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Assessing the effect of scale on the ability of landscape structure metrics to discriminate landscape types in Mediterranean forest districts

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Abstract

Scale is a key concept in landscape ecology. Although several studies have analyzed the effect of scale on landscape structure metrics, there is still a need to focus on the ability of these metrics to discriminate between landscape types at different scales, particularly in Mediterranean forest landscapes. In this paper we assess the scaling behavior and correlation patterns of eight commonly-used landscape metrics in two Spanish forest districts (Pinares in Burgos and Soria, and Alto Tajo in Guadalajara) in order to detect at which grain sizes the landscape type differences are emphasized. This occurred in both districts at fine spatial resolutions (25 m) for the metrics related to shape complexity and the amount of boundaries, while a coarser spatial resolution (500 m) was required for the landscape diversity and mixture metrics, suggesting that the differences in the spatial and compositional diversity of these landscape types are not so large locally (alpha diversity) but amplified at broader scales (gamma diversity). The maximum variability for the fragmentation-related metrics did not appear at the same scale in both districts, because forest fragmentation in the Pinares district is mainly driven by harvesting treatments that operate at considerably different scales from those related to the less intensively managed district of Alto Tajo. Our methodology and results allow identifying and separately assessing those complex land cover mosaics that result from a similar set of biological and social forces and constraints. This should be valuable for an improved forest landscape planning and monitoring with a quantitative ecological basis in the Mediterranean and other temperate areas.

Key words: grain size, spatial resolution, minimum mapped unit, variability analysis, metric correlation, forest planning.

Resumen

Evaluación del efecto de la escala en la capacidad de los índices de estructura del paisaje para discriminar tipos de paisaje en comarcas forestales mediterráneas

La escala es un concepto básico en ecología del paisaje. A pesar de que varios estudios han analizado el efecto de la escala en los índices de estructura del paisaje, todavía es necesario profundizar en la capacidad de estos índices para discriminar entre los tipos de paisajes a diferentes escalas, particularmente en los paisajes forestales mediterráneos. En este artículo analizamos, en dos comarcas forestales españolas (Tierra de Pinares en Burgos y Soria, Alto Tajo en Guadalajara), el comportamiento frente a la escala y los patrones de correlación de ocho de los índices del paisaje más ampliamente utilizados, con el fin de detectar a qué tamaños de grano se enfatizan en mayor medida las diferencias entre los tipos de paisaje. Esto ocurrió en ambas comarcas a las resoluciones espaciales más finas (25 m) para los índices relacionados con la complejidad de formas y cantidad de bordes, mientras que para los índices de diversidad del paisaje y entremezclado espacial se requirió una resolución espacial menor (500 m), lo que sugiere que las diferencias en la diversidad espacial y de composición en estos tipos de paisajes son menores a escalas locales (diversidad alpha) que a otras más amplias (diversidad gamma). Sin embargo, la máxima variabilidad de los índices relacionados con la fragmentación apareció a distintas resoluciones espaciales en cada una de las comarcas, probablemente como consecuencia de que en Tierra de Pinares los patrones de fragmentación del bosque están controlados por pautas de corta que operan a escalas sensiblemente diferentes a las de la comarca del Alto Tajo, con una mayor variabili-

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dad ambiental y una menor intensidad en la gestión. En definitiva, nuestra metodología y resultados permiten identificar y evaluar separadamente los complejos mosaicos de usos y cubiertas forestales que resultan de un conjunto similar de factores biológicos o sociales. Todo ello puede ser beneficioso para una mejor planificación y monitorización de los paisajes forestales en el Mediterráneo y otras regiones templadas.

Palabras clave: tamaño de grano, resolución espacial, unidad mínima cartografiada, análisis de variabilidad, correlación entre índices, planificación forestal.

Introduction

A landscape is a heterogeneous land area composed of a cluster of interacting ecosystems that are repeated in similar form throughout (Forman and Godron, 1986). Landscape ecology studies focus on three fundamental characteristics of landscapes: structure (or pattern), the spatial relationships among the distinctive ecosystems or «elements»; function, the interactions among the spatial elements; and change, the alteration in the structure and function of the ecological mosaic over time (Forman and Godron, 1986).

Landscape structure has two components: composition that refers to the number of patch types represented on a landscape and their relative abundance, and configuration which is the physical distribution or spatial arrangement of patches within the landscape. Landscape structure can be measured by certain spatial metrics that can be calculated using specific software like Fragstats (McGarigal and Marks, 1995) or GIS extensions such as Patch Analyst (Elkie *et al.,* 1999). Although there are plenty of metrics, studies by Riitters *et al.* (1995), Cain *et al.* (1997), Hargis *et al.* (1998) or Tischendorf (2001) demonstrated that most of them are highly correlated.

Numerous articles have focused on the analysis of forest landscape structure (Baskent and Jordan, 1995; Haines-Young and Chopping, 1996; Tang and Gustafson, 1997; Trani and Giles, 1999; Lausch and Herzog, 2002; Saura and Carballal, 2004; García *et al.,* 2005; De Clercq *et al.,* 2007). This type of analyses is particularly useful to assess certain aspects of forest spatial patterns (and their relation with ecological processes) such as fragmentation, connectivity, and the size, shape, proximity or diversity of patches (Leitao *et al.,* 2006). However, as Gustafson (1998) asserted, «the proper application of landscape pattern analysis is not trivial and perhaps the most critical step is to identify properly the scale of the heterogeneity (patchiness) of the landscape, so that subsequent analysis will be conducted at an appropriate scale».

A number of studies have tested the effects of changing scale on landscape structure analysis (Wickham and Riitters, 1995; Baldwin *et al.,* 2004; Li and Wu, 2004; Saura, 2004; Urban, 2005; Corry and Lafortezza, 2006; Buyantuyev and Wu, 2007; Diaz-Varela *et al.*, 2009). In particular, Wu *et al.* (2002) and Wu (2004) analyzed scaling relations of metrics within different landscapes (forested, agricultural and urban). These works assessed metric consistence of scaling relations across different landscapes, and robustness, understood as the similarity of scaling relations across different patch types within the same landscape. Other interesting study by Frohn and Hao (2006) evaluated landscape metrics with respect to the effects of spatial aggregation on six different years of Landsat data for a deforested area in Brazil. In this work, metric behavior in terms of consistence was studied as well. Furthermore, Saura and Castro (2007) analyzed a wide set of landscape data derived from remotely sensed images covering different study areas, sensor spatial resolutions, and classification approaches (pixel-based and object-based) in order to assess the accuracy of the landscape pattern metric estimates derived from available scaling functions.

Most of these previous studies have calculated landscape metrics for the entire study area, without previously identifying and discriminating the different landscape types that may exist within it and that may have distinctive environmental, social and physiognomic (*e.g.* pattern configuration) characteristics. Each of these landscape types may face and respond to different management problems, social forces and underlying dynamics and ecological processes. Therefore, when intending to go beyond a simply descriptive scaling analysis as needed for forest landscape planning applications, an adequate differentiation of these landscape types is a prerequisite for an appropriate understanding and process-related analysis that is valuable for aiding decision-making. This is typically the case in extensive and heterogeneous Mediterranean forest districts, which are formed by complex combinations of land uses, landscape types and spatial patterns.

A landscape-level analysis of Spanish forest ecosystems has become more important since the current Spanish Forest Law (*Ley 43/2003, de 21 de noviembre,* *de Montes*) sets as basic planning tools the Forest Resources Management Plans (in Spanish, *Planes de Ordenación de los Recursos Forestales*, PORF) whose scope are the forest districts. Indeed, adequate comparison and assessment of landscape type structure is a useful approach for decision making in forest planning and management (Leitao and Ahern, 2002; Leitao *et al.,* 2006; Perera *et al.,* 2006).

However, there is a lack of research regarding the ability of landscape structure metrics to discriminate landscape types. Among all the studies related to scale, none has focused on how scale variations allow to emphasize the existing differences between landscape types as evaluated by commonly-used landscape metrics. For these reasons, here we intend to bridge this gap in knowledge and to analyze the effect of changing scale on eight selected landscape metrics and whether they show consistent scaling relations in Mediterranean landscapes. We only consider one of the components of scale, grain, defined as the finest level of spatial resolution possible with a given data set (*e.g.,* pixel size for data in raster format) (Turner *et al.,* 1989). An analogous concept is the minimum mapped unit that refers to the smallest size area entity to be differentiated as a discrete area. Moreover, we aim to indicate, if possible, the most suitable scale for metric calculation in order to better discriminate the characteristics of the different landscape types within forests districts. Finally, we attempt to summarize the existing correlation patterns between the analyzed metrics after characterizing landscape types at the scale at which they show the maximum variability. For these purposes, we selected two Spanish Mediterranean forest districts as study areas.

In short, the major objectives of this paper are: (1) to assess landscape metric variability and discrimination ability for different grain sizes, and (2) to analyze their correlation patterns.

Material and methods

The analysis was developed in two Spanish forest districts: Pinares (Soria-Burgos) and Alto Tajo (Guadalajara). Their extents are 127,956 ha and 104,561 ha respectively. Both are located within the most continental part of the Mediterranean region (Fig. 1). They have however different biogeoclimatic characteristics

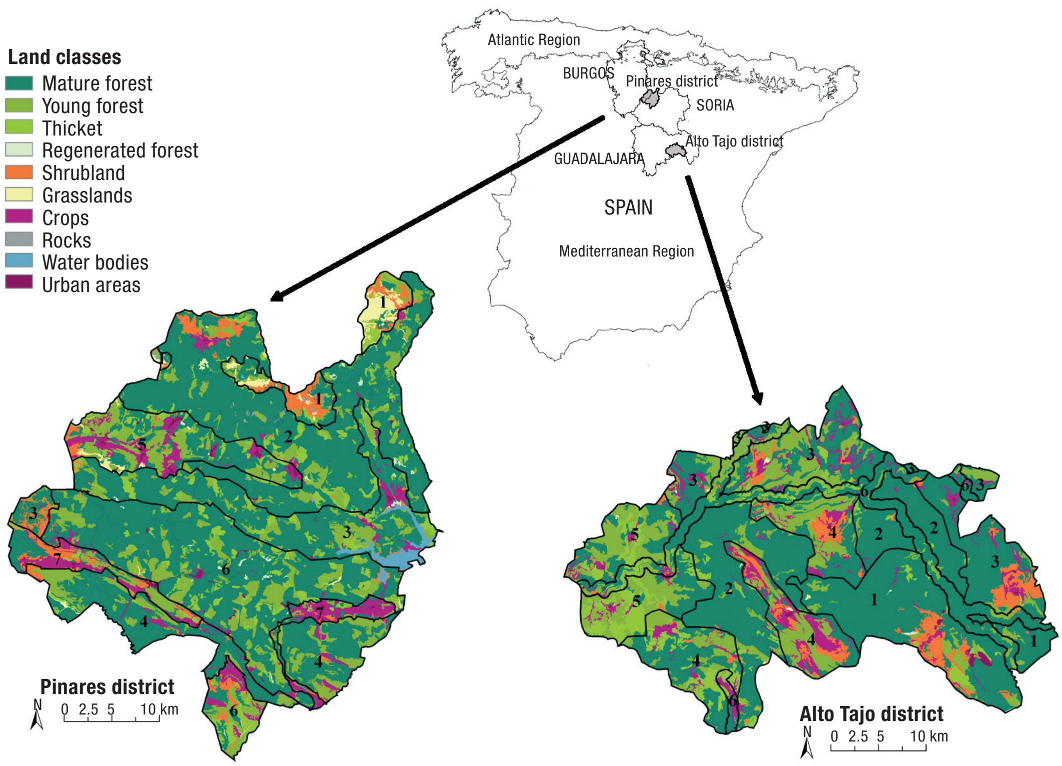

Figure 1. Location of the study areas and the land cover maps (25 m resolution) of both forest districts in the map of Spain. Numbers correspond to the discriminated landscape types according to García-Feced *et al.* (2008), as summarized in Table 1.

and forest management intensities. Management in Pinares district is oriented towards timber production, whereas in Alto Tajo it is focused on the protection of watersheds, biodiversity and geological heritage.

Landscape types have been previously defined in García-Feced *et al.* (2008). This typology integrates abiotic variables used in a land classification and biotic information provided by the Spanish Forest Map (SFM) at a scale 1:50,000 (Ministerio de Medio Ambiente, 2002a). As a result, seven landscape types were defined in Pinares and six in Alto Tajo. Each one has its characteristic altitudinal range, lithological type and land use and cover composition, as briefly summarized in Table 1.

In this study the SFM (vector format) was used as the digital source map. Its minimum mapped unit is 2.5 ha in forested lands and 6.25 ha in others. It has been developed from the interpretation of aerial photographs (dated 1997-1998 in the study area) combined with pre-existing maps and field inventory data.

It is the highest resolution national forest map available for all Spain to date and has been developed in coordination with the Third Spanish National Forest Inventory

Table 1. Characterization of the landscape types within both forest districts according to García-Feced *et al.* (2008)

Pinares district

Landscape type	Relative extent (%)	Average altitude (m)	Lithological type	Dominant land covers	Brief description
1	4.87	1,837	Conglomerates and quartz sands	Grasslands (37%) and *Pinus sylvestris* L. (34%)	High mountain grasslands
2	26.88	1,467	Conglomerates and quartz sands	*P. sylvestris* (86%)	*P. sylvestris* forest
3	15.3	1,160	Quartz sands	*P. sylvestris* (59%) and *Quercus pyrenaica* Willd. (21%)	Mixed forest (*P. sylvestris* and *Q. pyrenaica*)
4	11.93	1,130	Limestones	*Juniperus thuriphera* L. (58%) and *Pinus nigra* J.F. Arnold (25%)	*J. thuriphera* forest
5	8.8	1,154	Conglomerates	*P. sylvestris* (47%), *Q. pyrenaica* (23%) and crops (17%)	Urban and agricultural lands
6	26.44	1,154	Conglomerates	*P. sylvestris* (47%) and *Pinus pinaster* Aiton (23%)	Pine forest (*P. sylvestris* and *P. pinaster*)
7	5.77	1,103	Sands	Crops (38%) and *P. sylvestris* (16%)	Agricultural belt

Alto Tajo district

Landscape type	Relative extent (%)	Average altitude (m)	Lithological type	Dominant land classes	Brief description
1	17.01	1,372	Dolomites	*Pinus sylvestris* L. (46%) and *Pinus nigra* J.F. Arnold (34%)	Pine forest (*P. sylvestris* and *P. nigra*)
2	19.6	1,191	Dolomites	*P. nigra* (86%)	*P. nigra* forest
3	19.96	1,189	Dolomites	*Juniperus thuriphera* L. (40%) and *P. nigra* (28%)	Mixed forest (*J. thuriphera* and *P. nigra*)
4	19.23	1,157	Marls and conglomerates	*P. nigra* (28%), *J. thuriphera* (21%), shrubs (14%) and crops (14%)	Mixed landscape of conifers, shrublands and crops
5	12.1	904	Conglomerates	*Quercus ilex* L. (53%) and *P. nigra* (23%)	*Q. ilex* forest
6	12.11	949	Dolomites and marls	*P. nigra* (49%)	Tajo river canyons

(Ministerio de Medio Ambiente, 2002b). A new land use and forest cover map was generated by reclassifying the information available in the SFM into ten categories, the first four corresponding to forest types with increasing stand development: recently regenerated forest (up to canopy closure), thicket (up to natural pruning), young forest (up to a diameter at breast height of 20 cm), mature forest (diameter at breast height above 20 cm), shrubland, grasslands, crops, rocks, water bodies and urban areas (Fig. 1). In order to perform the scale assessment, this vector map was rasterized at four selected pixel sizes: 25, 50, 100 and 500 m. The 50 m spatial resolution is the one used for the analysis of forest biodiversity at the habitat level within the Third Spanish National Forest Inventory (Ministerio de Medio Ambiente, 2002b) from the SFM.

The landscape metrics for each specific grain size and landscape type were calculated through a series of Fragstats (McGarigal and Marks, 1995) analysis by regions. For this purpose, it was used an ArcView 3.2 extension called Patch Analyst 2.2 (Elkie *et al.,* 1999). Eight landscape structure metrics were selected for subsequent analyses at the landscape level (Table 2).

Table 2. List of the landscape structure metrics that were analyzed in the study

Landscape metric	Description[1]	Unit	Range
Patch Density (PD)	Number of patches of the landscape per unit area.	#/100 ha	PD > 0
Edge Density (ED)	Total length of all edge segments of the landscape per unit area.	m/ha	ED ≥ 0
Mean Patch Size (MPS)	The average area of all patches in the landscape.	ha	MPS > 0
Shannon's Diversity Index (SDI)	$SDI = -\sum_{i=1}^{m} p_i \ln(p_i)$ m = number of patch types (classes) present in the landscape, including the landscape border, if present. p_i = proportion of the landscape area occupied by patch type i.	None	SDI ≥ 0
Landscape Shape Index (LSI)	$LSI = \frac{0.25E}{\sqrt{A}}$ E = total length of patch edges in landscape. A = total area of the landscape.	None	LSI ≥ 1
Mean Shape Index (MSI)	$MSI = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\frac{0.25 p_{ij}}{\sqrt{a_{ij}}}\right]}{N}$ p_{ij} = perimeter of patch ij. a_{ij} = area of patch ij. N = total number of patches in the landscape.	None	MSI ≥ 1
Mean Nearest Neighbor (MNN)	The average distance to the nearest neighboring patch of the same type, based on shortest edge-to-edge distance.	m	MNN > 0
Interspersion and Juxtaposition Index (IJI)	$IJI = \frac{-\sum_{i=1}^{m}\sum_{k=i+1}^{m}\left[\left(\frac{e_{ik}}{E}\right)\ln\left(\frac{e_{ik}}{E}\right)\right]}{\ln\left(0.5\left[m\left(m-1\right)\right]\right)}(100)$ e_{ik} = total length of edge in landscape between patch types (classes) i and k. E = total length of patch edges in landscape, excluding background. m = number of patch types (classes) present in the landscape, including the landscape border, if present.	%	0 < IJI ≤ 100

[1] Descriptions are based on McGarigal and Marks (1995).

These metrics were chosen because of its widespread use in landscape analyses, their easy interpretation and their relevance as indicators of ecosystem functioning as related to fragmentation (Patch Density, PD; Edge Density, ED; Mean Patch Size, MPS) and isolation (Mean Nearest Neighbor, MNN) processes and to landscape diversity (Shannon's Diversity Index, SDI), heterogeneity (Interspersion and Juxtaposition Index, IJI) and shape complexity (Mean Shape Index, MSI). Landscape Shape Index (LSI) interpretation is discussed later in this article. Their effectiveness in quantifying spatial patterns and their ecological interest are well-documented (Turner and Gardner, 1991; Saura and Carballal, 2004; Weiers *et al.*, 2004; Farina, 2006; Leitao *et al.,* 2006; Gärtner *et al.,* 2008; Torras *et al.,* 2009; Peng *et al.,* 2010).

Moreover, the coefficient of variation (CV) of the metric values for the different landscape types at each grain size was calculated for each district in order to assess metric variability between landscape types. The grain size corresponding to the highest CV value for each metric was determined and the results between districts were compared. It was assumed that the metric ability to discriminate the underlying characteristics of the different landscape types was enhanced as CV increased.

Afterwards, at the scale for which the variability was maximum (possibly different for each metric) and using the software SPSS Statistics 17.0 (SPSS Inc., 2008), the Spearman's rank (non-parametric) correlation coefficient (r) was calculated between the values of the different metrics for each landscape type (separately for each forest district) in order to detect significant correlations between the information conveyed by the differing metrics.

Results

Half of the selected metrics showed the highest CV at the same grain size in both districts (Fig. 2), despite the different characteristics of these two study areas. ED and MSI maximum variability was detected at 25 m resolution in Pinares and Alto Tajo, while SDI and IJI highest CV value appeared at 500 m pixel size (Fig. 2).

For some metrics (PD, SDI and MSI) the CV varied only very slightly (less than 5% difference) across the range of spatial resolution considered. Therefore, metric robustness (*i.e.,* constant metric variability across different scales) was very high for these three metrics, and their discrimination ability was similar regardless the scale. The opposite occurred for MPS, MNN and IJI.

The coefficients of variation were always below 50% (Fig. 2). Besides, for certain metrics CV remained below 25% regardless the scale. Variability was particularly low for MSI, with CV about 5%.

Comparing both districts, Alto Tajo reported higher CV values in three of the metrics (SDI, LSI and MNN) whereas variability in Pinares was higher in PD and IJI (the CV values for ED and MSI were very similar in both districts and the pattern of MPS curves was opposite between districts).

Actual metric values at maximum variability scales (Table 3) seemed to show the existing differences between landscape types. For instance, in Pinares it could be emphasized that the landscape type corresponding to the *Pinus sylvestris* L. forest had the lowest SDI whereas the agricultural belt had the highest PD and the lowest MPS, probably due to the higher human influence in this latter landscape type that had yielded very numerous patches with simplified shapes matching to the ownership patterns and human-made boundaries. Similarly, in Alto Tajo, the *Pinus nigra* J.F. Arnold forest was the landscape type with the lowest SDI while the Tajo river canyons presented the highest PD and the lowest MPS, as a consequence of the considerable topographical and lithological heterogeneity within this landscape type.

Eleven out of 28 metric correlations were significant ($p < 0.01$) in Pinares. LSI and MNN were not significantly correlated to any other metric (Table 4). On the other hand, there were fewer significant correlations in Alto Tajo. However, both districts coincided with the positive correlation between PD and ED and the inverse correlation between these two and MPS. In addition, SDI and MSI had a perfect positive correlation in Pinares, and PD and MPS had a perfect negative correlation in both districts.

Discussion

Metric variability and discrimination ability for different grain sizes: how to emphasize their information content?

The effect of scale on landscape metrics in terms of their ability to differentiate the characteristics of Mediterranean forest landscape types has been assessed

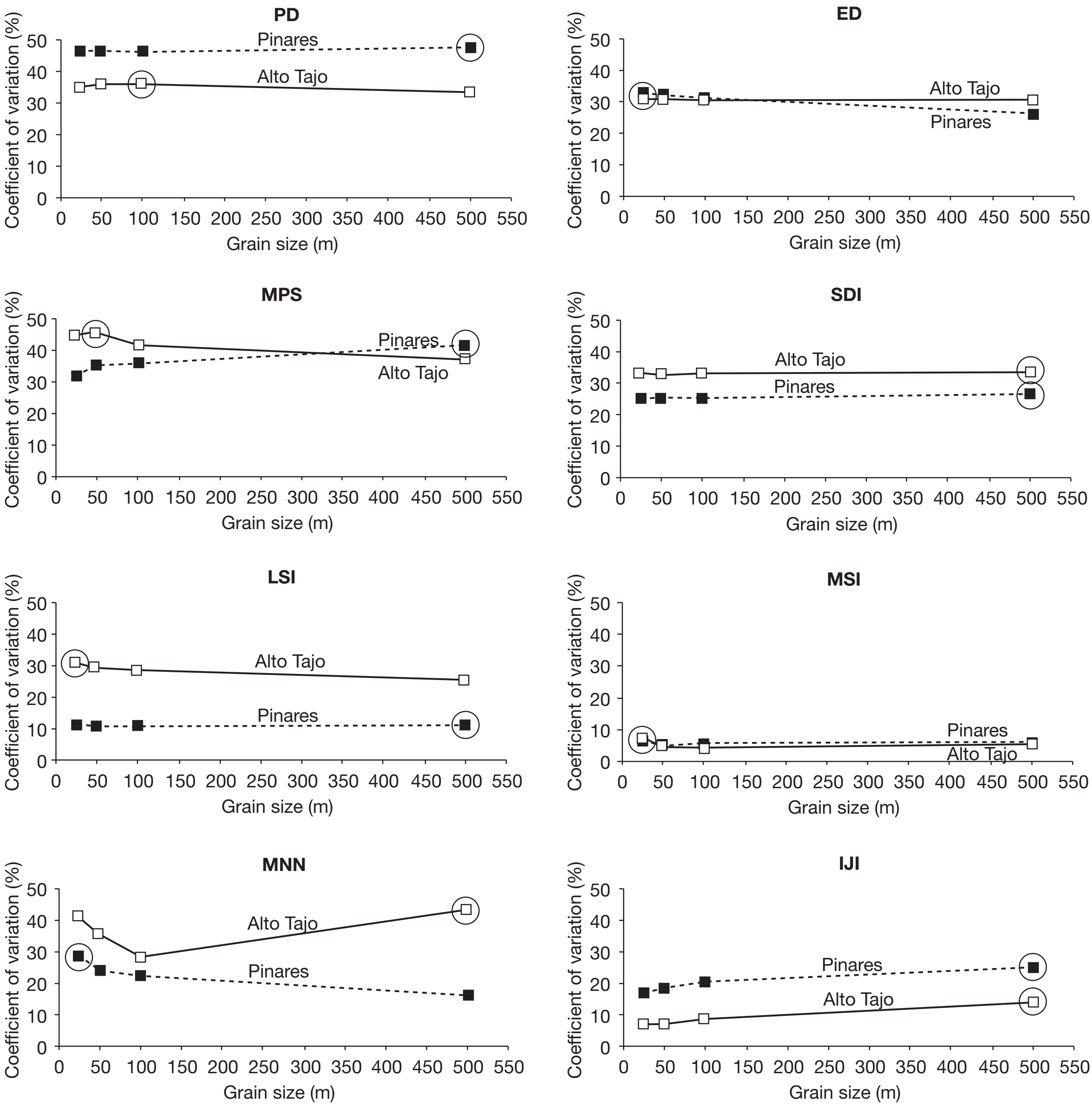

Figure 2. Coefficient of variation (CV, %) of the metric values for each landscape type as a function of grain size (25, 50, 100 and 500 m) in each forest district. Maximum CV values are highlighted by a circle.

in this analysis. The reported results showed that maximum variability between landscape types didn't always appear at the same scale in both districts. This was the case of PD, MPS, LSI, and MNN. Consequently, no common criteria can be suggested for these metrics, and a specific analysis in each forest district would be required to be able to maximize the information content conveyed by the metrics. These four metrics are all related to the degree of landscape fragmentation, either measuring the reduced size of the habitat units (MPS), the increase in the number of differentiated patches (PD) or the degree of isolation (MNN) as the fragmentation process progresses. LSI, despite being considered by some authors as a shape metric (*e.g.,* Frohn and Hao, 2006) has been shown to be in fact more largely affected by patch size and pattern fragmentation than by the complexity, irregularity or elongation of patches' boundaries (Saura *et al.,* 2008).

Table 3. Landscape metric values according to landscape type in the two studied forest districts

	Pinares district							
	PD (p/100 ha)	**ED (m/ha)**	**MPS (ha)**	**SDI**	**LSI**	**MSI**	**MNN (m)**	**IJI (%)**
Grain size (m)[1]	500	25	500	500	500	25	25	500
Landscape type								
1. Mountain grasslands	1.01	77.68	99.15	1.68	6.10	2.06	267.70	83.76
2. *P. sylvestris* L. forest	0.38	35.24	266.41	0.83	7.84	1.72	341.90	50.36
3. Mixed forest	0.52	48.2	192.33	1.23	7.85	1.85	330.20	61.66
4. *J. thuriphera* L. forest	0.38	48.04	263.79	0.92	6.75	1.74	181.70	45.35
5. Urb. and agric. lands	0.74	62.3	134.34	1.59	7.04	2.00	234.20	77.16
6. Pine forest	0.47	44.13	213.29	1.13	8.62	1.78	210.70	55.16
7. Agricultural belt	1.16	86.32	86.31	1.52	7.28	1.87	161.60	84.43
	Alto Tajo district							
	PD (p/100 ha)	**ED (m/ha)**	**MPS (ha)**	**SDI**	**LSI**	**MSI**	**MNN (m)**	**IJI (%)**
Grain size (m)[1]	100	25	50	500	25	25	500	500
Landscape type								
1. Pine forest	0.67	26.92	152.64	0.84	8.95	2.20	1,653.20	71.93
2. *Pinus nigra* J. F. Arnold forest	0.82	26.35	106.59	0.50	9.42	1.98	2,320.90	51.25
3. Mixed forest	1.32	47.97	69.23	1.15	17.31	2.17	1,322.30	58.86
4. Mixed landscape	1.73	55.17	54.96	1.49	19.53	2.29	1,101.80	71.38
5. *Quercus ilex* L. forest	1.26	45.32	72.61	1.27	12.74	2.22	1,211.90	58.67
6. Tajo river canyons	1.77	55.58	52.76	1.02	15.63	1.96	3,080.70	56.24

[1] Landscape metric values were calculated at the grain size that reported the maximum variability.

Landscape Shape Index largely increases for more fragmented patterns and actually conveys the same information than the landscape pattern aggregation index proposed by He *et al.* (2000), as noted by Bogaert *et al.* (2002). This could be observed in the results obtained in Alto Tajo, where the metrics that present the highest correlations (in absolute value) with LSI were PD and MPS (two classical fragmentation metrics), with $r = 0.829$ ($p = 0.042$), while the correlation between LSI and MSI was much lower ($r = 0.257$, $p = 0.623$), as shown in Table 4. However, in Pinares the correlation of LSI with MSI was more similar and even higher than the one between LSI and PD (Table 4), although the differences in these correlation coefficients were not significant. This distinctive correlation pattern in both districts may be due to the different variability of the LSI metric (as measured by CV) in both districts, being much lower in Pinares than in Alto Tajo (Fig. 2). It was in this latter forest district where a wider portion of the full range of possible LSI values was captured and therefore where the correlations reported matched better with the demonstrated analytical relationships for this LSI metric (Bogaert *et al.,* 2002).

The fact that all these four fragmentation-related metrics (PD, MPS, LSI, MNN) had this distinct behavior in the two districts may be the result of the different characteristic scales at which the fragmenting processes operated in each of them. Patterns of forest fragmentation in the Pinares district were mainly driven by harvesting treatments that operate at considerably different scales from those related to the topographic and climatic patterns that predominantly control the forest distribution in the more environmentally heterogeneous district of Alto Tajo, where the management was less intensive and frequent.

However, for the rest of the metrics (most of which were not directly related to pattern fragmentation) the highest CV values coincided at certain grain sizes for both study areas. In particular, MSI and ED, respectively related to the shape complexity and the length of the

Table 4. Spearman's correlation coefficients between the pattern metric values for the different landscape types (at the scale at which they showed the maximum variability) in the two studied forest districts

	Pinares district							
	PD	**ED**	**MPS**	**SDI**	**LSI**	**MSI**	**MNN**	**IJI**
PD	1.000	0.964*	–1.000*	0.893*	–0.321	0.893*	–0.393	0.964*
ED	0.964*	1.000	–0.964*	0.857	–0.500	0.857	–0.429	0.893*
MPS	–1.000*	–0.964*	1.000	–0.893*	0.321	–0.893*	0.393	–0.964*
SDI	0.893*	0.857	–0.893*	1.000	–0.464	1.000*	–0.143	0.857
LSI	–0.321	–0.500	0.321	–0.464	1.000	–0.464	0.179	–0.214
MSI	0.893*	0.857	–0.893*	1.000*	–0.464	1.000	–0.143	0.857
MNN	–0.393	–0.429	0.393	–0.143	0.179	–0.143	1.000	–0.214
IJI	0.964*	0.893*	–0.964*	0.857	–0.214	0.857	–0.214	1.000
	Alto Tajo district							
	PD	**ED**	**MPS**	**SDI**	**LSI**	**MSI**	**MNN**	**IJI**
PD	1.000	0.943*	–1.000*	0.543	0.829	–0.143	–0.029	–0.200
ED	0.943*	1.000	–0.943*	0.600	0.771	–0.029	–0.086	0.086
MPS	–1.000*	–0.943*	1.000	–0.543	–0.829	0.143	0.029	0.200
SDI	0.543	0.600	–0.543	1.000	0.771	0.714	–0.829	0.371
LSI	0.829	0.771	–0.829	0.771	1.000	0.257	–0.486	0.086
MSI	–0.143	–0.029	0.143	0.714	0.257	1.000	–0.943*	0.657
MNN	–0.029	–0.086	0.029	–0.829	–0.486	–0.943*	1.000	–0.543
IJI	–0.200	0.086	0.200	0.371	0.086	0.657	–0.543	1.000

* Asterisks were used for significance values ($p < 0.01$).

boundaries between different patches, could be considered as fine-grained metrics. When aiming to discriminate forest landscape types in relation to these characteristics, the use of high spatial resolution data should be avocated. In this particular case, where the SFM was used as the data source, a pixel size of 25 m seems to be, among the selected resolutions, the most appropriate for such purpose. This would concur with previous findings by Saura and Carballal (2004), who suggested that a high thematic and spatial detail (both of which increase the amount of edge or boundaries reported in a map) is required in order to make that differences in shape between differing forest types arise with sufficient prominence. Similarly, SDI and IJI are likely to provide more contrasted results if they are calculated at broader spatial resolutions in both districts (here a pixel size of 500 m for the SFM and the set of spatial resolutions considered). Both SDI and IJI are related to the diversity and spatial mixture of land cover types within the landscape. The fact that these two metrics may be understood as coarse-grained metrics (as derived from our analysis) suggests that the differences in the spatial and compositional diversity of these landscape types are not so large locally (alpha diversity) but comparatively enhanced at broader scales (gamma diversity), as a result of high turnover rates and changing environmental gradients that are characteristic of the heterogeneous and dynamic Mediterranean forest landscapes.

The optimal resolutions here reported for these latter four metrics is either finer (for ED and MSI) or coarser (for SDI and IJI) than the 50 m resolution that is being used to rasterize the SFM in order to assess and compare the pattern and configuration characteristics of the different forest habitats in the Third Spanish National Forest Inventory (Ministerio de Medio Ambiente, 2002b). Reported results suggested that, instead of fixing a single spatial resolution to compare the landscape pattern metrics for all the forest types as currently done in the Third Spanish National Forest Inventory (Ministerio de Medio Ambiente, 2002b) an effort should be made in order to adjust a different grain size for each of the analysed metrics, at least for those related to shape or edge effects and to spatial mixture and diversity, as described above.

Thus, the latter four metrics had the most consistent scaling relations in terms of variability. On the contrary, MNN and especially MPS showed the lowest consistence. Wu (2004) analyzed metric scaling relations but focusing on the variations of the actual metric values and not on their variability across landscape types. Besides, this study was also different from that by Wu (2004) in that the metrics were not calculated for a full study area without any stratification. Instead, here metric calculation focused on previously discriminated landscape types that presented different pattern and environmental characteristics within the studied forested regions. In spite of that, excepting MSI and MPS, conclusions about the consistence of the different metrics were coincident in both studies. On the other hand, reported results on MPS concurred with those from Frohn and Hao (2006) who, unlike Wu (2004), also concluded that MPS was a non-consistent metric against scale variations.

It was found a strong correlation between certain pattern metrics, although each district reports differing correlation patterns, probably due to the underlying different biotic and management characteristics as discussed above. Both districts coincided however with the positive correlation between PD and ED and the negative correlation between these two and MPS, in agreement with previous studies in the topic (Riitters *et al.,* 1995; Cain *et al.,* 1997; Hargis *et al.,* 1998; Tischendorf, 2001). This may be considered in order to guide the selection of non-redundant metrics for specific landscape assessments.

Discriminating landscape types within a forest district: why is it needed for forest planning?

This assessment is useful to compare ecological aspects between different landscape types within a forest district. Before metric calculation, it is highly recommended to set adequate grain sizes in order to maximize the discrimination between types and to emphasize their ecological differences. In this manner, critical landscape types in relation to certain structural characteristics may be detected. Forest planning can be developed according to these peculiarities, setting programmes and priorities depending on the ecological status and goals for each landscape type. For instance, the landscape types corresponding to the forest of *P. sylvestris* and *P. nigra*, in Pinares and Alto Tajo respectively, were the least diverse of their districts and it may be interesting to diversify their land cover and promote more heterogeneous patterns. Likewise, the agricultural belt of Pinares and the river canyons of Alto Tajo were the most fragmented landscape types, therefore being advisable to concentrate management efforts in creating or maintaining connecting elements along their landscape matrices that are able to mitigate the effects of the isolation and reduced size of habitat patches and to uphold potentially threatened ecological fluxes and processes. In short, if a given set of landscape types is analyzed altogether without a previous discrimination of their characteristics then all their differences may be compensated with one another and therefore remain unnoticed for the subsequent management, with the risk of implementing inadequate conservation actions that do not match with the actual variability of ecological conditions and needs therein.

Therefore, reported results are particularly interesting for forest planners and managers involved in the elaboration of the Spanish Forest Resources Management Plans or analogous plans in the Mediterranean or other regions throughout the world.

Further research

In the future, it may be interesting to carry out a similar sensitivity analysis in other Mediterranean and temperate forest areas in order to test the generality and width of scope of the proposed method and results. The same methodology could also be applied to other landscape metrics considered relevant in a particular forest district, region or conservation management problem. Furthermore, a similar assessment could be made using a digital source map with a different resolution or classification approach. As Saura and Castro (2007) previously demonstrated, this circumstance may affect the results of the landscape pattern assessment. Besides, further research efforts may focus on the other component of scale, extent, which here has not been addressed.

It is important to set frameworks for landscape metric assessment when modelling and monitoring natural resources. Nowadays, statistical approaches like the one here presented would be the more practical and operational way to achieve this goal. However, it would still be necessary to widen up the theoretical framework in landscape ecology so that landscape metrics were reduced to a minimum set of orthogonal axes of landscape pattern variation for which their general scaling behaviour could be formally derived and applied in a wide variety of landscapes and management situations.

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