The third dimension in landscape metrics analysis applied to central Alentejo - Portugal

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Abstract
Landscape metrics have been widely developed over the last two decades, although the question remains: How does landscape metrics relates with ecological processes?
One of the major recent developments in landscape metrics analysis was the third dimension integration. Topography has an extremely important role on ecosystems function and structure, even though the common analysis in landscape ecology only conceives planimetric surface which leads to some erroneous results, particularly in mountain areas.
The analytical process tested patch, class and landscape metrics behavior in 11 sample areas of 100 sqkm each in several topographical conditions of Central Alentejo. It is presented the significance analysis of the results achieved in planimetric and 3D environments.

Keywords: Landscape metrics; 3D, topography, Local Landscape Units, Alentejo, OTALEX

1. Introduction
Landscape ecology studies landscape structure, functions and changes. Landscape structure is characterized by the composition and configuration of landscape patterns. One of the main premise is that landscape structure is connected with landscape functions and processes (Turner 1989, von Drop & Opdam 1987, McIntyre & Wiens 1999). 3D-issue in Landscape Ecology have been studied and applied by several researchers in the past 10 years, in many different approaches (Dorner *et al* 2002, Bowden *et al* 2003, Jenness 2004, Lefsky *et al* 2002, MacNab 1992, Pike 2000, Sebastiá 2004, McGarigal *et al* 2008). Topography is actually a key factor for many ecological processes, such as erosion, flow direction and accumulation, temperature and biodiversity distribution and fire (Swanson *et al* 1988, Burnett *et al* 1998, Bolstad *et al* 1998, Davis & Goetz, 1990 and Blaschke *et al* 2004). However it is not taken in to account in most landscape ecological studies. Only a few recent studies applied 3D to landscape metrics (Hoechstetter *et al* 2006, Hoechstetter *et al* 2008, Hoechstetter 2009, Jenness 2004, Jenness 2010, Walz *et al* 2010). Others issues like viewsheds and landscape preferences have been studied by Sang *et al* (2008).
This paper presents part of the landscape studies carried out by the Environmental Indicators Working Group (EIWG) of OTALEX - Alentejo Extremadura Territorial Observatory (www.ideotalex.eu) (in OTALEX II Project co-financed by Operational Program for Cooperation between cross border Regions of Spain and Portugal - POCTEP), in Central Alentejo (Portugal). The main questions are analyzed:

- Are there significant differences in landscape metrics calculated using real surface area (3D) instead of planimetric area (2D)?
- Are there significant differences between the sample areas?

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2. Methodology

2.1 Characterization of study area

The study area is located in Central Alentejo, South of Portugal. It covers about 7.400 sqkm and has about 175000 inhabitants, concentrated in small and median villages and cities. Altimetry varies between 7 and 648 m. We selected 11 sample areas, of 100 sqkm each, located along Central Alentejo, representing 15% of the total area (figure 1).

2.2 Local Landscape Units (LLU)

The definition of landscape units (paths) was based on Corinne Land Cover level 5 (CLC N5) map at scale 1:10.000 (Batista *in press*), altimetry (MDT 25m) and soil units (at sale 1:25.000). Land cover (LC) map applies hierarchical CLC N5 legend developed by Guiomar *et al* (2006, 2009), with 295 LC classes. The land cover map was elaborated using digital ortophotomaps from 2005 (from DGRF 2006) and field validation at the end of 2008. The LC map has been previously generalized to create the LLU map. From the overlay of these maps derived 103 Local Landscape Units (LLU) (figura 2).

2.3 True Surface Area and Perimeter Calculation and Landscape Metrics

3D applied to landscape metrics implies to calculate those using true surface area and perimeter measurements (Hoechstetter 2009). Surface area provides a better estimate of the land area available than planimetric area, and the ratio of this surface area to planimetric area provides a useful measure of topographic roughness of the landscape (Jenness 2004).

It was used LandMetrics-3D developed by Walz *et al* (2010), which is an ARCGIS extension that integrates the available tools for calculating true surface area developed by Jenness (2004, 2010) (http://www.jennessent.com/arcgis/surface_area.htm, last modified April 8, 2010) and the fragstats landscape metrics of McGarigal *et al* (2002). The application uses a moving window algorithm and estimates the true surface area for each grid cell using a triangulation method (Figure 3). Each of the triangles is located in three-dimensional space and connects the focal cell with the centre points of adjacent cells. The lengths of the triangle sides and the area of each triangle can easily be calculated by means of the Pythagorean Theorem. The eight resulting triangles are summed up to produce the total surface area of the underlying cell (for details see Hoechstetter *et al* 2008, Hoechstetter 2009 or Jenness 2010).

The analytical process integrates the calculation of Patch, Class and Landscape metrics for the 11 sample areas, for 2D and 3D. The metrics analyzed where: Patch Geometry - Patch Area (Area) and Perimeter (Perim), Shape Metrics - Fractal Dimension (FractDim), Perimeter /Area Racio (Racio), Shape Index (Shape), Density/Edge Metrics - Edge Density (EdgeDens), Edge Contrast (Edgecont), number of patches (Numofp), Surface Metrology – Average Roughness (Avrough) and RMS Roughness (RMSrough).

3. Results

The statistical analysis involved 221.382 records generated by 3D-LandMetrics software, for the 2 dimensions (2D and 3D), 11 sample areas and 9 landscape metrics. An ANOVA with multiple comparing of means (LSD de Fisher method) was run (table 3), resulting in pairwise comparison, for $p<0,05$, significant differences between dimensions (2D and 3D) (table 4), between sample areas and between metrics and interactions between dimensions / sample areas and dimensions /metrics. In table 5 are presented the results of multiple comparisons between sample areas, with a significance level of 5%. Metrics presents a p-value=0,000, which means that all presents significant differences among them.

4. Discussion

This first approach to the analysis of landscape metrics in the Central Alentejo revealed that the introduction of the third dimension in landscape metrics calculation induces significant differences among the studied landscape metrics, and should be considered in landscape analysis. However these results should be carefully interpreted as in previous research developed by Hoechstetter (2009), certain metrics groups do not reveal a significant difference between their 2D- and 3D-versions (e.g. shape metrics), and some of the algorithms (especially for the distance metrics) involve a considerable computational effort.

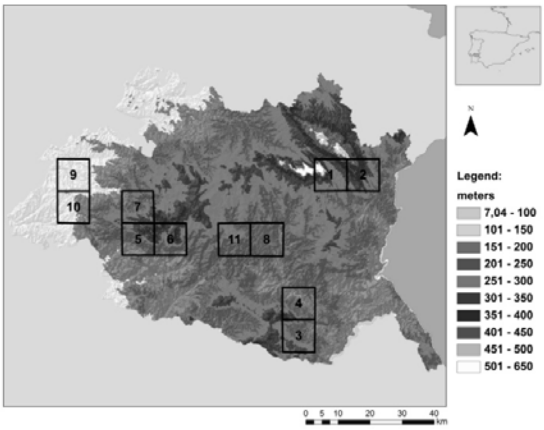

Figure 1: Sample areas localization. Central Alentejo – Portugal

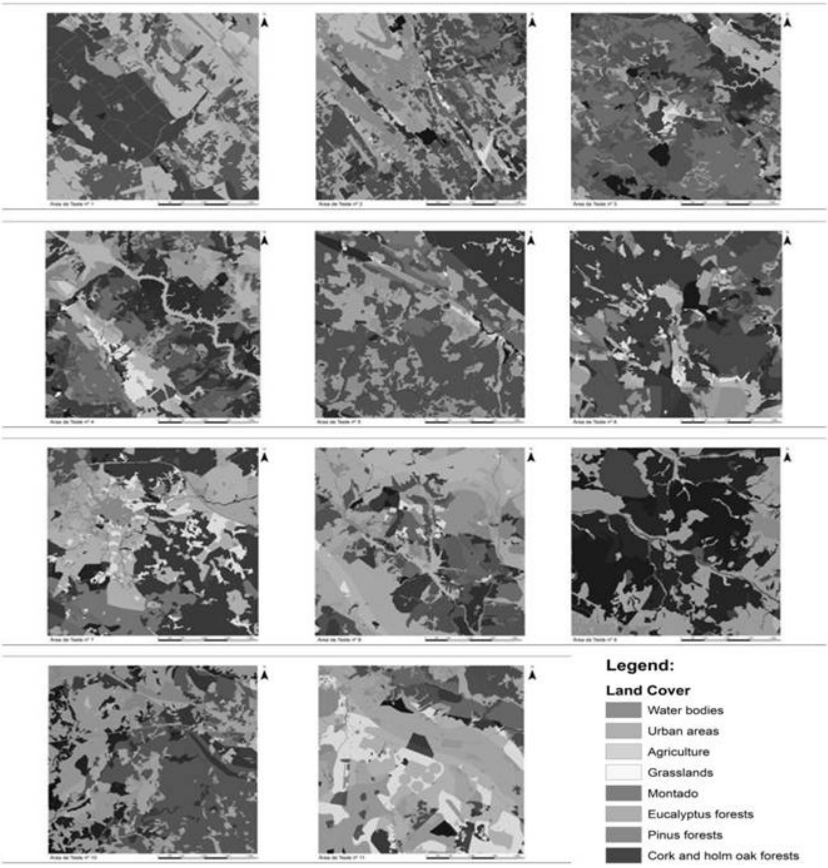

Figure 2: Sample areas local landscape units

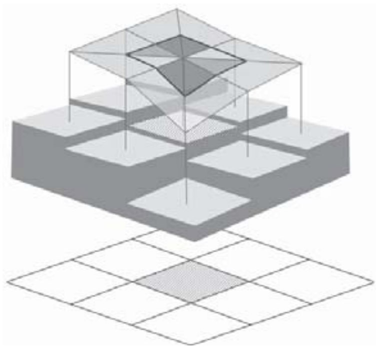

Figure 3: Method to determine true surface area and true surface perimeter of patches. (figure redrawn according to Jenness 2004 by Hoechstetter et al 2008).

Table 2: Subject factors for significance analysis

Between-Subjects Factors

		Value Label	Nº
Dimension	1	2D	110691
	2	3D	110691
Area	1	Quadr2 (A1)	18990
	2	Quadr4 (A2)	31842
	3	Quadr5 (A3)	25578
	4	Quadr6 (A4)	20538
	5	Quadr7 (A5)	18054
	6	Quadr8 (A6)	17892
	7	Quadr9 (A7)	22626
	8	Quadr10 (A8)	22158
	9	Quadr11 (A9)	9882
	10	Quadr12 (A10)	19980
	11	Quadr13 (A11)	13842
Metrics	1	EgdeDens_LSC	24598
	2	AvgRough_LSC	24598
	3	RMSRough	24598
	4	EdgeCont_LSC	24598
	5	Shape_LSC	24598
	6	NumOfP_LSC	24598
	7	Perim_P	24598
	8	Ratio_LSC	24598
	9	FractDim_LSC	24598

Table 3: ANOVA results

	Df	Sum Sq	Mean Sq	F value		Pr(>F)	
Dimension	1	4,18E+13	4,18E+13	62459,7	<	2.2e-16	***
SampleArea	10	1,36E+12	1,36E+11	203,75	<	2.2e-16	***
Metrics	8	6,23E+14	7,79E+13	116345,7	<	2.2e-16	***
Dimension/Area	10	7,48E+11	7,48E+10	111,66	<	2.2e-16	***
Dimension/Metrics	8	8,11E+13	1,01E+13	15147,26	<	2.2e-16	***
Residuals	221344	1,48E+14	6,70E+08				

Signif. Codes: 0'***'; 0,001 '**'; 0,01 '*'; 0,05 '.'; 0,1 ' ' ; 1

Table 4: Pairwise comparison between 2D and 3D

Dependent Variable:Rank of Results

(I) Dimension	(J) Dimension	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
2D	3D	-27062,292*	112,650	,000	-27283,082	-26841,502
3D	2D	27062,292*	112,650	,000	26841,502	27283,082

Based on estimated marginal means

*. The mean difference is significant at the ,05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 5: Results of pairwise comparison between the sample areas

	Differes from:
Quadrado 2 – A1	Quadrado 4,6,7,10,11,12,13
Quadrado 4 – A2	Quadrado 2,5,6,7,8,10,11,12,13
Quadrado 5 – A3	Quadrado 4,6,7,9,10,11,12,13
Quadrado 6 – A4	Quadrado 2,4,5,7,8,9,10,12,13
Quadrado 7 – A5	Todas as áreas
Quadrado 8 – A6	Quadrado 4,6,7,10,11,12,13
Quadrado 9 – A7	Quadrado 5,6,7,10,11,12,13
Quadrado 10 – A8	Todas as áreas
Quadrado 11 – A9	Todas as áreas excepto a do quadrado 6
Quadrado 12 – A10	Todas as áreas
Quadrado 13 – A11	Todas as áreas

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