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Full Length Research Paper

Application of the global indicators to landscape change modeling on Prahova Valley (Romanian Carpathians and Subcarpathians)

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Interdisciplinary approaches to landscape assessment are an extremely important component of environmental issues modelling 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. The aim of the present study was to reveal the importance of global landscape metrics for monitoring the diversity, the fragmentation, the complexity and the homogeneity of a region. Based on 1970 maps and on 2009 satellite images, the values of seven global landscape metrics were computed for the mountainous and sub-mountainous region of the Prahova valley (Romania). The values highlighted the tendency of clustering and homogenization correlated with a decrease of shape complexity at landscape level. The information obtained can be useful both in landscape planning and habitat monitoring, as well as control of human intervention and anthropization.

Key words: Landscape metrics, fragmentation, diversity, homogeneity, complexity.

INTRODUCTION

Landscape is an interdisciplinary global concept, approached and interpreted through various methods specific to geographers, ecologists, biologists, architects, urban planners, landscape planners, agronomists, foresters, plastic artists and not least, by mathematicians and computer scientists. All this domains have mainly considered the spatial dimension of the landscape as well as its functional and esthetical dimensions (Tudora, 2009). Moreover, the latest legal regulations, particularly the European Landscape Convention, Florence 2000 (Council of Europe, 2000) have the role to direct and to encourage local actors to appropriate the “principles stipulated in the convention and proposes member states of the European council to acknowledge the landscape and to integrate it in the territorial planning, cultural, environmental, agricultural, social, economical politics” and other politics that can directly or indirectly influence the landscape. In the considered convention context, landscapes are “an essential component of people’s surroundings, an expression of the diversity of their shared cultural and natural heritage, and a foundation of their identity*”* (Council of Europe, 2000).

The main question is how much the different research areas intercede and which are the common methods that can be used to create *a* bridge in order to answer to the

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environmental issues (using landscape as an indicator in establishing the diagnostic, syntheresis and prognosis for the environment). It was already pointed out (Savard et al., 2000) that the study of landscape dynamics is an important step for understanding the changes occurred at the level of ecosystems, biogeochemical circuits and biodiversity. Another important issue is to identify the common methods which are relevant to territorial management and planning (landscape planning), or in enhancing the regional competitive potential through valorisation and capitalisation.

A possible answer in this direction is given by introducing and using specific indicators, such as landscape metrics (McGarigal and Marks, 1995; Botequilha, 2001; McGarigal et al., 2002; Botequilha et al., 2006; McGarigal et al., 2009). The role of landscape metrics is to highlight quantitative information regarding the landscape structure, characteristics and functionality. Landscape metrics are an important tool in characterising landscape attributes, in landscape classification or in emphasizing landscape changes and perturbations (Antrop and Eetvelde, 2000). Moreover, such indicators can be successfully used in landscape planning (Botequilha and Ahern, 2002). The application of this metrics extended concomitantly with the large scale use of geographical information systems and of techniques involving satellite images (Skupinski et al., 2009). This subject benefits from a very diverse bibliography and a brief historical presentation of the metrics' use, accompanied by other references can be found in Farina (2007).

The case study presented in this paper intends to apply the mentioned landscape evaluation methods for Prahova valley, a highly touristic region, situated in the mountainous and sub-mountainous sector of the Romanian Carpathians. Such methods were already applied in Romania, but for a hilly area (Schreiber et al., 2003), or for a limited sample of the Carpathians (Pătru-Stupariu et al., 2009). Practically, we intend to compute global indexes, in order to highlight a series of fundamental components in the landscape functionality: diversity, fragmentation, complexity and homogeneity.

Each of the four selected features has its own importance and relevance at the level of landscape unit. The landscape "diversity" derives from geo-diversity (the geological, relief, soil, climatic conditions) and from the anthropical component. In the study area, the two types can be clearly delimited, because the human pressure footprint has dissociated and influenced the landscape structure and configuration over time. Moreover, the diversity indexes were applied on a large scale in landscape ecology, in order to quantify a fundamental aspect of the binominal landscape structure-landscape composition (O'Neill et al., 1988). The second feature analyzed is the "fragmentation", since in landscape ecological investigation, much of the presumed importance of spatial pattern is related to edge effects (McGarigal et al., 2002). New landscapes derive from the profound changes in land use and land cover. These changes can induce a higher degree of fragmentation, such that different species would be unable to identify the limits of their original habitat. This landscape fragmentation needs to draw the attention of local actors and one has to investigate new habitat models. Another phenomenon that should be considered is related to the frontier's irregularity (complexity) between different fundamental territorial units. The frontiers with highly complex/simple shapes can be directly related to the increase/decrease in the landscape biodiversity. The relationship between patch size and patch form may influence animal foraging strategies (Forman and Godron, 1986). Finally, landscape "homogeneity" facilitates the delimitation and indication in the study area of habitats that have not been degraded yet. As habitat fragmentation proceeds, habitat contagion decreases, habitat subdivision increases and eventually ecological function is impaired (Saunders et al., 1991).

The global indexes are calculated for the entire landscape area, achieving a synthesis of the phenomena recorded at patch or class level. Our purpose is to highlight the way in which indexes reflect the landscape diagnosis of an area. The diagnosis can provide useful information for the authorities competent to manage this data base applicable in landscape planning (Council of Europe, 2010).

MATERIALS AND METHODS

The study area

The study area (Figure 1), with a total surface of 146.12 km^2, includes entirely the sub-mountainous area of Prahova valley, as well as its northern limit, located at the contact with the mountainous sector of the valley.

The Romanian scientist George Vâlsan, one of the first geographers who studied the Prahova valley (Vâlsan, 1939) identified the source of this river in the town of Predeal, in Braşov County. In subsequent studies (Velcea, 1965) several geological and morphological differentiations were noticed. Hence, in the mountainous region appear harder and older rocks (cretaceous limestones, conglomerates), while in the sub-Carpathian sector prevail younger and weaker rocks (Miocene, Pliocene - diorite sands, clays). The geodiversity of the area gives rise to different landforms (mountain ridges, hills, valley corridor) and hence to a heterogeneous and complex landscape.

Due to the relation between the country`s capital, Bucharest, and the town of Braşov, a prominent center in Transylvania, the Prahova valley underwent through the recent centuries a profound landscape dynamic. It encompasses the most impressive

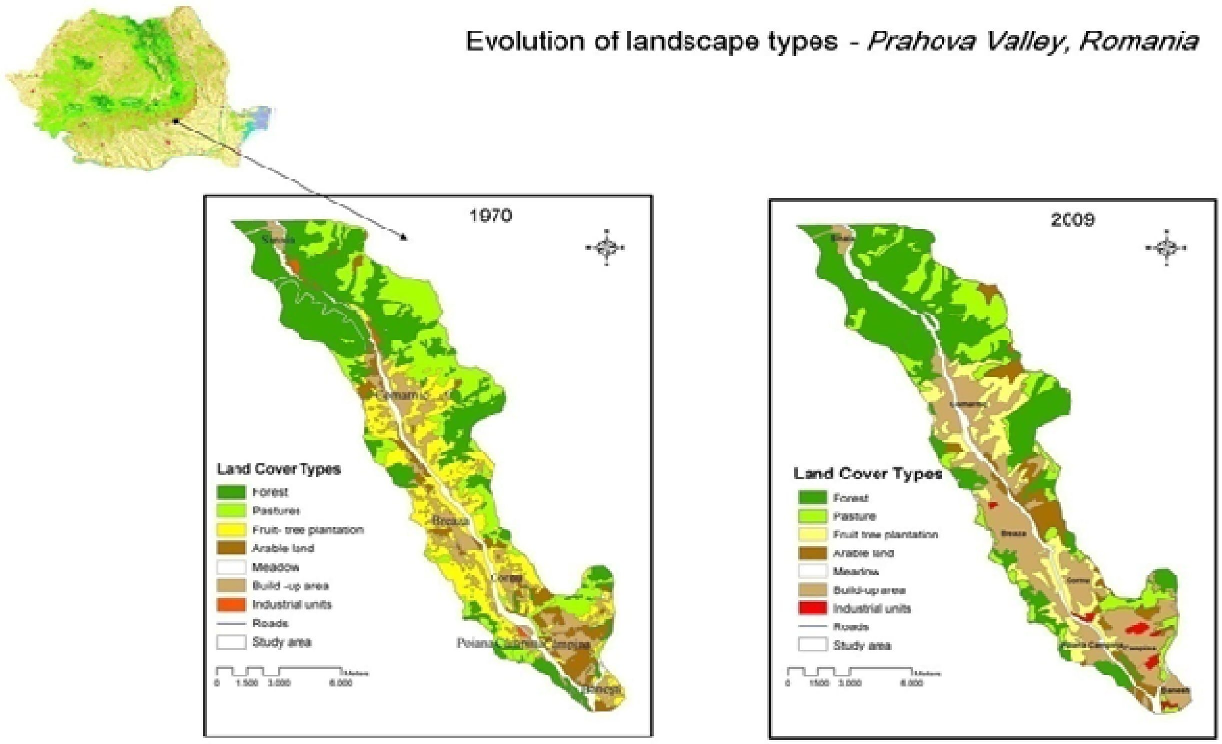

Figure 1. Location of the study area and land cover maps for the years 1970 and 2009.

humanization process of the country`s mountainous valleys; in less than fifty years gathering one of Europe`s most luxurious resorts. The upper sector of Prahova valley stands as a distinct discontinuity between the Eastern and the Southern Carpathians, including the most important resorts of the Romanian mountains that are exposed to high tourist pressures upon the infrastructure and the quality of both Bucegi Natural Park and Natural 2000 sites. The valley`s landscape in this section is dominated by the Bucegi mountains abrupt. Moreover, this section of the valley is developing the skiing infrastructure in order to reach the demands of the European Youth Olympic Festival that will be held in the Bucegi region in 2013. The passage to the plain is located in the proximity of the town of Comarnic, being realized through a specific sector, represented by the Southern Carpathians, which are very favourable to the extension of the residential space on large fluvial terraces that are located at medium heights of approximate 500 m, in a moderate climate. The middle sector of Prahova valley is heavily affected by slope and river processes that are main current issues in the territorial planning, especially related to intensive house building and high speed road construction. The plain sector becomes evident at south of the town of Campina, a representative center in the exploitation and the processing of petroleum. From the source to the confluence with Lalomița River, the Prahova valley covers 169 km that sustain the enhancement of territorial cohesion between localities of Prahova and Braşov counties.

The diversity and complexity of the landscape of the region, combined with its increasing dynamics define Prahova valley as a pole of attraction. It is thus necessary to use quantitative indicators which already showed their utility in previous studies (for example, landscape metrics), in order to assess the landscape character and functionality, respectively to make predictions concerning landscape evolution in Prahova valley.

Land-cover data and software

Taking into account the geographical description of the study area and the maps used, we identified the following seven land-cover types: forest, pastures, fruit-tree plantation, arable land, meadow, build-up area (rural and urban) and industry. These classes cover the whole study area and their limits were defined using both the ground reality and the data extracted from the digitization of the topographic support.

For the year 1970 we used maps at scale 1:50,000, acquired from ANCPI, which were scanned at 600 dpi. For the year 2009 we used satellite images at scale 1:21,000 (transformed at scale 1:50,000) with resolution 1200 dpi, achieved from Google Earth Pro. All these maps were geo-referenced using Image Analysis - *ArcGIS* software, version 9.3 (ESRI, 2008) in Stereo70 projection. In map production system we used geo-database, which included feature classes with different elements. Land cover type boundaries were digitized using the *ArcGIS* software, version 9.3. The software was equipped with a symbol library, which was necessary to represent all land-cover types. All vector files were verified by applying a set of rules provided by the software extension Topology. The vector files resulted by the digitization process were transformed into a raster format (grid image). The results were analyzed and processed with the software *FRAGSTATS,* version 3.3 (McGarigal et al., 2002).

Methodology – landscape metrics

The purpose of this section is to recall the definitions regarding the quantitative indicators used in the study. The following formulas and other commentaries related to their applicability and limitations can be found in McGarigal, Marks (1995), Botequilha Leitão et al. (2006) or in the complementary documentation to the *FRAGSTATS* software (McGarigal et al., 2002).

Diversity

We selected two global landscape metrics in order to characterise the area's diversity. The first one, Patch Richness (PR) is a fundamental indicator in determining an area's landscape diversity, representing the number of land cover type classes found in the given area. The second considered landscape metrics is Simpson's diversity index (SIDI), defined by the following relation: $SIDI = 1 - \sum_{i=1}^{PR} P_i^2$, (McGarigal et al., 2002), where $P_i = AREA_i/AREA$ is the fraction of terrain representing the land cover type *i* (we denoted by $AREA$ the total surface of the area and by $AREA_i$ the surface occupied by the *i* type class). If the area contains only one class (and consequently only one patch), meaning that there is no diversity, the value of this index is equal to 0. The more increases the area diversity (in regard to the land cover types and their distribution), the more this diversity index is close to 1. In fact, $SIDI$ represents the probability that two randomly selected pixels could belong to different class types (McGarigal et al., 2002). Although not spatially explicit, it still has important spatial effects (Gustafson, 1998).

Fragmentation

An elementary indicator of any landscape area is number of patches (NP), yielding a first information on the area's fragmentation. On the other hand, this indicator must be correlated with the total surface of the study area. Thereby, in reference to the landscape area's functionality and in order to analyse the processes which undergo in its interior, it is recommended to calculate certain density indicators, like patch density (PD), determined by the relation $PD = NP/AREA$ and edge density (ED), defined through the following formula $ED = E/AREA,$ where *E* represents the total frontier length (consisting in edges that separate different patches), hereby indicating the number of boundaries per area unit (McGarigal et al., 2002).

Homogeneity

One of the global landscape metrics which quantifies the homogeneity degree of a landscape area is contagion (*CONTAG),* indicating the predilection of different land cover types to group or disperse in smaller fragments. This index is defined by the following formula (McGarigal et al., 2002):

$$CONTAG = 1 + \frac{\sum_{i=1}^{PR}\sum_{j=1}^{PR}\left[P_i P_{ij} \ln(P_i P_{ij})\right]}{2\ \ln PR}.$$

In this relation, P_i is the fraction of terrain occupied by the land cover type *i,* and $P_{ij} = (g_{ij})/(\sum_{j=1}^{PR} g_{ij})$, where g_{ij} represents the number of adjacencies between pixels of type *i* pixels and those of type *j*, based on the double-count method. The range of this index is the interval (0, 1), a higher degree of aggregation between different patches determining a higher value for this index.

Complexity

A global indicator used in the complexity characterisation of the landscape area is Perimeter-Area fractal dimension (PAFRAC). It indicates how 'far' is the study area from the Euclidian geometry, in the sense of the increase of patch shape complexity. The range of PAFRAC is, theoretically, the interval (1,2), its value becoming higher for an increased patch frontier complexity. It has to be mentioned that this index was defined using regression techniques and its use is not recommended in the case of an area with a low number of patches (if $NP < 10$). The calculation formula for PAFRAC is (McGarigal et al., 2002):

$$PAFRAC = \frac{2\left[\left(NP\sum_{k=1}^{NP}\ln {p_k}^2\right) - \left(\sum_{k=1}^{NP}\ln p_k\right)^2\right]}{\left[NP\sum_{k=1}^{NP}(\ln p_k \cdot \ln a_k)\right] - \left[\left(\sum_{k=1}^{NP}\ln p_k\right)\cdot\left(\sum_{k=1}^{NP}\ln a_k\right)\right]},$$

where p_k and a_k represent the perimeter, respectively the area of the patch *k,* and *NP* is the number of patches.

RESULTS AND DISCUSSION

In Table 1 we presented the global indexes values, calculated for the study area at the level of the years 1970 and 2009. Concerning the diversity, a consistency in the number of land cover classes is registered, doubled by a decrease in the value of Simpson diversity index (SIDI). Taking into consideration the calculation formula for this index, it can be concluded that the surface occupied by one (or more) cover classes increased in the general surface distribution. In this respect, both the maps realised for the given area (Figure 1) and the historical realities confirm this conclusion. First of all it concerns the increase of forest surfaces, due to the forestation politics. Secondly it refers to the increase of build-up surfaces. This fact is related to the urban developments registered after the 1989 political changes (the emergence of new residential zones, of new tourist facilities, etc.).

Table 1. Global indices (patch richness, Simpson diversity index, number of patches, patch density, edge density, Contagion and perimeter-area fractal dimension) for Prahova valley, computed for the years 1970 and 2009.

Year/ Metric	1970	2009
PR	7	7
SIDI	0.7877	0.7689
NP	288	226
PD	1.9821	1.5535
ED	36.7955	23.0567
CONTAG	0.5557	0.5700
PAFRAC	1.3239	1.2068

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. This fact is actually related to the aforementioned phenomena: forestation and extension of the urban zones. Therefore, certain isolated construction zones were included in larger residential areas, and through forestation, detached clumps were connected to larger forested areas.

Subsequently we analysed the values of CONTAG homogeneity characterisation index. A first remark is that the values obtained for 1970 and 2009 are close to each other, indicating stability with respect to this characteristic. The tendency of this index, in the analysed period, reflects an increase that indicates the predilection for grouping and aggregating of different landscape units. After analysing the land cover maps, one can affirm that the land cover types with the highest degree of anthropization are those who impose the tendency towards homogenisation.

The last analysed metric, PAFRAC, indicated a decrease in the landscape complexity. This phenomenon can be, theoretically, explained through the landscape anthropization that leads to creating contours with a greater regular shape. In order to have a better understanding of the evolution of landscape complexity and since this landscape characteristic is less visual, we computed PAFRAC for each land cover type (Figure 2). The formula used for PAFRAC at class level is similar to that one used at landscape level. For classes with less than 10 patches, we replaced PAFRAC by the average value of Fractal dimension index (FRAC). The values obtained at class level confirmed the decrease in shape complexity for most land cover types. It is, however, surprising to notice that PAFRAC increased for the build-up area. This shows that the extension of the build-up area and its clustering tendency is not associated with a more regular spatial structure.

Conclusion

Considering the performed analyses, we can formulate two major conclusions:

The first conclusion has a general character and proves that the considered global indexes give an articulated image upon the landscape transformations underwent by an area. These global indexes are correlated and complete each over. Moreover, they support the identification of phenomena, independently from the map analysis or the terrain study; furthermore they can be used in landscape analysis and territorial planning.

The second conclusion regards the specific values obtained for the study area. It can be observed that a tendency toward the terrain 'monopolisation' by certain landscape types (forest, build-up areas) that can have both positive and negative effects. The positive effects regard a relative stability and the clear delineation of the two landscape types (natural- represented particularly by forests and anthropic).

Regarding the negative effects, we mention the decrease of landscape naturality degree and the decrease of its biodiversity. Another negative aspect is the fact that the extension of the build-up area was not correlated with the terrain's support capacity, yielding a chaotic character to the anthropized areas. This shows that the local authorities have to pay an increased attention to the preparation of the territorial development plans and they must check that these plans are respected.

Explicitly, one must control the development of the build-up area such that landscape biodiversity is preserved. This control is absolutely necessary, since the study area includes an important part of a natural reservation (Bucegi Natural Park).

Altogether the results obtained in the study show the usefulness of global indicators in landscape change modelling 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.

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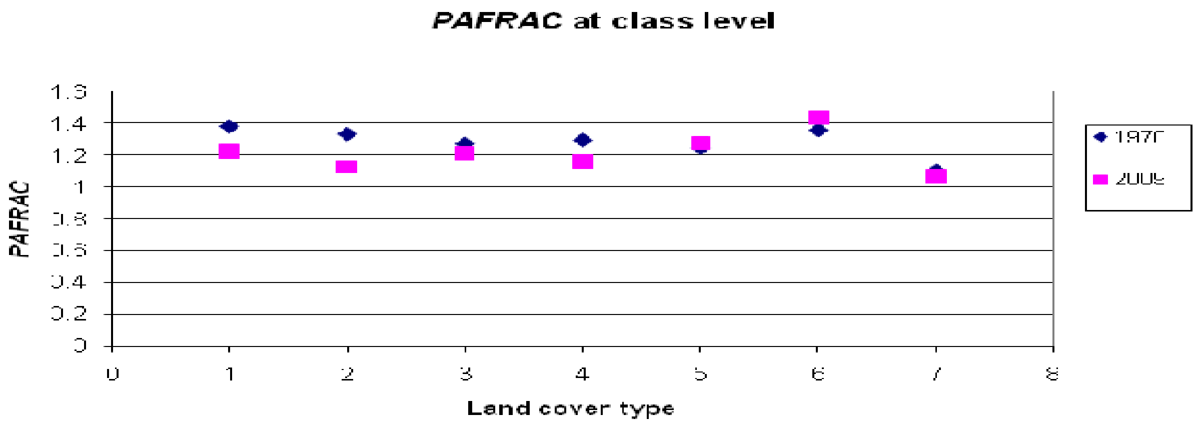

Figure 2. Perimeter-Area fractal dimension at class level (1 = forest, 2 = pastures, 3 = fruit tree plantation, 4 = arable land, 5 = meadow, 6 = build-up area, 7= industry).

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