Quantifying the changes in landscape configuration using open source GIS. Case study: Bistrita subcarpathian valley

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ABSTRACT

Gradually, the study of the landscape became a core topic of environmental studies, due to its interdisciplinary research methods, integrating both natural and socio-economic data. The goal of the study is to quantify the structural evolution of Bistrita subcarpathian valley landscape, by using several GIS applications, having an important role in highlighting its functionality. The applications were realized for the extended area limit of Bistrita subcarpathian valley, which presents a complex landscape morphology, with features ranging from forested mountains to densely populated lowlands. The analysis was based on the two land cover maps resulted from the extraction of the spatial layers from the 1986 cadastral plans, 1:10.000 scale, respectively the 2005/2006 ortophotomaps, 1:5.000 scale. For completing the study, were calculated for the two periods a series of specific indicators, called landscape metrics, which contain quantitative information about the structure and features of the landscape. The results of the analysis proved the utility of these indicators in quantifying the structural evolution of the landscape, and also highlighted the capabilities of using Open Source software for complex spatial analysis. This type of analysis has a great importance for the authorities and other decision making factors regarding the territorial planning processes.

Keywords: landscape metrics, Open Source GIS, Bistrita subcarpathian valley

INTRODUCTION

Interdisciplinary approaches to landscape assessment are an extremely important component of environmental issues modeling and, consequently, of sustainable development. Thus, in recent years, specific indicators whose understanding and application requires a multidisciplinary background have been widely introduced and used. Examples of such indicators are landscape metrics, which reveal quantitative information concerning the structure, the features and the functionality of landscapes [1]. The goal of these methods is to remove subjectivity and to create new possibilities to describe, analyze and compare different landscapes [2]. The results of these quantitative models are designed to bring the concept of landscape to the attention of the scientific community focusing on the possibilities of analysis and the utility of results.

The increasing evolution of Open Source softwares, especially in GIS field, lead to a proportional increase of advanced spatial analysis. Through this application we wanted on the one hand to demonstrate the capabilities of Open Source GIS to perform spatial quantitative analysis on the landscape morphology, and secondly to analyze the evolution of changes in landscape configuration emphasizing the quantitative, structural, but also functional aspects. The application was conducted for the extended area limit of Bistrita subcarpathian valley, a complex landscape with features ranging from forested mountains to densely populated terraces, located in the Eastern Romania.

DATA AND METHODS

The analysis aims to describe the geometric attributes of the landscape [3]. Choosing a method of analysis was difficult because there are many methods that address the quantitative analysis of landscape characteristics (ex: [4], [5], [6], [7], [3]). The methods chosen in applying the complex spatial analysis are conducted by landscape indices or landscape metrics, and zonal statistics. Although this type of analysis can be done in a variety of dedicated programs such as ArcGIS, LEAP II [8] or FRAGSTAT ([5], [7]), we chose to use the softwares QGIS and GRASS primarily because they are Open Source and provide various spatial analysis methods. The landscape indices that were calculated were made using the plug-in LeCos (Land Cover Statistics) belonging to the QGIS suite. Based on specific calculations, it identifies patches by class and calculates the landscape metrics. According to the creator of this plug-in, Martin Jung (Curlew), the user can choose to calculate individually or collectively the indicators of the classes converted into raster format. The spatial layers were produced using GRASS, using several dedicated modules and the interpreting operations and statistical analysis was carried out using QGIS.
The analysis was conducted using the two land cover maps resulted from the extraction of the spatial layers from the cadastral plans made in 1986, 1:10.000 scale, and the ortophotomaps from 2005/2006, 1:5.000 scale (fig. 1). Based on these two maps were compared the global indicators calculated for the study area, which contain features ranging from the mountains area to densely populated lowlands. The quantitative analysis was conducted from a evolutionary perspective, which allows to draw general conclusions regarding changes in landscape configuration.

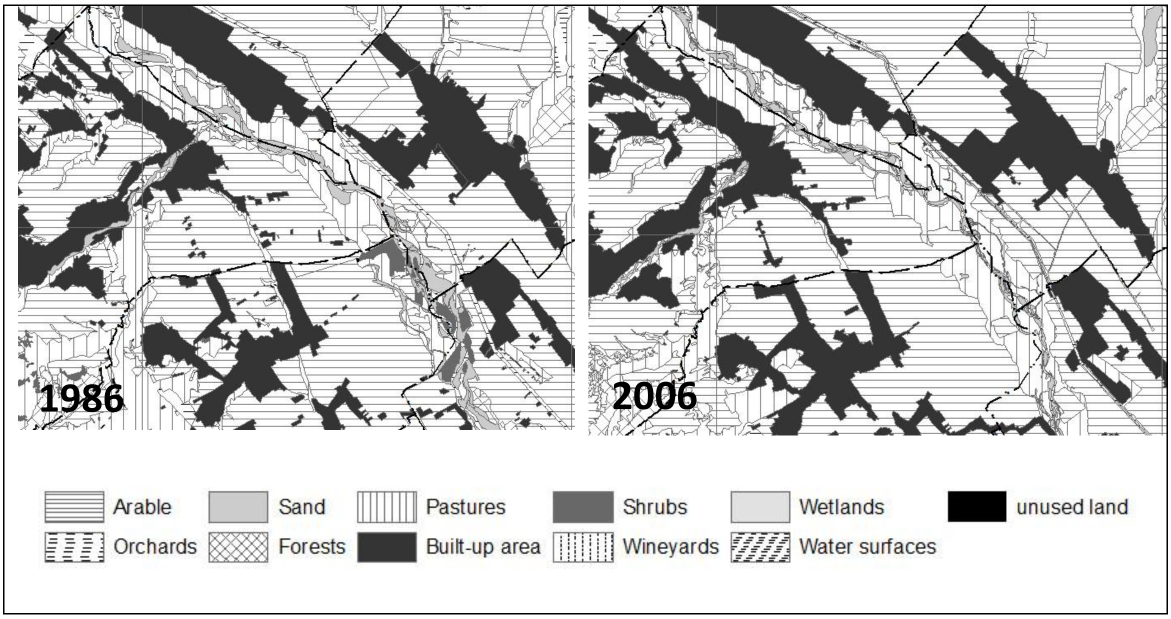


Fig. 1: Representative samples of land cover maps for 1986 and 2006

The first step of the landscape quantitative analysis was to convert the land cover vectors into raster format, with cell size chosen to be 5 meters. Next, we assigned to each class the same indicative for both periods. The land cover types were divided into 11 classes, numbered from 1 to 11 (tab. 1).

Tab. 1 – Land use classes and corresponding codes

Classes	CODE	Classes	CODE
Built-up area	1	Forests	7
Unused land	2	Shrubs	8
Arable	3	Sand	9
Vineyards	4	Wetland	10
Orchards	5	Water surfaces	11
Pastures	6		

RESULTS AND DISCUSSIONS

First, to get a general idea of the overall configuration of Bistrita subcarpathian valley landscape, were calculated several global indicators applied to the entire area. In order to characterize the diversity of the study area, we chose to highlight the diversity of global indicators, namely the Shannon Diversity Index (SHDI), Shannon Equitability (SHEI) or Simpson Diversity Index (SIDI).

Shannon Diversity Index expresses the proportional abundance of every patch of a certain type, multiplied by that proportion. When the landscape contains only a patch, SHDI is 0 denoting a lack of diversity. SHDI value increases with increasing number of patches of different types and the proportional distribution of each type of patch becomes equitable.

Simpson Diversity index has the same features as the Shannon index, but the results range from 0 to 1, when the diversity is higher. According to [7], the values of SIDI are less sensible to the presence of rare types, and its interpretation is more intuitive than Shannon's index. Specifically, SIDI values means the probability for two randomly selected pixels belong to different patches.

Shannon Evenness Index (Equitability) SHEI shows the distribution of the patches within the total area. SHEI = 0 when the landscape contains only one patch (no diversity) and approaches 0 once the distribution of different patches becomes increasingly unequal. In contrast, SHEI = 1 when the distribution of each class surfaces is equitable.

Tab. 2 – Evolution of landscape diversity indexes between 1986 and 2006

Year/Metrics	Values_1986	Values_2006
SHDI	*1.59*	*1.48*
SHEI	*0.66*	*0.62*
SIDI	*0.75*	*0.73*

Table 2 shows the values resulting from the calculation of global indexes performed for the two periods. In terms of diversity, there is a slight decrease of the values of the three indices (SHDI, SHEI, SIDI), as a result of the increase of some classes area reported to the general distribution of the landscape. The maps and the resulting diagrams show that the decrease of diversity values can be explained by an increase of forested areas due to local reforestation actions, but also due to the transition of significant shrub areas to forest category. Another reason, equally important, is the generally increase of built-up areas at the expense of arable land and pastures. However, the values of diversity and evenness remain relatively high, suggesting that the study area, which has favorable physical and geographical conditions, has a complex landscape with certain dominant types.

For a more complete analysis in terms of landscape configuration, features and functionality, we calculated a number of other landscape indexes that we considered to be representative (tab. 4, 5). Unlike diversity indexes, these other ones were applied to each class particularly. The table below (tab. 3) presents the indicators, the abbreviation used and a short description for each type.

Tab. 3 – Landscape metrics used in the analysis (references: [5]; [9]; [7]; 10])

Name	Abbreviation	Short description; Measure unit
Land cover (Total surface)	**LC**	Equals the number of cells for each class based on a classified land cover matrix. The resulting values were multiplied by the cell's value (in our case 5 meters); (*ha*).
Landscape proportion	**LP**	The proportion of the cells from a specific class of the total number of cells of the classified raster; (%).
Edge length	**EL**	Equals the total length of all patches from a specific class. The resulting values were, of course multiplied with the cell's value; (*m*).
Edge density	**ED**	The sum of the lengths of all edge segments involving the corresponding patch type, divided by the total landscape area; (*m/ha*)
Patch number	**NP**	Express the number of patches identified for each class; (*no.*).
Patch density	**PD**	Equals the number of patches of the corresponding patch type divided by total landscape area; (*no./100 ha*).
Greatest patch area	**GPA**	The patch that sums up the highest number of cells; at the end, for showing the exact area, the number is multiplied by the value of the cell; (*ha*).
Smallest patch area	**SPA**	The patch that sums up the smallest number of cells, the result being multiplied too; (*ha*).
Mean patch area	**MPA**	The patch that represents the average number of cells identified in the entire area; (*ha*).
Mean patch distance	**MPD**	Calculate the average Euclidean distance between all patches from the same class; (*m*).
Landscape division	**D**	The possibility that two cells, randomly chosen form the landscape, to be found in the same patch; ($0 \leq D < 1$).
Effective mesh size	**m**	the probability that two randomly chosen cells are connected (to be included into the same patch); (*ha*).
Splitting index	**S**	The number of patches one gets when dividing the total region into parts of equal size in such a way that this new configuration leads to the same degree of landscape division desired; (*nr.*).

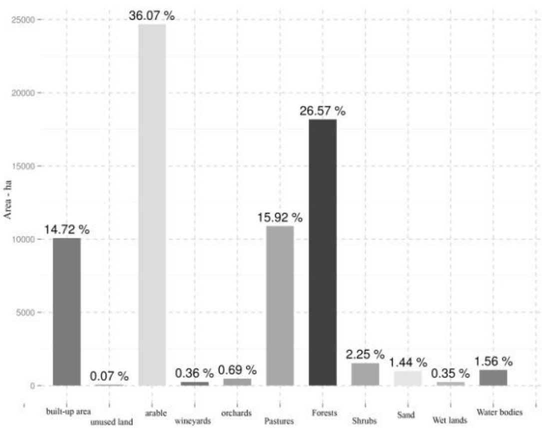
Tab. 4 – Landscape metrics computed for every patch type for 1986

1986 /Class	LC	LP	EL	ED	NP	PD	GPA	SPA	MPA	MPD	D	m	S
1	10068.64	14.72	1060400	15.50	436	0.637	1243.12	0.015	23.09	147.86	0.999046637	65.231	1048.92
2	51.235	0.07	28160	0.41	45	6.576	16.27	0.035	1.14	9.88	0.999999927	0.005	13734876.71
3	24677.3925	36.07	1805360	26.39	436	0.637	8340.21	0.0025	56.60	630.49	0.981705558	1251.734	54.66
4	248.84	0.36	117150	1.71	180	0.26	23.18	0.0025	1.38	61.41	0.999999607	0.027	2544943.36
5	472.2675	0.69	78790	1.15	52	7.6	80.88	0.0425	9.08	112.74	0.999995399	0.315	217336.99
6	10893.3275	15.92	2127950	31.10	546	0.798	2768.22	0.0025	19.95	922.63	0.998018464	135.580	504.65
7	18179.415	26.57	822960	12.03	125	0.183	8179.81	0.02	145.44	1308.58	0.981418174	1271.397	53.81
8	1536.745	2.25	473640	6.92	477	0.697	148.39	0.0025	3.22	449.32	0.999986935	0.894	76538.53
9	987.2025	1.44	312230	4.56	157	0.29	170.35	0.005	6.29	394.14	0.99999056	0.646	105931.07
10	242.01	0.35	37250	0.54	10	1.46	135.03	0.1675	24.20	105.43	0.999995549	0.305	224651.40
11	1064.445	1.56	438470	6.41	25	3.65	585.96	0.005	42.58	521.12	0.999915413	5.788	11822.15

Tab. 5 – Landscape metrics computed for every patch type for 1986

2006 /Class	LC	LP	EL	ED	NP	PD	GPA	SPA	MPA	MPD	D	m	S
1	11258	16.42	1038930	15.15	195	0.284	2138.91	0.0025	57.73	155.67	0.997777726	152.356	449.99
2	41	0.06	9700	0.14	6	87.5	15.85	1.185	6.86	6.06	0.999999913	0.006	11522413.55
3	24189	35.28	1545820	22.55	342	0.498	5292.19	0.0025	70.73	623.41	0.989778615	700.762	97.83
4	7	0.01	1320	0.02	1	14.6	6.52	6.52	6.52	2.12	0.999999991	0.001	110567136.1
5	477	0.70	58830	0.86	23	3.54	80.65	0.1675	20.73	99.66	0.999994827	0.355	193317.72
6	10800	15.75	2040620	29.76	384	0.56	2017.79	0.0025	28.13	913.46	0.998693512	89.571	765.41
7	20146	29.38	1177890	17.18	410	0.598	8472.60	0.0475	49.14	1374.71	0.978817237	1452.256	47.21
8	302	0.44	88920	1.30	33	4.81	67.01	0.2025	9.16	141.72	0.999997967	0.139	491945.71
9	601	0.88	239360	3.49	159	0.23	106.15	0.0025	3.78	288.48	0.999995483	0.310	221369.13
10	184	0.27	54410	0.79	65	9.48	86.75	0.0075	2.83	119.11	0.999998141	0.127	537798.39
11	554	0.81	397090	5.79	133	0.194	442.18	0.0025	4.17	372.51	0.999958051	2.876	23838.31

The role of the first indicator (*Total surface*) is to measure the landscape composition (structure), quantifying the abundance of each class, without any reference to the spatial arrangement. The second indicator, *landscape proportion*, equals the fraction of a certain class from the total analyzed area. This indicator is similar to the previous one, but the percentage expression makes it easier to interpret by the users. Regarding the evolution of the total area of the 11 land cover classes, one can observe significant changes over the analyzed period (fig. 2, 3), being highlighted the built-up area, arable land and also forests.



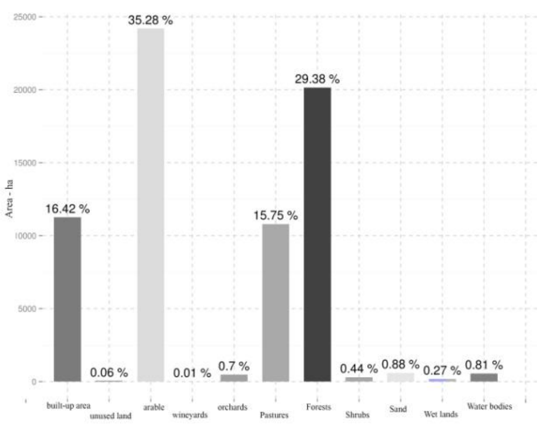


Fig. 2: Land cover classes - 1986 **Fig. 3: Land cover classes - 2006**

The *edge length* and *edge density* has the same utility for the quantitative interpretation of the landscape, except that the second one reports edge length on a per unit area basis that facilitates the comparison among different sized landscapes [7]. By the analysis of the tables can be observed a decrease of the two indexes values for most classes, suggesting a tendency of landscape homogenization.

Regarding the evolution of the *patch number* of each class can be noticed a significant decrease in built-up area values, from 436 to 195, which shows the agglutination of the isolated areas into larger residential areas. Also, the patch number of the arable land decreased from 436 to 342 following the tendency of association of the farmers during the last few years and hence, the transition from a subsistence agriculture to a more productive one. The same tendency can be observed in the case of grasslands, which have reduced the patch number from 546 to 384. The plots cultivated with vineyards and orchards suffered significant cuts, not due to the increase in their surfaces, but mainly due to their abolition in favor of arable land. A different situation is recorded for the forests class, whose patch number increased significantly. The explanation lies in afforestation works during recent years and the transformation of the shrubs into forests. These facts can be explained following also the values of edge density.

Edge density, with *patch number* and *patch density* are representative for establishing the *fragmentation degree* of the landscape. The values obtained for the fragmentation (NP and, consequently, PD and ED) reveal a decrease in the study area's fragmentation degree, inducing a clustering tendency [1]. The degree of landscape fragmentation is an important environmental indicator in the fields of biodiversity and sustainable development. In addition, information on the degree of landscape fragmentation is relevant in regional planning and for decisions about infrastructure placement or removal. Its analysis on different time series show how strong the current trends are and what their direction is [11].

The greatest patch area is related to the *degree of homogeneity* of the landscape. As can be seen from the table, the values for 1986 are directly proportional to 2006, indicating a certain stability. Therefore, can be noticed the built-up area, with 1243, respectively 2138 ha, arable land with 8340, respectively 5292 ha, or forests, with 8178, respectively 8472 ha. *Mean patch area* is also higher for the categories mentioned above, while the *smallest patch area* show quite low values, ranging from 0,0025 ha to 6,25 ha, which contributed to the landscape's fragmentation.

Calculating *mean patch distance* has an important role in determining the degree of their isolation in the landscape. The higher the resulting values are, the higher is the degree of isolation of a certain class with implications on functional relations of the system.

The last three indicators (D, M and S) are interconnected and measure the fragmentation degree of the landscape. These indicators were introduced by [9], as a result of the criticism over the simple measurements such patch number or patch density, which presents some limitations for certain phases of fragmentation process. According to [9], this suite of metrics derives from the cumulative distribution of the patches and provides a series of alternative measures and more explicit on the landscape's subdivisions. They have the advantage, unlike other conventional indicators, that any omissions or additions of other small sized patches does not influence the final result.

The values of *landscape division* may vary from 0 to 1, the value 0 being recorded when the landscape is represented by a single patch, approaching to 1 when each patch of the chosen class has an area of one cell. Because the raster was created on a 5 meters resolution, the values close to 1 of the D are explicable. However, one can clearly observe the variations of the indicator between the two intervals.

Although landscape division and Mesh are perfectly correlated, but inversely, both metrics are included because of the differences in units and interpretation. Split is based on the cumulative patch area distribution, and is interpreted as the effective mesh number, or number of patches with a constant patch size when the corresponding patch type is subdivided into S patches, where S is the value of the splitting index [7]. [9] defines the splitting index as the number of patches resulted after dividing the total area into equal size parts so that this new configuration leads to the same degree of landscape division (D). When its value is 1, the landscape is represented by a single patch, the value increasing as the landscape is divided into several patches. Considering these aspects, the results interpretation must take into account the correlation of these three complementary indicators.

The resulting values of the three indicators suggest different degrees of fragmentation for each class. Thus, the areas with a high degree of homogeneity are represented by arable land, forests and water bodies, having significant variations during the analyzed period. If arable land and water bodies records for 2006 a decrease of the MESH (m) index from 1251 ha to 5788 ha, to 700 ha, respectively 2876 ha, the forests keep the previously recorded trend, showing an increase of the index from 1271 ha, to 1452 ha, which indicates a slight increase in the degree of homogeneity. Of particular importance is class 1 (built-up area), which, in 2006 reduced its fragmentation degree due to a continued expansion of the constructed areas and by incorporating isolated constructions (MESH values increased from 65231 ha to 152356 ha). These facts can also be explained using the other two indicators, due to their complementarities.

CONCLUSIONS

In summary, one can say that landscape metrics vary with varying landscape attributes; correlate highly with one another and often provide redundant information—(which is not surprising, given they derive from a rather small set of possible attributes: area, border or edge length, distance, that one can measure), and relate differently according to the process under investigation. These results should not be surprising. The fragmentation of the landscape is a complex process that acts on a complex system and results in a wide arrangement of spatial patterns [10].

Altogether the results obtained in the study show the usefulness of global indicators in landscape change modeling and that this type of landscape analysis becomes increasingly important for the local actors, which must take decisions in agreement with the landscape potential of each region [1]. Regarding the study area landscape, there is a predominance of specific categories (built-up area or arable land), which have expanded over others, putting a high pressure over the natural conditions and local biodiversity.

The latest evolution of Open Source GIS software, especially of those who can offer integrated desktop solutions such as QGIS, had created many opportunities for the development of new tools for spatial analysis. Besides of numerous plug-ins designed to ease the work of the researchers one of the most prominent feature of QGIS is it's flexibility and capacity to interact with other packages, and by doing this the array of analyses that can be performed in spatial domain are limitless [12].

REFERENCES

[1] Pătru-Stupariu, I., Stupariu, M. S., Cuculici R. & Huzui, A. Application of the global indicators to landscape change modeling on Prahova Valley (Romanian Carpathians and Subcarpathians), International Journal of the Physical Sciences, vol. 6(3), pp. 534-539, 2011;

[2] Pătroescu, Maria, Toma, Simona, Sasaki, L. And Apostol, G. Priorities in the rehabilitation and re-naturation of rural landscape of the Roumanian Plain, southern Romania, Analele Universităţii Bucureşti – Geografie, XLIX, 2000;

[3] Farina A. Principles and methods in Landscape Ecology. Towards a Science of Landscape, Springer, 412 p, 2006;

[4] Turner M.G. & Garnder R.H. (edit.). Quantitative methods in landscape ecology, Springer, New York, 1991;

[5] McGarigal K. And Marks B. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-GTR-351. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA, 1995;

[6] Turner M., Gardner R., O'Neill R. Landscape Ecology in Theory and practice. Pattern and process, Springer, 403 p, 2001;

[7] McGarigal, K., SA Cushman, Mc Neel, & E Ene. - FRAGSTATS v3: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. http://www.umass.edu/landeco/research/fragstats/fragstats.html, 2002.;

[8] Perrera A.H., Baldwin D.J.B. And Schnekenburger F. LEAP II: A Landscape Ecological Analysis Package for Land Use Planners and Managers. Forest Research Report no. 146, Ontario, Canada, 1997;

[9] Jaeger J.A.G. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. Landscape ecology 15.2, pp. 115-130, 2000;

[10] Rutledge D. Landscape indices as measures of the effects of fragmentation: can pattern reflect process ?, Doc Science Internal Series 98, 27 p, 2003;

[11] Jaeger J.A.G., Esswein H., Schwarz-Von Raumer H.G. Measuring Landscape Fragmentation with the Effective Mesh Size meff, Zurich, http://gpe.concordia.ca/documents/faltblatt_engl.pdf, 2006;

[12] Roşca B., Chelaru D.-A., Pleşcan S. The Analysis Of Landscape Morphology In Lower Bistrita Valey Using Grass And Quantum Gis, 13th International Multidisciplinary Scientific GeoConference SGEM 2013, Conference Proceedings - Informatics, geoinformatics and remote sensing, pp. 951 – 959, 2013.