COMPLEMENTARITY OF FRACTAL ANALYSIS AND GIS METHODS IN THE ANALYSIS OF THE SPATIAL-TEMPORAL DYNAMICS OF THE FOREST FUND

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Adrian Gabriel Simion[1,2]
Cristian Constantin Drăghici[1,2]
Ion Andronache[1,2]
Karina Andreea Gruia[1,2]
Alexandra Grecu[1,2]
[1] University of Bucharest – Faculty of Geography, Bucharest, **Romania**.
[2] Research Centre for Integrated Analysis and Territorial Management, Bucharest, **Romania**.

ABSTRACT

Forest is an important component of the ecosystem, which has been under increasing pressure in recent decades to provide raw material to emerging industries. Under these circumstances, it is necessary to develop methodologies for assessing the economic pressure on forest resources. In order to be able to assess forestry changes at regional level, a complex methodological approach is required, which implies GIS-based methods for obtaining quantitative information and fractal analysis, in order to obtain qualitative information. Applying GIS methods was designed to extract information on the spatial dynamics of the forest fund from post-processed satellite imagery and to obtain the basis of the fractal analysis. However, in order to obtain qualitative information about the degree of homogeneity / heterogeneity, fragmentation / compacting, anisotropy / isotropy and complexity of the deforested forest areas, a non-Euclidean complex analysis was applied based on the fractal analysis methods. It has been identified that in the years with very intense deforestation (2001, 2014 and 2016) the largest increases in the degree of complexity, heterogeneity, anisotropy, but insignificant increases of the fragmentation of the forest areas occurred. In antithesis, the years with low deforestation (2002, 2003 and 2005) were characterized by the smallest increases in complexity and heterogeneity (close to 0), decreases in anisotropy, but more pronounced increases in forest fragmentation. Thus, we have shown that the fractal methodology along with the GIS is very useful and provides additional information on forest dynamics.

Keywords: Forest dynamics, deforestation, fractal analysis, fragmentation, GIS.

INTRODUCTION

The economic pressure on the forest fund is one of the most interesting contemporary issues, causing imbalances at the territorial level. Among the important causes that have led to this evolution, are the change of the land use category and especially the conversion of the areas occupied with forests into agricultural areas [1]. A direct consequence of this situation is the change in the concentration of CO2 in the atmosphere and the acidity of ocean water [2], [3] with a negative global impact [4].
Another change generated by deforestation is acceleration of soil erosion [3], [5], [6]. Thus, it has been shown that the rate of erosion increases in areas where the forest has been replaced with agricultural plantations, especially if there is a high degree of declivity

and climatic conditions favorable to precipitation [7], [8], [9], [10]. Fighting these changes, with negative effect on the ecosystems, can be achieved by two ways: increasing the surface of forested and deforested areas [11], [12], [13]. The first refers to the activity that transforms a non-forestry into a forest, and the second defines a terrestrial area that had forests in the past.

At both global and European Union level, the protection and monitoring of the evolution of forest areas has become an important objective [14], which is necessary in the context presented previously. The most efficient way to track the spatial and temporal evolution of the forest fund is by using remote sensing and GIS by providing and interpreting satellite images [15], [16], [17], [18], [19]. Globally, this is done by the FAO (Food and Agriculture Organization of the United Nations) through its Forest Resources Assessment (FRA-FAO) report, which also monitors the evolution of forest areas through a Global Remote Sensing Survey (RSS), the purpose of which is to observe the forested and deforested areas [20].

Another method by which we can obtain additional data on the spatio-temporal changes occurring at the level of the forest areas, is the fractal analysis. This method gives us data on the degree of fragmentation of forest areas and their evolution by quantifying how much space is occupied by tracking the irregularity and texture of these surfaces. The most known methods that can help us estimate the fractal dimension of an object are: box-counting [21], information dimension [22] mass-radius [23], dividers [24], Bouligand-Minkowski approach [25] and can be added a lacunarity method that complements the fractal dimension by quantifying how space is occupied by the forestry area.

In this study we have proposed the development of methodologies to monitor the spatial and temporal changes suffered by forest areas as a result of anthropogenic economic pressures. In particular, these fractal analysis offers useful information on the degree of homogeneity and heterogeneity, fragmentation and compaction, and the complexity of a forest area, contributing to a better assessment of the size and impact of the deforestation phenomenon.

METHODS

The area of study we have chosen includes the Retezat-Godeanu Mountains Group, which is part of the Meridional Carpathians, the highest Carpathian sector in Romania. The Retezat-Godeanu Group sit between Jiu River Valley (East), Timis-Cerna (North) and Mehedinţi Plateau, Getic Sub-Carpathians (South) [26]. From an administrative point of view, it intersects with 4 counties, Hunedoara County, Gorj County, Mehedinţi County and Caras Severin County (Figure 1).

Image processing

In this material, the used forest data is distributed by the Department of Geographic Science, Maryland University, and comes from Landsat images. The dataset provided, is an analysis that highlights in particular forest losses for each year, the analysis being reported to 2000. From the Global Forest Change database, the images related to Romania were downloaded in GeoTIFF format, with a spatial resolution of approximately 30m. The downloaded images containing the forest fund in 2000, two images containing the differences in the forest fund, one showing forest loss for each year between 2000 and 2017. The image with forest loss was classified into the 17 values it contains, from 1-17, each value corresponding to one year in the period 2001-2017. Finally, 17 TIFF images were used to apply fractal methods. [15].

The initial image processing was done with QuantumGIS software and aimed at obtaining a forest loss area for the analyzed study area and preparing the fractal analysis images. Preparing the images implied choosing a template for each of the 10 mountain groups, and the use of important rules such as preserving the same position in the templates, maintaining the same chromatics of the objects in the image and the same display scale. The resolution of all the analyzed images was 3020 * 2298 pixels, being also very important for the analysis. The images were binarized in IQM 3.5 open source software [27] using the 1-255 threshold for fractal analysis.

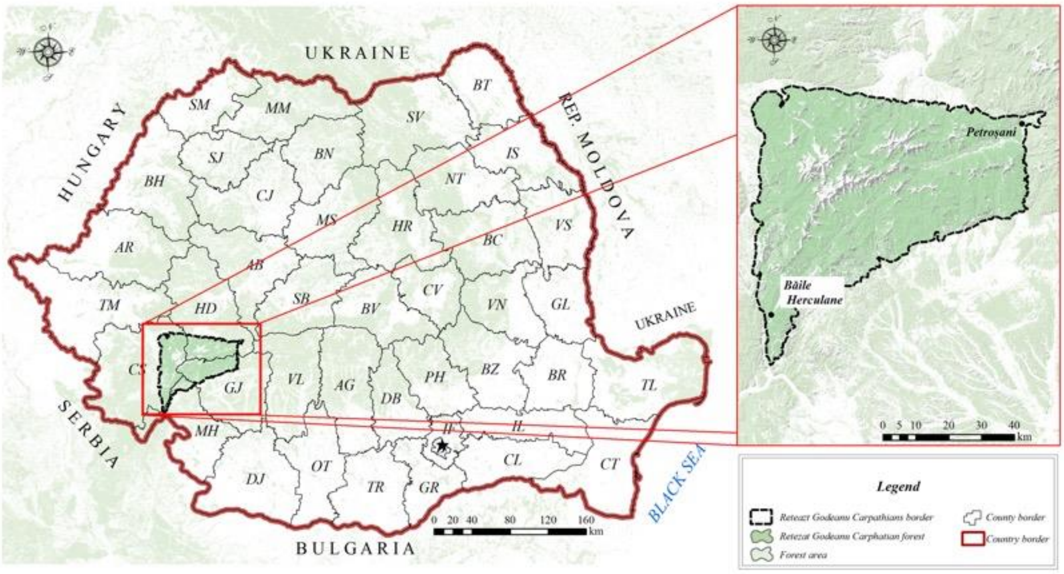


Figure 1. Study area

Fractal Analysis

In fractal analysis, four fractal analysis methods were used to monitor forest dynamics.

Kolmogorov Complexity (KC)

The Kolmogorov complexity of a fractal object, represents the length of the shortest computer program in Kilobytes (Kb), in a predetermined programming language, which produces the fractal object as output. The complexity of Kolmogorov is a measure of the computational resources needed to specify the object, and is also known as the algorithmic entropy [28]. The more complexity of an image increases (the image is more fragmented as a distribution of grayscale, more irregular), the more the fractal dimension KC increases and vice versa. In the case of forest dynamics, the higher the degree of disorder and fragmentation of the forest is, the degree of complexity increases.

Fixed Grid 2D Lacunarity (Box-Counting)

To determine the heterogeneity of gaps in a fractal image such as images containing forest images, we applied the Fixed Grid 2D Lacunarity (FG2DL) algorithm. Lacunarity completes the fractal dimension with its ability to quantify how space is occupied [29]. The FG 2DL algorithm measures the degree of heterogeneity / homogeneity of a fractal image by analyzing how pixels are placed and they are calculated using the equation:

$$\Lambda = (CV_{\Lambda})^2 \quad (1)$$

where CV_{Λ} is the coefficient of variation

The more the forest will be heterogeneous, the value of the lacunarity will increase, and the more homogeneous the forests will be, the value of the lacunarity will decrease [30].

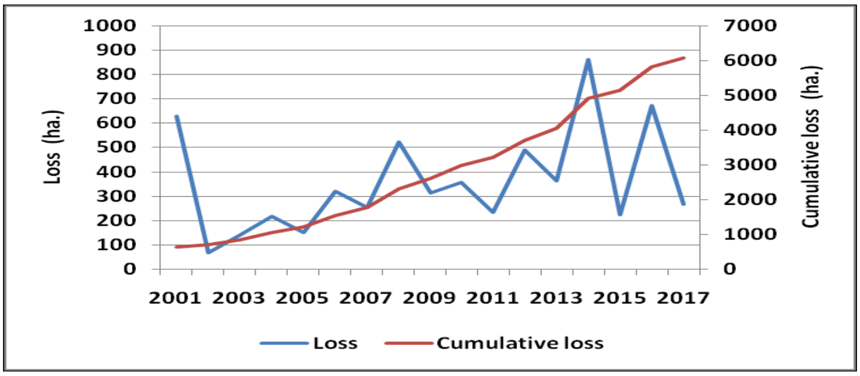
Fractal Fragmentation Index

To identify or quantify the degree of fragmentation of forest areas, we applied the Fractal Fragmentation Index (FFI) [31]. It can also be interpreted as a compaction index and represents the difference between the fractal dimension of the areas and perimeters. The more the forest areas are fragmented, the fractal dimension of the area is more close to the fractal dimension of the perimeters. The more compact the forest is, the difference between the two increases.

RESULTS

Spatio-temporal evolution of treecover, loss and gain areas

The dynamics of the forest area of the Retezat-Godeanu Group shows a general tendency of decrease due to both legal and illegal exploitation, generated both by the economic and legislative changes in the field that took place during the analyzed period. (Figure 1).



Graphic 1. Evolution of treecover and loss areas in Retezat-Godeanu Group, 2001-2017.

In total, 4,254.8 ha were deforested, the forest area increasing for the period 2001-2017 only by 1.3%, the regenerated area was 2,835.4 ha, the deficit being 33.3% (Figure 2.).

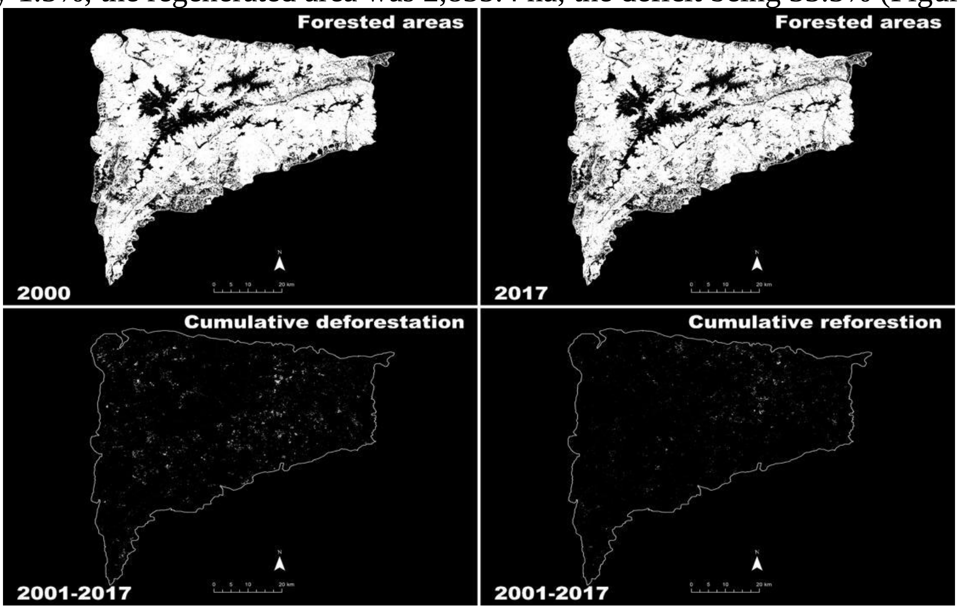


Figure 2. Spatial distribution of treecover, loss and gain areas over the period 2001-2017 in the Retezat-Godeanu Group (a = treecover areas 2000; c = loss areas 2001-2017; d = gain areas 2001-2017).

Fractal analysis of the treecover, loss and gain areas

Fractal analysis of cumulative loss has revealed that, as the loss areas increases, the complexity of spatial distribution and compaction also increase, but the heterogeneity decreases. The reason is that a significant part of the new loss patches is made in the continuation of the old loss patches.

Figure 4 summarizes the results of the four fractal analyzes. The analysis of these results is as follows:

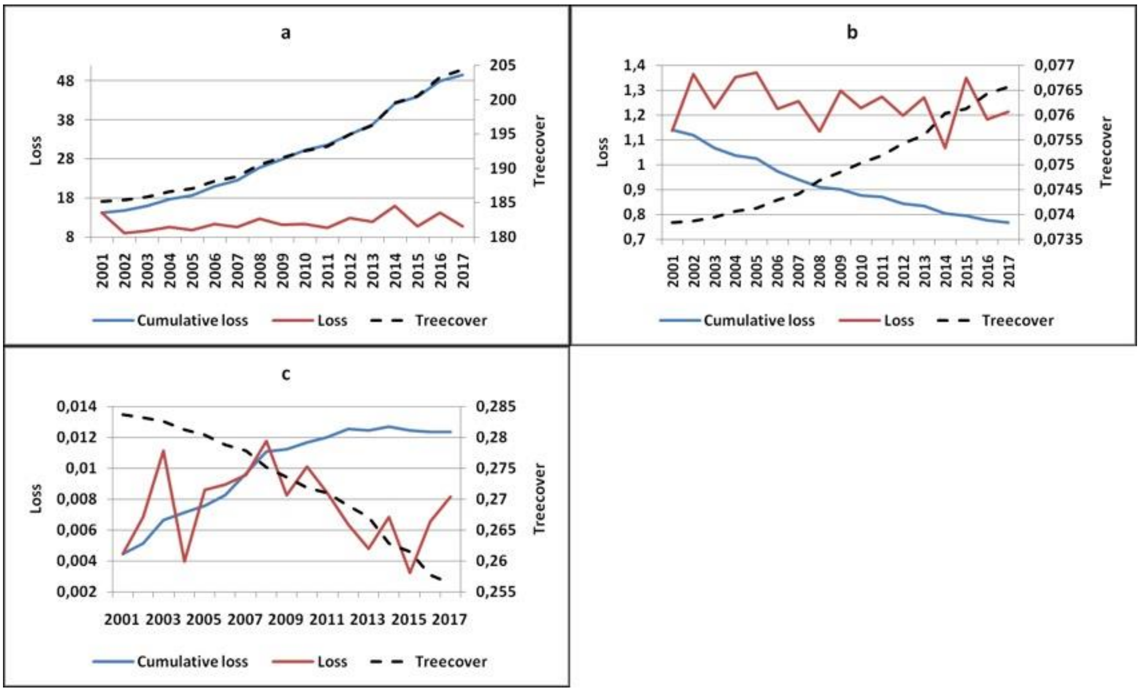


Figure 4. Dinamica a. Kolmogorov Complexity, b. FG2DL; c. FFI

CONCLUSIONS

The spatial and temporal analysis of forest areas is particularly important because the changes taking place in this area can have negative effects both in terms of biodiversity and economics. In this context, it becomes vital to identify the underlying causes of such change in order to be able to intervene effectively through management plans adapted to changes at the territorial level.

The tracking of these spatio-temporal changes in forest areas can be achieved through fractal analysis, a field that provides valuable information that can be used in the development of specific management plans. In this study, by analyzing the fractal indices, we differentiate the dynamics of the loss areas and their implications on the treecover characteristics.

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