DETERMINING FOREST FUND EVOLUTION BY FRACTAL ANALYSIS (SUCEAVA-ROMANIA)

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Abstract. The main objective of this study is developing an analysis methodology for the forest fund dynamic. One of the most severe current issues which Romania faces is the extent of deforestation, under the pressure of economic activities, also affecting forest areas. The Global Forest Change 2000-2013 data, supplied by Maryland University, was used for the analyses conducted, being further subjected to a segmentation process, using the Colour Deconvolution plug-in of ImageJ 1.49s. The segmented images have been manually binarized, and based on the latter, the covered areas have been further calculated and expressed in km². For this purpose, a macro was written, implemented in ImageJ 1.49s. The resulting binarized images have been fractal analyzed, using the software ImageJ 1.49s - FracLac 2015Mar6206 - Box-counting Fractal and Lacunarity Analysis. ArcGIS platform was used to draft the cartographic materials, justifying and supporting this study. The main results of this study comprise of the alarming increase in deforested areas and the large difference between official data and statistical data reported from the real field situation, which illustrates the high extent of illegal logging, reached lately. Coherent strategies for territorial management are highly required to reduce, halt and even fight against these illicit activities.

Key words: deforestation, forest fund, territorial management, fractal analysis, lacunarity

1. Introduction

In the XXIth century, the components of the economic system of Romania exert a particularly strong pressure on forest ecosystems. Large forest areas have been cleared in recent years to ensure raw material for the wood industry. The purpose of the deforestation, more or less legal, is to ensure the export of timber and wood traditionally used for domestic heating. Therefore, from the beginning, it can be stated that these economic activities do not bring any added value to local communities, in the areas where said operations are carried out. On the other hand, illegal logging has reached alarming levels.

Numerous studies from the literature describe and analyze in-depth the factors contributing to the increase of economic pressure on forest ecosystems, and among them we can mention: poverty, corruption, government policies, scarcity of forest areas, agricultural development at the expense of reforestation (Vanclay and Prabhu, 2008; Angelsen and Kaimowitz, 1999; Meyfroidt and Lambin, 2008; Meyfroidt and Lambin, 2011; Damayanti and Prasetyo, 2014; Petrişor, 2015).

The international experience of some states with large forest areas is illustrated in these studies, as well as the pressure on the forest ecosystem of Maine province, from the U.S., where the alarming deforestation of the 1970s-1990s have been based on the intense activities of paper manufacturers (Acheson and McCloskey, 2008). Furthermore, on the European continent, in Portugal, during the economic boom period, the forest management system was forced to adapt to development needs (Reboredo and Pais, 2014; Sivaramanan, 2014).

Particular attention on deforestation is granted in the Kyoto Protocol, which outlined the beneficial role of the forest, on adjusting the amount of carbon dioxide (CO_2) from the atmosphere (Brown et al., 2000), however, the annual rate of deforestation continued to be growing.

Another reason for mass deforestation was determined by the continuous development of agriculture, to answer the increasing demand at world level, also determined by the continuously growing World population. Therefore, developing countries have registered the highest increases of deforestation and a growth trend is estimated due to increasing demand for agricultural products, particularly food (Angelsen and Kaimowitz, 1999; Tilman *et al.*, 2001; Goldewijk and Ramankutty, 2004; Thongmanivong *et al.*, 2005; Gibbs *et al.*, 2010; Phalan *et al.*, 2011).

The available forecasts on future developments of the world economy, under globalization, estimate growing pressure on the forest ecosystems. Given the latter, the reduction or the cessation of the forest logging becomes one of the largest challenges, which the current decision-making factors have to face (Yuan *et al.*, 2015). In order to ensure sustainable exploitation of timber, they shall coherently draft the territorial management strategies, leading to alleviation of imbalances generated by the ecosystem destabilization, particularly of forests.

Therefore, deforestation, along with pollution, and corroborated with climate changes, to a particular scale, are the biggest challenges of the contemporary society, with an important role in increasing the imbalances created by deforestation of forests, along with intensive cultivation of soils fragile (Bandoc, 2012; Prăvălie *et al.*, 2014). Under these circumstances, it is required to adopt efficient environmental risk management systems, providing solutions for the decision-making component of affected local communities (Peptenatu *et al.*, 2010, 2011, 2013; Popescu, 2015; Yuan *et al.*, 2015).

Because the forest areas are irregularly, fragmented and can divide into parts, each part is approximately a smaller copy of the whole pot fi assimilate to fractal objects. In nature these copies are not exact representations but are nevertheless scale invariant (Jelinek *et al.*, 2006).
The main advantage of the fractal analysis against classical methods is that fractal dimension indicates how much space is occupied by the object, representing the degree of complexity that the figure has and it is not scale sensitive.

The purpose of this study is to develop a robust research method addressing the dynamics, fragmentation and complexity of the forested, deforested and regenerated areas, based on fractal analysis of areas (fractal texture) and lacunarity, can offer useful information on the degree of homogeneity and heterogeneity of a forest area and can alert the forestry management of deforestation.

2. Materials and Methods

In view of analyzing the impact of deforestation, as well as for highlighting its magnitude, the process of building a database at territorial-administrative unit level has been initiated, comprising of land areas affected by deforestation, but also those where afforestation works had been carried out or regenerated naturally. Hence, the Maryland University, Department of Geographical Sciences, (Global Forest Change 2000-2013) has made available a comprehensive database, resulting from the analysis based on 654,178 Landsat 7 ETM+ images, characterizing the global expansion of forest areas by the year 2000 2013 (Hansen *et al.*, 2013). Its detailed processing was performed with the ArcGIS platform, following an algorithmic succession of several stages.
In order to extract table data, the initial data base processing was started, by converting the initial geographical projection (WGS 1984) into a

Stereographic projection 1970 - Dealul Piscului 1970, specific to Romania. After cutting the Raster image overlapping Romania from the entire world map, we continued, through the same ArcGIS platform, converting it into points per classes, except class 0. Since class 0 refers to the afforested areas, from which the analysis started, each class from 1 to 13 shall be assigned to the areas deforested since 2001 until 2013. After the conversion in points per classes, we continued with the analysis and processing of each class, from 01, for year 2001, and until class 13, for year 2013. Furthermore, for each year, the pixel with the cell dimension 27.239*27.239, from the Raster images, was converted into a point sized to 741.941 m^2, corresponding to the deforested area. For the calculation of deforested areas for each administrative territorial unit, the number of points for each unit was summed up. The methodology was repeated to calculate afforested land surfaces.

Moreover, in order to increase data accuracy, but also to measure the compaction degree for deforested areas, another method used was the fractal method. The latter means covering a series of stages, as follows.

During a first stage, the afforested, deforested and regenerated areas have been extracted from the same images of Global Forest Change 2000-2013, and stored in uncompressed tiff format (by using the ArcGIS platform). The optimum resolution selected was 1637*895, according to a numerical scale of 1:550,000.

During the second stage, since the resulting tiff images are in color, they have been subjected to a segmentation process, using the Colour Deconvolution plugin from ImageJ 1.49s, plugin developed by Gabriel Landini (The School of Dentistry, College of Medical and Dental Sciences, University of Birmingham, UK) - Haematoxylin, Eosin and DAB (H&E DAB) vector (Ruifrok *et al.*, 2001).

In the third stage, the segmented images have been manually binarized, and based on the latter, the covered areas have been further calculated and expressed in km^2.

During the last stage, the resulting binarized images have been fractal analyzed, using IQM 3.2 (Kainz *et al.*, 2015). For verify and ROI analysis was used Fractal Analysis System for Windows 3.4.6 (Sasaki *et al.*, 1994).

The method to determine the fractal dimension was selected box-counting (Russel *et al.*, 1980; Di Ieva *et al.*, 2007; Muenzner *et al.*, 2014). The mathematical expression is:

$$D_o = \lim_{\varepsilon \to 0} \left(\frac{\log N(\varepsilon)}{\log \frac{1}{\varepsilon}} \right) \quad (1)$$

where D_o is the box-counting fractal dimension, ε the side length of the box, and $N(\varepsilon)$ the number of contiguous and non-overlapping boxes of side ε required to cover the area of the object (Russel *et al.*, 1980; Di Ieva *et al.*, 2007). As the zero limits cannot be applied to digital images, D_o was estimated by means of the equation:

$$D_0 = d \quad (2)$$

where d is the slope of the graph $\log[N(\varepsilon)]$ against $\log(1/\varepsilon)$ (Di Ieva *et al.*, 2007).

Fractal dimension of forest areas (D_{0A}) describes how the mass of forest is concentrated across scales, on a given areas.

Since the tiff reference images are in 2D, D_{0A} may be situated between 0 (the presence of an isolated, solely pixels (in our paper 1 pixel = 0,022 Km^2 [area] and 0,416 km [perimeter]), and 2 (100% afforested area). If $1<D_{0A}<2$ the forest area is disposed in connected clusters with different sizes. Because fractal analysis of areas reflects the method space employment and not just the occupation itself, to the same occupied area, but differently distributed, it will have different values of the D_{0A}.

The *lacunarity* (Λ) measures the size and frequency of image lacunae, describes the texture of a fractal and reflects invariance to scaling. The high values of Λ reflect heterogeneity (varied distribution of pixels), whereas low values indicate homogeneity.

Λ of the forest area (was calculated using the the software IQM based on the method described by Segupta-Vinoy (Sengupta and Vinoy, 2006), as well as FracLac plug-in of ImageJ (Karperien 1999-2013; Karperien *et. al.*, 2013).

3. Results

Detailed analyses on measuring the economic impact of deforestation on local communities have been carried out in Romania and, for the purpose of this study, we selected and performed in-depth analyses for Suceava County, this being the most affected county of Romania in terms of deforestation.

The most affected territorial administrative unit from Suceava County is Cârlibaba, a large commune of this county (Figure 1).

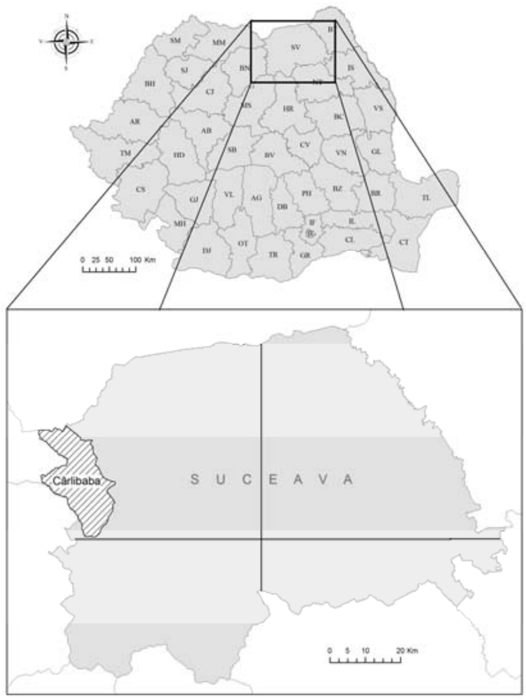

Fig. 1. Map with the geographical position of Carlibaba, Suceava, Romania

3.1. Dynamic of forest areas

The analysis of deforested areas highlights the growing trend, with uneven evolution, determined by political decisions on restitution of forests confiscated by the communists, mostly deforested after they came into possession of private owners.

If approximately 17,500 hectares of forest land have been deforested in 2001, the logging activities will be reduced in the coming years, reaching 10,000 hectares in 2003, namely the smallest deforested area nationwide for the time frame included in the analysis (Figure 2a).

The years 2004 and 2005 have faced the doubling of the deforested areas, as compared to 2003, with a reduction of up to 14,000 hectares in 2006, after which the logging operation activity reached the peak of the analyzed period, in 2007, to about 37,000 hectares. In the upcoming years, 2008-2011, we reach a variable value of 16000-17000 hectares, once again, since in the last analyzed year, namely 2012, the value of the deforested covers more than 28,000 hectares.

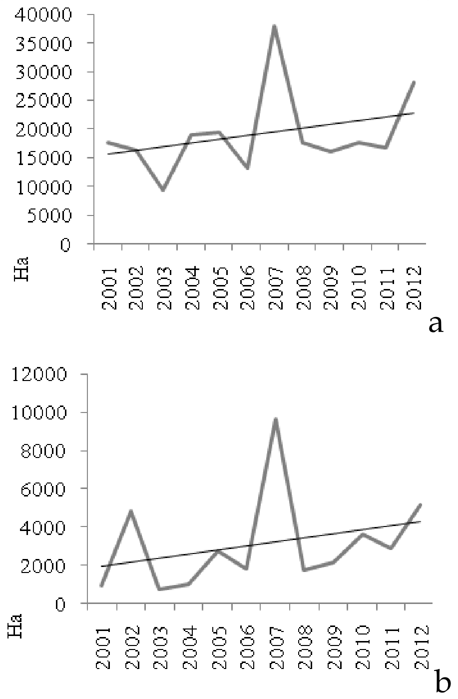

Fig. 2. Deforested areas evolution: a. at national level b. in Suceava County

The evolution of deforested areas in Suceava County during the period 2001-2012 registers extensive progress from one year to another, with an upwards multi annual trend correlated with the nation level evolution (Figure 3). Suceava County amounts an area of 8,555 square km, of which approximately 0% comprise of afforested areas.

The high share of forests with high economic value has generated enormous pressure for the restitution of large forest areas to their former owners. Therefore, compact forest areas are deforested on a short-term, taking advantage of several errors from the legislation on forest ecosystem protection. Therefore, around the year 2001, approximately 1,000 hectares of the total afforested area of the country was being deforested, and within the following year the value increased to approximately 5,000 hectares. Starting with 2004-2006 there are variable increases. The maximum value of the analyzed period is registered in 2007, amounting to 9,500 hectares of deforested land, with a decrease of up to 2,000 hectares in the next year. There is an ascending trend for the expansion of the deforested areas, reaching over 4,500 hectares at the end of 2012 (Figure 2b).

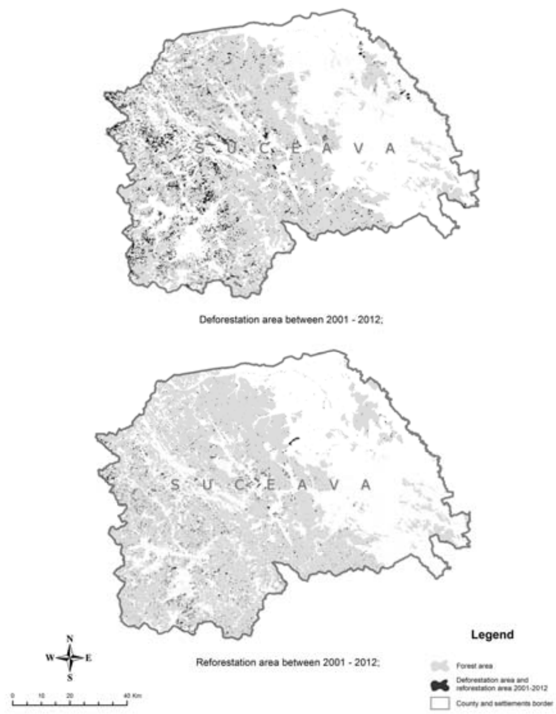

Fig. 3. Dynamic of deforested areas in Suceava County

The total deforested areas from the analyzed interval have varied at commune level, the highest values being recorded in the commune overlapping mountain units, such as Cârlibaba (4,690 hectares), followed by Poiana Stampei, Dorna Candrenilor, Iacobeni, etc, and the lowest values being in the Suceava Plateau, with an area of woodland at a lower rate than the county average (Figure 4).

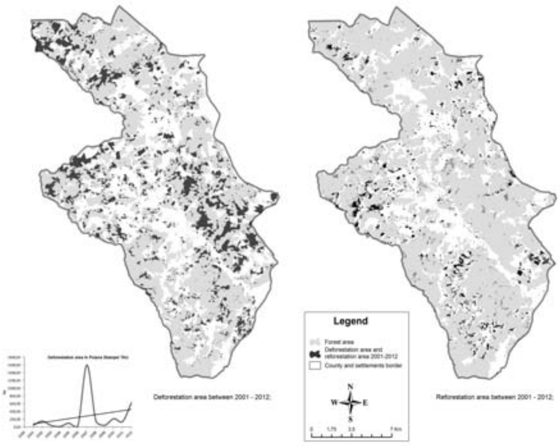

Fig. 4. Dinamic of deforested areas in Cârlibaba (Suceava County)

The commune of Cârlibaba is the administrative-territorial unit with the largest deforested area of this interval. The locality amounts a surface of 27,400 hectares and a population of 1717 inhabitants. Most of its territory is covered by forests (80%) so that the main economic activities are focused on exploitation and its processing.

The most significant extraction of wood was in 2001-2007, when more than 1,300 hectares of forest have been cleared, in only one year. After the year 2007, the dimension of deforested areas has declined gradually to about 200 hectares/year and even under 100 hectares/year. During the interval 2001-2012, 4,690, namely 4 hectares of land have been deforested, mostly privately-owned. The authorities consider this disaster as the near natural consequence of legislative and economic circumstances created to facilitate mass cutting of high economic value of forests (Zhang *et al.*, 2014).

The area covered by forests in Suceava County, around the year 2012, has been 463,207 hectares, comprising 6% of the afforested area of Romania (ranking second, after Caraş-Severin County). As compared to the year 2000, when 38,388.8 hectares were deforested, namely 8.29% of the total deforested area at the level of Romania (1st place), and only 18,120.7 hectares were regenerated, namely 3.09 % of the total deforested area at the level of Romania (Vth place after Harghita, Suceava, Sibiu, Covasna). Follows a deficit (deforestation-regeneration) of 20,268.2 hectares (only regenerating 47.2% of the deforested area), thus registering the highest deficit at Romanian level.

From the North Eastern Development Region (NE D.R.), Suceava County ranks first, both in terms of the total area (37.3%, of forest area in the region), as well as in the deforested, regenerated area, or in the deforestation-regeneration difference (Table 1).

Table 1 The afforested, deforested and regenerated area in hectares (2012)

Region	Forested area	% of the total afforested area	Deforested area	% of the afforested area of Romania	Regenerated area	% of the afforested area of Romania	Area deficit (deforested - regenerate)	% of the afforested area of Romania
Suceava	463207	6.00143	38388.8	8.28762	18120.7	3.912	20268.2	4.37562
NE Development Region	1243235	16.1077	59930.8	4.82055	28894.9	2.32417	31035.9	2.49638
Romania	7718275	100	231525	3.00	156960	2.03	74564.855	0.97

Data source: GFC 2013

3.2. Fractal dimension and lacunarity

The arrangement of the forest area was determined by fractal and lacunarity analysis with IQM and for verify with Fractal Analysis System (D_{0A}) and FracLac/ImageJ (Λ).

Global fractal dimension (IQM). D_{0A} of the afforested area of Suceava County, obtained is 1.731 (Vth place in Romania, after Arges, Valcea, Caras-Severin, Hunedoara, these 4 counties exceeding Suceava in terms of fractal dimension given the higher degree of homogeneity of the forest area) being higher than the D_{0A} of the NE D.R., and of Romania, demonstrating that this is a well-afforested county.

For deforested areas of Suceava County, D_{0A} is 1.3539, being also the largest throughout Romania, reflecting both the large deforested area, as well as the deforestation of the compact area. D_{0A} of Suceava is highly superior to the NE D.R. (with reduced value, considering Botoşani, Iasi and Vaslui County, counties with D_{0A} of the deforested area < 0.8) and of Romania.

In the situation of the regenerated areas D_{0A} of Suceava County is 1.2501, ranking second after Harghita County, as a result of the relatively large regenerated surface, achieved in relatively compact areas. And in this situation D_{0A} of Suceava is highly superior to the NE D.R. (0.8493 with reduced value considering Botoşani, Iasi and Vaslui County, these 3 counties with D_{0A} of the deforested area < 0.7) and of Romania is 0.8590 (Table 2).

The difference between the D_{0A} of the deforested and regenerated area of Suceava County is 0.1038, ranking XVIII^th^ (the largest difference is 0.2087 in Argeş County and the smallest -0.1106 in Covasna County) both given the extended deforested area, in relatively compact areas, but also given the well-distributed regeneration. D_{0A} difference between deforestation and regeneration of Suceava County is close to the NE D.R. (0.0982) but higher than the one of Romania (0.0633).

Fractal analysis of ROIs (Fractal Analysis System). By analyzing Suceava County in the four ROIs, it is noted that the largest D_{0A} of afforested is in the SW (better afforested and more compact), and the smallest in the NE (less afforested and more widely spread), with a difference of 0.3741.

For deforested areas it is noted that the higher D_{0A} is in the SW (better and more compactly afforested), and the smallest is in the NE (less afforested and more widely spread), with a difference of 0.5211.

For regenerated areas it is noted that the bigest D_{0A} is in the SW (better and more compactly afforested), and the smallest is in the NE (less afforested and more widely spread), with a difference of 0.4445 (Table 2).

IQM lacunarity. Λ of the afforested area of Suceava County is 1.0706 (XXIXth place), with the smallest Λ of the afforested area in the N-E development region. A smaller Λ indicates a higher homogeneity of the regenerated area of Suceava County, from the Romanian counties.

For deforested areas Λ is 1.1190 (XXIXth place), with the smallest Λ of the afforested area in the NE D.R. (1.1732) and for regenerated areas is 1.1170 (XXXVIII^th^ place), with the smallest Λ of the afforested area in the NE D.R. (1.1762). (Table 2).

Table 2 Fractal dimension and lacunarity of the afforested, deforested and regenerated areas in Suceava County (2012)

Afforested areas

	Fractal dimension		Lacunarity	
Region	IQM	Fractal Analysis System	IQM	FracLac
Romania	1.5433	1.5689	1.0899	1.0145
NE region	1.5726	1.6026	1.0941	1.14431
Suceava	1.73102	1.7777	1.0706	0.7127
NW of Suceava		1.8192		
NE of Suceava		1.4798		
SE of Suceava		1.6822		
SW of Suceava		1.8539		
		Deforested areas		
	Fractal dimension		Lacunarity	
Region	IQM	Fractal Analysis System	IQM	FracLac
Romania	0.9223	0.8615	1.1641	1.5720
NE region	0.9476	0.8999	1.1732	1.6641
Suceava	1.3539	1.3331	1.1190	1.1497
NW of Suceava		1.3701		
NE of Suceava		0.9059		
SE of Suceava		1.0905		
SW of Suceava		1.4270		
		Regenerated areas		
	Fractal dimension		Lacunarity	
Region	IQM	Fractal Analysis System	IQM	FracLac
Romania	0.8590	0.7910	1.1727	1.3958
NE region	0.8493	0.7847	1.1762	1.55451
Suceava	1.2501	1.2148	1.1170	1.1061
NW of Suceava		1.1805		
NE of Suceava		0.7852		
SE of Suceava		0.8948		
SW of Suceava		1.2297		

Data source: GFC 2013

The difference between Λ of the deforested and regenerated area of Suceava County is 0.0020 (XXIVth place), being higher than the difference between Λ of the deforested and regenerated area of the NW development region, namely - 0.0030 (IIIrd place throughout the regions) and of - 0.0086 in Romania. If deforestation Λ is higher than the regeneration (extensive heterogeneity upon deforestation), in Suceava County, in the NE Development Region and of Romania, things go the other way around.

The D_{0A} and Λ of Suceava County obtained IQM was confirmed by analysis obtained by Fractal Analysis System for Windows and FracLac/ImageJ.

From the analyses of the fractal dimension analysis and lacunarity complementary information and classical analyzes resulted. Fractal analysis brings added information about how the forest area fill existing forest area, and its degree of fragmentation and irregularity perimeter. Box-counting fractal analysis done though is precise, versatile, user-friendly disadvantage that is strictly global analysis, providing information throughout the entire image or ROI analysis. The results should be linked with local fractal analysis (Mass dimension, SubSample analysis – for areas and Ruler dimension – for perimeters) or succolarity (De Melo and Conci, 2013).

4. Conclusions

The deforestation phenomenon in Romania has become a current aspect lately, on the one hand given the extent of its evolution, and on the other, given the major imbalances it creates, within the territorial systems involved. The methods illustrated above, used within this study, have achieved scientific grounds and objectively illustrate the extremely alarming situation, contributing to the development of forest fund dynamic analysis methodologies.

The fractal analysis highlights a series of characteristics for the forest or deforested areas, which the methodologies fail to emphasize, with the methodological bonus that contributes to modeling the complex impact on the natural environment. Compact deforestation effects may be catastrophic, leading to imbalances such as landslides or floods.
Isolated afforestation, corroborated with the previous stipulated ones, has complex consequences on the territorial systems in question. The most important consequences can be the occurrence and multiplication of primary economic activities (logging and wood transportation), low-income generating activities, subsistence activities for the economic systems involved, thus creating a mono specialization of said systems. Functional mono specialization of territorial systems leads to their economic vulnerability.

For this reason, the optimal solution for territorial systems dependent on timber processing is not considered, except for the rational, efficient and sustainable operation. This can be achieved only by the collaboration between all stakeholders. Out of these, an important role is raising awareness on the forest role, as well as efficient and rational operation thereof in local communities.
The forest role shall designate, in one word, the estimated available resource (forest area protection role), whereas efficient and rational operation shall designate its commercialization by adding value for the purposes of selling the added value timber (finished products, not raw products), rationally, by continuous regeneration of forest areas, through replanting (Vanclay and Prabhu, 1998; Wang and Wilson, 2007).
Of course, to achieve this goal, local authorities play an important role, creating timber operational and efficient processing micro enterprises. This leads up to the level of central authorities, resulting in the mode of adoption and enforcement of a legal framework in the forestry area.

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