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# Fractal analysis for studying the evolution of forests

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ABSTRACT

Deforestation is an important phenomenon that may create major imbalances in ecosystems. In this study we propose a new mathematical analysis of the forest area dynamic, enabling qualitative as well as quantitative statements and results. Fractal dimensions of the area and the perimeter of a forest were determined using digital images. The difference between fractal dimensions of the area and the perimeter images turned out to be a crucial quantitative parameter. Accordingly, we propose a new fractal fragmentation index, *FFI*, which is based on this difference and which highlights the degree of compaction or non-compaction of the forest area in order to interpret geographic features. Particularly, this method was applied to forests, where large areas have been legally or illegally deforested. However, these methods can easily be used for other ecological or geographical investigations based on digital images, including deforestation of rainforests.

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## 1. Introduction

Geographical forms are complex, often described as serpentines, growing bacteria, spiders, twisted-corner shapes or as DNA fragments [25]. Geography was one of the first areas that adopted the fractal theory which was applied for analyzing the shoreline, the land relief appearance [2,12,28], the appearance of clouds, river basins, and also in the analysis of distribution curves of climatic or hydrologic parameters [1].

The purpose of this article is to develop a robust research method addressing the dynamics, fragmentation and complexity of the forested, cleared and regenerated areas, based on fractal analysis and lacunarity that can alert the forestry management of deforestation and provide an effective model for the control of deforestation and sustainable management.

The analysis of the deforestation progression, particularly within the North-East Development Region in Romania and the reasons of this progression become important for the development and maintenance of sustainable, self-reliant local communities [5,8,17,18,30,31].

Currently, the north-east area of Romania is subject to increasing pressure from socio-economic factors, materialized by the increasing of legally and illegally deforested areas. In this context the study of the dynamics of the forest areas plays a key role in developing and implementing strategies to ensure better forest monitoring and management that can be adapted to other areas worldwide where there is a logging industry [13,16].

## 2. Materials and methods

The research was conducted in the North Eastern-Development Region where large areas of forest were cleared due to local economic pressures (Fig. 1). The North-Eastern Development Region was created in 1998 and is one of eight regions in Romania consisting of six counties (Botosani, Bacau, Iasi, Neamt, Suceava and Botosani). The main governmental intention was to coordinate the regional development process in Romania, as this was one of the main conditions for Romania to become part of the European Union.

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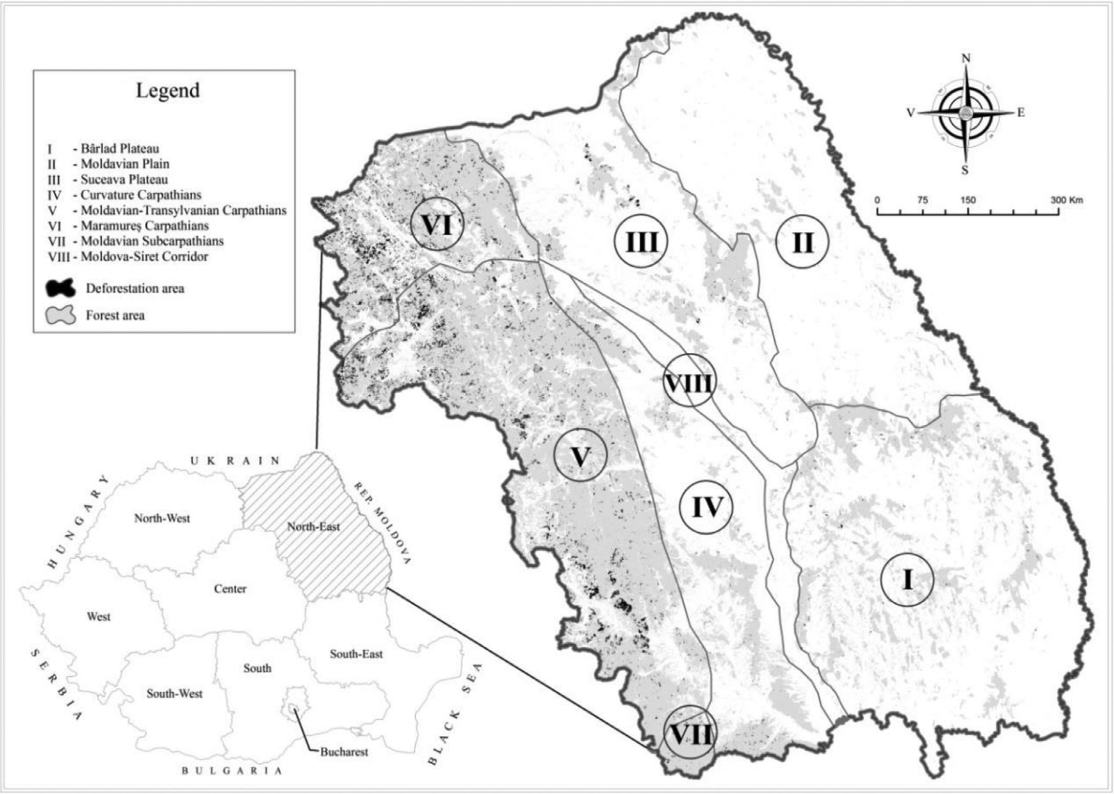

**Fig. 1.** North Eastern-Development Region.

Digital images were obtained from the Global Forest Change 2000–2012 database tendered by the Department of Geographical Sciences, Maryland University. This database is the result of analyzing globally 654,178 Landsat 7 ETM + images of forest areas during 2000–2012 [7]. The images had a resolution of 1642 × 860 pixels and were stored in uncompressed tiff format.

The color digital images of the forested, deforested and regenerated areas (corresponding to a 1:550,000 scale), were segmented using the ImageJ 1.49t: Color Deconvolution plugin - vector H&E DAB [24] and converted to binary images for fractal dimension analysis using ImageJ 1.49t [23] and IQM 3.2 [9].

In order to determine the fractal dimension of the perimeters, the contour of each image was extracted, resized and converted to a single pixel outline (ImageJ – Process – Binary – Outline). One pixel was equal to 147.06 m (6.8 pixels at 1000 m).

Box counting was used for determining the fractal dimension both of areas and of perimeters [1,14]. Box counting fractal dimension of areas consists of determining the number of N ($\varepsilon$) cells required to cover the structure to be measured, depending on the size $\varepsilon$ of these cells. For different values of the cell size $\varepsilon$, cells that cover the figure are counted. Then they are represented in logarithmic coordinates log N = f (log $\varepsilon$). Finally, the slope of a linear regression is an estimate of the fractal dimension. The mathematical expression for areas is:

$$D_A = \lim_{\varepsilon \to 0} \left( \frac{\log N(\varepsilon)}{\log \frac{1}{\varepsilon}} \right), \tag{1}$$

where $D_A$ is the box-counting fractal dimension of the area, $\varepsilon$ the side length of the box, and $N$ ($\varepsilon$) the number of contiguous and non-overlapping boxes required to cover the area of the object [4,25].

$D_A$ measures the degree of mass concentration across the scales. If $D_A = 0$, the mass concentration is a single point. If $0 \langle D_A \rangle 0.5$, the mass concentration is scattered in several isolated points, such as a Fournier dust. If $0.5 \langle D_A \rangle 1$, the mass concentration consists of unconnected elements and/or detached clusters. If $1 < D_A > 2$, the mass concentration consists of a mix of connected and unconnected elements and if $D_{A}. \approx 2$, the mass concentration is a single cluster. In conclusion, high values of $D_A$ indicate homogenous and dense forest patterns and low values of $D_A$ indicate fragmented forest patterns concentrated in multi-scale clusters.

For perimeters the mathematical expression is similarly:

$$D_P = \lim_{\varepsilon \to 0} \left( \frac{\log N'(\varepsilon)}{\log \frac{1}{\varepsilon}} \right), \tag{2}$$

where $D_P$ is the box-counting fractal dimension of the perimeter, $\varepsilon$ again the side length of the box, and $N'(\varepsilon)$ the number of contiguous and non-overlapping boxes required covering just the perimeter of the object.

$D_P$ measures the degree of tortuosity of the perimeters and generally, the values are smaller than the values of $D_A$. If $D_P > 1$, the shapes of the perimeters are very twisted and tortuous. If $D_P \approx 1$, the perimeters are nearly linear and if $D_P = 1$, the perimeters are linear.

As the zero limits cannot be applied to digital images, $D_A$ and $D_P$ were estimated by the slope of a double logarithmic plot [4].

For forest areas, the fractal dimension may range from 0 (when the forest or fractions of the forest are equivalent to one pixel) to 2 (when the area has a perfect geometrical shape and is fully occupied).

The minimum area extracted from the tiff images for the counties of the North-East Development Region was 0.022 km$^2$ and corresponded to a perimeter of 0.416 km (1 pixel at 1:550,000).

As natural objects, represented in digital images, cannot be treated as mathematically exact fractals, the estimations of fractal dimensions are always limited and may be prone to some errors. Particularly for this study, two possible limitations are the

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