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Towards a core set of landscape metrics for biodiversity assessments: A case study from Dadia National Park, Greece

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ABSTRACT

Spatial heterogeneity has an important influence on a wide range of ecological patterns and processes, and many landscape metrics in GIS environment are used to facilitate the investigation of the relation between landscape structure and biodiversity. Data reduction analyses have been applied to tackle the problem of highly correlated indices, but valid landscape predictors for fine scale Mediterranean forest-mosaics are still missing. Therefore, we analyzed the landscape structure of Dadia National Park, Greece, a Mediterranean forest landscape of high biodiversity, characterized by pine, oak and mixed woodland. By distinguishing nine land cover classes, 119 variables were computed and factor analysis was applied to detect the statistical dimensions of landscape structure and to define a core set of representative metrics. At landscape level, diversity of habitats, fragmentation and patch shape and at class level dominance of mixed forest and the gradient from one pure forest type to another turned out to be the crucial factors across three different scales. Mapping the encountered dimensions and the representative metrics, we detected that the pattern of landscape structure in Dadia National Park was related to dominating habitat types, land use, and level of protection. The evaluated set of metrics will be useful in establishing a landscape monitoring program, to detect the local drivers of biodiversity, and to improve management decisions in Dadia NP and similar mosaic-landscapes.

1. Introduction

Fragmentation, loss and degradation of habitat are widely considered as the most important threats to biodiversity on a global scale (Wilcove et al., 1986; Soulé, 1987; Fahrig and Meriam, 1994; Tilman et al., 1994; Wiens, 1995). On the other hand, in many European ecosystems, where human activities have shaped the landscape for many centuries, a positive relationship between spatio-temporal heterogeneity of ecosystems and local biodiversity has been detected (e.g. Brotons et al., 2004; Kati et al., 2004; Saïd and Servanty, 2005). Mosaics of semi-natural habitats, which characterize forest landscapes of many parts of Europe (Forman, 1995; Blondel and Aronson, 1999; Ernoult et al., 2003), play an important role for many species of fauna (e.g. Chust et al., 2004; Carrete and Donázar, 2005; Saïd and Servanty, 2005). But the landscape structure, often regarded as important background for local biodiversity, underlies rapid changes due to current trends in socio-economic and agri- and silvicultural development (e.g. Rocchini et al., 2006). Thus, a negative impact on local and regional biodiversity has been encountered in several studies (e.g. Zechmeister et al., 2003; Scozzafava and De Sanctis, 2006).

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Landscape structure variables are easily obtainable over large areas (see Groom et al., 2006) and their calculation is less demanding in terms of time and money than collecting detailed data on species distribution and abundance. Thus, an increasing number of studies analyze relations of landscape structure and biodiversity, aiming at the use of related variables as predictors for modelling spatio-temporal distribution patterns of species and communities (Bissonette, 1997; Dufour et al., 2006). Many landscape structure variables are currently available (McGarigal and Marks, 1995; Riitters et al., 1995), and many of them can be computed for the overall landscape (landscape level) and for specific land cover classes (class level). It is often necessary to use several metrics to characterize a particular landscape, because different qualities of spatial pattern do exist (Tischendorf, 2001; McAlpine and Eyre, 2002; Neel et al., 2004), but the use of many highly correlated indices does not yield new information and leads to problems in the interpretation of the results (Jones et al., 2001; Li and Wu, 2004). For these reasons, the analyst should select metrics that are relatively independent of one another, providing a unique and ecological meaningful contribution to our understanding of landscape structure (Hargis et al., 1998; Turner et al., 2001). In order to define an optimal set of metrics, theoretical considerations (Li and Reynolds, 1994) and statistical data reduction analyses have been used to detect unique dimensions of landscape structure (McGarigal and McComb, 1995; Riitters et al., 1995; Cain et al., 1997; Scånes and Bunce, 1997; Tinker et al., 1998; Griffith et al., 2000; Lausch and Herzog, 2002; Cifaldi et al., 2004). Despite these research efforts from mainly temperate and boreal regions, an optimal set of landscape metrics for Mediterranean landscapes – especially their biodiversity rich forest-mosaics – has not been defined yet.

We studied the landscape structure of the National Park of Dadia-Lefkimi-Soufli Forest (hereafter Dadia NP), Greece, a Mediterranean forest of high biodiversity (e.g. Kati, 2001; Kati et al., 2004; Poirazidis et al., 2004). Most of the area is under intensive forest management, thus a landscape monitoring should be established to determine effects of land use and management on landscape structure and to improve the conservation management (Poirazidis et al., 2002). The importance of the heterogeneity of the habitat for the local biodiversity has been recognized (e.g. Kati et al., 2004), but the pattern of the landscape structure remains unidentified. For these reasons the objectives of this study were (a) to analyze the statistical dimensions of landscape structure at landscape and at class level, (b) to provide a core set of representative variables, (c) to evaluate the stability of the detected dimensions across different scales, and (d) to describe characteristic patterns of the landscape structure of Dadia NP.

2. Methods

2.1. Study area

Our study area, the Dadia NP (26°00′ to 26°19′N, 40°59′ to 41°15′E), is situated in the Evros prefecture, north-eastern Greece (Fig. 1). It has an extent of about 430 km^2, including two strictly protected core areas that cover 73.5 km^2. The mountainous area (altitudes ranging from 20 to 645 m above see level) is covered by extensive pine (*Pinus brutia*, *P. nigra*) and oak (*Quercus frainetto*, *Q. cerris*, *Q. pubescens*) forest, but it includes also a variety of other habitats such as pastures, fields (cultivations), torrents and stony hills. Dadia NP is an essential refuge for breeding populations of a unique assemblage of raptors (Poirazidis et al., 1996), contains the only remaining Black Vulture (*Aegypius monachus*) breeding colony in the Balkan Peninsula (Poirazidis et al., 2004), and a high diversity of passerines (Kati and Sekercioglu, 2006), amphibians and reptiles (Helmer and Scholte, 1985), butterflies (Grill and Cleary, 2003), grasshoppers (Kati et al., 2003), and orchids (Kati, 2001).

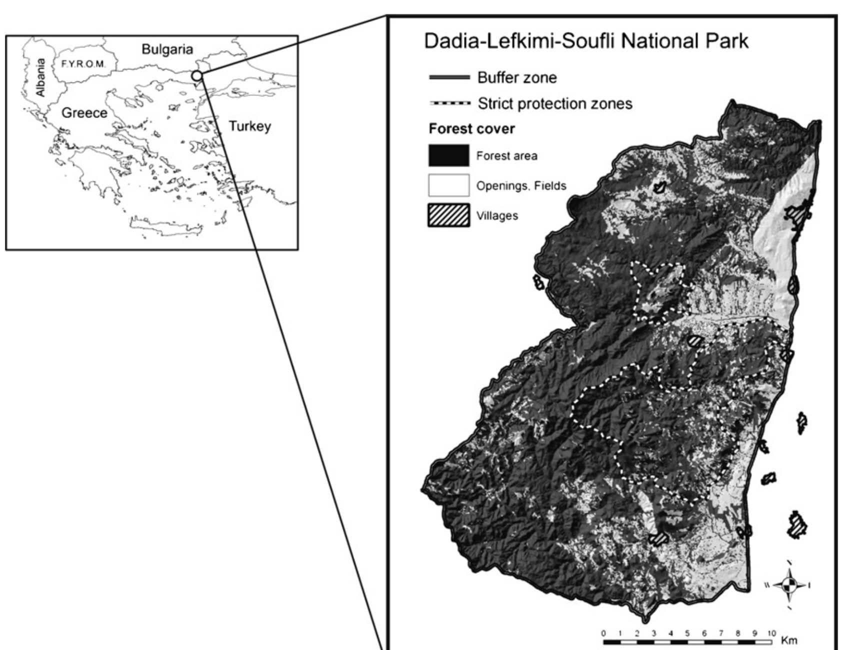

Fig. 1 – Habitat of Dadia NP, located in Evros, Greece.

2.2. *Land cover data set, hexagonal grid and landscape metrics*

Satellite images (IKONOS, July 2001, pixel size 1 m) of the study area were digitized on screen to produce a vector-map including 25 different habitat types related to the dominant forest tree species and the percentage of mixed forest. The initial habitat map was merged into nine land cover categories, namely oak forest (OA), pine forest (PI), pine–oak forest (PO), oak–pine forest (OP), broadleaves (BL), openings (OO), fields (FI), roads (RO), and urban areas (UR). This map was then converted to raster format with a grain of 5 m, using the spatial analyst module of ArcGIS® (ESRI, Inc., Redlands, CA). In this study OA and PI are pure forests, while PO and OP are mixed forests, dominated by pine and oak, respectively. BL is dominated by broadleaves other than oaks, and OO includes several natural and semi-natural non-forested areas like patches of grassland, rocks and torrents.

In order to achieve homogenous spatial units for proper statistical analysis, we produced a hexagon grid and clipped samples from the land cover data set. Because changes in the extent of maps can produce unpredictable behavior of landscape metrics (e.g. Wu et al., 2002; Wu, 2004), we used an adaptive approach, proposed by Turner et al. (1989) and tested for stability of the results across three different scales (grid units, i.e. extents of maps). Hence we chose the specific scale of 500 ha for the hexagon grid and assessed later the robustness of the results using grids of 1000 and 250 ha (see Fig. 2 for an overview of the methodology). The extent of 500 ha was chosen, because it guaranteed a representative sample of patches per hexagon ($n = 230.2 \pm 136.8$, see O'Neill et al., 1996) and enough hexagonal maps for the total study area. After the exclusion of all hexagons with more than 20% of their area uncovered by the land cover data, eighty-five 500 ha hexagonal maps of land cover categories (hereafter hexagons), covering 422.5 km^2, remained for further analysis.

The landscape structure was analyzed at landscape level (considering all landcover categories) and at class level (considering one focus landcover category only), because the variables concerning the two levels contain different kind of information. Using FRAGSTATS 3.3 (McGarigal and Marks, 1995), we computed for each hexagon 55 landscape level metrics, and 64 class level metrics (16 for each of the four forest categories PI, PO, OP, and OA). In order to even out the number of metrics, we modified the approach of Lausch and Herzog (2002) and applied correlation tests and factor analyses in a first step for five separated groups of metrics regarding the aspects (i) patch size and patch density, (ii) shape, edge and contrast, (iii) isolation, proximity and connectedness, (iv) texture, and (v) diversity of habitats (Table 1). Thus, we evaluated smaller sets of metrics that explained most of the variance of these five aspects of landscape structure, and used the variables with the highest loadings per factor in a next step as input in an overall analysis to detect the statistical dimensions of landscape structure. We performed corresponding analyses for both the landscape and the class level (Fig. 2).

For the computation of the landscape metrics, the land cover patches were delineated applying the eight neighbor rule to guarantee that linear patches along a direction diagonal to the grid axes were identified as a single patch. Each hexagon was

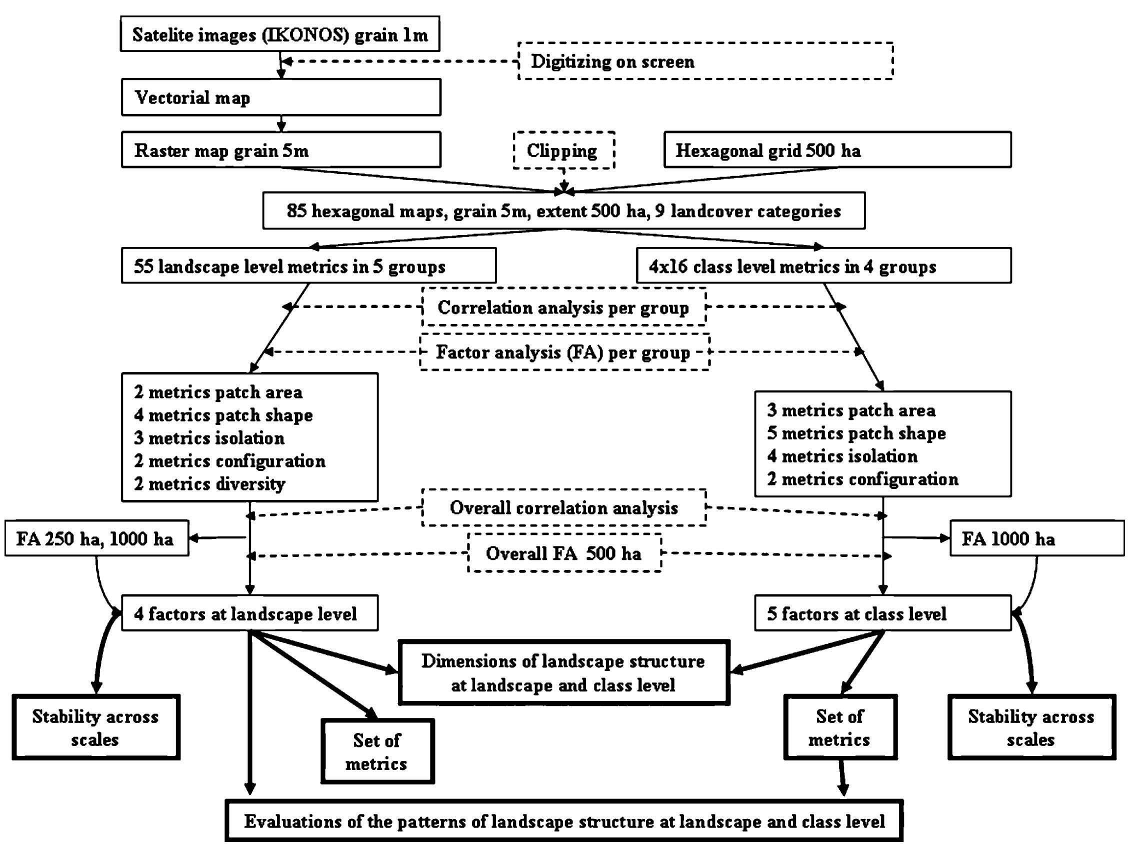

Fig. 2 – Overview of the methodology of the study.

Table 1 – Landscape level (LL) and class level (CL) metrics used in this study

Group	Acronym	Metric name	LL	CL	Sum	Description
Group I. Patch size and patch density			8	12	20	
	AREA	Patch area	3	4	7	DSt; size of the patches
	GYRATE	Radius of gyration	3		3	DSt; radius of gyration, i.e. the mean distance for each cell of one patch to the patch centroid
	PD	Patch density	1	4	5	Number of patches per area
	LPI	Largest patch index	1		1	Percentage of total area occupied by the largest patch
	PLAND	Percentage of landscape		4	4	Percentage of area occupied by certain land cover class
Group II. Shape, edge and contrast			**23**	**24**	**47**	
	LSI	Landscape shape index	1		1	Ratio of the total edge to the minimum total edge
	NLSI	Normalized landscape shape index		4	4	Ratio of the total edge to the minimum total edge per class, rescaled according the proportion of the classes
	ED	Edge density	1	4	5	Total length of edge per unit area
	SHAPE	Shape index	3	4	7	DSt; equals 1 when all patches are circular; increases with complexity of patch shapes; independent of patch size
	PARA	Perimeter–area ratio	3		3	DSt; patch shape complexity measure that measures perimeter per area
	CIRCLE	Related circumscribing circle	3	4	7	DSt; patch elongation measure; equals 1 minus patch area divided by the area of the smallest circumscribing circle
	FRAC	Fractal dimension index	3		3	DSt; patch shape complexity measure that approaches 1 for simple shapes and 2 for complex shapes
	CONTIG	Contiguity index	3		3	DSt; equals 0 for a one-pixel patch and approaches 1 as patch contiguity, or connectedness increases
	PAFRAC	Perimeter–area fractal dimension	1		1	Patch shape complexity measure, which approaches 1 for shapes with simple perimeters and 2 for complex shapes
	CWED	Contrast-weighted edge density	1	4	5	Total amount of edge per area, weighted by the contrast between the different land cover types
	TECI	Total edge contrast index	1	4	5	Ratio of the contrast-weighted total length of edge to the not contrast-weighted total length of edge per grid
	ECON	Edge contrast index	3		3	DSt; ratio of the contrast-weighted to the not contrast-weighted edge length per patch
Group III. Isolation, proximity and connectedness			**10**	**16**	**26**	
	PROX	Proximity index	3	4	7	DSt; considers size and proximity of all patches with the same land cover type inside a specified search radius
	SIMI	Similarity index	3	4	7	DSt; considers size and proximity of patches within a search radius, weighted by their similarity to the focal patch
	ENN	Euclidean nearest neighbour distance	3	4	7	DSt; minimum edge to edge distance to the nearest neighbouring patch of the same type
	COHESION	Patch cohesion index		4	4	Measure of the physical connectedness of the focal land cover class
	CONNECT	Connectance index (%)	1		1	Percentage of patches which are joined, i.e. inside a specified threshold distance
Group IV. Texture			**6**	**12**	**18**	
	CONTAG	Contagion index	1		1	Measure of the aggregation of the land cover classes
	PLADJ	Percentage of like adjacencies	1	4	5	Percentage of neighbouring pixel, being the same land cover class, based on double-count method
	AI	Aggregation index	1		1	Percentage of neighbouring pixel, being the same land cover class, based on single-count method
	IJI	Interspersion and juxtaposition ind. (%)	1	4	5	Measure of evenness of patch adjacencies, equals 100 for even and approaches 0 for uneven adjacencies
	DIVISION	Landscape division ind. (proportion)	1	4	5	Equals the probability that 2 randomly chosen pixels in the landscape are not situated in the same patch
	SPLIT	Splitting index	1		1	Equals the number of patches of a landscape divided into equal sizes keeping landscape division constant
Group V. Diversity			**8**	**0**	**8**	
	PRD	Patch richness density (no./100 ha)	1		1	Equals the number of patch types (i.e. land cover categories) per 100 ha
	RPR	Relative patch richness	1		1	Percentage of present patch types out of all categories
	SIDI	Simpson's diversity index	1		1	Diversity measure, which equals 1 minus the sum of the squared proportional abundance of each patch type
	SHDI	Shannon's diversity index	1		1	Equals minus the sum of the proportional abundance of each patch type multiplied by the ln of that proportion
	MSIDI	Modified Simpson's diversity index	1		1	Diversity measure, which equals minus the ln of the sum of the squared proportional abundance of each patch type

Table 1 (*Continued*)

Group	Acronym	Metric name	LL	CL	Sum	Description
	SHEI	Shannon's evenness index	1		1	Diversity measure, which considers only evenness of patch sizes, not the number of patches
	SIEI	Simpson's evenness index	1		1	Diversity measure, which considers only evenness of patch sizes, not the number of patches
	MSIEI	Modified Simpson's evenness index	1		1	Diversity measure, which considers only evenness of patch sizes, not the number of patches
Sum			55	64	119	

Regarding the distribution statistics (DSt), mean (MN), area-weighted mean (AM) and coefficient of variation (CV) were used at landscape level, but only the mean at class level. Each class level metric was computed for each of the four forest types PI, PO, OP, and OA.

analyzed separately and hexagon boundaries were not counted as edges. The Proximity and Similarity Metrics as well as the Connectance Index were computed using search radii and threshold distances of 1000 m, respectively. In order to compute the Similarity Indices and the Contrast Metrics, a Similarity Matrix and an Edge Contrast Matrix were produced for the nine land cover classes, assigned weights were based on logical values according to the authors experience in the study area.

2.3. Data reduction analyses

Within each of the variable groups (five at landscape and four at class level, Table 1) we examined pairwise Spearman correlation coefficients, and of the pairs of metrics with coefficients >0.9, only one metric was retained (Riitters et al., 1995; Griffith et al., 2000). Density metrics were chosen over absolute metrics, because some of the hexagons were not fully covered by the land cover data set. In cases where the distribution statistics were highly correlated, the mean of the metrics was preferred to the area-weighted mean, which in turn was preferred to the coefficient of variation. With respect to the diversity and evenness indices, Simpson-based metrics were preferred, because the use of Shannon-based metrics is recommended only if patch richness is greater than 100 (Yue et al., 1998). For all the other pairs of highly correlated metrics, we selected the metric, which is more commonly used in biodiversity literature.

Using this procedure, the original set of landscape level metrics was reduced from 55 to 35, and the class level set from 64 to 60. With the remaining metrics, within each of the groups, a factor analysis (FA, e.g. Johnston, 1980) was performed. By using orthogonal (varimax) rotations of the axes, we accounted for additional variance and produced non-correlated factors. We retained factors by using two criteria: the shape of the scree plot and Kaisers rule of thumb that the eigenvalue of the factor should be greater than 1.0. In the cases of disagreement between these two criteria, both possibilities were evaluated and interpretability of results was the ultimate criterion for the final selection. For each retained factor of all groups, the metric with the highest absolute loading was defined as representative and included in the overall analysis. The selected metrics were checked first for high correlations and then an overall FA was performed (Fig. 2), applying the same methodology as described above. To detect the most important dimensions of landscape structure, we interpreted the overall factors using the variables that had high loadings and defined the optimal set of metrics to quantify landscape structure as the representative metrics of the overall analyses.

At landscape level we used all the 500 ha hexagons for the factor analyses ($n = 85$), whereas at class level, we included only the hexagons that contained patches of all four forest types ($n = 60$).

2.4. Evaluation of the stability of the detected dimensions across maps of different extents

To evaluate the stability of the encountered factors across different extents of maps, we performed at landscape level FAs for the scales of 250 ha ($n = 177$ hexagons) and 1000 ha ($n = 39$). At class level, the FA was only performed for the 1000 ha scale ($n = 36$), because a high percentage of the hexagons lacked at least one of the four land cover categories at the scale of 250 ha. To permit the comparison of the resulting factors, we included the same metrics as for the overall FAs at 500 ha and retained the same number of factors. Finally, we calculated coefficients of congruence (Johnston, 1980; Cain et al., 1997) to evaluate the similarity among the factors emerged at the different scales.

2.5. Mapping of the landscape structure and description of the resulting patterns

To detect the patterns of landscape structure at landscape level, we calculated the factor scores of each hexagon for each encountered dimension of landscape structure. Then we mapped the factor scores and compared the resulting patterns with dominating habitat type, land use and level of protection. Finally pattern analysis was performed at class level, using the values of the representative metrics instead of the factor scores, because they were available for more hexagons (76–85 instead of $n = 60$), being of advantage when evaluating the landscape patterns.

3. Results

The number of land cover classes per 500 ha hexagon ranged from four to nine and the number of patches per hexagon ranged from 36 to 664. Oak forest (OA) accounted on average for 26.7%, PI for 12.9%, OP for 10.7%, and PO for 21.2% of the hexagons. The other land cover categories accounted on average for 1.9% (BL), 8.9% (OO), 14.7% (FI), and 3.2% (RO and UR together).

At landscape level, the number of factors retained per aspect of landscape structure ranged from two until four, and

Table 2 – Overall factor analyses for the 500 ha hexagon grid of landscape and class level, including the 13 and 14 variables, respectively, determined as representatives for the retained factors of the factor analyses per group

Landscape level

Metrics	Group	Factor 1	Factor 2	Factor 3	Factor 4
Eigenvalue		4.186	2.148	2.017	1.844
Percent of variance explained		32.199	16.521	15.517	14.187
Percent of cumulative variance explained		32.199	48.720	64.237	78.424
SIDI	**Diversity**	**0.923**			
PROX_MN	Isolation	**−0.889**			
CIRCLE_AM	Shape	**0.823**			
IJI	Texture	**0.765**			
PLADJ	Texture	−0.694	−0.463	0.387	
PRD	Diversity	0.519		−0.453	
ECON_MN	**Shape**		**0.928**		
SIMI_CV	Isolation		0.619		
SIMI_MN	Isolation	−0.429	−0.539	0.392	0.492
FRAC_MN	**Shape**			**0.894**	
GYRATE_MN	Area		−0.581	0.658	
SHAPE_AM	**Shape**				**0.950**
AREA_CV	Area	−0.546			**0.765**

Class level

Metrics	Group	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Eigenvalue		3.170	2.357	2.233	1.626	1.325
Percent of variance explained		22.642	16.838	15.952	11.615	9.463
Percent of cumulative variance explained		22.642	39.480	55.432	67.048	76.511
PO_PLADJ	**Texture**	**0.963**				
PO_PLAND	Area	**0.897**		0.385		
PO_NLSI	Shape	**−0.841**		0.335		
PO_PROX_MN	Isolation	0.679		0.418	−0.362	
OA_PLAND	**Area**		**−0.826**			
PI_ED	Shape		**0.782**		0.320	
OP_COHESION	Isolation		−0.668			
PI_AREA_MN	Area		0.646	−0.548		
PO_SIMI_MN	**Isolation**			**−0.770**		
PO_CWED	Shape	0.340		**0.737**		
PO_IJI	**Texture**				**0.722**	
OA_CIRCLE_MN	Shape				0.623	
OP_CIRCLE_MN	**Shape**					**0.866**
OP_ENN_MN	Isolation			−0.387	−0.395	0.679

Due to limitation in space, the tables concerning the analysis per group are not presented here, but they can be obtained from the corresponding author. Bold metrics are chosen as representative for the corresponding factors, bold numbers indicate factor loadings >|0.7|, loadings <|0.3| are not presented.

the cumulative variance explained by these factors from 66 to 91%. Most factors were retained for the patch shape group (Table 2). The metrics of the diversity group were highly correlated, and only the pair of metrics SIDI and PRD obtained a Spearman Correlation Coefficient less than 0.9. Thus, instead of performing a FA for this group, these two metrics were directly included in the overall analysis. At class level three until five factors were retained per aspect and the cumulative variances ranged from 70 to 77%. Selecting the metrics with the highest absolute loading per factor, totally 13 metrics remained for the overall analysis at landscape and 16 at class level.

3.1. *Statistical dimensions of landscape structure*

At landscape level, none of the metrics included in the overall analysis was redundant. We found four statistical dimensions of landscape structure, which explained 78% of the variance of the 13 metrics included (Table 2). They were labeled: diversity of habitats, fragmentation, mean patch fractal dimension and area-weighted mean patch shape, respectively. The first factor was characterized by a high negative loading of PROX_MN and high positive loadings of SIDI, CIRCLE_AM and IJI. It described a gradient from areas with few, dominating and clustered habitat classes towards areas with high diversity, high interspersion and a large amount of area covered by elongated patches. The second factor was characterized by a high positive loading of ECON_MN, obtaining high values for hexagons with high edge contrast, thus very fragmented areas. The third factor was characterized by a high loading of FRAC_MN, obtaining the highest values for hexagons with many irregular shaped patches, while the fourth factor was determined by high positive loadings of SHAPE_AM and AREA_CV, indicating a gradient from areas with regular patches towards those with large variation in patch size and a large amount of area covered by very irregularly shaped patches.

To provide a visual impression of the emerged factors and to demonstrate the differences between the gradients they represent, we inspected hexagons with very high and very low factor scores (Fig. 3). As expected, landscape-mosaics with a high value for habitat diversity contained many land cover

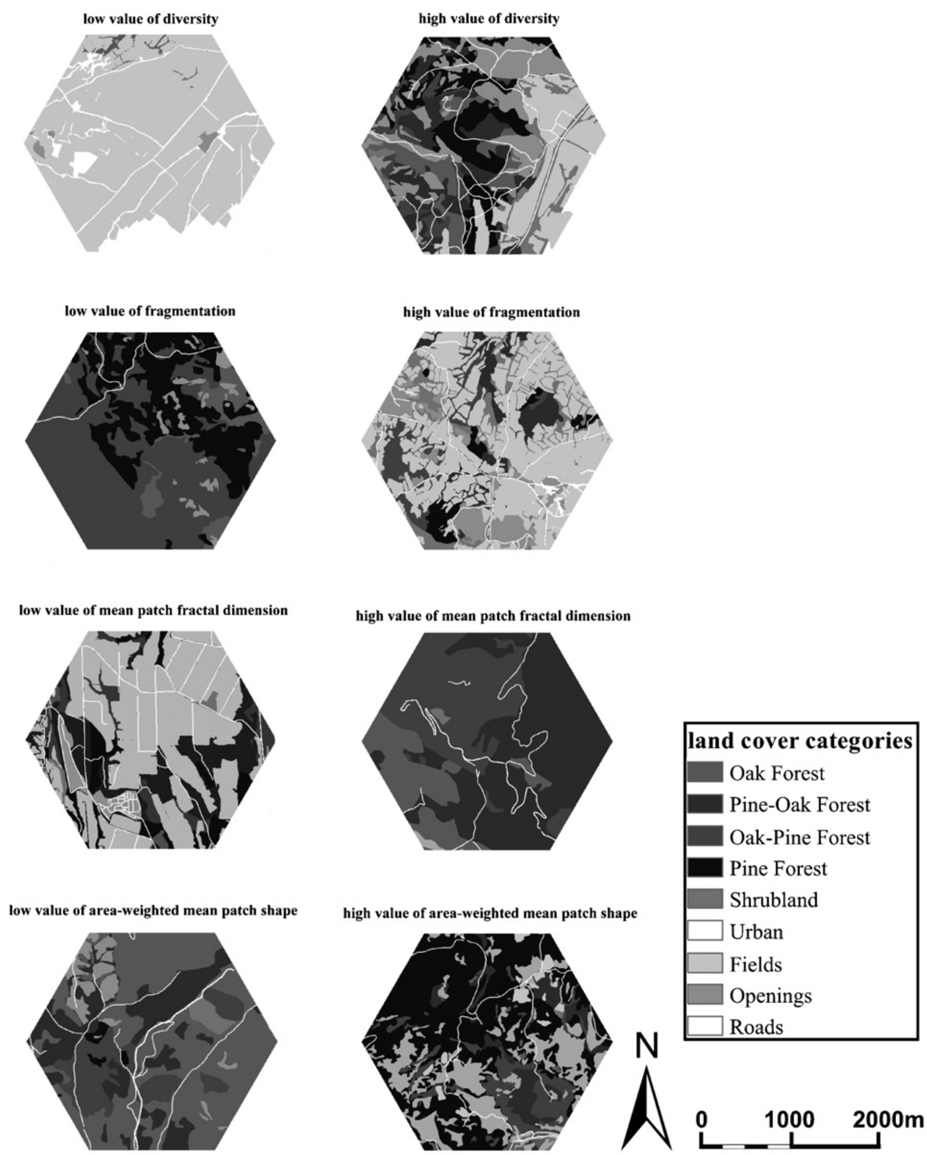

Fig. 3 – Resulting landscape level gradients of landscape structure, described by characteristic 500 ha hexagons.

classes of even distribution and little variation in patch size, whereas highly fragmented forest areas were characterized by the additional occurrence of non-forest habitats like openings, fields and roads. When comparing hexagons with low values for the factors three and four (mean patch fractal dimension versus area-weighted mean patch shape), it is obvious, that the decreasing importance of area is related with a high number of small regular shaped patches.

Regarding the overall analysis at class level OA_DIVISION and PI_PLAND were redundant with OA_PLAND and PI_AREA_MN, respectively, and excluded from the analysis. The five retained factors of the overall analysis explained 77% of the variance of the remaining 14 metrics (Table 2). The factors were labeled PO dominance, OA–PI gradient, PO fragmentation, forest interspersion and OP patch elongation.

3.2. *Evaluation of the stability of the detected dimensions across maps of different extents*

The retrieved factors were remarkably stable across hexagons of different extents (Table 3), when comparing them by applying coefficients of congruence (hereafter CoC – the measure approaches an absolute value of |1| when the loadings are proportional). At landscape level, the factors 1 and 2, concerning habitat diversity and fragmentation, obtained specifically high values (CoC: range |0.87|–|0.97|), and factor 4 of the 500 ha scale emerged clearly as the third factor in the FAs of the scales of 250 and 1000 ha (CoC: range |0.89|–|0.96|). Only factor 3 of the 500 ha scale was not stable. This factor was moderately correlated with different factors at the other scales. At class level, the result was analogous, with very stable factors 1 and 2 (CoC: |0.85| and |0.95|, respectively) and lesser congruence among the factors 3–5 (Table 3).

Table 3 – Coefficients of congruence for the combinations obtained from hexagons of 250, 500 and 1000 ha at landscape level (LAND), and of 500 and 1000 ha at class level (CLASS)

	Factors	1	2	3	4	5
LAND			500 ha			
1000 ha	1	**−0.97**	−0.23	0.35	0.48	
	2	−0.27	**−0.87**	**0.81**		
	3	−0.51			**0.96**	
	4	0.27	0.56	**−0.64**		
LAND			500 ha			
250 ha	1	**−0.92**	−0.33	**0.62**	0.33	
	2		**0.95**	−0.51		
	3	−0.34	0.28	−0.28	**0.93**	
	4	−0.59	−0.41	0.52		
LAND			250 ha			
1000 ha	1	**0.86**		0.39	**0.66**	
	2	0.49	**−0.80**	−0.40	0.51	
	3	0.43		**0.89**		
	4	−0.48	**0.61**	0.24		
CLASS			500 ha			
1000 ha	1	**0.85**	−0.30		0.28	
	2		**0.91**		0.43	
	3			**−0.60**	−0.30	**0.66**
	4	0.59		**0.71**	0.27	
	5				**0.67**	0.48

Note that the measure approaches a value of one, when the loadings are proportional, and that the absolute value (not the sign) of the congruence statistic is important for the comparison. Bold numbers indicate values ≥|0.6|, values <|0.2| are not presented.

3.3. *Sets of metrics for landscape monitoring*

Regarding the overall landscape level analysis, the metrics SIDI, ECON_MN, FRAC_MN and SHAPE_AM contributed with the highest loadings on the four factors representing the dimensions of landscape structure (Table 2). In similar way, at class level, the metrics PO_PLADJ, OA_PLAND, PO_SIMI_MN, PO_IJI, and OP_CIRCLE_MN contributed with the highest loadings on the five emerged class level factors (Table 2). In this set, metrics concerning the three land cover types PO, OA, and OP were included, while metrics regarding pure pine forest (PI) became rejected during the data reduction analysis. These nine metrics were the optimal surrogate of the nine factors, including a maximum of the information provided by the other metrics, and forming a core set of structural features for landscape monitoring.

3.4. *Description of the patterns of landscape structure*

When mapping the factor scores at landscape level (Fig. 4), the first factor, diversity of habitats, resulted in a dispersed pattern with highest values around the borders of the strictly protected areas. The pattern of the second factor, concerning fragmentation, was clustered and the differences between neighboring hexagons were on average smaller than for the first factor. Highest values of the second factor occurred in the eastern part of the study area, indicating a higher level of fragmentation than in the western part and in the strictly protected areas. Regarding the third factor, mean patch fractal dimension, the pattern was homogeneous and gradients were slighter than for the other factors. The pattern of the forth factor, area-weighted mean patch shape, was again clustered with lowest values for the western part of the study area (Fig. 4). At class level different patterns were observed (Fig. 5), as the first four metrics were clustered, while the pattern of the fifth metric, OP_CIRCLE_MN, was homogenous. Clusters of high values in the center of the park and in two small areas in the periphery characterized the pattern of the metric PO_PLADJ, representing the first factor. Highest values of the second metric, OA_PLAND, occurred in the periphery of the park, while PO_SIMI_MN, the third metric, obtained clusters of high values in the southwest and in the strictly protected areas. PO_IJI, the forth metric, obtained clusters of high values around and inside the strictly protected areas of Dadia NP (Fig. 5).

4. Discussion

4.1. *Dimensions and patterns of landscape structure at landscape level*

The total amount of variance explained by the overall analysis at landscape level was very similar to the variance explained

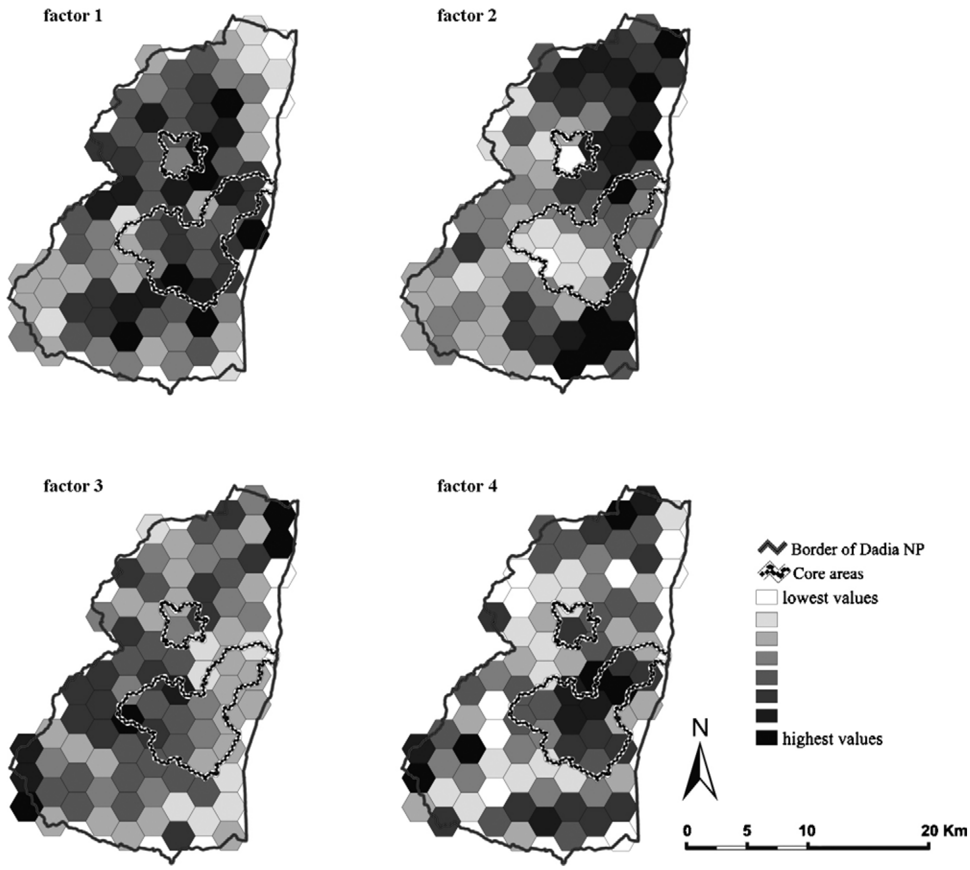

Fig. 4 – Landscape level patterns of landscape structure. The maps present the factor scores of each hexagon for the four factors (1) diversity, (2) fragmentation, (3) mean patch fractal dimension, and (4) area weighted mean patch shape.

by the first four factors of similar studies in other ecosystems (Riitters et al., 1995; Cain et al., 1997; Tinker et al., 1998; Griffith et al., 2000; Cifaldi et al., 2004). Other researchers retain in addition a fifth or sixth factor, but in most cases these factors do either explain little variance (Riitters et al., 1995; Cain et al., 1997), or are related to class level attributes (Griffith et al., 2000; Cifaldi et al., 2004).

According to previous research in different mosaics of temperate and boreal biomes, the most important dimensions of spatial structure at landscape level are usually related to diversity/aggregation of landcover categories and patch shape aspects (Riitters et al., 1995; Cain et al., 1997; Griffith et al., 2000; Cifaldi et al., 2004). In our study additionally fragmentation was an important and stable factor. Our results indicate the importance and the independence of the aspects diversity of habitats and fragmentation in a Mediterranean forest like Dadia NP. Although in some parts of the study area, both factors coincide, in other areas high diversity of habitats coincides with low fragmentation. Areas with a high level of habitat diversity were located mainly where different forest types were mixed with openings and fields, like around the borders of the core areas of the National Park (Fig. 4). The lowest values of habitat diversity were caused by dominance of agricultural areas in the northeast and southeast and of oak forests close to the northern and southwestern border. The first factor was determined very well by the pair of metrics SIDI and PROX_MN, being measures of diversity and dominance. The high positive loadings of CIRCLE_AM and IJI on this factor indicate that high diversity of habitat is related in our study area to elongated patches and a high interspersion and juxtaposition of landcover categories. The four metrics defining this factor were obtained from the four different groups, diversity, isolation, patch shape, and texture. Because in factor analysis, the composition and order of the emerged factors is a result of the number of indicators that are included in the analysis (Cain et al., 1997), this factor could probably be encountered in this composition only by reducing the large amount of metrics that measure very similar values during the data reduction process per group.

As outlined above, new insight could be gained by this study as two contrast-weighted structural attributes – edge contrast and Similarity Index – determined an important and stable factor. However, as the related metrics have been scarcely used by other researchers so far, we could not evaluate, if this is a specific characteristic for Mediterranean fine grained landscapes or should be regarded as factor of general importance. Edge contrast was included at class level in the analysis of Griffith et al. (2000), who recommend further studies, and it is supposed to be important for quantifying fragmentation and thus to distinguish between fragmented and undisturbed landscapes (McGarigal and McComb, 1995). A similar approach, using edge contrast metrics at landscape level, has been presented by Tinker et al. (1998) for forest-dominated landscapes in Wyoming. Since a large and

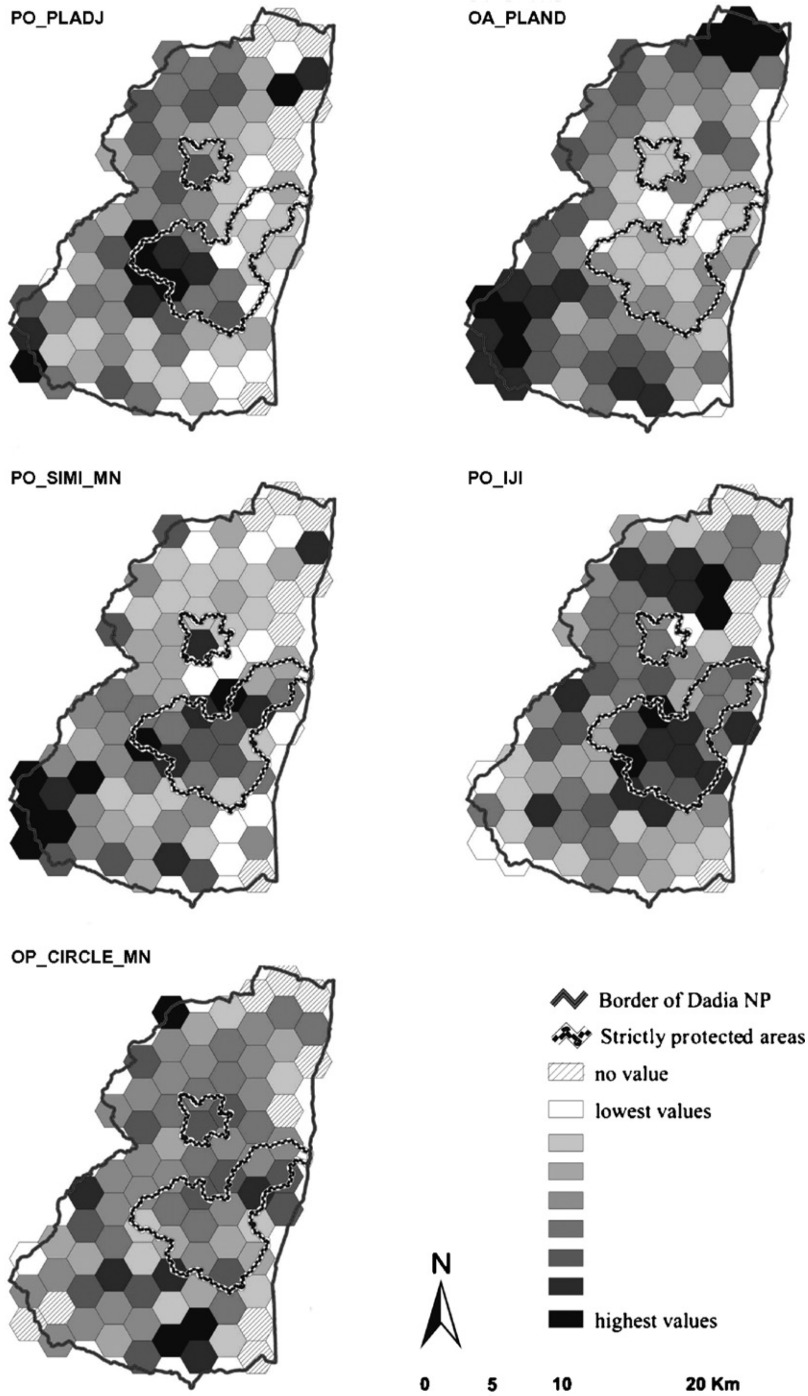

Fig. 5 – Class level pattern of landscape structure. The maps present the scores of the five metrics PO_PLADJ, OA_PLAND, PO_SIMI_MN, PO_IJI, and OP_CIRCLE_MN, which represent the five retained factors. Note that the second and third factors have high loadings of "–OA_PLAND" and"–PO_SIMI_MN" (Table 2), thus the pattern of these factors is reverse to the pattern of the representing metrics.

dominating set of core area metrics was included in this study, comparisons with our findings and general conclusions are difficult. Cifaldi et al. (2004), analyzing the dimensions of landscape structure of two watersheds of Michigan, detected one factor strongly related to fragmentation, and highest values occurred where agricultural and natural land was converted to urban. But using only four land cover categories, and excluding contrast metrics, it was not possible to differentiate between heterogeneity of habitats and fragmentation. Neither Hargis et al. (1998), testing the behavior of six metrics with artificially generated landscapes, could detect a good measure of fragmentation. Hargis et al. (1998) also recommend the use of metrics concerning interpatch distances, which we added to the commonly used sets of metrics (e.g. Riitters et al., 1995; Cain et al., 1997; Lausch and Herzog, 2002; Cifaldi et al., 2004). Out of these variables, PROX_MN obtained a high loading on the first factor, SIMI_MN and SIMI_CV formed the contrast-weighted character of the fragmentation factor, while the nearest neighbor metrics became rejected during the data reduction analysis per group. However, including the contrast metrics, our evaluated dimensions have come closer to the five attributes, Li and Reynolds (1994) identified based on theoretical considerations: (a) number of cover types, (b) proportion of each type, (c) spatial arrangement of patches, (d) patch shape, and (e) patch contrast.

The choice of appropriate scales is fundamental in landscape analysis (Gustafson, 1998; Meisel and Turner, 1998; Turner et al., 2001; Wu et al., 2002). Due to the strong influence of scale on the behavior of landscape metrics (e.g. Baldwin et al., 2004; Wu, 2004), landscape pattern should be analyzed at a local scale when applied for local land management and conservation (Cifaldi et al., 2004). In this study the use of fine grain data permitted us to quantify the landscape structure of the diverse mosaic of habitats. The high stability of the factors habitat diversity, fragmentation and area-weighted mean patch shape across the three scales proved that our samples sizes have been large enough to reduce the effects of the map boundaries on the values of the metrics and indicated that our results could be applicable for a wider range of conditions. Also Cain et al. (1997) detected that the stability of the six factors that emerged in their study, decreased from the first to the last when analyzing maps of different resolution, numbers of attributes, and methods of delineating landscape unit boundaries. Their second and third factors were still relatively stable in composition, but the remaining three factors were very unsteady.

4.2. *Statistical dimensions of landscape structure at class level*

The five class level factors are not directly comparable with factors other researchers detected, because of differences in land cover categories, the area under concern and in the applied methodologies. Griffith et al. (2000), for instance, analyzed the landscape structure of Kansas (USA), using class level metrics for grassland and cropland and performing a mixed data reduction analyses including both, class and landscape level metrics. McGarigal and McComb (1995) and Tinker et al. (1998) performed class level analyses for several forest types separately, thus, factors presenting the gradient from one type to another could not emerge. In our study, the emerged factors describe gradients related to class attributes. They explain a high proportion of the variance of the class level metrics, provide additional information to the dimensions at landscape level, and resulted in different pattern when mapped. We included class level metrics only for the forest land cover categories PI, PO, OP, and OA, because these categories appeared in most of the hexagons and formed the matrix of the study area. Class level metrics regarding the interspersed forest types were often related, and as a result metrics of all four categories contributed with important loadings on the overall factors.

4.3. *Sets of metrics for landscape monitoring*

It is proposed to develop a suite of metrics that measure the fundamental dimensions of landscape structure and can be applied for a landscape monitoring (Riitters et al., 1995; Botequilha Leitão and Ahern, 2002). Single metrics as surrogates of the factors have the advantage that they simplify the mental model and facilitate comparisons among different sets of maps. The simplest rule for the choice is the single metric with the highest absolute loading on each factor, being especially reasonable when the metric has a high loading for only that factor (Riitters et al., 1995). In this study the four highest loading metrics at landscape level fulfill the criteria and are proposed as a core set of variables for a landscape monitoring. At class level the representative metrics of the overall analysis also fulfill the criteria, but obtained on average lower loadings. Although it is more difficult to obtain general conclusions at class level, our results indicate that a core set of metrics for a monitoring of the landscape structure of Dadia NP or a similar forest should contain class level metrics concerning (1) the amount of mixed forest types, (2) the gradient from one pure forest type to another, (3) the quantification of the fragmentation of a mixed forest type, (4) the interspersion of the forest types, and (5) the patch shape of a mixed forest type.

It is remarkable that also Botequilha Leitão and Ahern (2002), reviewing previous works that studied dimensions of landscape structure and core sets of metrics (Li and Reynolds, 1994; McGarigal and McComb, 1995; Riitters et al., 1995; Hargis et al., 1998; Tinker et al., 1998), proposed a core set of nine landscape and class level metrics to address the principal needs of applied landscape structure analyses. They also included edge contrast in the core set and coincide with our study in totally five of the nine cases. However, we recommend to evaluate the importance of the detected dimensions of landscape structure across other landscape-mosaics and to consider the evaluated sets of metrics for landscape monitoring and assessments of the effects of landscape structure on Mediterranean biodiversity.

4.4. *Implications for management and conservation*

In order to improve conservation management of Dadia NP, a monitoring plan has been established, mainly focusing on the assemblage of birds of prey (Poirazidis et al., 2002). Birds of prey seem to be good indicators of biodiversity (Sergio et al., 2005), and it is likely that the high abundance and diversity of birds of prey in Dadia NP is related to characteristics of landscape structure. However, the relation of landscape structure and biodiversity must be assessed yet for our study area, where the strictly protected areas, delineated to protect the Black Vulture breeding colonies, are dominated by pine and mixed forest, while the surrounding parts of the managed buffer zone are characterized by the highest diversity of habitats (see Fig. 4). As these parts of the buffer zone are of particular interest, because they host a great number of different taxa of flora and fauna (e.g. Grill and Cleary, 2003; Kati et al., 2004; Kati and Sekercioglu, 2006), changes in composition and configuration must be monitored and effects of land use and management on landscape structure must be analyzed. This knowledge can then be used to achieve better conditions in the impoverished parts of the park, to assess progress in conservation efforts, and to improve management decisions not only in Dadia NP, but also in similar landscape-mosaics and other Mediterranean forests.

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