neves, 1991). "Lameiros" also contribute to the beauty of the landscape mosaic, thus with impacts on tourism, particularly relative to nature trails (Farinha, 2000). The common lands ("baldios") and oak and riparian groves are also characteristic elements of this mountain landscape and also contribute to the economy of the rural populations, for the landscape mosaic value, and for high fauna and flora value (ICNB, 2008; IDRHa, 2004). However, the mountain areas of Portugal are facing high decline and aging of the population, which cause changes in land use and in the landscape. This creates the need to develop appropriate tools for monitoring and assessing the changes of these landscapes, which could support their protection and enhancing their patrimonial and economic value.

Earth Observation Satellites provide valuable data for studies on landscape changes since they provide synoptic and repetitive observations, capture information in a broad range of the electromagnetic spectrum, and are available since the 1970s, and the access to data is often easy and at low cost. However, the heterogeneity and fragmentation of the traditional mountain landscapes, associated with steep slopes and related shadow effects, are sources of difficulties in remote sensing applications (Millette, Tuladhar, Kasperson, & Turner, 1995; Poudel, 2008; Wundram & Löffler,

* Corresponding author. Centro de Engenharia dos Biossistemas, Tapada da Ajuda, 1349-017 Lisboa, Portugal. Tel.: +351 252660400; fax: +351 252661780.
E-mail addresses: ipocas@mail.icav.up.pt (I. Pôças), mcunha@mail.icav.up.pt (M. Cunha), lspereira@isa.utl.pt (L.S. Pereira).

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2008). Therefore, using remote sensing for monitoring changes in mountain landscapes is challenging but an appropriate way to identify landscape changes (Bayarsaikhan, Boldgiv, Kim, Park, & Lee, 2009; Weiss & Walsh, 2009). Monitoring approaches of the Portuguese mountain landscapes are yet scarce and few studies cover similar landscapes in Europe (Geri, Amici, & Rocchini, 2010; Maia, 2007; Pelorosso, Leone, & Boccia, 2009; Serra, Pons, & Sauri, 2008).

Landscape changes have been more sudden and occurring at a large scale in the last few decades (Antrop, 2005; Calvo-Iglesias, Fra-Paleo, & Dias-Varela, 2008). The dynamics of these changes is often related to socioeconomic factors and to regional or agricultural policies, including the Common Agricultural Policy (CAP) in case of European landscapes (Lasanta-Martínez, Vicente-Serrano, & Cuadrat-Prats, 2005; MacDonald et al., 2000; Olsson, Austrheim, & Grenne, 2000). There is a growing need for landscape monitoring and assessment of changes in spatial patterns over time, and identifying driving forces for landscape changes. Interactions between landscape spatial pattern and ecological processes explain impacts of landscape changes on habitats, biodiversity, complexity and fragmentation of the landscape, and often on cultural values (Dramstad et al., 2001; Zeng & Wu 2005). Therefore, the quantification of landscape changes must consider both modifications in spatial arrangements and their consequences.

The landscape metrics, based on the geometric properties of the landscape elements, are indicators widely used to measure several aspects of the landscape structure and spatial pattern, and their variation in space and time (Li et al., 2005). These metrics have been used to landscape monitoring, including landscape changes (Lausch & Herzog, 2002; Peng et al., 2010; Petrov & Sugumaran, 2009; Rocchini, Perry, Salerno, Maccherini, & Chiarucci, 2006), assessing impacts of management decisions and human activities (Geri et al., 2010; Lin, Han, Zhao, & Chang, 2010; Narumalani, Mishra, & Rothwell, 2004; Proulx & Fahrig, 2010), supporting decisions on landscape and conservation planning (Leitão & Ahern, 2002; Sundell-Turner & Rodewald, 2008), and to analyze landscape and habitats fragmentation (Hargis, Bissonette, & David, 1998; Zeng & Wu, 2005). Landscape metrics area mainly applied to categorical/thematic maps, such as maps of land use, land cover or vegetation, which can be derived from historical maps, aerial photographs and remote sensing data. The digital nature of the information of land cover obtained from satellite imagery enables the derivation of a potentially large number of metrics, which is advantageous (Haines-Young & Chopping, 1996).

The landscape structure and spatial pattern can be analyzed through composition and configuration (Leitão & Ahern, 2002; Leitão, Miller, Ahern, & McGarigal, 2006). Metrics related to composition measure landscape features like proportion, richness, evenness or dominance of different patch types or classes; metrics relative to configuration consider spatial attributes and are related to geometry, distribution and spatial relationships of different patches in the landscape (Gustafson, 1998; Leitão & Ahern, 2002). A great variety of landscape metrics have been developed in the past decades (Gustafson, 1998; McGarigal & Marks, 1995), thus the selection of the appropriate metrics and their interpretation should be performed carefully to avoid redundancy (Cushman, McGarigal, & Neel, 2008; Leitão et al., 2006; Uuemaa, Antrop, Roosaare, Marja, & Mander, 2009). Many metrics incorporate multiple aspects of composition and configuration in its calculation, making difficult their interpretation (Gustafson, 1998). For the quantification of the landscape structure it is desirable to use the smallest number of independent metrics taking into account the correlations among metrics and the goals of the study (Cushman et al., 2008).

Considering the need to improve knowledge on the mountain landscapes of Northern Portugal and of their dynamics of change in recent decades, a study area was considered in Montalegre region. The main objectives of this study were to analyze the landscape changes between 1979 and 2002 using landscape metrics derived from remote sensing, and the causes for those changes, including socioeconomic factors and agricultural policies. Further, it was also aimed to contribute for developing a methodology that may be applied for monitoring of mountain landscapes of Northern Portugal and similar areas.

Material and methods

Study area

The study area was selected in the mountain region of Northeast Portugal, in Montalegre municipality (Fig. 1), approximately between 41°56′34″N and 41°34′47″N latitude and 8°08′03″W and 7°33′23″W longitude. The western part of Montalegre is included in the National Park of Peneda-Gerês (Fig. 1), which is a protected area with around 70,000 ha. About 26% of the municipality is classified as Site of Community Importance (SCI) from the Atlantic biogeographical region ("Site Peneda/Gerês", code PTCON0001), following the Directive 92/43/EEC (ICN, 2006b).

Traditionally, the agriculture was the main economical activity in this study area. The traditional landscape of Montalegre combines a mix of land uses (Pôças, Cunha, Marçal, & Pereira, 2010): mountain semi-natural irrigated meadows ("*lameiros*") and common lands ("*baldios*") explored for hay and grazing; crop fields; vegetable gardens located close to the villages; evergreen forests (mainly *Pinus pinaster*), and deciduous forests, mainly oaks (e.g., *Quercus pyrennaica*), chestnuts (*Castanea sativa*), and riparian species (e.g., *Betula celtiberica*). Mountain semi-natural meadows are irrigated in winter for temperature regulation and in summer for improved crop growth (Pôças et al., 2009). They comprise several permanent herbaceous species (e.g., *Arrhenatherum elatius, Holcus lanatus, Plantago lanceolata, Dactylis glomerata, Anthoxanthum odoratum, Trifolium dubium*). Common lands are also used for grazing and mainly are constituted by shrubs (e.g., *Cytisius spp., Pterospartum tridentatum, Ulex spp.* and *Erica spp*) and other permanent herbaceous species (e.g., *Festuca rubra, Agrostis spp., Nardus stricta,* and *Holcus mollis*).

Data sources

The analysis of spatiotemporal changes in Montalegre traditional landscape was based in three land cover maps derived from the implementation of a supervised classification over three satellite images. These satellite images were selected within the Landsat historical archive: Landsat2 MSS of April 30th, 1979, Landsat5 TM of March 14th, 1989 and Landsat7 ETM+ of May 29th, 2002 (path 204/row 31). The selection was oriented for images free of clouds from late winter or early spring relative to years close to those when statistical data from agricultural census was available: 1979, 1989 and 1999. For the years 1999, 2000 and 2001 there were not adequate Landsat images available and so an image from 2002 was selected. The Landsat TM and ETM+ images had pixel of 30×30 m, but the Landsat2 MSS image was acquired with pixel 57×57 m. In this Landsat2 MSS image, the pixel was converted to a 30×30 m pixel using the nearest neighbor resampling algorithm (Richards & Jia, 2006). This downscaling procedure provided for improved comparability among the images studied but did not increase the details of perception to that of later images.

Based on the main land cover types of the region, 11 classes where identified in each image: meadows, annual crops, sparse vegetation, closed heathlands, open heathlands, low shrublands,

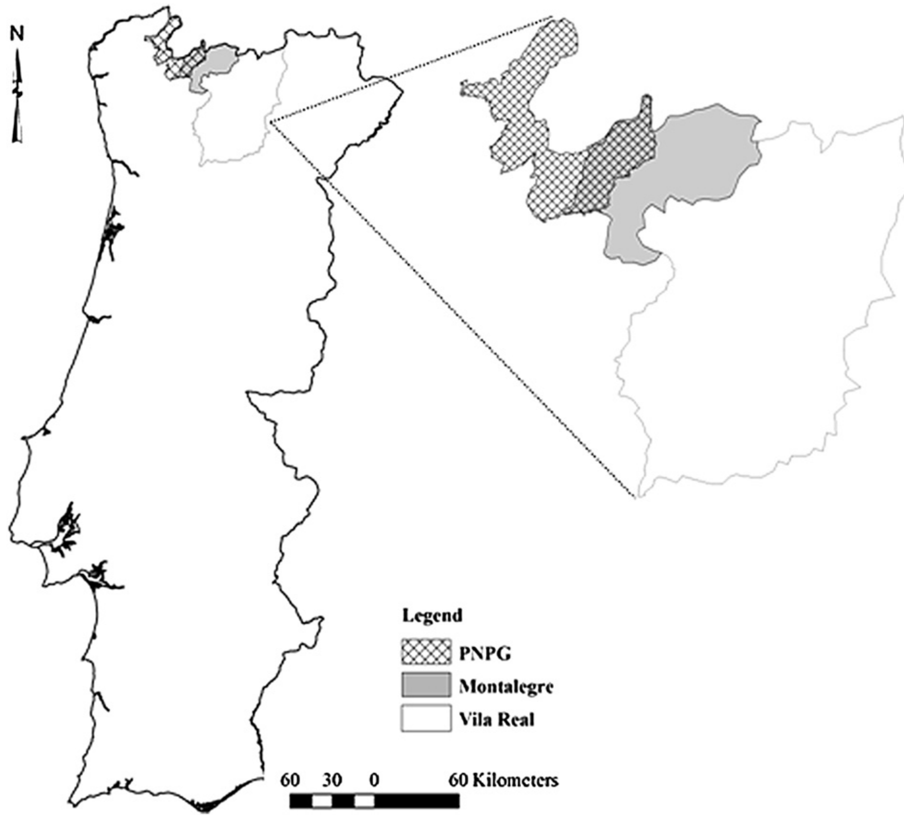

Fig. 1. Location of Montalegre study area, with the identification of its location in relation to Vila Real district, Northeast Portugal, and to the National Park of Peneda-Gerês (gridded area).

deciduous forests, evergreen forests, bare soil and/or rocks, urban areas, and water. Sparse vegetation refers to very sparse foliage cover (<10%) dominated by grasses and herbs, and some shrubs. Closed heathlands refer to shrubs with dense foliage cover (70–100%), open heathlands to shrubs of mid-dense foliage cover (30–70%), and low shrublands to shrubs with sparse foliage cover (10–30%). In these three last classes also grasses and herbs are present. The supervised classification was performed using a maximum likelihood algorithm (Richards & Jia, 2006). To support the classification procedure training areas were selected per class in each satellite image. These areas were identified over pixels of well-known land cover to provide a reference spectral signature per class. The selection of training areas per image allowed minimizing the impact of the differences at the time of acquisition of the three Landsat images. A mode filter of 3×3 was applied to the classification-derived maps to reduce the effect of "salt & pepper" noise produced by the classification procedure. The overall accuracy of the classification, corresponding to the percentage of pixels correctly allocated to each class in a confusion matrix, was tested over validation areas defined for each class. The results of the overall accuracy for each classification map were 92.5% for 1979, 93.14% for 1989 and 95.20% for 2002. Further details are described by Pôças (2010).

Landscape metrics

Selected landscape metrics were used to characterize the spatial heterogeneity, fragmentation and complexity of Montalegre's landscape for the three years studied – 1979, 1989 and 2002, thus covering three decades. The landscape patterns were quantified at three levels: patch, class, and landscape. The patch level constitutes the basic unit of landscape and represents homogeneous areas that differ from the adjacent ones by nature or appearance (Turner, Gardner, & O'Neill, 2001).

The software FRAGSTATS version 3.3 (McGarigal & Marks, 1995) was used to extract the landscape metrics from each land use map of 1979, 1989 and 2002. FRAGSTATS computes metrics for each patch in the landscape mosaic (patch), each patch type (class) in the mosaic, and for the landscape mosaic as a whole (landscape). The metrics used were selected from those available in the software FRAGSTATS: 21 metrics of area/edge/density and 31 metrics of shape for the class level; 18 metrics of area/edge/density and 25 metrics of shape for the landscape level; 8 metrics of contagion/interspersion and connectivity both for class and landscape level; and 9 metrics of diversity (landscape level). For the patch level, only one metric of area/edge/density was considered. The selection of the metrics for the class and landscape levels was based on an analysis of the correlations between metrics of each type. A correlation matrix for each type of metrics was used to select the non correlated metrics taking as reference the critical values ($p < 0.05$) for the Pearson correlation coefficient. The metrics selected were the following (see Table 1 for descriptions):

- Patch level: one metric of area/edge/density – total area. Based on this metric later was computed the number of patches per classes of area.
- Class level: four metrics of area; one metric of shape; and three metrics of contagion/interspersion.
- Landscape level: three metrics of area and one metric of shape. It was observed that all the metrics of contagion/interspersion were highly correlated; therefore, based on results obtained with this metric by Peng et al. (2010), only the contagion index was selected. The diversity metrics were also highly correlated.

Table 1
Metrics selected for the quantification of landscape patterns in Montalegre.

Metrics[a]	Units	Description	Levels[b]		
			P	C	L
Metrics type: area/edge/density					
Total area (ha)	ha	Total area per patch, class or landscape	×	×	×
Number of patches, NP	[ ]	Number of patches per class or landscape. It is a measure of landscape configuration that indicates the level of subdivision of each class or landscape		×	×
Mean patch size, AREA_MN	ha	Average size of patches from a specific class. Like the NP this metrics also measures the subdivision of the class or landscape		×	
Largest patch index, LPI	%	Percentage of landscape comprised in the largest patch of each class		×	×
Metrics type: shape index					
Shape index (mean), SHAPE_MN (>1)	[ ]	Quantifies the geometric complexity of the shapes at several landscape levels. The highest			×
Shape index (area-weighted mean), SHAPE_AM	[ ]	values of the index represent the greater complexity of the landscape		×	
Metrics type: contagion/interspersion					
Interspersion and juxtaposition index, IJI	(%)	Degree of intermixing of patch types		×	
Landscape division index, DIVISION [0,1]	[ ]	Measures the degree of landscape division based on the cumulative patch area distribution		×	
Aggregation index, AI	(%)	Measures de degree of proportional aggregation of each class using an adjacency matrix, which shows the frequency with which different pairs of patch types appear side-by-side on the map		×	
Contagion, CONTAG	(%)	It is a measure of configuration that quantifies the degree of spatial aggregation of land cover types			×
Metrics type: diversity					
Simpson's diversity index, SIDI [0,1]	[ ]	Diversity index that quantifies the landscape composition			×
Simpson's evenness index, SIEI, [0,1]	[ ]	It is a measure of configuration that quantifies the distribution of area among patch types			×

[a] Definitions and equations for calculation of the metrics are provided by McGarigal and Marks (1995).
[b] Levels: P – Patch; C – Class. L – Landscape.

Still, the Simpson's diversity index was selected, together with the Simpson's evenness index, since it is a very intuitive index and is less sensitive to the presence of rare patch types (McGarigal & Marks, 1995).

The comparability between some metrics computed from classification maps derived from Landsat MSS downscaled to 30 × 30 m and Landsat TM and Landsat ETM+ has some problems concerning the spatial scaling effect. This effect is particularly sensitive for metrics related with fragmentation, like the number of patches, mean patch size, and aggregation index (García-Gigorro & Saura, 2005; Wu, 2004). Several authors refer the use of scaling laws to predict metrics values at multiple scales and overcome this problem (e.g., Saura & Castro, 2007; Wu, 2004). In our case study, little would be gained by their use because the value of a metric in a certain spatial resolution could only be obtained by computing the scaling laws fitting on aggregated data (since fine-scale maps are not available for 1979), which would imply the increasing of errors. Therefore, the interpretation of the metrics results related with fragmentation for 1979 data and their comparability with data from 1989 and 2002 was done carefully.

Results

Landscape metrics of area

The metrics of area refer to the area per patch, class and landscape, and the number of patches per class, which are related with landscape configuration and measure the landscape subdivision.

The areas per class of vegetation computed for each land use map (1979, 1989 and 2002) are summarized in Table 2 and Fig. 2. To be noted that areas not classified as vegetation are not included, thus the percentage does not sum to 100%. Differences in areas between 1979 and 2002 are affected by classification errors, but the classification overall accuracy was larger than 92.5% for all the images, which is acceptable for highly fragmented landscapes (Bayarsaikhan et al., 2009; Millette et al., 1995). As an example, 5% of the pixels of the sparse vegetation class were incorrectly classified as bare soil or rock because that vegetation is of quite low density (10–30%), particularly in late winter or early spring when the images were captured. Results show that most of landscape of Montalegre is occupied by shrub and sparse vegetation, averaging 67% of the landscape area, which is more difficult to accurately classify. This vegetation is typically associated to grazing common lands.

In the period 1979–2002, the vegetation classes with greater changes in area are meadows (+60%) and annual crops (−43%) (Table 2). All classes related with shrub vegetation (shrublands and heathlands) have a great decrease. Meadows are likely to have increased from areas of annual crops and private heathlands and shrublands. The increase in meadows' area between 1979 and 2002 relates with the observed increase in livestock, manly bovines (INE, 1979, 2001). Between 1979 and 2002, deciduous forests show an increase (1421 ha) while evergreen forests show a decrease (−729 ha). Results for the first decade (1979–1989) show a decrease of 1984 ha and 1384 ha of deciduous and evergreen forests, respectively. Possible discrepancies in these changes may be due to the fact that, by late winter and early spring, the differentiation between some classes (e.g., between deciduous forests and heathlands) is more difficult due to the vegetation conditions. The lack of homogeneity in stand types and the effects of topographic shadows associated to mountain areas also contribute to

Table 2
Statistics of the total area per class of vegetation for the period studied (1979, 1989 and 2002).

Vegetation Classes	Area (ha)			Average (n = 3)		Δ 2002–1979
	1979	1989	2002	(ha)	(%)	(ha)
Low shrublands (LS)	21,884.9	22,791.4	21,139.4	21,939	21.3	−746
Closed heathlands (CH)	17,302.4	15,075.7	15,329.1	15,902	15.4	−1973
Sparse vegetation (SV)	10,194.0	9386.5	9215.5	9599	9.3	−979
Open heathlands (OH)	21,144.0	24,855.4	18,622.2	21,541	20.9	−2522
Deciduous forests (DF)	5133.0	3148.7	6554.3	4945	4.8	1421
Evergreen forests (EF)	7231.6	5847.7	6502.7	6527	6.3	−729
Meadows (MW)	5069.0	8400.6	12,663.6	8711	8.5	7595
Annual crops (AC)	10,877.0	8939.8	7581.7	9133	8.9	−3295

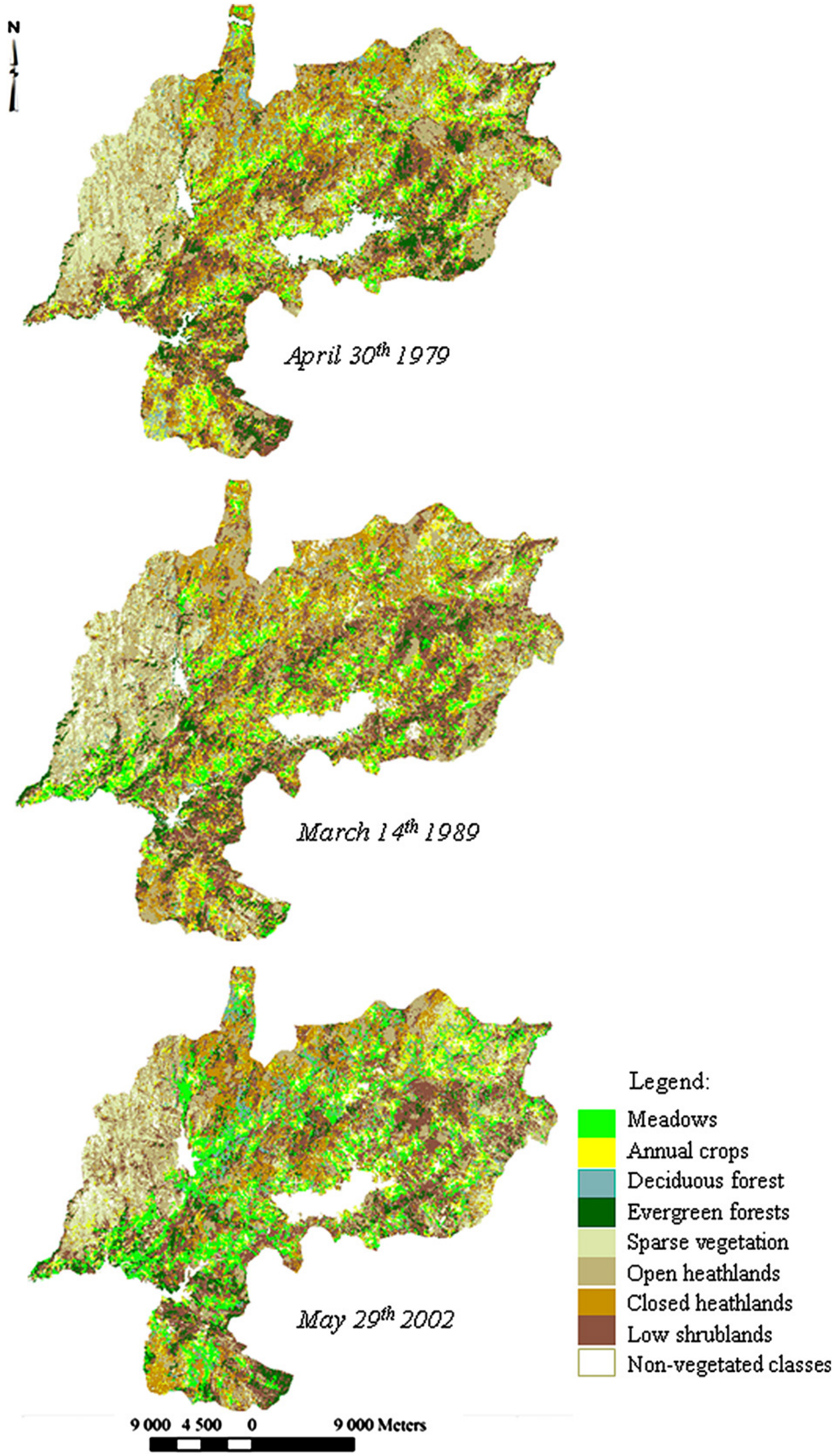

Fig. 2. Classification maps derived from Landsat images from April 30th 1979, March 14th 1989 and May 29th 2002 (adapted from Pôças 2010).

the difficulty in distinguishing forest classes, as referred by Millette et al. (1995).

Classes of sparse vegetation, open heathlands, closed heathlands and low shrublands are the most representative of the Montalegre's landscape, as mentioned above. All these classes show a decrease between 1979 and 2002, particularly open heathlands. This is probably due to the conversion of some areas of this class into meadows, as well as into other classes of shrub

Table 3
Statistics of the number of patches (NP) per class of vegetation and landscape for the years 1979, 1989 and 2002.

Classes	Number of patches			*Average (n = 3)*	*Δ 2002–1979*
	1979	1989	2002		
Low shrublands (LS)	3886	5579	5295	*4920*	*1409*
Closed heathlands (CH)	6003	8002	8001	*7335*	*1998*
Sparse vegetation (SV)	2610	4728	4852	*4063*	*2242*
Open heathlands (OH)	4214	7116	6166	*5832*	*1952*
Deciduous forests (DF)	3987	5001	6810	*5266*	*2823*
Evergreen forests (EF)	2098	3623	4053	*3258*	*1955*
Meadows (MW)	2285	4107	3301	*3231*	*1016*
Annual crops (AC)	3496	6986	5489	*5324*	*1993*
Landscape	30,214	47,978	46,599	*41,597*	*16,385*

vegetation following the decline of the traditional grazing activity in common lands (Santos, 1995), or due to ecological succession process.

Table 3 presents the number of patches (NP) from 1979 to 2002. Results show larger variations in NP between 1979 and 1989 than during the following decade. At the landscape level, NP increased 59% between 1979 and 1989 (Table 3), which however may be partially due to the spatial scale effect above mentioned in Section 2.3. Between 1989 and 2002, NP increased for the classes of forest but decreased for open heathlands, meadows and annual crops. The largest number of patches refers to closed heathlands, open heathlands, annual crops and deciduous forests (in average NP > 5265, Table 3).

The small patches (less than 0.5 ha) prevail in all vegetation classes, particularly for 1989 and 2002 (Fig. 3). The class of deciduous forests presents the highest percentage of small patches, indicating a high level of fragmentation. Vegetation in this class mainly corresponds to oaks and riparian groves. High fragmentation of forest areas is also supported by the fact that the number of patches with areas between 0.5 and 1 ha decreased between 1979 and 2002 for all classes except for forests (Fig. 3).

From 1989 to 2002, the percentage of patches with less than 0.5 ha decreased in the meadows class, indicating a possible trend for increase of the contiguous areas of meadows (Fig. 3), which goes together with the increase in the area of meadows by about 60%. This hypothesis is in agreement with the fact that meadows and low shrublands have the highest percentage of patches with more than 1 ha: 45% and 42% of NP for meadows in 1979 and 2002, respectively, and 45% and 34% of NP for low shrublands in the same years (Fig. 3).

Table 4 presents the results of the mean patch size and largest patch index, which refer to the subdivision of the classes in the landscape. Since mean patch size is very sensitive to the spatial scale effect (García-Gigorro & Saura, 2005), the comparison between dates is mainly focused on the period between 1989 and 2002. Most of the vegetation classes show a decrease of the mean patch area index. The exception is the class of meadows, which shows an increase of the mean patch area, mainly between 1989 and 2002, thus indicating an increase of contiguous areas of meadows. The mean patch size is greater for the classes of low shrublands and open heathlands, while the lowest refers to deciduous forests, already referred as highly fragmented since they are traditionally located as discontinuous patches across the landscape.

In 1979, the class of sparse vegetation had the largest patch area, occupying 4.0% of the Montalegre's area, while in 1989 (3.5%) and 2002 (4.1%) the largest patch area occurs for the open heathland class. Both classes refer to common lands. Maia (2007), in a study relative to the National Park of Peneda-Gerês (Fig. 1), observed larger patches for similar classes of sparse vegetation and heathlands.

Landscape metrics of shape

The shape index was used to assess the complexity of shapes for the patches of the various vegetation classes (Table 5). This shape index is often considered as an indicator of biodiversity (e.g., plant species richness) because the degree of intensity of land use, which is inversely related with biodiversity, impacts on the complexity of the landscape shapes (e.g., Bailey et al., 2007; Moser et al., 2002); e.g., landscape classes that are highly humanized often present low shape complexity and have low biodiversity. Results show that larger values of the shape index (more complex shapes) correspond to the classes of open heathlands, low shrublands, sparse vegetation and closed heathlands, i.e., referring to common lands. The increase in this shape index for the landscape level, suggests lower human intervention in the referred landscape classes. Shape index results suggest high levels of biodiversity for the classes related to shrubs (heathlands and shrublands) and sparse vegetation. This is also supported by a study in the National Park of Peneda-Gerês, that includes part of Montalegre area, where high value of fauna and high richness of flora species were observed in shrub cover areas (ICNB, 2008).

Landscape metrics of contagion/interspersion

The metrics of contagion/interspersion are configuration metrics that measure the spatial aggregation of land cover types. The interspersion and juxtaposition index (IJI) approaches 0 when

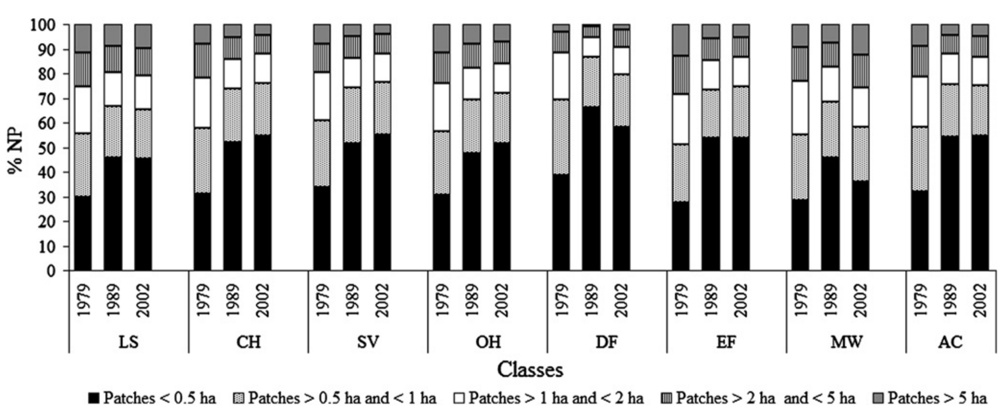

Fig. 3. Number of patches (NP) per area and vegetation class (in percentage). LS – Low shrublands; CH – Closed heathlands; SV – Sparse vegetation; OH – Open heathlands; DF – Deciduous forests; EF – Evergreen forests; MW – Meadows; AC – Annual crops.

Table 4
Statistics for mean and largest patch area indices per class and year, for the period between 1979 and 2002.

Classes	Mean patch size (ha)			*Average (n = 3)*	*Δ 2002–1979*	Largest patch index (%)			*Average (n = 3)*	*Δ 2002–1979*
	1979	1989	2002			1979	1989	2002		
Low shrublands (LS)	5.63	4.09	3.99	*4.57*	*−1.64*	0.92	2.69	1.31	*1.64*	*0.39*
Closed heathlands (CH)	2.88	1.88	1.92	*2.23*	*−0.97*	0.66	0.85	1.47	*0.99*	*0.81*
Sparse vegetation (SV)	3.91	1.99	1.90	*2.60*	*−2.01*	4.03	1.18	0.70	*1.97*	*−3.33*
Open heathlands (OH)	5.02	3.49	3.02	*3.84*	*−2.00*	1.57	3.45	4.10	*3.04*	*2.54*
Deciduous forests (DF)	1.29	0.63	0.96	*0.96*	*−0.32*	0.11	0.02	0.11	*0.08*	*0.00*
Evergreen forests (EF)	3.45	1.61	1.60	*2.22*	*−1.84*	0.23	0.16	0.22	*0.20*	*−0.01*
Meadows (MW)	2.22	2.05	3.84	*2.70*	*1.62*	0.09	0.22	0.54	*0.28*	*0.45*
Annual crops (AC)	3.11	1.28	1.38	*1.92*	*−1.73*	0.41	0.08	0.18	*0.22*	*−0.23*
Landscape	–	–	–	–	–	4.03	3.45	4.10	*3.86*	*0.07*

a patch type is adjacent to only one other patch type; the IJI approaches 100 when the corresponding patch type is equally adjacent to all other patch types (McGarigal & Marks, 1995). High values for this index are indicative of great landscape heterogeneity. In average, IJI is greater than 67.5% for most of the classes studied. Results show a decrease of IJI between 1989 and 2002 for the classes of low shrublands, sparse vegetation, open heathlands and deciduous forests (Table 6). These results indicate that the spatial distribution of the adjacencies among these classes became less interspersed and juxtaposed to other patch types.

The aggregation index (AI) gives the frequency with which different pairs of patch types appear side-by-side on the map. The maximum aggregation (100%) is achieved when the patch type consists of a single, compact patch, which is not necessarily a square patch (McGarigal & Marks, 1995). The aggregation index decreased for all classes between 1979 and 1989, but these results may be partially influenced by the spatial scale effect as already mentioned in Section 2.3. For the period between 1989 and 2002 the variation in the aggregation index was generally small, although there was a slight increase for various classes (Table 6). These results are coherent with the variation in the number of patches. For all the observation period, the class of deciduous forests showed higher disaggregation (AI = 59.7% in average) when comparing to other classes (AI > 67.1%), which relates to the fact that deciduous forests are distributed in discontinuous patches over the landscape. The other classes present high aggregation indices, ranging from 67.1% (Annual Crops) to 77.6% (Open Heathlands) as shown in Table 6.

The contagion index, computed only for the landscape level, measures the degree of clumpiness of the overall landscape pattern. A value of 100% for the contagion index means that the entire landscape is constituted by a single patch. The results for this index were: 39.3% (1979), 35.4% (1989) and 33.6% (2002), indicating a trend for increasing the landscape disaggregation.

Table 5
Shape index – Area weighted mean shape index for class level, and mean shape index for landscape level (>1) per class/landscape and year (1979, 1989 and 2002).

	Shape Index [ ]			*Average (n = 3)*	*Δ 2002–1979*
	1979	1989	2002		
Classes	Area weighted mean shape index				
Low shrublands (LS)	6.701	9.969	7.239	*7.970*	*0.538*
Closed heathlands (CH)	5.075	5.249	6.965	*5.763*	*1.890*
Sparse vegetation (SV)	10.985	6.531	5.538	*7.685*	*−5.448*
Open heathlands (OH)	6.077	9.175	12.354	*9.202*	*6.277*
Deciduous forests (DF)	1.915	1.687	2.543	*2.048*	*0.627*
Evergreen forests (EF)	2.648	2.640	3.076	*2.788*	*0.428*
Meadows (MW)	2.034	2.738	4.021	*2.931*	*1.987*
Annual crops (AC)	3.981	2.747	2.993	*3.240*	*−0.987*
	Mean shape index				
Landscape	1.284	1.354	1.369		

The division index, which measures the degree of landscape division based on the cumulative patch area distribution, showed nearly invariant values for all classes (ranging from 0.99 to 1.00). Thus, this index has shown low sensitivity for the analysis of this landscape.

Landscape metrics of diversity

Two metrics of diversity were computed for the landscape level: the Simpson's diversity index (SIDI) and the Simpson's evenness index (SIEI). SIDI values are equal to zero when the landscape contains only one patch (no diversity) and approaches to one as the number of different patch types increases (McGarigal and Marks 1995). Therefore, higher values of SIDI represent greater likelihood that any 2 randomly patches would be different patch types. The SIDI index shows high values, particularly in 2002, suggesting an increased diversity in landscape composition between 1989 and 2002 (Table 7). These results may be related to the increased landscape fragmentation and disaggregation, which are also occurring in other European regions (e.g., Carranza, Acosta, & Ricotta, 2007; Mottet, Ladet, Coqué, & Gibon, 2006). Differently, SIEI measures the distribution of area among patch types; high values for the SIEI index (Table 7) indicate a high evenness in the distribution of area among patch types (McGarigal and Marks 1995). The variation of this index was very low throughout the three years studied, which indicates low sensitivity of the index when applied to this landscape.

Discussion

The major changes in the landscape metrics of area/edge/density, shape and contagion/interspersion for the study period occurred between 1979 and 1989. Between 1989 and 2002 the changes were smoothed and, for some cases, was not detectable a defined trend for all the classes. The results show a high heterogenic landscape, as indicated by the interspersion and juxtaposition index values above 67.5% for most of the vegetation classes identified. These results reflect the heterogeneity and complexity characteristic of landscapes based on traditional agricultural systems (Geri et al., 2010), as it is the case for the mountain landscape under study.

Results also indicated an increase in the landscape fragmentation (mainly between 1979 and 1989), that was observed together with an increased number of patches (+16385 NP for the landscape level, Table 3), and a reduced patch mean area (Table 4). This change from 1979 to 1989 is likely to have been increased by the change in pixel size from the MSS to the TM and ETM+ Landsat images; nevertheless, an increase in the number of patches and a reduction of the patch mean area is very likely to have occurred. The decrease of the contagion index for the three years studied also

Table 6
Interspersion and juxtaposition index (IJI) and the aggregation index (AI) per class and year (1979, 1989 and 2002).

Classes	IJI (%)			*Average (n = 3)*	*Δ 2002–1979*	AI (%)			*Average (n = 3)*	*Δ 2002–1979*
	1979	1989	2002			1979	1989	2002		
Low shrublands (LS)	68.4	67.1	64.8	*66.8*	*−3.6*	79.8	75.2	75.5	76.8	−4.3
Closed heathlands (CH)	71.3	77.4	77.7	*75.5*	*6.4*	74.9	67.8	69.3	70.7	−5.6
Sparse vegetation (SV)	67.1	73.1	68.3	*69.5*	*1.2*	81.5	69.5	70.3	73.8	−11.2
Open heathlands (OH)	72.9	72.3	66.8	*70.7*	*−6.1*	82.2	75.8	74.9	77.6	−7.3
Deciduous forests (DF)	71.2	72.8	67.9	*70.6*	*−3.3*	68.7	53.1	57.4	59.7	−11.3
Evergreen forests (EF)	46.5	55.2	57.4	*53.0*	*10.9*	78.8	68.4	67.8	71.7	−11.0
Meadows (MW)	59.2	69.2	74.2	*67.5*	*15.0*	75.0	71.9	77.5	74.8	2.5
Annual crops (AC)	79.5	77.7	79.3	*78.8*	*−0.2*	76.3	62.3	62.8	67.1	−13.5

suggests a trend of fragmentation. This trend may be due to the abandonment of crop fields and their substitution by other types of land use such as meadows, or to the colonization by a succession of plant communities. It may also result from changes in the ecological succession in noncropped fields. A similar fragmentation pattern was also observed in other European mountain regions (Serra et al., 2008; Zomeni, Tzanopoulos, & Pantis, 2008).

The population fluxes in the district of Vila Real, where the region under study is located, denoted large variations, with a decline of the population from 347,000 inhabitants in 1979, to 264,400 in 1984 and to 217,000 in 2000, i.e., 37.5% of population decrease in the period in the region (INE, 1970, 1984, 2002). Between 1979 and 1999, the agricultural population of Montalegre decreased from 14,400 to 7396 individuals, i.e., nearly 50% in 20 years. Aging occurred together with depopulation: in 1999 the percentage of farmers older than 55 years was 60%, with 35% of those older than 65 years (INE, 1979, 2001). Depopulation and aging influenced detected changes, mainly cropland abandonment with impacts on the landscape fragmentation.

Despite the trend for increasing fragmentation highlighted by several metrics, the aggregation index has shown that the aggregation levels are still high for most of the vegetation classes. Lower aggregation was identified for deciduous forests and annual crops, which agrees with results for the low mean patch size of these two classes.

Shape index results showed lower complexity of shapes for the classes of shrub (heathlands and shrublands) and sparse vegetation, which are mostly related to common lands and are generally used for livestock grazing, which is practiced adopting an extensive management, therefore with low human intervention.

Results have shown a decrease of annual crops area between 1979 and 2002. To some extent, this decline relates to the decrease in the potato seed production due to the loss of economical competitiveness and difficulties related with the seed certification requirements imposed by CAP regulations, along with problems with nematodes (Bernardo et al., 1992).

Contrasting, the metrics of area showed an increase of the total area of meadows (7600 ha, Table 2) and suggest an increase of the contiguous areas for this class (+1.62 ha of mean patch size, Table 4), mainly between 1989 and 2002. In the region, meadows are mostly represented by mountain semi-natural irrigated meadows ("lameiros") that, in association with common lands, constitute the main grazing and hay resource for livestock production. They also contribute to the conservation of plant and animal biodiversity, the conservation of water and soil resources, the prevention of forest fires when acting as buffer zones (Pôças et al., 2009). During the period considered, and following the CAP reform of 1992, various agro-environmental measures were implemented to provide for the conservation of "lameiros" (Regulation (CEE) 2078/92 and, later, the Decree 475/2001). These regulations also focused the conservation of autochthon bovine breeds, e.g., the "Barrosã" breed produced in the considered meadows, while other measures supported the certification of meat produced by that autochthon bovine breed (Order 18/94, DR II Serie). These agro-environmental and livestock support measures are likely to have positively impacted the "lameiros", contributing to their expansion, thus to the conversion of the traditional subsistence mixed farming systems into specialized livestock farming systems. Mottet et al. (2006) also observed an increase in the meadows areas in the French Pyrenees after 1975. According to these authors, the traditional mixed crop-livestock farming systems characteristic in the region were progressively converted into specialized livestock farming systems, with the substitution of crop fields by meadows. Calvo-Iglesias et al. (2008) reported a similar change in Northern Galicia (Spain).

Table 7
Metrics of diversity computed for the landscape level for the three years studied (1979, 1989 and 2002).

Metrics of diversity (landscape)	1979	1989	2002	*Average (n = 3)*	*Δ 2002–1979*
Simpson's diversity index, SIDI [ ]	0.85	0.84	0.87	*0.85*	*0.01*
Simpson's evenness index, SIEI [ ]	0.94	0.93	0.94	*0.94*	*0.01*

The results of the metrics used highlight the impact of the implementation of agricultural policies and of the demographic dynamics on the land uses changes and in the landscape structure. Dramstad et al. (2001) refer that the landscape dynamics largely depends on national and international agricultural policies. Thus, impacts recognized in this study must be considered in future actions focusing landscape conservation.

Conclusions

The different landscape metrics studied provided information relevant and complementary for the study of the landscape changes in Montalegre mountain region between 1979 and 2002. However, the metrics landscape division and Simpson's evenness showed low sensitivity for the analysis of the vegetation classes in this application.

The main trends identified through the analysis of metrics indicate an increase in landscape fragmentation, although the aggregation index is still high for most of the landscape classes. The area of meadows (and contiguous meadows) shows to have increased, which is coherent with data reporting an increase in the number of bovines in the area. These results suggest a trend toward changing from traditional mixed crop-livestock farming systems into specialized livestock farming systems, which is a consequence of the CAP policies and of the implementation of agro-environmental measures appropriately focusing the mountain areas. This change in farming systems is coherent with depopulation and aging observed in the area since these demographic conditions does not favor cropping in arable lands.

Results highlight the importance of using the landscape changes detected by different metrics derived from remote sensing images to create knowledge on the landscape dynamics and related driving forces. Despite the difficulties in classification of vegetation classes from remote sensing data, the mechanisms developed for monitoring and analysis shown in this study have the potential to be used in other mountain areas with high landscape fragmentation and diverse land use patterns.

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