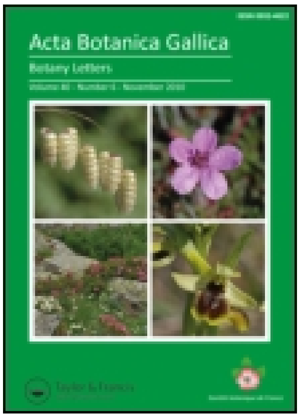

Acta Botanica Gallica
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tabg20

Suitable methods for landscape evaluation and valorization: the third dimension in landscape metrics

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Version of record first published: 02 Aug 2012

To cite this article: Teresa Batista, Paula Mendes, Luisa Carvalho, Carlos Vila-Viçosa & Carlos Pinto Gomes (2012): Suitable methods for landscape evaluation and valorization: the third dimension in landscape metrics, Acta Botanica Gallica, 159:2, 161-168

To link to this article: http://dx.doi.org/10.1080/12538078.2012.696930

Acta Botanica Gallica: Botany Letters
Vol. 159, No. 2, June 2012, 161–168

Société botanique de France

Suitable methods for landscape evaluation and valorization: the third dimension in landscape metrics

Des méthodes appropriées pour l'évaluation et la valorisation du paysage: la troisième dimension dans les métriques du paysage

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Abstract: Landscape metrics have been widely developed over the last two decades. One of the major recent developments in landscape metrics analysis was the integration of the third dimension. Topography has an extremely important role in ecosystems function and structure, even though the common analysis in landscape ecology only considers a planimetric surface, which leads to some erroneous results particularly in mountain areas. In this study we tested landscape metrics behaviour in 13 sample areas of 10,000 m^2 each in several topographical conditions of Central Alentejo, Portugal. The significance analysis of the results achieved in planimetric and three-dimensional environments is presented.

Keywords: Alentejo; landscape metrics; local landscape units; OTALEX II; three dimensions; topography

Resumé: Les métriques du paysage ont été largement développées au cours des deux dernières décennies. Un des récents développements dans le paysage paramètres d'analyse a été l'intégration troisième dimension. La topographie a un rôle extrêmement important sur la fonction des écosystèmes et sur sa structure, même si la commune analyse d'écologie du paysage ne conçoit que la dimension planimétrique, qui peut conduit à des résultats erronés, en particulier dans les zones de montagne. Dans cette étude nous avons testé paysage métriques, et son comportement en 13 zones de l'échantillon avec des 10.000 m^2 chacun et dans plusieurs conditions topographiques au Centre de l'Alentejo, au Portugal. Il est présenté l'analyse de la signifiance des résultats obtenus dans les environnements en 3D et en planimétrie.

Mots-clés: 3D; Alentejo; Métriques du paysage; OTALEX II; Topographie; Unités Locales du Paysage

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 premises is that landscape structure is connected with landscape functions and processes (von Drop and Opdam 1987; Turner 1989; McIntyre and Wiens 1999). Topography is actually a key factor for many ecological processes, such as erosion, flow direction and accumulation, temperature and biodiversity distribution and fire propagation (Swanson et al. 1988; Burnett et al. 1998; Bolstad, Swank and Vose 1998; Davis and Goetz 1990; Blaschke, Tiede and Heurisch 2004). The importance of three-dimensional (3D) aspects in landscape ecology was already declared by Carl Troll, at the end of the 1930s, who "hoped that a new science could be developed that could combine the spatial 'horizontal' approach of geographers with the functional 'vertical' approach of ecologists" (Farina 1998).

In the past 10 years, 3D issues in landscape ecology have been studied and applied by several researchers using many different approaches (MacNab 1992; Pike 2000; Dorner, Lertzman and Fall 2002; Lefsky et al. 2002; Bowden et al. 2003; Jenness 2004; Sebastiá 2004; McGarigal, Tagil and Cushman 2009). However, most of the landscape ecological studies use the patch–corridor–matrix model to describe the spatial arrangement of landscape mosaics and patches. This model, used to calculate landscape metrics, is based on area, perimeter and distance planimetric measurements, which can lead to erroneous results, especially in mountainous areas (Hoechstetter et al. 2008).

Recent landscape ecological studies applied 3D to landscape metrics (Hobson, 1972; Jenness 2004, 2010; Hoechstetter, Xuan Thinh and Walz 2006; Hoechstetter et al.

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ISSN 1253-8078 print/ISSN 2166-3408 online

http://dx.doi.org/10.1080/12538078.2012.696930
http://www.tandfonline.com

2008; Sang, Miller and Ode 2008; Hoechstetter 2009; Walz et al. 2010). The study developed by Hoechstetter et al. (2008) provides basic approaches to include relief properties into large-scale landscape analyses, including the calculation of standard landscape metrics on the basis of "true" surface geometries and the application of roughness parameters derived from surface metrology. Others issues when applying 3D, like viewshed to landscape preferences, have been studied by Sang, Miller and Ode (2008).

The aim of the present study was to analyse whether the third dimension is significant in the characterization of a landscape, when based on landscape metrics, as it has already been determined that there are significant differences between patch, class and landscape metrics calculated in planimetric or in 3D environments (Batista, Mendes, Carvalho 2010). It is also tested whether there are significant differences between the sample areas, according to the roughness of the underlying terrain.

This work was carried out by the Environmental Indicators Working Group (EIWG) of OTALEX – Alentejo Extremadura Territorial Observatory (www.ideotalex.eu) (in the OTALEX II Project co-financed by Operational Programme for Cooperation between cross-border regions of Spain and Portugal – POCTEP), in Central Alentejo (Portugal).

Material and methods

Characterization of study area

The study area is located in Central Alentejo, in southern Portugal. It covers about 7400 km^2 and has about 175,000 inhabitants, concentrated in small and medium-sized villages and cities. Altitude varies between 7 and 648 m. We selected 13 sample areas, of 100 km^2 each, located along Central Alentejo, representing about 17% of the total area (Figure 1).

Local Landscape Units

To characterize the landscape in the study area, a map was produced using the Local Landscape Units (LLU) based on the methodology proposed by Batista et al. (forthcoming), which integrates Corinne Land Cover level 5 (CLC N5) land cover map at scale 1: 10,000 (Batista, forthcoming), altimetry (Digital Elevation Model (DEM) 25 m), geology and soil units (at scale 1: 25.000). The land cover map applies the hierarchical CLC N5 legend developed by Guiomar et al. (2006, 2009), which has 295 land cover classes. This map was expanded using photo interpretation of digital ortophotomaps from 2005 (DGRF, 2005) and field validation at the end of 2008. The Land Cover map was previously generalized to create the LLU map. The relief was analysed using a DEM of 25 × 25 m pixel. The DEM was reclassified into three altimetry classes according to area roughness (class 1, 0–200 m; class 2, 200–400 m and class 3, 400–655 m). The geology applies the Geologic and Miner Portuguese Institute Map, which has 71 geological classes at scale 1: 50,000. To create the LLU map, the geological map was reclassified into four classes, according to their most important geological substrate – Sand, Limestone, Volcanic Rocks (such as granites, granodiorites and tonalities) and Metamorphic rocks (such as schists and greywacke). The soils map was developed by the Portuguese Institute of Hydraulic,

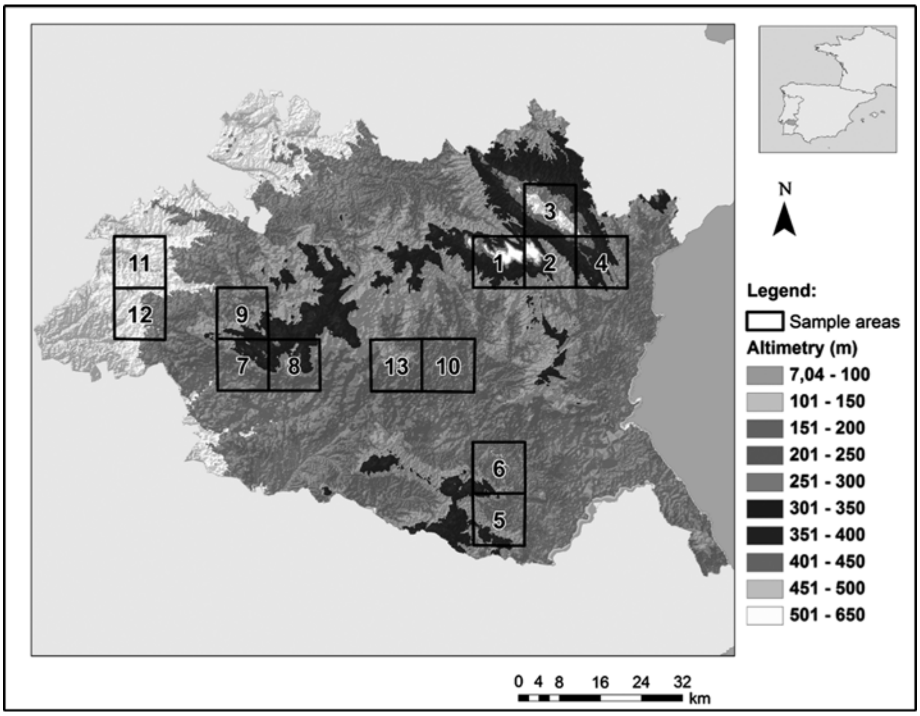

Figure 1. Sample areas localization. Central Alentejo – Portugal.
Figure 1. Localisation de las Zones d'échantillons – Alentejo Central – Portugal.

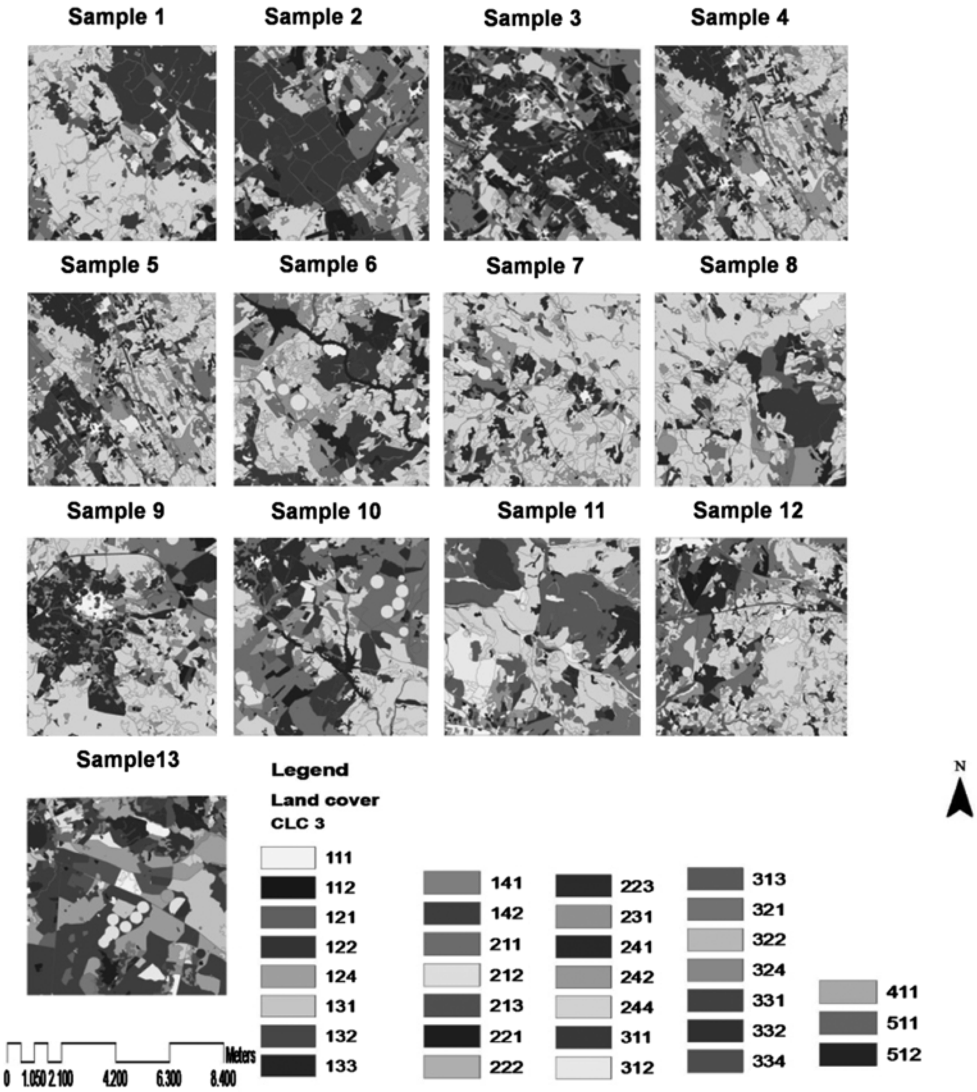

Figure 2. Sample areas local landscape units.
Figure 2. Zones d'échantillons des unités locales du paysage.

Rural Engineering and Environment and has 71 combined classes at scale 1: 25,000 that were aggregated into 12 main soil classes, following Carvalho Cardoso (1965). From the overlay of these four maps, 103 LLU classes were derived that can be observed in Figure 2.

True surface area and perimeter calculation and landscape metrics

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

We used LandMetrics-3D, developed by Walz et al. (2010). LandMetrics-3D 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 8 April 2010) and the fragstats landscape metrics of McGarigal et al. (2002). This application is based on Jenness (2004), whose technique 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 be calculated by means of the Pythagorean theorem. The eight resulting triangles are summed to produce the total surface area of the underlying cell (for details see Hoechstetter et al. 2008; Hoechstetter 2009; Jenness 2010).

LandMetrics-3D permits calculation not only of the true surface and perimeter of the cell, but also of each patch, so as to calculate the landscape metrics. It uses two raster files of equal resolution (25 $\times$ 25 m) and extent (10,000 $\times$ 10,000 m): the elevation model and the LLU raster. Also the surface distance is calculated.

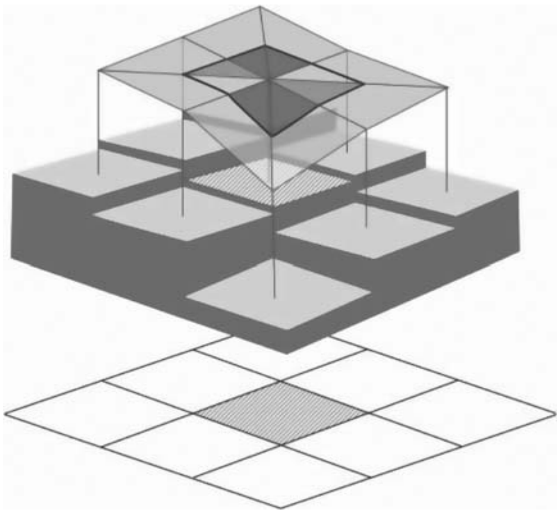

Figure 3. Method to determine true surface area and true surface perimeter of patches. (Figure redrawn according to Jenness 2004 by Hoechstetter et al. 2008).
Figure 3. Méthode pour déterminer l'area réelle de la surface et le périmètre réelle de la surface des taches. (Figure redessiné selon Jenness 2004 par Hoechstetter et al. 2008).

The following landscape metrics, available in LandMetrics-3D, were calculated for the 13 sample areas, for 2D and 3D: Area (Area), Perimeter (Perim), Fractal Dimension (Fractdim), Perimeter/Area Racio (Ratio), Shape Index (Shape), Total Edge (TEdge), Edge Density (EdgeD), Edge Contrast (EdgeContrast), Largest Patch Index (LPidx), number of patches (PatchNr), Average Roughness (Avg. Roughness), RMS Roughness (RMS Roughness), Shannon Diversity Index (ShannonDivInd), Shannon Evenness Index (ShannonEvenInd), Simpson Diversity Index (Simpson-DivInd), Efective Mesh Size (EffectiveMeshSize), Skewness and Kurtosis (for more details of the metrics formulae see Hoechstetter 2009 or MacGarigal and Marks 2004).

Results and discussion

Table 1 presents the results for the landscape metrics as well as the minimum and maximum elevations of each sample area. To test the similarity of the metrics for 2D and 3D, the non-parametric Wilcoxon test was used. The results (Table 2) indicate that all the studied landscape metrics were significantly different (p < 0.05) when calculated planimetrically or with the use of the true surface area, perimeter or distance. The only non-significant difference was PatchNr, which was not variable across the 2D and 3D and was used as the "blank". This result support the results achieved in our previous work when we analysed 221,382 records, for the two dimensions (2D and 3D), applied to patch, class and landscape metrics in 11 sample areas and nine landscape metrics (Batista, Mendes and Carvalho 2010).

The range of variation for each landscape metric is also presented, calculated based on the variation in percentage of the 3D landscape metrics in relation to the calculation in the planimetric environment (Figure 4). Both base metrics **Area** and **Perim** show visible variation, more in Area (0.04%) than in Perim (0.01%) (Figure 4). These variations induce the positive variation of EffectiveMeshSize, EdgeContrast, TEdge and diversity metrics ShannonDivInd, ShannonEvenInd and SimpsonDivInd. We observed negative variations in Ratio, EdgeD, LPidx and Shape (very slightly in Shape). This can be explained by the fact that all of these metrics are divided by the Area, which increases in 3D calculations.

FractDim and Shape are the most stable metrics, because they reflect the relations between Perim and Area.

The surface metrology metrics Avg. Roughness, RMS Roughness, Skewness and Kurtosis are also presented in the Table 1. Avg. Roughness approximates surface roughness by calculating the mean absolute departure of the elevation values from the mean plane in m and RMS Roughness is a modification of Ra, used as an equivalent

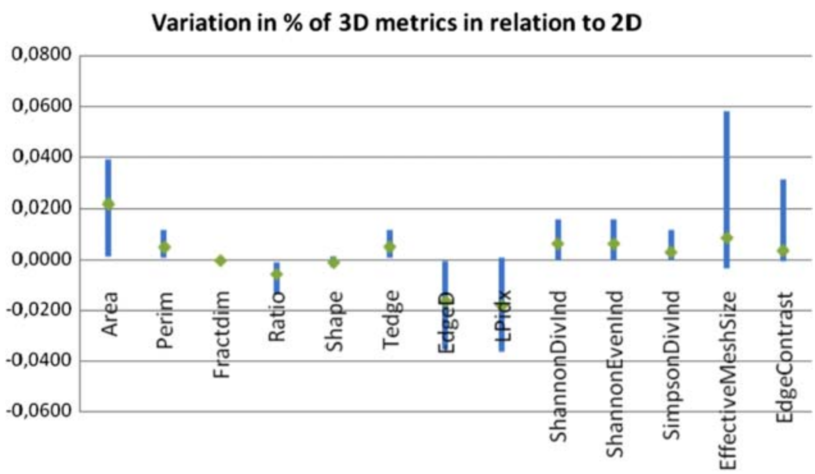

Figure 4. Variation (%) of the three-dimensional landscape metrics in relation to the planimetric calculated metrics.
Figure 4. Variation (en%) des 3D métriques en relation avec les 2D métriques.

Table 1. Landscape metrics results for the 13 sample areas.
Tableau 1. Résultats des metriques du Paysage aux 13 zones de l'echantillon.

Metrica	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
2D Met_Area_LSC	100500625,00	101252500,00	103016875,00	101757500,00	104295000,00	102000000,00	101757500,00	100747500,00	101505625,00	107640625,00	101505000,00	101505000,00	103016875,00
3D Met_Area_LSC	101268056,57	104259222,12	107038784,33	104877674,06	106885187,56	105050744,39	105008686,40	102764880,46	101822603,17	107787065,19	102655444,21	103186957,43	107038784,33
2D Met_Perim_LSC	1403850,00	1675100,00	1670850,00	2342600,00	1974150,00	1886000,00	1497400,00	1457250,00	1663450,00	1544600,00	1201650,00	1775550,00	1670850,00
3D Met_Perim_LSC	1409686,55	1690485,71	1674091,22	2364641,10	1991765,14	1902349,60	1514860,92	1466812,50	1666046,98	1545814,50	1202662,33	1777130,37	1674091,22
2D Met_ Fract LSC	1,0815	1,0843	1,0659	1,0767	1,0716	1,0825	1,0651	1,0717	1,0689	1,0647	1,0767	1,0775	1,0659
3D Met_ Fract_LSC	1,0815	1,0843	1,0658	1,0763	1,0714	1,0824	1,0653	1,0715	1,0688	1,0646	1,0765	1,0774	1,0658
2D Met_ Ratio_LSC	0,0854	0,0894	0,0952	0,0831	0,0862	0,0716	0,0936	0,0836	0,0892	0,0953	0,0757	0,0781	0,0952
3D Met_ Ratio_LSC	0,0850	0,0886	0,0951	0,0822	0,0850	0,0707	0,0929	0,0830	0,0890	0,0952	0,0756	0,0781	0,0951
2D Met_Shape_LSC	1,6417	1,6492	1,4742	1,5716	1,5398	1,6277	1,4900	1,5329	1,5055	1,4602	1,6319	1,5968	1,4742
3D Met_Shape_LSC	1,6418	1,6482	1,4729	1,5673	1,5358	1,6275	1,4918	1,5317	1,5053	1,4601	1,6282	1,5946	1,4729
2D Met_TEdge_LSC	721975,00	857675,00	855725,00	1191475,00	1007500,00	963200,00	768875,00	748700,00	851875,00	793050,00	620975,00	907925,00	855725,00
3D Met_TEdge_LSC	724942,48	865656,77	857744,22	1202750,44	1016528,48	971638,27	777859,68	753679,41	853199,04	793667,85	621576,26	908853,75	857744,22
2D Met_EdgeD_LSC	0,0072	0,0085	0,0083	0,0117	0,0097	0,0094	0,0076	0,0074	0,0084	0,0074	0,0061	0,0089	0,0083
3D Met_EdgeD_LSC	0,0072	0,0083	0,0080	0,0115	0,0095	0,0092	0,0074	0,0073	0,0084	0,0074	0,0061	0,0088	0,0080
2D Met_LPidx_LSC	19,6790	15,8132	18,9168	4,1858	5,5731	4,2659	9,5276	11,3948	11,5320	9,5224	10,1325	19,8685	18,9168
3D Met_ LPidx LSC	19,5919	15,5857	18,2289	4,0770	5,4577	4,1595	9,2350	11,2017	11,5451	9,5192	10,0331	19,5893	18,2289
2D Met_EdgeContrast_LSC	9,7629	5,8015	6,3137	4,5860	5,7856	5,5754	5,7626	6,7918	7,7159	9,1638	14,5266	7,9404	6,3137
3D Met_EdgeContrast_LSC	9,7730	5,8055	6,3559	4,5867	5,7824	5,5819	5,9429	6,7894	7,7170	9,1641	14,5389	7,9539	6,3559
2D Met_PatchNr_LSC	827,00	1055,00	1311,00	1769,00	1421,00	1141,00	1003,00	994,00	1257,00	1231,00	549,00	1110,00	1311,00
3D Met_PatchNr_LSC	827,00	1055,00	1311,00	1769,00	1421,00	1141,00	1003,00	994,00	1257,00	1231,00	549,00	1110,00	1311,00
2D Met_ShannonDivInd_LSC	2,4832	2,7025	2,3672	3,2216	2,9404	3,3762	2,7878	3,4333	2,7469	2,9046	1,9757	2,8106	2,3672
3D Met_ShannonDivInd_LSC	2,4829	2,7231	2,4047	3,2398	2,9628	3,3865	2,8032	3,4411	2,7466	2,9047	1,9996	2,8318	2,4047
2D Met_ShannonEvenInd_LSC	0,6644	0,6944	0,6115	0,7195	0,6876	0,7772	0,6380	0,7688	0,6824	0,7123	0,5557	0,6661	0,6115
3D Met_ShannonEvenInd_LSC	0,6643	0,6997	0,6212	0,7236	0,6928	0,7796	0,6415	0,7705	0,6823	0,7124	0,5624	0,6711	0,6212
2D Met_SimpsonDivInd_LSC	0,8838	0,9026	0,8277	0,9337	0,9101	0,9508	0,8983	0,9452	0,9013	0,9067	0,8051	0,8878	0,8277
3D Met_SimpsonDivInd_LSC	0,8839	0,9049	0,8373	0,9351	0,9119	0,9518	0,9009	0,9462	0,9013	0,9067	0,8086	0,8906	0,8373
2D Met_EffectiveMeshSize_LSC	6386324,59	4416584,37	7376060,43	795199,73	1204267,66	995949,98	3632484,40	2905357,08	3218919,20	2956715,43	4290210,97	5090375,16	7376060,43
3D Met_EffectiveMeshSize_LSC	6415045,76	4430565,32	7377231,76	811302,62	1205333,58	1054004,86	3727508,59	2908962,74	3232066,72	2959040,65	4277989,96	5073026,14	7377231,76
Avg. Roughness	3,9078	2,7566	1,8182	2,5502	2,5434	2,6603	2,9892	2,3410	1,8805	1,1140	1,9696	1,6474	1,8182
RMS Roughness	4,6198	3,2676	2,1866	3,0322	3,0252	3,1889	3,8107	2,7754	2,2249	1,3161	2,3476	1,9615	2,1866
Skewness	0,0138	0,0048	0,0047	-0,0075	-0,0460	-0,0074	-0,0069	0,0304	0,0598	-0,0222	-0,0472	-0,0151	0,0047
Kurtosis	1,6866	1,6737	1,4725	1,7241	1,6550	1,9564	1,9755	1,6576	1,6032	1,4632	1,8769	1,8159	1,4725

Table 2. Wilcoxon signed ranks statistics test.
Tableau 2. Wilcoxon signalee statistique.

Landscape Metrics 3D versus 2D	*Z*	Asymp. Sig. (two-tailed)
3D Met_Area_LSC - 2D Met_Area_LSC	–3.181[a]	0.001
3D Met_Perim_LSC - 2D Met_Perim_LSC	–3.181[a]	0.001
3D Met_Fract_LSC - 2D Met_Fract_LSC	–2.342[b]	0.019
3D Met_Ratio_LSC - 2D Met_Ratio_LSC	–3.181[b]	0.001
3D Met_Shape_LSC - 2D Met_Shape_LSC	–2.412[b]	0.016
3D Met_TEdge_LSC - 2D Met_TEdge_LSC	–3.181[a]	0.001
3D Met_EdgeD_LSC - 2D Met_EdgeD_LSC	–3.181[b]	0.001
3D Met_LPidx_LSC - 2D Met_LPidx_LSC	–3.041[b]	0.002
3D Met_PatchRD_LSC - 2D Met_PatchRD_LSC	–3.181[b]	0.001
3D Met_PatchNr_LSC - 2D Met_PatchNr_LSC	0.000[c]	1.000
3D Met_ShannonDivInd_LSC - 2D Met_ShannonDivInd_LSC	–2.831[a]	0.005
3D Met_ShannonEvenInd_LSC - 2D Met_ShannonEvenInd_LSC	–2.831[a]	0.005
3D Met_SimpsonDivInd_LSC - 2D Met_SimpsonDivInd_LSC	–3.041[a]	0.002
3D Met_EffectiveMeshSize_LSC - 2D Met_EffectiveMeshSize_LSC	–2.062[a]	0.039
3D Met_EdgeContrast_LSC - 2D Met_EdgeContrast_LSC	–2.552[a]	0.011

a. Based on negative ranks.
b. Based on positive ranks.
c. The sum of negative ranks equals the sum of positive ranks.

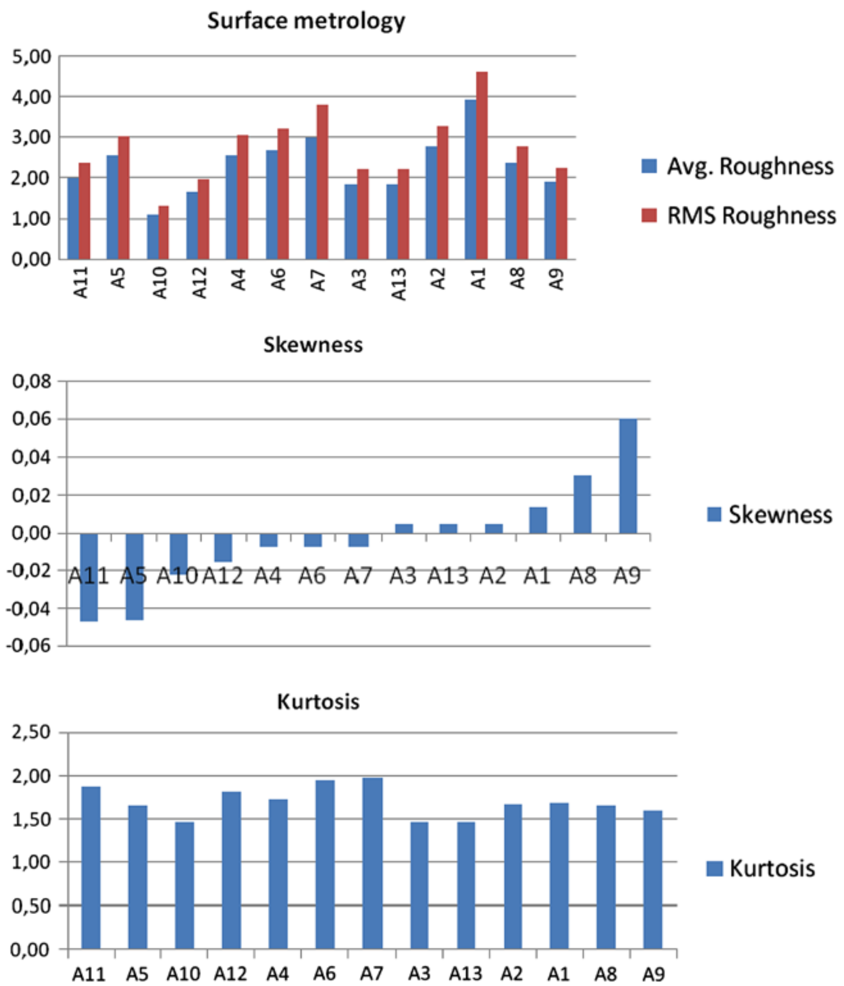

Figure 5. Surface metrology metrics in the 13 sample areas.
Figure 5. Surface métrologie métriques aux 13 zones d'échantillon.

of the sample standard deviation in statistical analysis. These two metrics provide information about the roughness of the terrain. Figure 5 shows that area 1 (A1 = 3.91 m) is the area that presents more roughness, and area 10

(A10 = 1.11 m) shows less roughness. All the remaining values varied between 1.5 and 3 m. Hence none of the present sample areas had high roughness, but they still presented significant differences between the metrics in 2D and 3D.

Skewness varied from – 0.05 (A11) to 0.06 (A9), but was very close to zero, which indicates a symmetrical shape for the surface height distribution on average. Skewness may be negative if the distribution has a longer tail at the lower side of the mean plane, or positive if the distribution has a longer tail at the upper side of the mean plane. As a consequence, it can give some indication of the existence of "spiky" features (Hoechstetter 2009).

Kurtosis varies between 1.46 (A3 and A13) and 1.98 (A9), which indicates a well spread distribution of the surface height, in every sample area.

Conclusion

This study supports the thesis that use of the third dimension can be important in landscape metrics calculations. The results achieved here reveal that all landscape metrics have significant differences when calculated in 3D instead of planimetrically. Only two of the studied metrics, FractDim and Shape, show almost no difference between 2D and 3D, but the Shape metric presents a very slight negative difference. These results agree partially with the results achieved by Hoechstetter (2009), but our sample areas have low roughness, symmetrical shape for the surface height distribution and well spread distribution of the surface height, which indicates that, even in areas with less relief, the use of the real surface metrics can make a difference in landscape analysis. LandMetrics-3D was shown to be a very useful tool for landscape analysis in 3D and should its development should continue.

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