Estimation of plant diversity in a forested mosaic landscape: the role of landscape, habitat and patch features

B. Fidalgo [1*] R. Salas [2], J. Gaspar [2], P. Morais[2]

[1] Universidade Técnica de Lisboa, Instituto Superior de Agronomia, Centro de Estudos Florestais, Tapada da Ajuda 1349-017, Lisboa, Portugal.

[2] Instituto Politécnico de Coimbra; Centro de Estudos de Recursos Naturais, Ambiente e Sociedade, Escola Superior Agrária, 3040-316, Bencanta, Coimbra, Portugal.

Abstract

In Europe traditional mosaic landscapes have been experienced dramatic changes through either intensification or abandonment of land use. Both trends are thought to affect plant diversity in forest areas.

To evaluate the sustainability of specific forest systems we need approaches for 1) assessment of the contribution of different land use systems for plant species diversity and 2) identification of habitat and landscape features that lead to patterns of biodiversity. Despite good theoretical knowledge about determinants of plant species richness in mosaic landscapes, validations based on surveys are scarce. We conducted a case study in a forested landscape in Central Portugal, with an area of 130 km^2, were the already referred drivers of change have been shaping the landscape in the past decades.

We used aerial photo-interpretation to identify land cover/use types; and a multi-scale field inventory to assess plant species diversity. Diversity measures were calculated at patch, habitat and landscape level.

Hypothetical influencing factors were also categorized at patch, habitat and landscape. Influencing factors were assessed by means of metrics that reflect structure and dynamics of the landscape at patch, habitats and landscape level. The relationship between species diversity and influencing factors was investigated by means of multiple linear regression models.

Results showed significant differences between cultivated forests in what plant diversity is concerned. The main influencing factors were identified. The evidence and indicatives values found and their interest for the development of sustainable landscape management is discussed.

Key words: Landscape metrics; species diversity monitoring; Cultivated forests.

Resumen

En Europa los mosaicos de paisajes tradicionales han cambiado drásticamente debido a la intensificación o abandono del uso del suelo. Ambas tendencias han afectado la diversidad en las áreas forestales.

Para evaluar la sustentabilidad de los ecosistemas forestales será necesario: 1) evaluar la contribución de los diferentes usos del suelo en la biodiversidad, 2) identificar las características del hábitat y del paisaje relacionadas con la diversidad. A pesar del cuadro teórico estar bien desarrollo en relación a los determinantes en los mosaicos del paisaje y su contribución para la biodiversidad, la validación basada en monitoreo es de hecho escasa. En el presente trabajo es un caso de estudio realizado en un paisaje forestal en la región Centro de Portugal, que cuenta con 130 km^2, donde las referidas fuerzas de cambio se han dejado sentir en esta región.

El trabajo consistió en la fotointerpretación para identificar los tipos cobertura/uso, en la realización de un inventario a escala múltiple para evaluar la diversidad en el área de estudio. La diversidad fue calculada al nivel de la mancha, del hábitat y del paisaje. Factores hipotéticos que podían influenciar también fueron categorizados en esos mismos niveles. La relación entre la diversidad de especies y los factores que la

* Autor de correspondencia

E-mail:bfidalgo@esac.pt; FAX +351 239 802 979.

influencian, fue investigada a través de modelos de regresión lineal múltiple.
Los resultados mostraron diferencias significativas de diversidad entre los bosques cultivados. Los principales factores fueron identificados. Discutimos las evidencias y los valores indicativos encontrados, así como su interés para el desarrollo del manejo sustentable del paisaje.

Palabras clave: Métricas del paisaje, monitoreo de la diversidad, bosques manejados.

Introdution

Rural areas in Portugal, as in other European and Mediterranean countries, have experienced quit dramatic land-use land cover change over the past century.

In the last decades, forest wild fires and the intensification of forest management with the introduction of fast growing species in privately owned forests, have changed both locally and regional characteristics of Portuguese rural landscapes.

The fragmented ownership pattern in areas with non-industrial private forest ownership NIPF, in combination with these forestry practices, have created fragmented forests with relatively low proportions of habitat types important to many species, such as the native broadleaved species and, at the same time, large areas of other species such as pine stands. Thus, changes in species composition and structure of Portuguese forests are assumed to affect the overall biodiversity value of forest areas. Landscape analysis has been used to access the overall effect of landscape change in forests biodiversity. However, landscape studies have been developed for areas with homogenous ownership patterns and not for areas with fragmented ownership. The objective of this study was to investigate: (1) how quantitative indicators of spatial heterogeneity of the landscapes (metrics) behave in this kind of landscape; (2) the relationships between landscape patterns of forest types and plant diversity estimates. This idea is based on the suggestion of several studies that spatial patterns may be important determinant of species distribution at landscape level (Honnay *et al.*, 1999b, Jeanneret *et al.*, 2003).

Metrics are quantitative indices that address the spatial heterogeneity of the landscapes. They are commonly used to describe structural landscape characteristics, to document landscape change or its relation to the occurrence of several species or groups of species (Turner *et al.*, 2001, Olsen *et al.*, 2007).

The number of measures used as landscape pattern metrics is extremely large (Formam and Godron 1986, Gustafson and Parker 1992) and considering that they can be calculated on the overall landscape, a specific land cover classes or in each polygon or land cover unit, the number of metrics that can be computed is extremely large. One focus of our research, therefore, was to find a sub group of metrics that represents the structural characteristics of the landscape being studied.

On the other hand, and in accordance with Jeanneret *et al.*, (2003) there are no general models relating components of biodiversity such as overall species diversity to landscape characteristics. Biodiversity of landscapes, even when focusing on single components such as species diversity, will depend on numerous landscape characteristics related to land use (Waldhardt *et al.*, 2004). Consequently, it appears to be very unlikely that should be possible to find one single indicator for landscape biodiversity. Therefore, the second objective of this study is to identify sets of metrics that could be used as indicators of landscape species diversity.

Material and methods

Study area

The study was conducted in a region of central Portugal, Lousã council with an area of 13 841 ha (see Fig. 1).

This is a cultural landscape bearing the impact of human activity since pre-historical times. All the forests are planted forests belonging to small non-industrial forest owners (NIFO), or common land that is managed by the local forest services.

Agriculture and forestry are no longer the main activity, or source of income of farmers and forest owners. The majority of them work in the urban areas that are located near by this area. As in other areas of central Portugal, rural areas are being

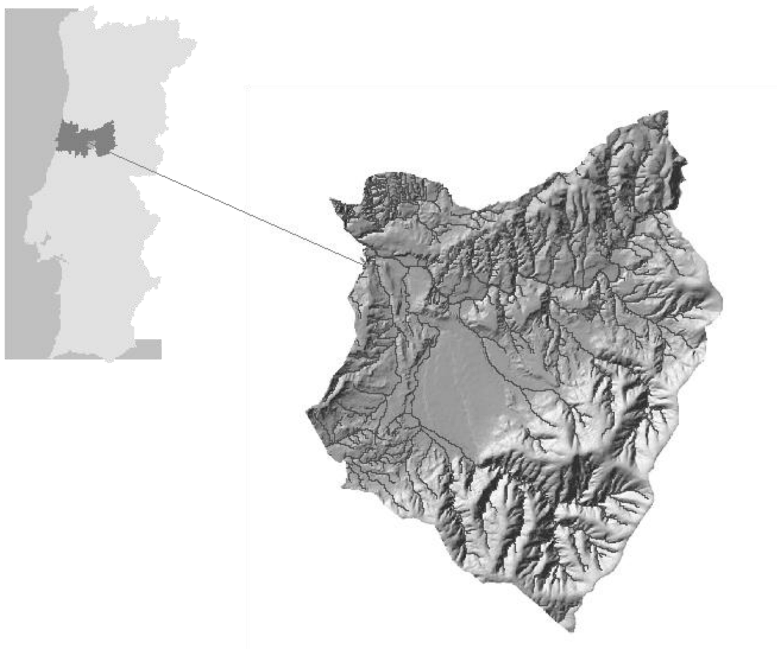


Figure 1. Location of the study area.

abandoned.

Variation in land cover occur in the study area along a topographic gradient (altitude and slope), ranging from the low valley were the main settlements and agricultural areas are located to the top hills were uncultivated land and forests are the dominant land cover types.

Data acquisition and methods

For the application and testing of landscape metrics as indicators of spatial heterogeneity of the landscape and of species diversity, several methodological steps, from the generation of the baseline geometry, to the actual calculations and evaluation of the metrics were followed.

Once the results of landscape metrics depend on the thematic resolution and the classification scheme used, it is of crucial importance to ensure the quality and consistency of the baseline geometry derived from the land cover map produced (Riitters *et al.*, 1995, Gustafson, 1998). The base line material was produced by on-screen aerial photo interpretation of infrared false color photographs using ARCGIS v9.2 software and a 1:25000 scale.

Table 1 shows the classification key used to produce the land cover/use map.

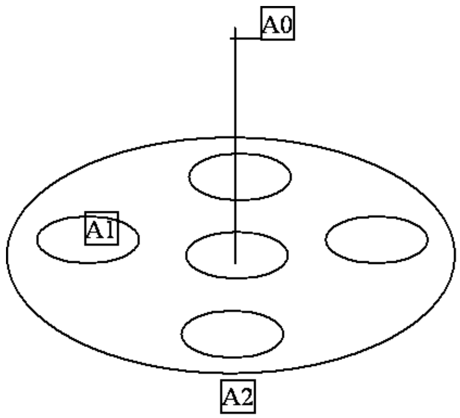
Table 1. Land use/cover classification used in the study.

Land use/cover	Forest type	Code
Agriculture	Permanent crops	1
	Temporary crops	2
Forest	Pines	3
	Eucalypts	4
	Native broadleaved	5
	Other conifers	6
Settlement		7
Uncultivated land		9

Forest areas were stratified according to their main occupation. Agriculture areas were only stratified in permanent and temporary crops. Other land cover classes considered without further stratification were settlements and uncultivated areas.

Species data were collected in a forest inventory using a stratified random sampling design in forest patches. A GIS procedure was used to randomly select sampling plots within forest patches, which were located on the ground using a GPS unit.

A plot design of 500 $2m^2$ circular sample unit (A2) were used to measure forest trees species. In A1 trees with dbh (diameter at breast height) less then 7.5 cm and shrub species were recorded and, in A0 plot, only herb species were recorded (Fig. 2). In the shrub and herb layers the species cover was estimated using the Braun-Blanquet scale.



A0: 1x1 m (mínimum area method)
Herb layer

A1: R1=5 m (area=80 m^2)
Trees layer dnh <7.5 cm, shrub layer

A2: R2=12.6 m (area=500 m^2)
Trees layer dnh <7.5 cm, shrub layer

Figure 2. Plot design for inventory of plant species.

All selected plots were visited at least twice, in winter, and in summer season. The species list only contains vascular plants. A total number of 74 plots were installed and measured.

In order to obtain different replicas of landscape configuration the land cover map was clipped in landscape samples, using 1218 ha hexagons with an edge of about 5000 m. Different replicas allow us to calculate some metrics at the class level and to study their relation with forest diversity and with vascular plants occurrence. The hexagon shape and size was selected to optimize tractability of data processing (Griffith *et al.*, 2000) while still allowing an adequate number of samples to allocate biodiversity inventory data and perform the analysis about the correlation between landscape metrics and species richness. Landscape metrics at patch and class level were calculated based on raster files with a 5 m x 5 m grid cell, using the public domain software package FRAGSTATS v3.0 (McGarial *et al.*, 2002). Metrics were calculated for the whole landscape and for all the hexagons.

To identify the major trends within the data, principal component analysis (PCA) was performed for the class and patch levels. Before PCA, a pre-selection of landscape metrics, based on Pearson correlation coefficients, was performed. For each level (patch and class) all the pair-wise correlation coefficients were calculated among the metrics. Groups of metrics were formed, such that all within group correlations were 0.9 or more (Riitters *et al.*, 1995).

To investigate the relationship between plant diversity and landscape metrics at patch and landscape level, multiple regression analysis were performed, using a forward stepwise procedure.

The dependent variable was the mean numbers of species per unit area, estimated at patch and landscape type level. The explanatory variables were the group of landscape metrics already referred which needed to be transformed with log10(x+1) to meet the assumptions of linearity.

Estimates of variance explained (EV%) were calculated from the ratios of the sums of squares of a significant predictor variable to the total sum of squares in the respective multiple linear regression model. The significance of each independent variable was determined from the standardized partial regression coefficient (β).

The software package SAS v9 was used to perform all the statistical analysis.

Results and discussion

Land use and major land use changes

As it can be seem from table 2, forests are the dominant use in the study area with a proportion of occupation above the 55%.

Table 2. Land use in the study area.

Land Cover	Area ha	%
Forests (FL)	7875	56,9%
Agriculture (AG)	2010	14,5%
Uncultivated (IC)	3598	26,0%
Settlements (SC)	358	2,6%
Total	13841	100,0%

Forests are followed by uncultivated land (IC) with a proportion of 26%, and in a far less extent, by agricultural crops (14,5%). Settlements accounts for less than 3% similarly to other rural areas in the inland of Portugal.

Forest areas are largely dominated by *Pinus pinaster* stands (66,6% of the forest area and 38% of the landscape area), followed by eucalypts plantations, an exotic species that start to emerge in the last 20 years (with a proportion of 23.2 % of the forest area and 13% of the landscape area, see Table 3).

Native broadleaved stands have a very small occupation with less that 6% of the whole forest area, and less that 3% of the landscape area.

Exotic conifer plantations occupy the remaining area (less than 350 ha, see table 3).

Table 3. Landscape area by forest type.

Forest type	Area (ha)	%
Pine forests	5246	66.6%
Eucalypts plantations	1818	23.1%
Native broadleaves	462	5.9%
Other conifers plantations	349	4.4%
Total	7875	100.0%

The proportion of land cover classes is uneven distributed with pine forest dominating the landscape, and the structural metrics being largely influenced by which happen with pine forests.

This trend was already identified for other landscapes in the same region of Portugal and similar biophysical and social contests (Fidalgo and Gaspar 2001, Fidalgo 2005).

Structural changes and landscape metrics selection

PCA results at patch level

Table 4 shows the eigenvalues and cumulative proportion of the amount of variation found for the twelve variables included in PCA analyses at patch level.

Table 4. Eigenvalues and amount of variance explained by the first four factors of the PCA (patch level).

Factors or components	1	2	3	4
Eigenvalue	5.48	1.71	1.34	0.98
Difference	3.77	0.36	0.36	0.26
Cumulative proportion of variance explained	0.55	0.72	0.85	0.95

Following the rule that axes or components with an eigenvalue greater then one should be retained, it was found a set of three components as it is showed in table 4.

The first three components accounted for more then 85% of the total amount of variation, and thus these three axes were considered enough to explain the whole data set. The first component explains more then a half of the variance, the second about 17%, the third 13% and the fourth 10%.

The rotated component matrices and the loading of different metric on each component are shown in table 5. Shape measures, shape area index (SHAPE) and the standard deviation for the class average of the same index (SHAPE_CSD), showed the highest positive association with the first component. A measure of fragmentation, the number of core areas (NCORE) and its standard deviation for landscape average, loaded highly in the second component. In the third component emerges again a fragmentation measure, nearest neighbouring distance (ENN) and its standard deviation for class average.

Table 5. Rotated component matrices showing factor loadings (patch level).

Metrics	First three PCA componentes		
	1	2	3
AREA	0.65	0.27	-0.02
PARA	-0.03	-0.16	-0.06
SHAPE	**0.85**	0.41	-0.07
SHAPE_CSD	**0.85**	0.36	-0.07
FRAC	0.60	0.42	-0.05
CORE_CSD	0.80	0.11	-0.04
NCORE	0.34	**0.93**	-0.02
NCORE_CSD	0.36	0.83	-0.02
NCORE_LSD	0.35	**0.93**	-0.02
CAI_CSD	0.19	-0.02	0.02
ENN	-0.04	-0.02	**0.90**
ENN_CSD	-0.07	-0.02	**0.90**

* Metrics with loads above 0.85 are in bold. AREA_ Patch area; SHAPE- Shape patch index; FRAC-Fractal dimension; NCORE- Number of core areas; PARA- Perimeter area ratio; CAI- Core area index; ENN Nearest neighbouring distance (CSD- Standard deviation for class average; LSD- Standard deviation for landscape average).

PCA results at class level

Eigenvalues and the amount of variation explained by each component in PCA at class level are shown in table 6.

Table 6. Eigenvalues and amount of variance explained by the first five factors of the PCA (class level)

Component	1	2	3	4	5
Eigenvalue	13.54	8.25	2.36	1.10	0.85
Difference	5.29	5.89	1.26	0.25	0.18
Cumulative proportion of variance explained	0.50	0.81	0.89	0.94	0.97

The proportion of variation explained by the first three components is 89%. These are the amounts of expected variance considered as acceptable by research literature in similar analysis (Riitters *et al.*, 1995, Griffith *et al.*, 2000), which suggests that might be enough to retain three axes in the PCA analysis at the class level.

The first component explains more than 50% of the data variance, the second component explains 31% and the third component less then 10 %.

The rotated component matrice and the loading of different metric on each component are shown in table 7.

Table 7. Rotated component matrices showing factor loadings at class level.

Metrics	First three PCA Components		
	1	2	3
CA	0.55	-0.75	0.18
NP	0.65	-0.27	-0.46
ED	0.72	-0.61	0.08
AREA_MN	-0.68	-0.57	0.40
AREA_CV	0.82	-0.46	-0.22
LSI	<u>**0.96**</u>	0.13	0.01
SHAPE_AM	0.72	-0.41	0.48
SHAPE_MD	-0.57	0.38	**0.61**
SHAPE_RA	**0.91**	-0.01	0.34
SHAPE_SD	0.83	0.22	0.44
FRAC_MN	-0.04	0.73	0.57
FRAC_RA	<u>**0.96**</u>	0.27	0.02
FRAC_CV	**0.90**	0.40	-0.03
PARA_AM	0.32	**0.93**	0.10
PARA_MD	0.80	0.48	-0.21
PARA_RA	0.67	-0.63	-0.03
PARA_SD	0.58	-0.47	-0.14
PAFRAC	0.83	0.45	-0.10
DCORE_SD	0.30	-0.80	0.47
CAI_MN	**-0.87**	-0.34	0.19
ENN_AM	-0.80	0.52	-0.04
ENN_MD	**-0.88**	0.12	-0.14
ENN_RA	0.48	0.75	-0.29
ENN_CV	0.83	0.52	0.01
IJI	**0.87**	-0.01	0.32
COHESION	-0.01	<u>**-0.98**</u>	0.00
SPLIT	-0.05	**0.91**	0.33

*Metrics with loads above 0.85 are in bold and metrics loading highly are underlined. CA-Class area; NP-Number of patches; ED-Edge density; LSI-Landscape shape index; AREA-Area of the class; SHAPE-Shape index; FRAC-Fractal dimension; PARA-Perimeter area ratio; PAFRAC-Perimeter area fractal dimension; DCORE-Disjunctive core area; CAI-Core area index; ENN-Nearest neighbouring distance; IJI-Interspersion and juxtaposition index; COHESION-Patch cohesion index; SPLIT-Splitting index; (MN-average; AM-area-weighted average; MD-median; SD-standard deviation ; RA-range of variation; CV-coefficient of variation).

The first component presents a larger number of metrics with a positive association when compared with the other components. Here, the higher positive association comes from shape metrics namely from landscape shape index (LSI), closely followed by other shape measure, the range of variation of fractal dimension (FRAC). In this axis other shape metrics that express variation in shape, such shape Index (SHAPE) have also a high loading.

In the second place, the contribution comes from the group of fragmentation measures: core area index (CAI) and nearest neighbouring distance (NNN) presented also a high loading.

In the second component, the major positive association came from the patch cohesion index (COEHSION) with a high negative association with this axis. Patch cohesion index measures the physical connectedness of the corresponding patch type increasing as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected (McGarial and Marks, 1994).

As it was already referred the contribution of the third axis for the explanation of the data variation was less then 10%, and again, the metric with high loading is a configuration measure the average shape index for the class (SHAPE).

The two most highly correlated metrics in the first three principal components at the patch and class level are presented in table 8. Its analysis shows that the initial set of metrics can be substantially reduced when the objective is the landscape characterization.

Relationship between species richness and landscape metrics

From the 74 plots installed only 52 were forest areas with cover. A total of 184 plant species were recorded within these 52 sample plots. Table 9 summarizes the results in terms of the number of species recorded for each landscape type.

Table 8. Most highly correlated metrics with each principal component in each year (patch level).

Component	1	2	3
Patch	SHAPE;	NCORE;	ENN
Class	LSI; FRAC_RA ;ENN ; CAI	COEHSION; SPLIT	SHAPE_MD

Metrics having the highest loading in each year and each axis. SHAPE-Shape patch index; NCORE-Number of core areas; ENN-Nearest neighboring distance; LSI-Landscape shape index; FRAC-Fractal dimension; CAI-Core area index; SHAPE-Shape index; COHESION-Patch cohesion index; SPLIT-Splitting index.

Table 9 Results of the number of species by landscape type.

Landscape Type	Number of Plots	Layer	Minimum value	Maximum value	Mean(±SD)
Pine Forests	31	Herb	1	22	9.48 (±5.09)
		Shrub	1	15	5.52 (±3.62)
		Tree	1	5	2.55 (±1.23)
		Total	**4**	**40**	**17.55 (±7.89)**
Eucalypts plantations	13	Herb	2	15	7.85 (±3.95)
		Shrub	1	10	3.38 (±2.90)
		Tree	1	6	2.36 (±1.63)
		Total	**6**	**29**	**13.38 (±6.46)**
Native broadlevead	17	Herb	5	26	13.29 (±5.76)
		Shrub	1	23	5.24 (±5.18)
		Tree	1	5	3.06 (±1.25)
		Total	**8**	**54**	**21.59 (±9.89)**
Other conifers	1	Herb			2
		Shrub			2
		Tree			4
		Total			**8**

Results showed only one sample plot in other conifers land use type and this class will be not considered in the further analysis. The average number of total species ranged from 21.59 in native broadleaved forest type to 13.38 in eucalypts stands. Pine forests presented an intermediate value of 17.56.

The number of herb layer species follows the order of the total number of species with native broadleaved with the higher value, followed by pine forests and finally by eucalypts plantations. The number of species in shrub layer is similar for pine and native broadleaved forest types and lower for eucalypts. Only eucalypts plantations have fewer shrubs than tree species.

The number of tree species is similar for pine and eucalypts trees and higher for native broadleaved species.

The results of multiple linear regression models are presented in table 10. The model for landscape class metrics accounted for 69.13% of the variance (adjusted r^2, P<0.0001).

At the class level six metrics where found significantly related with species richness. The more influent are configuration measures, coincidently with metrics found important for structural landscape characterization. The total number of species increases with shape index (SHAPE); perimeter area ratio (PARA), total forest type area (CA) and mean patch density (PD), and decreases with landscape shape index (LSI) and proportion of landscape covered by forest type (PLAND).

The results also showed that landscape metrics founded important for structural characterization of the spatial heterogeneity, does not necessarily coincide with metrics founded as significant to explain species richness. This fact reinforces the point of view of several of metrics based on its sensitivity to the pattern of concern (Li and Wu 2004).

Landscape type area (CA) and patch density (PD), were found significant on the relation with species diversity and had a low factor loading in the PCA analysis, suggesting their lower relevance to explain spatial heterogeneity.

The model for patch metrics captured a far lower proportion of the total variance, only 21% (adjusted r^2, P<0.0001). Total species richness is positively associated with forest type and the percentage of patch area considered as core area (CAI).

Species richness seems to be low correlated with patch metrics what suggests that these metrics play a minor role on forest species richness and composition: This might indicate the prevalence of small scale processes over those operating at patch scale as suggested by several authors (Honnay *et al.* 1999a) among others).

Conclusions

In this type of landscape, changes in land use/cover occur in relatively short periods of time and with high magnitude or intensity.

The results found in this work support the need for selection few metrics for landscape characterization and monitoring, already recommended in other

Table 10. Results of the linear regression models on the total species richness and landscape metrics at patch and class level.

Dependent variable	β	Partial r^2	Model r^2	*F* value	*P*
MLR of species richness and landscape variables (F=8.21 r^2 = 0.6913; P<0.0001)					
Intercept	-0.20			20.89	0.0001
SHAPE_MN	0.27	0.2437	0.2437	30.86	<.0001
PARA_MN	0.03	0.066	0.4709	12.08	0.0021
LSI	-0.14	0.0626	0.5336	12.66	0.0018
CA	0.12	0.0836	0.6172	8.77	0.0072
PLAND	-0.14	0.0422	0.6594	9.94	0.0046
PD	0.09	0.0342	0.6936	8.76	0.0072
MLR of species richness and patch variables (F=4.41; r^2 = 0.2111; P<0.020)					

works.

The main features of landscape structural characteristics are similar to the other landscape in the inland of central Portugal. Cultural landscapes are shaped by drivers of change that have, in the study area, quit different consequences on its structural characteristics. One of the outstanding consequences is the creation of large variations within land cover/use classes. Being so, for spatial heterogeneity characterization, measures expressing the amount of variation are then preferred to the average or even area-weighted averages that are referred in many other studies. Other distinctive feature in this landscape is the importance that configuration measures such as clumpiness and division have at the class level.

At the patch level SHAPE and NCORE are the most relevant metrics for landscape characterization. Additional characterization of shape is need at the class level calling for the use of other shape metrics such as PARA and FRAC.

The study of the relationship between total species number and landscape metrics found landscape metrics at class level, more relevant then metrics at the patch level. Beyond shape measures, CA and PD were also found associated to total species number.

From the overall analysis it can be concluded that the set of metrics found important for landscape characterization are not necessarily coincident with the metrics having a significant relation with species diversity. This fact recommends a methodological approach used to select the set of metrics, combining statistical analysis and also expert knowledge in order to conduct the analysis toward specific aspects that are object of concern, such as forest species diversity.

Acknowledgements

This work was developed under FORSEE research project, financed by the European Union (INTERREG IIIB; project Nº20). The authors would like to thank this financial support.

Bibliografía

Fidalgo, B. 2005. Analise de decisão multicritério em paisagens florestais. Phd. Thesis. Universidade técnica de Lisboa, Lisboa.

Fidalgo, B., and J. Gaspar. 2001. Utilização da fotointerpretação e indicadores cartográficos na caracterização do mosaico florestal à escala do município. in IV Congresso Florestal Nacional, Évora, pp: 87-91.

Formam, R. T. T., and M. Godron. 1986. Landscape Ecology. John Wiley &Sons, USA.

Griffith, J. A., E. A. Martinko, and K. P. Price. 2000. Landscape structure analysis of Kansas at three scales. Landscape and urban planning, 52:45-61.

Gustafson, E. J. 1998. Quantifying Landscape Spatial Pattern: What Is the State of the Art? Ecosystems, 1:143–156.

Gustafson, E. J., and G. R. Parker. 1992. Relationships between landcover proportion and indices of landscape spatial pattern. Landscape Ecology, 7:101-110.

Honnay, O., M. Hermy, and P. Coppin. 1999a. Effects of area, age and diversity of forest patches in Belgium on plant species richness, and implications for conservation and reforestation. Biological Conservation, 87:73-84.

Honnay, O., M. Hermy, and P. Coppin. 1999b. Impact of habitat quality on forest plant species colonization. Forest Ecology and Management, 115:157-170.

Jeanneret, P., B. Schüpbach, and H. Luka. 2003. Quantifying the impact of landscape and habitat features on biodiversity in cultivated landscapes. Agriculture, Ecosystems and Environment, 98 98:311–320.

Li, H., and J. Wu. 2004. Use and misuse of landscape indices. Landscape Ecology, 19:389-399.

McGarial, K., S. A. Cushman, M. C. Neel, and E. Ene. 2002. FRAGSTATS: Spatial Pattern Analysis for Categorical Maps. University of Massachusetts.

McGarial, K., and B.J. Marks. 1994. FRAGSTATS. spatial pattern analysis program for quantifying landscape structure. Oregon State University.

Olsen, L. M., V. H. Dale, and T. Foster. 2007. Landscape patterns as indicators of ecological change at Fort Benning, Georgia, USA. Landscape and urban planning, 79:137-149.

Riitters, K., R. O'Neill, Hunsaker, W. C., J., D. Yankee, S. Timmins, K. Jones, and B. Jackson. 1995. A factor-analysis of landscape pattern and structure metrics. Landscape Ecololgy, 10.

Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. Landscape ecology in theory and practice: pattern and process. Springer-Verlag, New York.

Waldhardt, R., D. Simmering, and A. Otte. 2004. Estimation and prediction of plant species richness in a mosaic landscape. Landscape Ecology, 19:211-226.