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USING FRACTAL FRAGMENTATION AND COMPACTION INDEX IN ANALYSIS OF THE DEFORESTATION PROCESS IN BUCEGI MOUNTAINS GROUP, ROMANIA

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Abstract: In Romania, the spatial dynamics of the forests has fluctuated due to a complex of factors, an important role being given by economic pressure (yearly harvesting plan, pest control, forest fires, illegal cuts, etc.). The precise quantification of these actions on the tree cover area was addressed using new methods of analysis using fractal algorithms. The principle of their analysis consists in the imagistic discrimination of spaces with the same characteristics. Thus, a fractal method was used, to estimate geometrically, quantitatively, the tree cover loss areas in the period 2000-2014. It should be noted that the present study analyzes a natural forest area; therefore, the tree cover area is not compact or homogeneous in terms of tree distribution, of their size like height or crown surface. The researched area is part of the Romanian Carpathian mountain chain, which represents more than 50% of the total chain of the Carpathian Mountains. Within the analyzed area, during the mentioned period, an area of 2230.7 ha was loss, representing 2.9% of the tree cover area. The gain areas were only 1014.7 ha, that means about 1.32% of the tree cover areas. The method applied in the research of the phenomenon highlights the distribution and the size of the loss areas in this area of study. This makes a significant contribution in quantifying the dynamics of the fragmentation of the areas covered with forest vegetation, and offers the possibility of correlation with other quantitative parameters, in order to substantiate environmental policies, to reduce negative impacts: landslides, flood scale, training of debris, with economic repercussions and loss of life.

Keywords: forest, deforestation, fractal dimension, economic pressure, forest management

1. INTRODUCTION

Globally, forests cover about 30% of the land area, accounting for about 4 billion ha (FAO, 2005). The forest areas gradually decreased by 129 million ha in the period 1990-2015, area losses being comparable to the size of Peru (FAO, 2016). Most forest lands are covered by natural forests (36%) or modified (53%) (Kauppi et al., 2006), offering the necessary wood for the industry, or firewood for the population. At the same time, it possesses several ecosystem services, including biodiversity conservation, soil and water protection, storage of carbon or tourist function. Worldwide, 8% of forests have the primary role protecting water and soil resources, 12% biodiversity conservation, 24% multiple use and 30% production (FAO, 2010). The reduction of forest areas is due to wood exploitation, the extension of agricultural land and the consequence of global climate change, which is manifested by changes in the air temperature regime, wind speed, precipitation and CO_2 concentration in the atmosphere, which led to frequent forest fires, the drying of some tree species or their winding (IPCC, 2001; House et al., 2002; Nabuurs et al., 2007; Ajani et al., 2013; Keith et al., 2014; Mackey et al., 2015).

The forest area is globally decreasing, its rate being -0.20%/year, in 1990-2000 and -0.13%/year, for 2000-2010. It is encouraging that forests that play a role in protecting water and soil resources have increased by 1.23%/year in 1990 and 2000 and 0.97%/year, over the period 2000-2010 (FAO, 2010).

At European level, it is noticed that the most visible forest management actions consist of deforestation and replacement measures of indigenous species from the initial composition. According to the FAO 2010, the representations at European level (excluding the Russian Federation) shows us that the area covered by forests represent 34%, namely 195.911.000 ha.

Reducing the areas covered by forests is reflected directly in the transformations of the soil layers. Organic layers, distribution and root density, under certain humidity conditions, reduce the precipitation infiltration capacity (Doerr et al., 2000; Jorgensen et al., 2002). Forests play an important role in flood protection, as it is expected that floods will occur more frequently due to climate change (Beratende Organ für Fragen der Klimaänderung, 2007).

In rural areas in countries with a less developed economy (Bluffstone, 1995), or poor in other resources, wood is the main source of income for the population, this being sold, generally unprocessed, without any financial contribution to local communities which continuously accelerates the process of deforestation, generating for sure other social and environmental problems (Prăvălie, 2014a; Prăvălie, 2014b). In 2010, a FAO study showed that, on average, total tree cover revenue was around US$4.5 per hectare, ranging from just over US$6 per hectar in Europe to less than US$1 per hectare in Africa. (FAO 2010). Also, inappropriate or permissive legislative framework (Aurenhammer, 2013), associated with a corrupt or populist political class (Galinato & Galinato, 2013), constitute additional risk factors for the sustainable exploitation of forests (Braghină et al., 2011).

Fractal Fragmentation and Compaction Index *(FFI)* is a fractal indicator that allows quantifying the fragmentation/compaction of the fractal objects. In previous studies, *FFI* has been used to determine forest fragmentation/compaction at TAU level (Territorial Administrative Unit) (Drăghici et al., 2016; 2017; Diaconu et al., 2017; Pintilii et al., 2017) or at county level (Andronache et al., 2016; Ciobotaru et al., 2016). In this research, we have quantified the dynamics of the *(FFI)* over a period of 15 years and at the detailed spatial level of the Bucegi Mountains Group.

The main objective of this study is the use of methodologies to analyze the anthropic pressure on the forest, the *FFI* creating a consistent plus of understanding the processes generated by loss of compact forest areas. The main objective of this study is the development of the use of a rapid, cost-free method of anthropogenic pressure on forest areas, the algorithm proposed by the authors being the *FFI*. The research sought to develop rapid methods to assess the size and position of loss areas; by using cartographic materials, satellite imagery and cost-effective processing methods. It also offers a high degree of precision in their spatial analysis.

2. MATERIALS AND METHODS

2.1 Study area

The territorial complexity of the Carpathians offers a research area with common landscape features and several local particularities that have led to their division into sectors. At their level, several features can be identified and extrapolated, allowing them to be divided into distinct subunits, namely: Bucegi, Făgăraș, Parâng and Retezat-Godeanu Mountains.

The Bucegi Mountains Group (Fig.1), occupies an area of approx. 300 km^2, located in the eastern part of the Southern Carpathians. This massive mountain group enters the shape of a semi-circle arranged in an amphitheater, with a southern opening, to the Ialomița Valley, wearing in his landscape the footprint of the structure and the lithology. The main orographic node is Omu Peak (2507 m), from which the quasi-geometric relief lines enclose two peak alignments: the first in the East, the Prahova Valley steep, dominated by the, Vânturiș (1851 m), Varful cu Dor Peak (2030 m), Piatra Arsă (2071 m), Jepii Mari (2072 m), Furnica (2103 m), Jepii Mici (2143 m), Caraiman (2284 m), Coştila peak (2480 m); and the second in the West, the Bran-Rucar couloir steep marked by the Doamnei Peak (2189 m), Tătarul Peak (1998 m) and Lucăcilă Peak (1895 m).

Within the Bucegi Mountains, unity of the Carpathian Mountains, the first dates of the exploitation of the forest areas occur in 1550 when the pastures are mentioned and in 1592, on the occasion of the sale of some land in Cerbului Valley. Utilization of natural resources, especially wood, mineral waters such as limestone, but also the construction of small water accumulations has led to changes in the mountain landscape (Diaconu et al., 2017; 2019; Zelenakova et al., 2018).

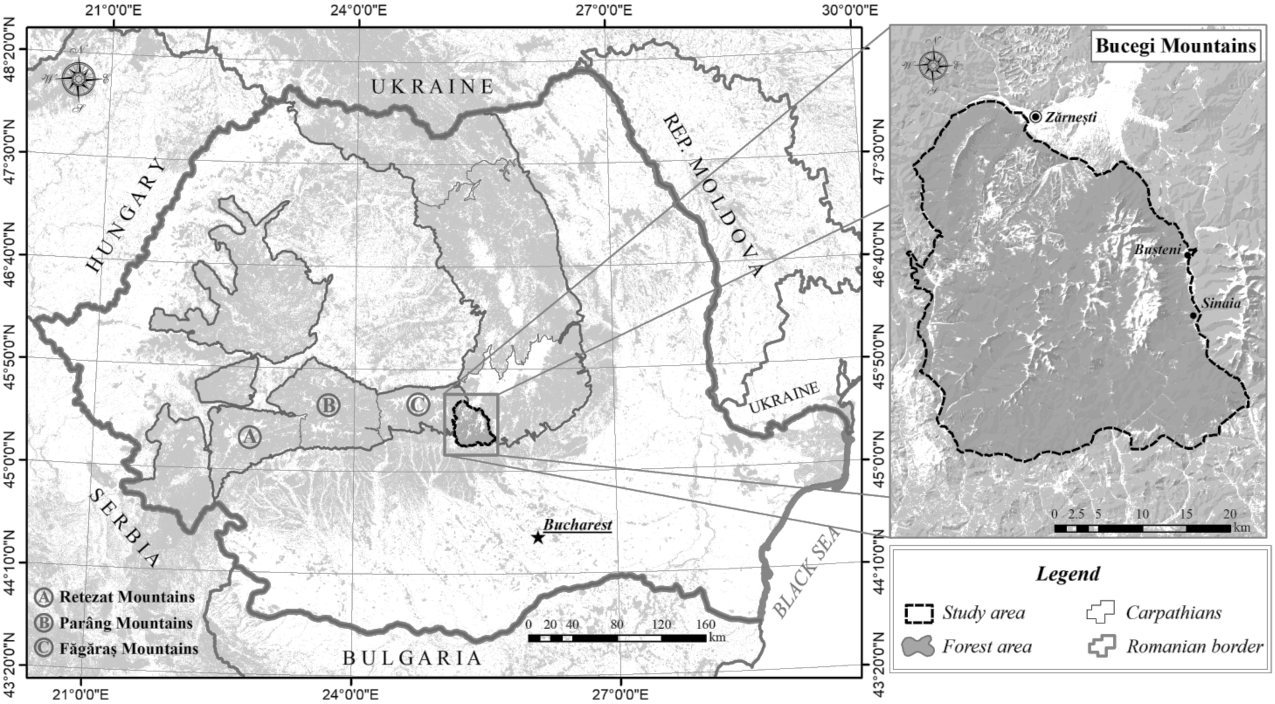

Figure 1. The geographic location of the study area

Thus, at first, the forests on the eastern slope of the Bucegi Mountains were removed, in order to supply raw material to the Bușteni paper mill; afterwards, the exploits from the Ialomita and Brateiului valleys were extended, and the first cable railway was built. Also, Ialomita's waters were barred to exploit the hydropower potential, being built the hydroelectric stations from Moroeni and Dobrești. The dam from Bolboci was built (19 million m³ of water) and the Scropoasa hydroelectric station, with an installed capacity of over 12 MW. To all this is added the exploitation of limestones in Bătrâna Mountain and Lespezi Mountain, where is also the longest conveyor belt in the mountain area. The presence of numerous natural objectives of particular interest for environmental protection has led to the delimitation of some scientific interest areas such as: the forest reserves in the Prahova Valleay steep, where forests of fir and beech forests prevail *Fagetum dacicumabietosum* and herbs - Carpathian or Carpathian-Balkan elements such as *Hieraciumtransilvanicum, Pulmonaria rubra*, *Deantaria Glandulosa* etc., copies of fir high over 20m, clusters of yew (*Taxus baccata*). In the scientific area of absolute protection in Caraiman Mountain, the Jepilor Valley, Jepii Mici Mountain, there are some endemism such as swiss pine and larch tree, and on the alpine meadows with the Edelweiss *Leontopodiumalpinum*, *Poaviolacea*, *Sesleriahaynaldiana* etc. The Omu Mountain Reserves, with associations of *Elynetum, Salix herbaceae*, the Ialomița and Zanoaga Cave, shows a great scientific interest. All these are added to the protected species of Poiana Crucii, where there is a perimeter of hayfield with subalpine vegetation and Lăptici peat bog, situated at 1470 m, characterized by *Sphagnum, Eriophorum sp*., *Carexrostrata*, dwarf willow (*Salixphylicifolia*). Since 1990, the Bucegi Mountains area is part of the Bucegi Natural Park (PNB), with an area of 32497 ha, attracting more than 1 million tourists yearly. The forests occupy 65% of the protected area's surface, the most common being beech, fir, spruce, but also the mixture of these species, depending on altitude and slope orientation. At the boundary between the tree cover and the alpine pastures, there are spruce and larch trees. Also, on the territory of the Bucegi Natural Park, is an area of 208 hectares, covered with juniper tree (*Pinus mugo*), protected species of community interest, which at some point, and suffered a strong territorial decline, increasing the area of meadows.

2.2 Image preprocessing

For the assessment of tree cover, loss and gain areas, the Global Forestry Database, provided by the Maryland University, Department of Geographic Sciences, was used. The database is the result of the analysis of 654,178 Landsat 7 ETM +, and offers the evolution of globally loss areas in the period 2000-2014, in the form of images designed in GeoTIFF format, containing relevant metadata (e.g., the loss of tree cover image contains pixels grouped according to the year when the forest fund disappeared, reported to the original image from 2000) (Hansen et al., 2013). With the ESRI ArcGIS platform, the images to be used in fractal analysis were prepared and exported in TIFF format. Each original raster was exported as a simple image, considering a single scale and chroma to all the images in the temporally analyzed range and also their position in the template. From the original GeoTIFF file, containing the data on loss of tree cover areas, a TIFF image for fractal processing was produced for each year (14 such images). The GeoTIFF image of 2000, which contains the forestry fund to which the analysis relates, has information with the coverage of a pixel with forest (0-100% - the percentage is the forest density per pixel), this factor was considered a correction factor for the areas calculated initially. For better fractal processing, the images were exported at a resolution of more than 400 dpi in TIFF format.

2.3 Fractal Analysis

Based on images in binary TIFF format, the fragmentation-compaction of the tree cover, loss and gain areas from Romania was also determined, for 2000-2014, using Fractal Fragmentation and Compaction Index (*FFI*).

FFI describes fractal fragmentation features of the fractal objects (Eq. 1).

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

where, ε represents box dimension; $\log N(\varepsilon)$ represents the number of non-overlapping and contiguous boxes necessary to cover the objects area; $\log N'(\varepsilon)$ represents the number of non-overlapping and contiguous boxes to cover only the perimeter of the object; D_A is the box-counting dimension of the summed areas and D_P is the box-counting dimension of the summed perimeters (Andronache et al., 2016). According to Andronache et al., 2016 there are 3 situations:

1. *FFI* = 0, when the fractal objects analyzed are very small, so cannot extract their outline. In this situation $D_A = D_P = 0$;
2. (0>*FFI*<1)
   - *FFI* tends to 1 when the fractal objects are large and compact;
   - *FFI* is closer to 0 when the fractal objects are smaller, more fragmented and/or dispersed.
3. *FFI* = 1 is recorded when the analyzed objects are Euclidean, like a square, a circle, so 100% compact, with no discontinuity. In this situation D_A= 2 and D_p =1.

FFI was determined using the FFI plugin for IQM software (Kainz et al., 2015; Ahammer & Andronache, 2016).

3. RESULTS AND DISCUSSIONS

3.1 Spatio-temporal evolution of the tree cover, loss and gain areas

Dynamics of the tree cover area of the Bucegi Mountains Group indicates a general tendency of decreasing of the size of forests as a result of forest exploitation. Legislative and economic norms have changed during this period and have encouraged the deforestation activities (Fig. 2).

Tree cover areas have diminished continually year after year, but inconsistent as rhythmicity, from 77012.2 ha in 2000 to 74781.5 ha in 2014. In 2004 and 2005 there were the highest annual average decreases, decreasing minima being registered in 2001 and 2003, as a result of the occurrence and enforcement of several forest law legislation (Law, 1/2000; Law, 400/2002; Law, 247/2005) (Fig. 3), although the area under investigation is largely covered by regulations of protected areas.

In total, 2230.7 ha were loss, the tree cover area being reduced by 2.9% in the period 2000-2014. Only 1014.7 ha were gain during this time, with a 54.5% deficit (Fig.4).

Until 2004, the loss of tree cover areas was dispersed on small areas, but starting with 2005, there is a process of grouping them (Fig. 5), by creating compact loss areas in Piatra Craiului Mountains and in the North of the Bucegi Mountains.

3.2. Spatio-temporal dynamics of Fractal Fragmentation and Compaction Index (*FFI*)

Relatively small *FFI* amounts, above 0.25, show that for the Bucegi Mountains, the degree of fragmentation of the tree cover is relatively high (Fig. 6). As the extent of loss increased, in the analyzed period, the FFI of the tree cover areas in the Bucegi Mountains (Fig. 6), was reduced by 0.05 from 0.32 in 2000 to 0.27 in 2014, indicating a continuous growth of fragmented tree cover areas, especially in the Piatra Craiului Mountains, where there is a process of clustering of the cumulative loss areas.

In 2002 and 2008 the largest decline of *FFI* was registered (0.008) against the background of a more severe loss of the tree cover areas (243.6 and 255.4 ha). The lowest reduction of *FFI* was recorded in 2003 (0.001) when small tree cover areas (only 23.7 ha) were loss.

The loss of tree cover areas on dispersed areas determines that the *FFI* values be between 0.01 and 0.03. Relatively clustered of loss areas (*FFI* > 0.03) occurred between 2005 and 2008, while fragmented loss areas (*FFI* < 0.013) were recorded between 2001-2003. The different values of the indicator are closely related to the ownership of forest areas and the moment of legislative adoption on the restitution to owners and the type of property (private, public), such as individuals, public institutions (local governments, church).

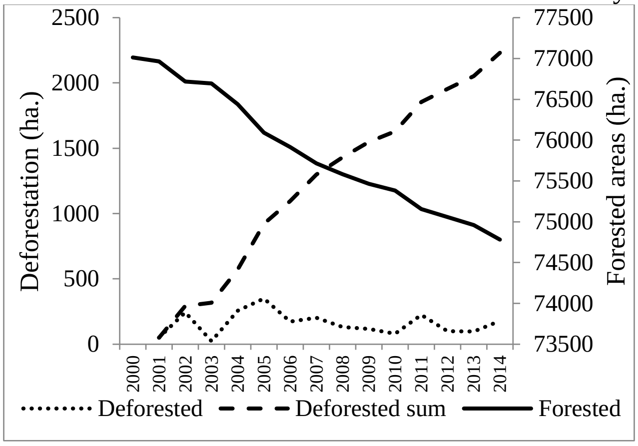

Figure 2. Dynamics of the tree cover (Forested), loss of the tree cover areas (Deforested) and cumulative loss of tree cover areas (Deforested sum) from Bucegi Mountains Group, between 2000-2014

Figure 3. Average Annual Growth Rate of tree cover areas from Bucegi Mountains Group between 2001-2014

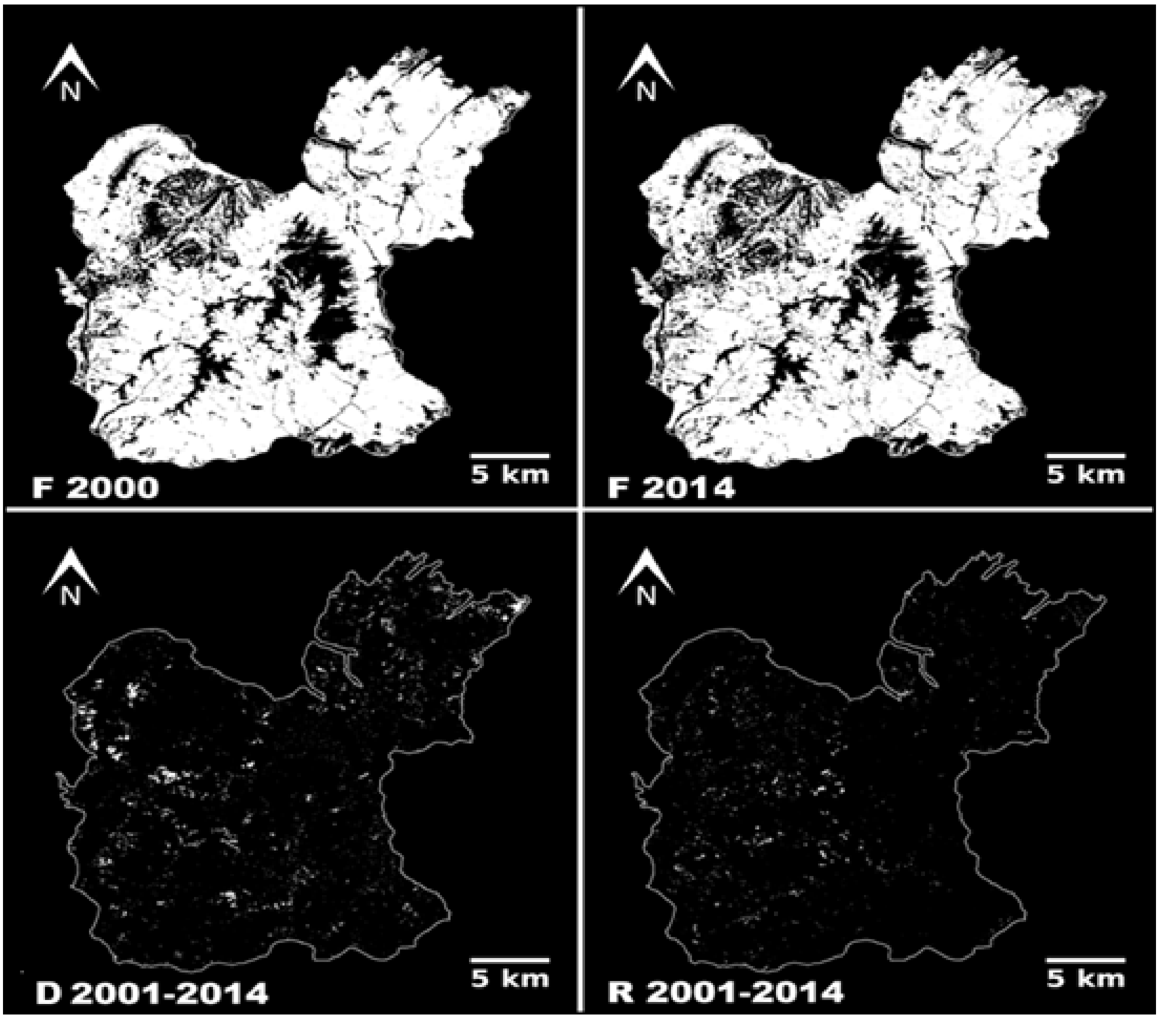

Figure 4. Spatial distribution of tree cover, loss and gain areas between 2000-2014 from the Bucegi Mountains Group (white pixels represent tree cover areas for F 2000 and F 2014; cumulative loss for D 2001-2014 and cumulative gain for R 2001-2014)

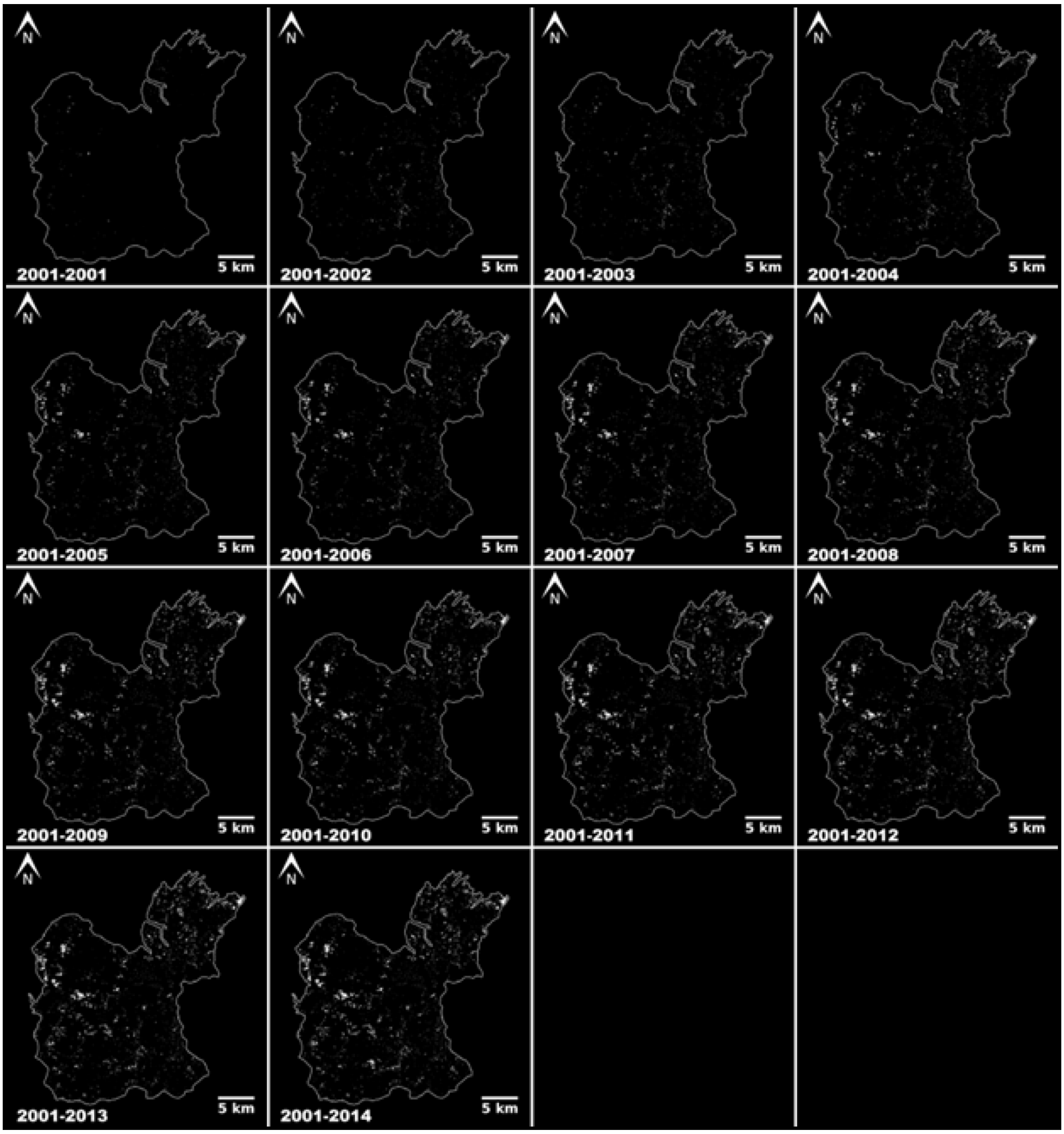

Figure 5. Dynamics of the loss of the tree cover areas in the Bucegi Mountains Group, between 2001-2014 (white pixels represent cumulative loss)

Regarding the summation of the loss areas, it is observed that since 2004 there is a tendency to increase the compaction degree (Fig. 6), from 0.02 at 0.04. For 2001-2014 the *FFI* value of the gain areas was very low, of 0.03, being with 0.01 lower than the loss areas. This shows that gain has been made much less compact, on small areas and more widespread than the loss areas.

In fractal analysis, the most commonly used method is box-counting (Russel et al., 1980). It was also used in forest analysis (Sun & Southworth, 2013) and in the analysis of deforestation effects (Pintilii et al., 2016). In this study we used the analysis of the fragmentation of tree cover areas affected by loss of the forests through *FFI* (Andronache et al., 2016).

In earlier studies, *FFI* was used to quantify the fragmentation-compaction of the forests at the territorial administrative unit level (Drăghici et al., 2017; 2016; Diaconu et al., 2017; Petrişor et al., 2016) or at county level (Andronache et al., 2016).

Based on our research, it turned out that:

- the dynamics of the tree cover areas in the Bucegi Mountains Group, during the period 2000-2014, reveals a general trend of decrease, because of the increased level of legal and illegal logging. Those dynamics were generated by the economic changes and by some legislative changes, which had the effect of loss increasing (Pintilii et al., 2017).
- there is a agglutination tendency of the loss of the tree cover by increasing compaction,

especially after 2005;

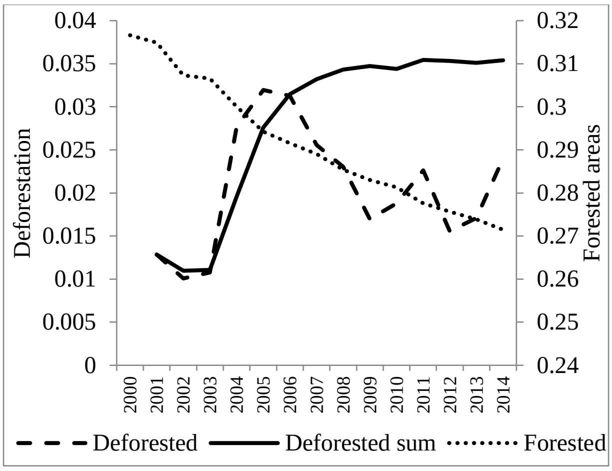

Figure 6. Dynamics of the Fractal Fragmentation and Compaction Index (*FFI*)

- the loss of tree cover has been made more compact than gain;
- our results confirm the hypothesis that fractal analysis on Landsat imagery in a 30 m spatial resolution (Hansen et al., 2013), can provide valuable quantitative information on the spatial-temporal dynamics of the loss and gain of the tree cover. Thus, because the fractal analysis can quantify irregular spatial structures, it has allowed us to obtain additional qualitative information about loss or gain of the tree cover areas.

4. CONCLUSIONS

The Fractal Fragmentation and Compaction Index presents an important role in quantifying the dynamics of the fragmentation degree of the tree cover, loss or gain areas. *FFI* show the quantity and quality of the spatial fragmentation mode. It can be correlated with other quantitative indicators, like liquid leakage, biodiversity, climatic or other factors. It can also contribute to the future development of dynamic vegetation models that integrate wood production and the effects of fires, insect outbreaks and extreme events as well as climate change.

The development of new methodologies for the analysis of the impact of anthropogenic pressure on tree cover areas provides the possibility of identifying some qualitative elements, useful in developing public policies, designed to reduce the imbalances generated by the deforestation of a large, compact, forest areas.

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