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Chapter

Use of Fractal Analysis in the Evaluation of Deforested Areas in Romania

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Abstract

Spectacular spatial dynamics of forest areas is one of the biggest challenges for the scientific world, concerned with completing the methodologies devoted to new methodological approaches, to provide new information that is indispensable in assessing the impact of deforestation within the ecosystem. In this study, we analyzed the evolution of the deforested areas, using the fractal fragmentation index (FFI). The research is based on high-resolution satellite images of forest areas between 2000 and 2017. The use of fractal algorithms allowed the modeling of the grinding patterns, identifying obvious differences between compact and fragmented cuts. Information is needed especially in the evaluation of the areas cleared because of illegal actions. Research has shown spectacular increases in deforestation in the mountain area, the northern and central groups of the Eastern Carpathians being the most fragmented geographical regions in Romania. The study showed that deforestation led to the fragmentation of forests, which generates major natural changes. The results obtained can contribute to the identification of new approaches in national forest fund management policies by establishing a critical fragmentation threshold.

Keywords: fractal analysis, deforestation, forest fund, ecosystem, fragmentation of the forest

1. Introduction

Forests represent perhaps the most complex terrestrial ecosystem, given their ecosystem role, as well as habitat and socioeconomic development. The increasing pressure exerted by the global economy and climate change leads to the degradation and shrinking of global forest areas [1–4]. The reduction of the forest area and its degradation have negative repercussions on the environment, in general, but especially on the quality of the air, the soil, and the security of the water resources [5–12]. Thus, a series of programs and researches were initiated aimed at evaluating, monitoring, and reporting the physical and biological states of the forest (Convention on Long-Range Transboundary Air Pollution (CLRTAP) [13];

UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD) [14]; International Long Term Ecological Research Network (ILTER) [15]; NASA's Carbon Monitoring System (CMS) [16]; Climate Change Initiative (CCI) [17]).

The reduction of forest areas as well as the process of fragmentation of the forest is a ubiquitous problem worldwide. Haddad et al. estimated that half of the planet's forests are less than 500 m from an inhabited area and most of the forested areas have an area of less than 10 hectares [18].

The satellite images offer an unprecedented perspective on the spatial evolution of the cover surfaces with forest vegetation, allowing the mapping of the compactness of the surfaces as well as their degree of fragmentation over time [19–22].

Forest fragmentation assessments have been completed for many countries, such as Canada, China, the Democratic Republic of Congo, India, the UK, or the USA [23–26]. Many of the researchers who developed these studies point out that fragmentation of forest areas has negative effects on the natural ecosystems by increasing the isolation, creating artificial margins, and reducing the basic areas of habitats.

In Romania, forests are under pressure due to climate changes (extreme temperatures, low rainfall, strong winds, and even tornadoes) and natural disturbances (insect outbreaks), but mainly due to anthropogenic causes (various forms of property, poor pest control, illegal logging, large demands on wood for export, etc.). Although Romania's forest area is estimated at about 29% of the country's total area, well below the EU average level of 40%, logging is still at a high rate [27].

A continuous, accurate, and reliable monitoring of the territorial evolution of forests as well as their state of sanogenesis is required both locally, in Romania, and regionally, Europe or worldwide. Such monitoring systems can be based on the information provided by the satellite monitoring networks correlated with on-site measurements and with accurate methods of quantification [28–32].

Establishing methods of continuous observation and accurate determination of long-term environmental changes is necessary to ensure the sustainability of the forest ecosystem and the efficiency of the planned ecological restoration [33].

The method proposed in this study wants to perform a fractal analysis regarding the deforestation of forests at the level of Romania.

2. Methodology

In order to start the analyses for GIS and fractal methods used, we downloaded layer (a raster image in tiff format) corresponding to the granule with the top-left corner at 50°N, 20E (in which Romania is situated), containing the forest loss (loss year) data, for the 2001–2018 [34].

The images prepared for the fractal analyses followed a step-by-step algorithm, consisted on the extraction by mask procedure. The input feature mask was the vector limit of each relief unit of Romania, in our case 11 vector limits (the Carpathians, the Subcarpathians, the West Hills, the Danube Delta, Transylvania Depression, Dobrogea Plateau, Mehedinți Plateau, Getic Plateau, Moldova Plateau, Romania Plain, and West Plain). For each of the 11 input limits, 21 images in tiff format were exported providing pixels with useful informations. The first image exported contains the geographical limit for the relief unit, the other 18 images contain the yearly forest loss, from 2001 to 2018, and another image contains the cumulated forest loss for the entire period (2001–2018) and the last image the

tree-cover information. We have to mention that for the best results, all the images exported were in black-and-white tones (the pixels corresponding to limits, to the forest loss, and to the tree cover were in white, while the background was in black color). Other important aspects were the scale and the image position: in order to avoid the information errors that might have appeared during the export processes, for each input feature mask (relief unit), the same scale and the same unmoved image position were kept.

The exported images provided useful informations that were extracted by using some specific softwares for the fractal and nonfractal analyses. We mentioned that, depending on the surfaces of the relief units, the images were exported to different scales and analyzed later fractal objects. Thus, for the Carpathians, the exported images kept the scale 1:1,750,000; for Subcarpathians, 1:1,300,000; the Transylvanian Depression, 1:1000,000; Moldova Plateau, 1:1,500,000; Dobrogea Plateau, 1:800,000; Getic Plateau, 1:650,000; Mehedinți Plateau, 1:200,000; the West Hills, 1:1,500,000; Romania Plain, 1:1,350,000; West Plain, 1:1,500,000; and the Danube Delta, 1:600,000. Even if the exported images were analyzed at different scales, the pixel sizes being the same for each exported image, there were no distortions or errors in their subsequent processing.

The applicability of fractal geometry is limited not only to static phenomena but also to the study of dynamic phenomena, in evolution, such as the phenomena of growth in biology or of development of urban populations [35].

A versatile possibility to determine the deforestation patterns but also their impact on forest compaction is the fractal fragmentation index (FFI). FFI is a recent indicator and describes fractal fragmentation and can also be interpreted as an index of compaction of the analyzed surfaces, being a dimensionless indicator [36].

The FFI is calculated using the equation (Eq. (1)):

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

where *FFI* is the fragmentation fractal index, D_A is the fractal dimension of the summed areas, and D_P is the fractal dimension of the summed perimeters; ε represents the size of the box; $\log N(\varepsilon)$ represents the number of contiguous and non-overlapping boxes needed to cover the object area; and $\log N'(\varepsilon)$ represents the number of contiguous and non-overlapping boxes needed to cover only the object's perimeter.

When the value of the indicator has *FFI* = 0, it means that the analyzed fractal objects (in our case the deforested areas or forests) are very small, of the order of 1–4 pixels, so that their outline cannot be extracted, D_AD = D_P =0. When the FFI value tends to be 1, the occupied areas are large and compact. *FFI* = 1, when analyzing a Euclidean object, 100% compact, without any discontinuity (D_P = 1 and D_A = 2). When the areas occupied by the fractal are smaller, more dispersed, and more fragmented, the value of the FFI approaches more than 0. The FFI was calculated using IQM-plugin-FFI, available online at https://sourceforge.net/projects/iqmplugin-ffi/, for open source software IQM 3.5 [37].

The analysis of the evolution of the analyzed parameter is carried out through a series of steps. In advance, IQM 3.50 software is downloaded from https://sourceforge.net/projects/iqm/files/latest/download; then, IQM-plugin-FFI is downloaded from the address https://sourceforge.net/projects/iqm-plugin-ffi/files/latest/download. The downloaded plug-in is inserted in the plug-in folder of the IQM program, and a series of steps are taken.

Step 1: Import the images into the information quality metric (IQM - An Extensible and Portable Open Source Application for Image and Signal Analysis in Java) [File—Open Image(s)] (**Figure 1**).
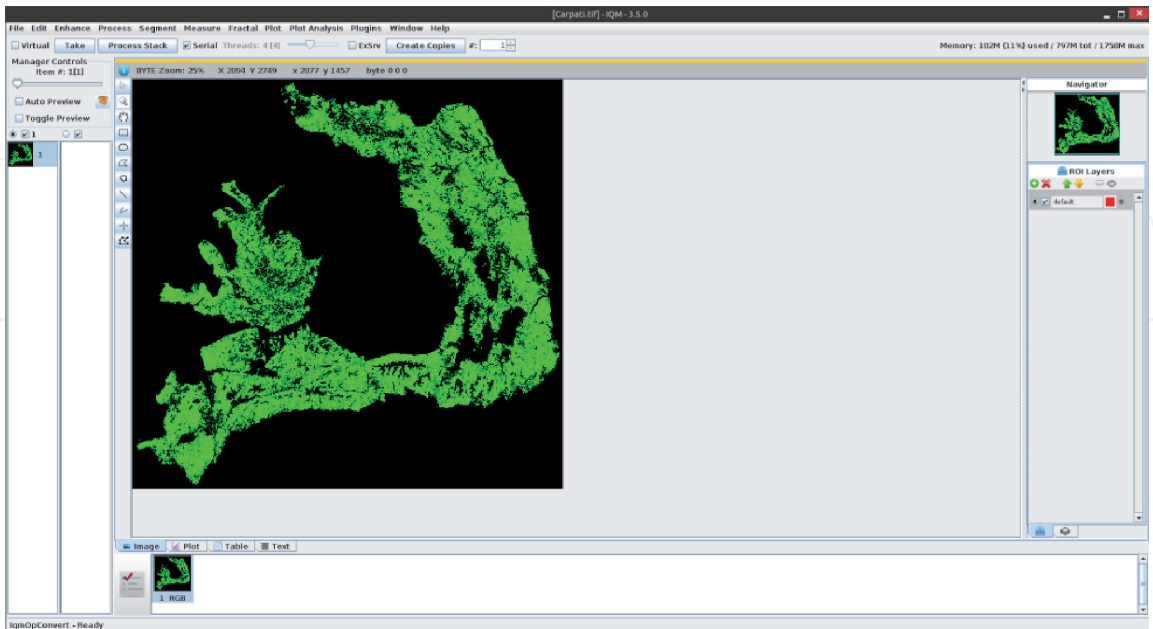

Figure 1.
Importing images to analyze.

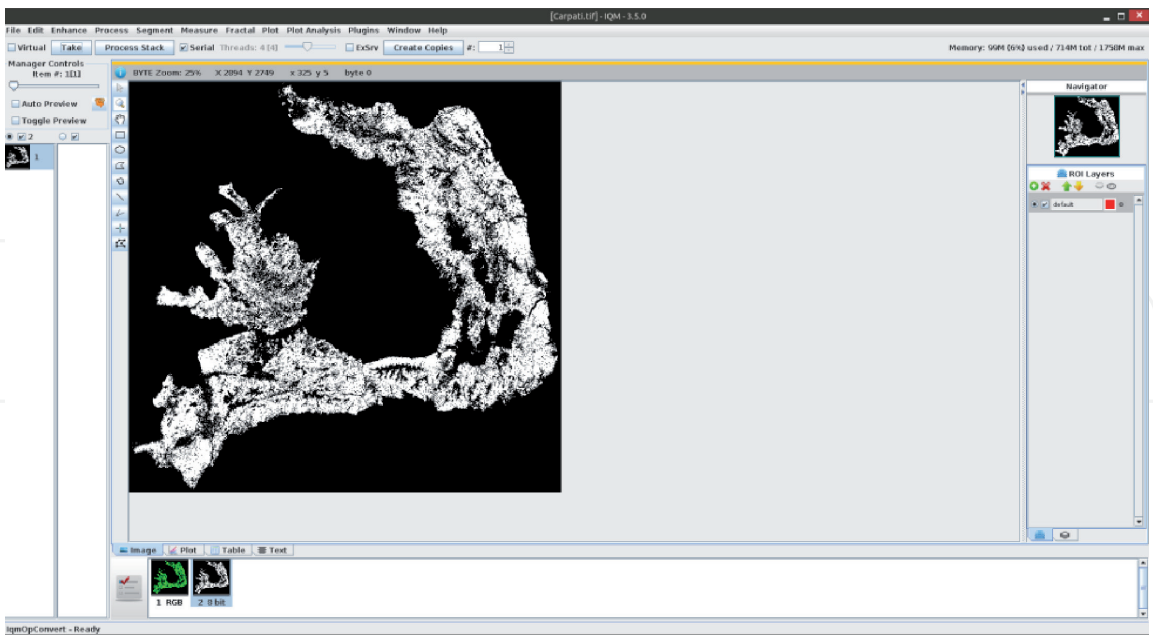Step 2: Convert RGB images into 8 bits [Process—Convert Image–extract G] (**Figure 2**).

Figure 2.
Convert RGB images to 8 bits.

Step 3: Open the FFI plug-in [Plug-in—Image—FFI v2.0].
Method P-Dimension (Pyramid Dimension) is selected (because it is much faster than box counting and the results are similar), and the number of boxes is 9; then press Preview and the fractal analysis is done (**Figure 3**).
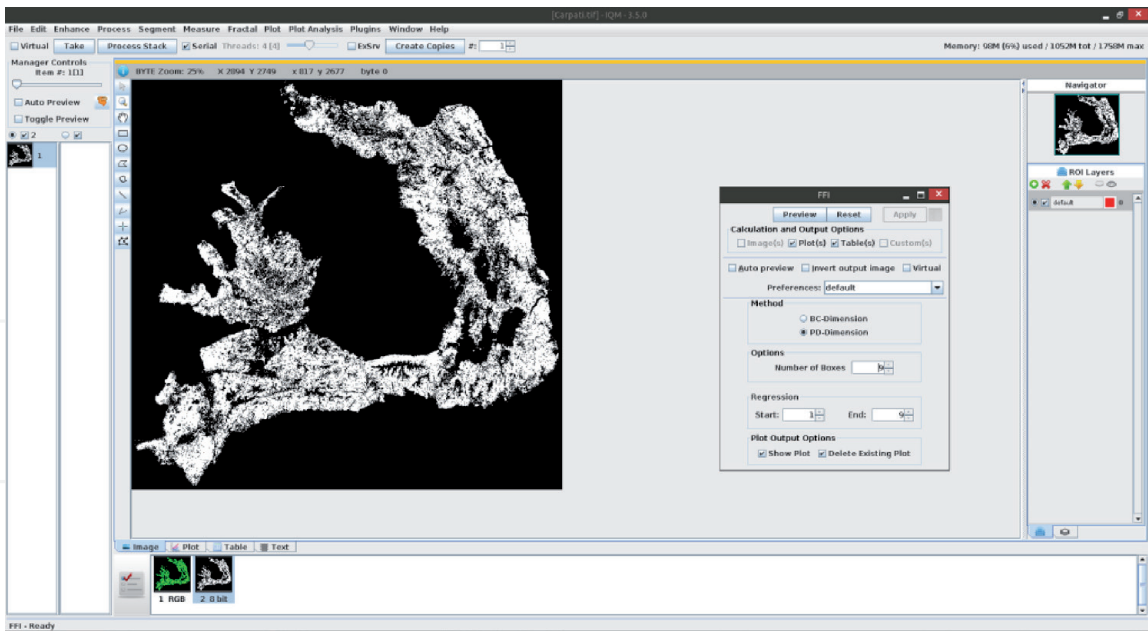
Figure 3.
Using the FFI plug-in.

Step 4: This gives the FFI value on the last column of the displayed table
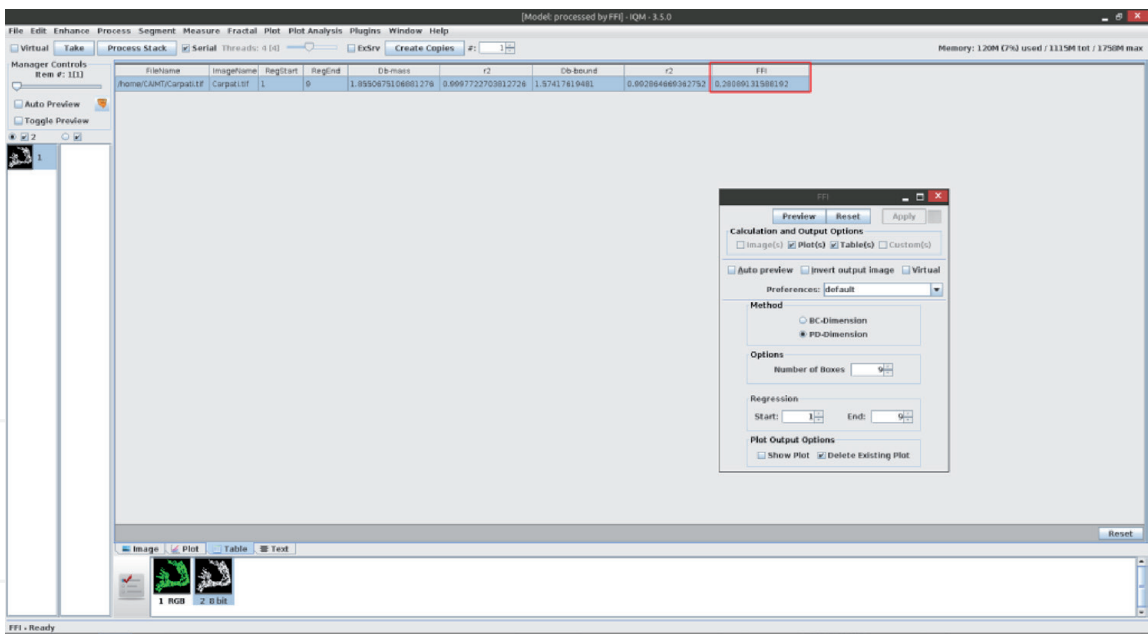(**Figure 4**).

Figure 4.
Obtaining the results of the FFI index.

3. Study area

Romania is a state located in the Southeast of Central Europe, on the lower
Danube, north of the Balkan Peninsula, and on the northwestern shore of the Black
Sea. The population, at the level of 2019, is estimated at 19.4 million citizens. On
its territory are the southern and central parts of the Carpathian Mountains and
the lower Danube basin. It borders Bulgaria to the south, Serbia to the southwest,
Hungary to the northwest, Ukraine to the northeast, the Republic of Moldova to the
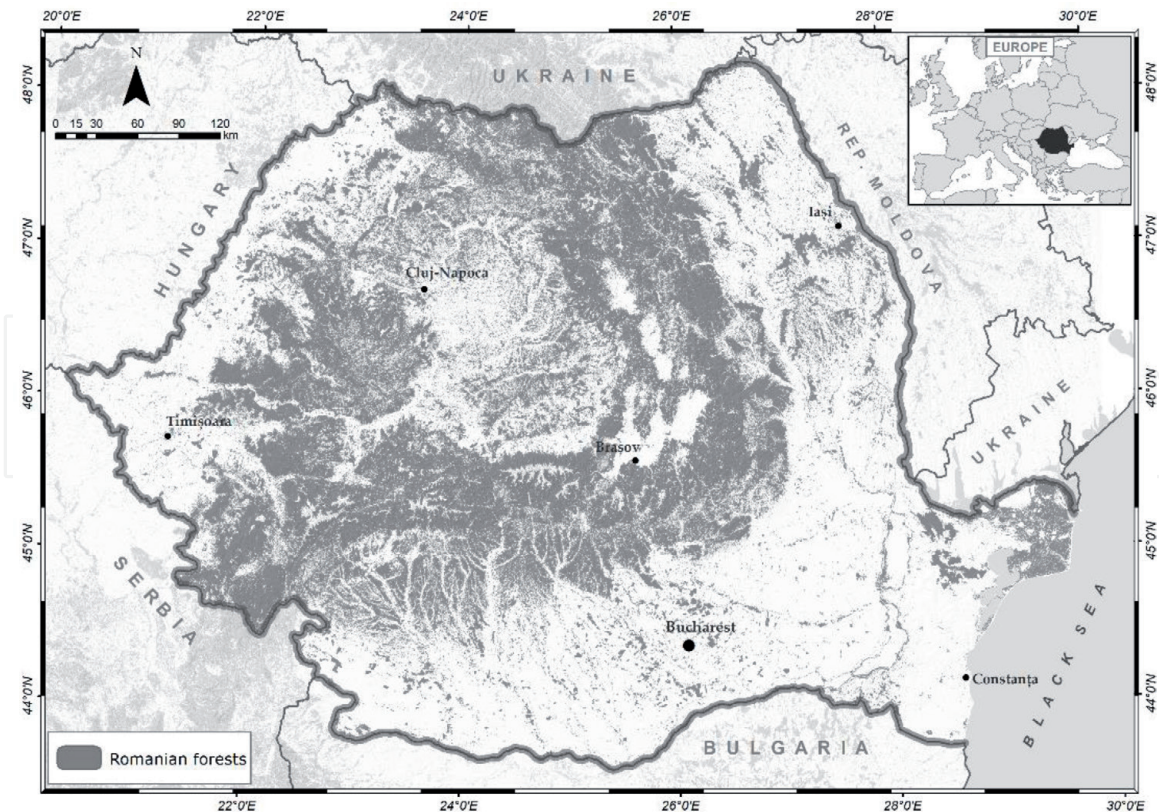east, and the Black Sea to the southeast (**Figure 5**).

Figure 5.
Romania—Study area.

According to the National Institute of Statistics, Romania's forest fund covers an area of 6,529,000 hectares, representing 27.3% of the country's territory. The total volume of forest stands is estimated at over 1340 million m^3.

The multifunctional character of forests is given by their multiple roles: ecological, economic, and social. From a socioeconomic point of view, forest exploitation generates resources, especially wood, but it also plays an important role in the regeneration of water resources and air quality. Their use is multiple starting from the energy role (about half of the renewable energy consumed in the EU is produced from wood mass), for timber, paper industry, wood fiber panels, etc. The relationship between man and the forest is complex, and the dependence is obviously mutual.

The territory of Romania represents a point of intersection between different biogeographic regions: Arctic, Alpine, Western and Central European, Pannonian, Pontic, Balkan, sub-Mediterranean, and even Colchian and Turanic-Iranian. This high level of diversity of ecological conditions/systems also determines a great diversity of flora and fauna, estimated at 3700 species of plants and over 33,000 species of animals. A large number of these species (over 220 plants and over 1000 animals) are endemic species, adapted to local conditions and are found only in Romania.

Important areas of natural, virgin, and quasi-virgin forests are preserved in Romania. However, these areas are rapidly narrowing, currently occupying only about 280,000 hectares, that is, less than half of the existing area 20–25 years ago. These forests are located in a proportion of 99% in mountain regions (in karst areas, in hard-to-reach regions, on steep slopes and screes) and only in a proportion of 1% in the hill and plain regions (hard-to-reach areas of the Danube Delta or compact forest massifs located at a considerable distance from localities). Most of them are located in the area of beech and spruce and mixtures of spruce, fir, and beech. Currently, parts of the virgin and quasi-virgin forests of unique value, including for the biodiversity of natural ecosystems, are included in officially protected areas.

The division of the property regime of the national forestry fund after the 1990s, the great dynamics of the laws in the forestry field, the lack of a coherent policy in this field, and the desire for quick financial gains generated significant deforestation of the forests at the national level. The lack of precise statistics of the deforested surfaces and the quantities of wood exploited has generated at the level of some groups of researchers or environmental organizations of solutions for the prevention and quantification of the deforested areas.

4. Results

Economic pressure and extreme environmental factors have led to the reduction of forest areas worldwide. Romania has also registered a marked dynamics of the national forestry fund in the last decades.

The division of forest fund ownership, inadequate or poorly applied legislation, poor monitoring of the way the wood is exploited, and the occurrence of natural phenomena that have affected the forest (wind blows, biological attacks, etc.) led to the reduction of forest areas and especially to a strong fragmentation of them.

Finding methods that determine the most precisely deforested areas, the density of the existing forest, and its territorial fragmentation is of great importance for sustainable management of the national forestry fund but also within a sustainable development of the environment (protection against landslides, floods, air quality, groundwater resources, etc.).

The analysis was performed according to the types of relief units and their degree of forest cover. Thus, it is found that socioeconomic and natural factors of the last decades have generated a decrease of the compaction of the forest areas (**Figure 6**). The most affected unit of relief is that of the Carpathian Mountains and of the Mehedinți Plateau. All the relief units have suffered over time decreases of the compaction of the forest surface following the deforestation.

The tested and analyzed method may also indicate the technical way of extracting the wood from the logging. A selective extraction of valuable and mature trees or a
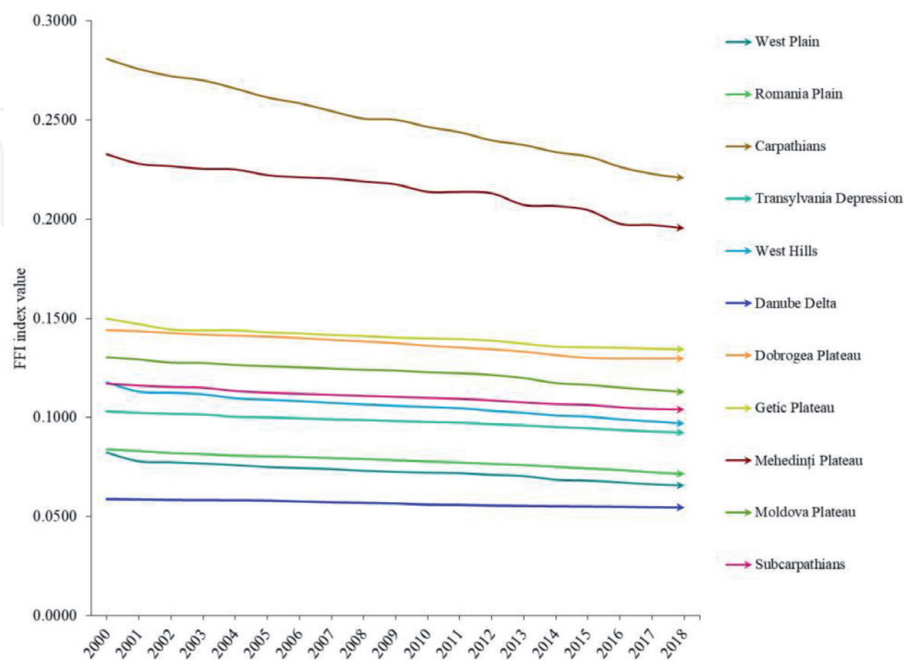

Figure 6.
Evolution of the compaction of the areas occupied by the forest, at the level of relief units, between 2001 and 2018, in Romania.

"shaved" exploitation, regardless of the size and nature of the successive species within those plots. This can be determined by comparing the obtained values of the FFI at the level of any reference year in the analyzed period.

By performing the value difference of the FFI obtained at the level of 2018 and the one from 2001, it can be seen which relief unit was more intense and more fragmented and deforested (**Figure 7**).

The area of the Carpathian Mountains, by the nature of the relief, leads to the clearing of surfaces arranged on different slopes and positions. This is also due to the access to the exploited plots and the shelving of the species. Instead, in the Romanian Plain or in the Danube Delta where the forest surfaces are composed of
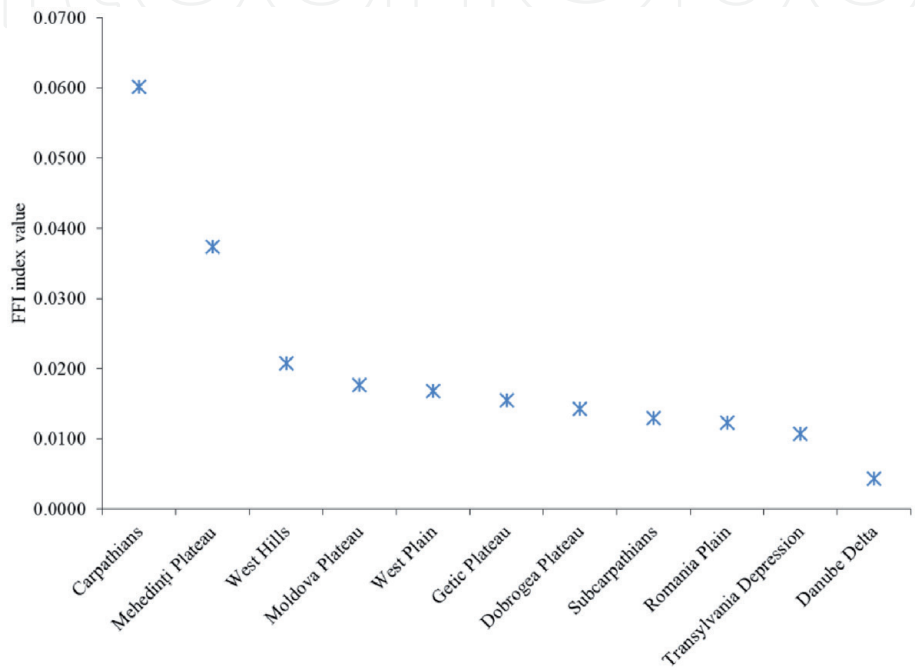

Figure 7.
The degree of fragmentation of forests, obtained by comparing the value of the FFI 2018–FFI 2000.
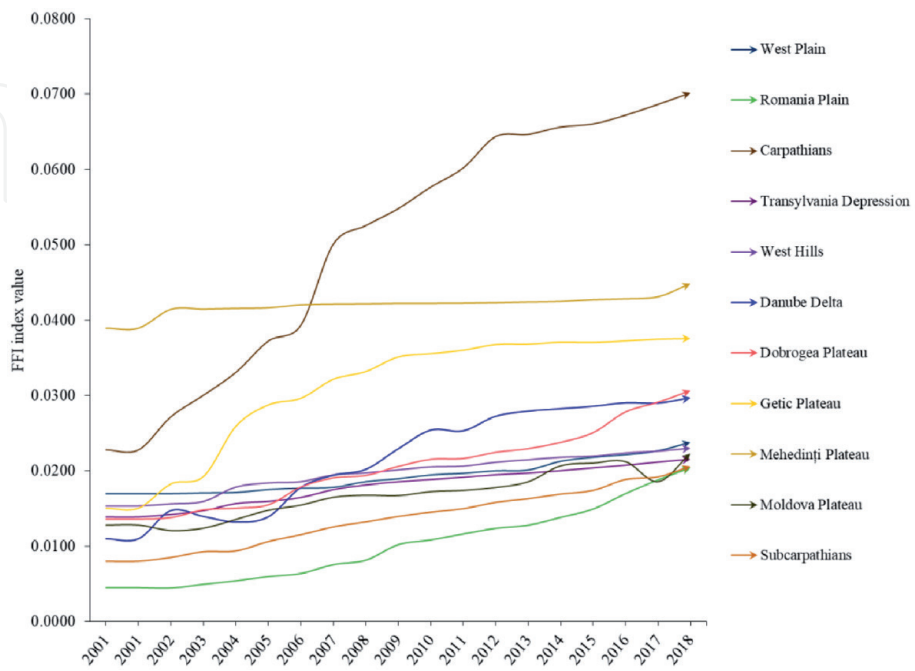

Figure 8.
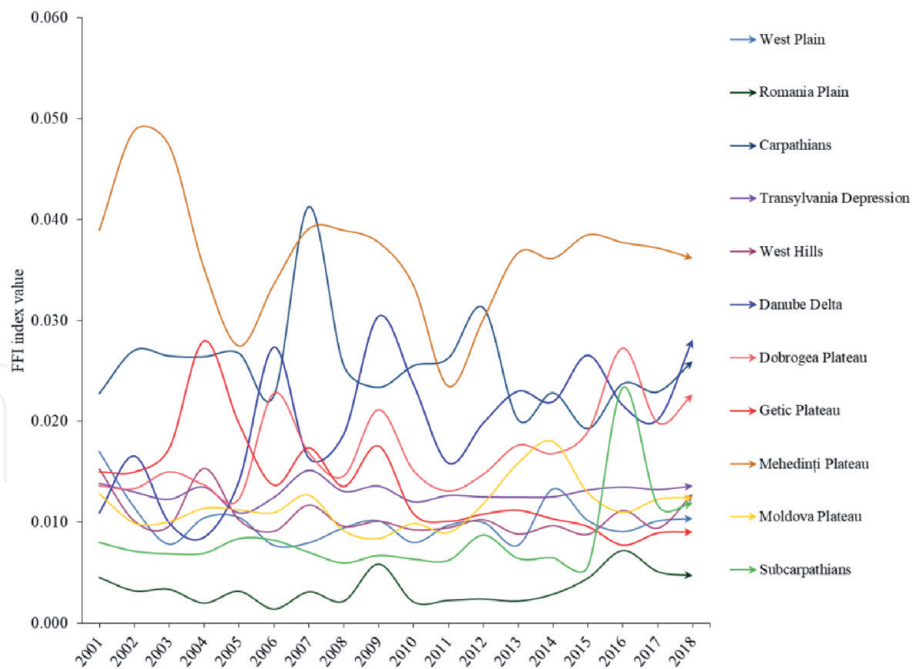*Dynamics of cumulative deforestation.*

Figure 9.
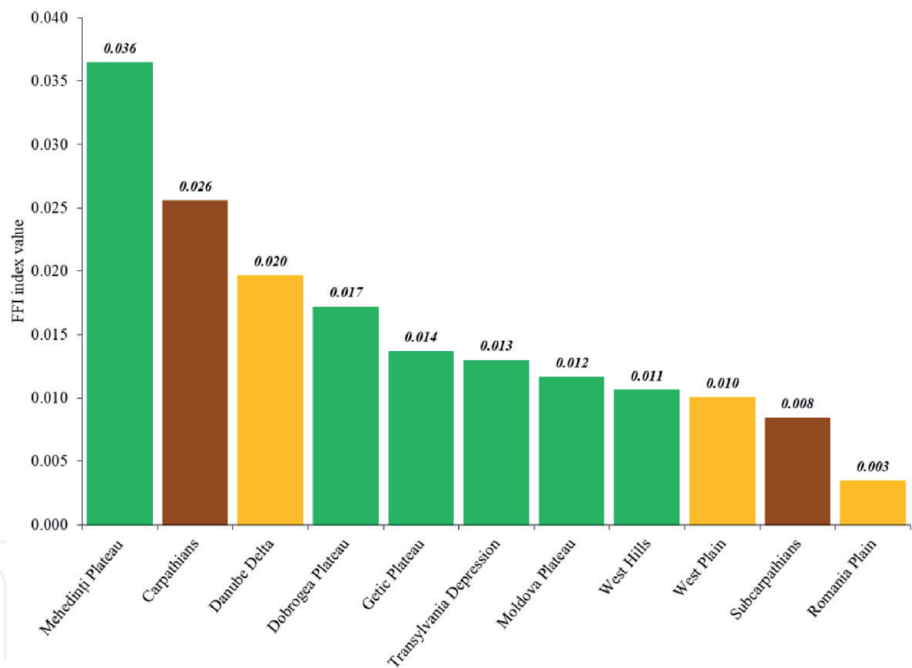*Annual dynamics of deforestation, by relief units, between 2001 and 2018.*

Figure 10.
The average of the FFI deforestation index, between 2001 and 2018 (plateau, green color; plain, yellow color; mountain and premontane units, brown color).

the same species, the exploitations are generally made from the marginal areas of the forest fund; thus, a decrease of the forested surface is recorded, but maintaining its degree of fragmentation, in general.

If the deforestation is done on small and isolated surfaces from year to year, the values of the FFI will be zero or very close to zero. The more the deforestation is done in continuation of the previous deforestation, expanding some deforested areas spatially, the more the value of the FFI will increase.

The Carpathian Mountains have reduced accessibility to the forest fund. In the absence of adequate exploitation technologies (funiculars, helicopters, etc.), the arrangements in the immediate vicinity of the roads are overexploited [38].

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In the relief units where the forest fund is naturally fragmented and the access is much easier, we have forest exploitations on various locations (**Figure 8**).

It can be seen that the deforestation carried out within all the relief units varied from year to year. They are highlighted by the values of the annual FFI for each relief unit separately (**Figure 9**).

Figure 10 shows the average FFI for all 18 years of analysis. The most compact deforestation, on average, took place in the Mehedinți Plateau, in the Carpathian Mountains, and in the Danube Delta. Instead, they were more fragmented in the plains and hills (Subcarpathians).

5. Conclusion

Today, logging is one of the most important pressures on the natural environment, which causes major imbalances on all systemic components, the most important being the modification of microclimates [39, 40], floods, and landslides [41, 42]. In many specialized works, the need to develop methodologies for obtaining data on deforested surfaces and patterns in which they are made, especially for illegal cutting, is highlighted [43–46]. Fractal analysis offers a considerable amount of information, regarding the spatial characteristics of some fractal objects, whether or not they are in dynamics. The proposed index quantifies these characteristics, being very useful in establishing patterns.

Fractal analysis has proven to be a versatile method for evaluating the dynamics of deforestation, as well as identifying deforestation patterns; thus, it can be used complementary to the classical analyses by which data are obtained. FFI is useful in quantifying the degree of fragmentation and implicitly fractal compaction of forest areas and also provides important information on the effect of deforestation on forests, identifying also the moments of agglutination (clustering) of cumulative deforestation.

Being a fractal index, the FFI analyses are invariant at scale, bringing a significant addition to the classical analyses, thus being relevant in the realization of strategies for forest management. The FFI was used in the analysis of deforestation in Romania and the effect of deforestation at the county level [19, 36], indicating in all cases that fragmentation of forests increases following deforestation, having negative consequences on the stability of the hydrographic network and on the habitats. Like any fractal analysis, FFI analysis has limitations. For a correct analysis, but also to be able to make comparisons, all images, which are analyzed, must be at the same resolution, scale, and position and equally binarized.

In this study, FFI analysis allowed a clear differentiation of some patterns regarding the degree of fragmentation of the forests, but also of the compaction of the cumulative deforestation from the relief units in Romania, highlighting different dynamics. Thus, we have shown that the fragmentation of the forest is also relevant for the complex methodologies for calculating the flood risk and offers new perspectives for understanding the way in which the economic pressure on the forests is manifested.

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Conflict of interest

The authors declare no conflict of interest.

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