Assessment of the Forest Disturbances Rate Caused by Windthrow Using Remote Sensing Techniques

Paula Furtuna[1], **I. Haidu**[2], **I. H. Holobaca**[1], **M. Alexe**[1], **Cristina Rosca**[1], **and D. Petrea**[1]

[1]Faculty of Geography, "Babes Bolyai" University, Cluj Napoca, Romania
[2]Laboratoire LOTERR, Université de Lorraine, France

Abstract— Change detection using multi-temporal satellite images data is an important domain with various applications in forestry and can allow an evaluation of areas extended to the same spatial temporal scale. The focus of the study is to assess the changes occurring after catastrophic wind events using Landsat time series data. Estimates of disturbance rates are derived using 8 sample sites selected across the Apuseni Mountains during 2000–2014 periods. Multi-temporal analysis on annual basis has detected the patterns of the changing forest ecosystem and the trends that are occurring and give more accurate results. The satellite images have been calibrated and the root mean square error has been made The satellite images preprocessing is made in order to transform the DN values into the surface reflectance. The approach requires images during the peak growing season. Local knowledge and available ancillary data about windthrow occurrence are required in order to fully understand the nature of these trends. The statistical algorithms are applied to characterize the magnitude of the disturbance. We found evidence of systematic change in the forest ecosystem of the Apuseni Mountains by analyzing multi-temporal surface data. The accuracy of forest disturbance detection diminishes with the decrease of the temporal resolution. Therefore, the approach described in this paper demonstrates that the Landsat time series data can be used operationally for assessing forest cover changes analysis after a windthrow occurrence across a large area.

1. INTRODUCTION

Forests are one of the most important components of the global biosphere and have critical influences on the Earth's ecological balance, [11]. The forest vegetation is constantly changing [6]. The changes causes can be determined by anthropic or natural factors. Natural disturbances play an important role in forest ecosystem, but they can cause huge economic damage. Forest disturbance by wind varies from large-scale to small scale perturbations operating at the scale of individual trees [4]. According to [1] storms are responsible for more than 50 % of all primary abiotic and biotic damage by volume to European forests from catastrophic events. In the Romanian Carpathians, recent statistics shows that about 28% from the Romanian afforested surface is vulnerable to windthrow phenomena, [9].

The overall aim of this research is to detect and assess the forest disturbances rate over Apuseni Mountains by using Landsat multi-temporal images and by calculating spectral indices, including the red-edge band and other commonly used vegetation indices. Based on the differences of histograms among different forests we obtained the 2000–2014 forests distribution for Apuseni Mountains at a spatial resolution of 30-m $\times$ 30-m.

2. METHODS

2.1. Study Sites and Data Used

The study area is located in the Western Romanian Carpathians, Apuseni Mountains-which lies between the Pannonian Plain and Transylvanian Plateau, (Fig. 1). It encompasses 10750 km^2, with geographic center located at 46°21' N and 23°02'E. The mountains are of no great height except for a central area where there are several peaks higher than 1800 m.

The mean annual air temperature is 6–10°C and means annual precipitation is 700–1000 mm [5]. The air circulation is predominantly westerly and the mean annual values of air temperature are generally lower on the western slopes, compared to the eastern ones at the same altitude, as a result of the interaction processes between the surface of the slopes and the moving air. Prevailing winds in the region generally came from the west, on the eastern side of the Apuseni Mountains the föehn is felt as a local wind. In certain synoptic conditions the wind may reach maximum speeds of over 40 m/s in the area with high altitudes. On the eastern slopes of the Apuseni the maximum wind speeds reach 28 m/s and 16–27 m/s in the rest of the areas.

The potential natural vegetation is formed by zonal mixed beech (Fagus sylvatica)-fir (Abies alba)-spruce (Picea abies) forests and spruce (Picea abies) forest.

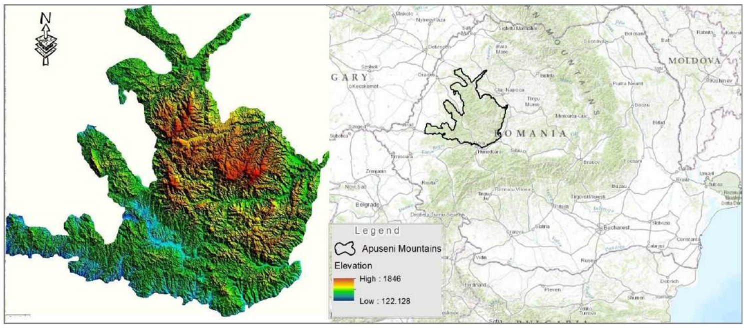

Figure 1: Location of study area.

Assessment of the windthrow occurrence using the remote sensing data requires satellite images from the year before and the year after the windfall event. At the same time the estimation of rate disturbance requires the use of scenes covering a longer period of time to achieve better results and representation of changes in the forest environment and to determine trends. Use of dense image acquisitions is therefore necessary in order to minimize potential omission errors in derived disturbance products [3].

To conclude the study we used database which contain Landsat satellite imagery and forestry data. Forestry data is represented by inventory tables of windthrow occurrence for the years 2002, 2004, 2006 2007, 2011 and 2013.

The satellite images was obtained for 2000-2014 period and corresponding for Path 185/Row 28 and were acquired during the growing season. The Landsat sensors are particularly appropriate for providing the imagery used to generate change information for assessing and monitoring natural resources, [10].

2.2. Spectral Indices

The pre-processing operation was made in order to calculate the root mean square error (RMSE) and to convert the digital number into surface reflectance, necessary to carry out the following operations. A low pass filter (kernel size: 3×3) was applied to the images to reduce radiometric noise as well as enhance the effectiveness in detection process.

The main workflow steps of windthrow analysis include: (i) detecting the disturbance pixels; (ii) calculate the spectral index; (iii) filtering training data and disturbances pixel through a number of statistical filters; (iv) mapping forest disturbance.

We generated indices to evaluate the optical properties of disturbance in forest ecosystem. The spectral indices used in this paper including: NDVI, NDVI 750, GI, and NNIR, (Table 1).

NDVI was used because is positively correlated with total green biomass [8] and is useful because it shows spatial and temporal trends in vegetation dynamics, productivity and distribution [7]. The NDVI 750 index was found to show maximum sensitivity to a wide range of chlorophyll contents [2].

Table 1: Vegetation indices used for the performance evaluation.

Name	Formula	Application	References
NDVI (Normalized Difference Vegetation Index)	(NIR–Red)/(NIR + Red)	Biomass, stress, vitality	[12]
NDVI 750 (Red-edge Normalized Difference Vegetation Index)	(R750-R750)/(R750+R750)	Changes in leaf and canopy structures	[2]
GI (Greenness Index)	Green/Red	Chlorophyll activity	[5]
NNIR (Normalized Near Infrared)	NIR/(NIR + Red + Green)	Biomass, chlorophyll activity	[11]

3. RESULTS

The forestry area was analyzed by first masking out the non-forest land cover classes and the spectral indices were standardized around the scene mean forest value to obtain better results. The windthrow detection was made based on the relationship between the spectral indexes. Tracing the polygons for affected areas (Fig. 3) was made automatically by establishing the difference between the spectral indices calculates for each year's corresponding for before and after period of each windthrow.

Next step consisted in delineating of windthrow concentrations. The separability filters allowed us to determine how distinct and separable the vegetation indices for the disturbed surface are from each other. The frequency filter was applied to spectral indices used for 2000–2014 period to show the spatial frequencies of each pixel for disturbed areas. Also to determine the number of pixels associated with the major disturbance and to characterize the temporal trajectory for a change pixel. The scatter plots were used to locate the disturbed pixels and capturing change

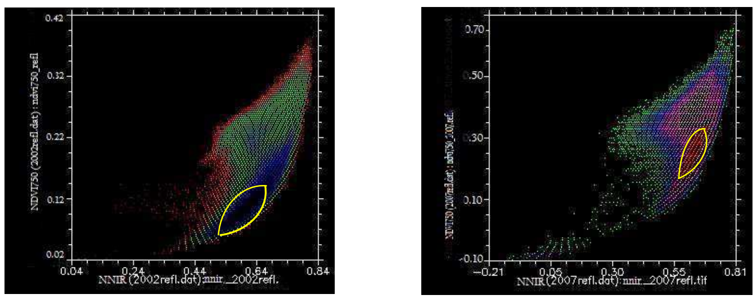

Figure 2: Scatter plots used to locate the disturbed pixels (example for year 2002 and 2007).

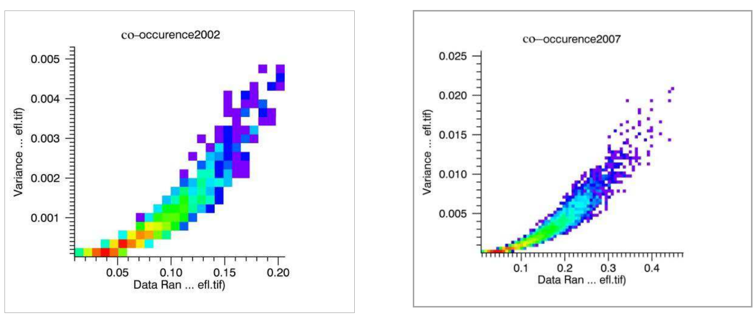

Figure 3: Relationship between the co-occurrence variance and the vegetation indices (example year 2002 and 2007).

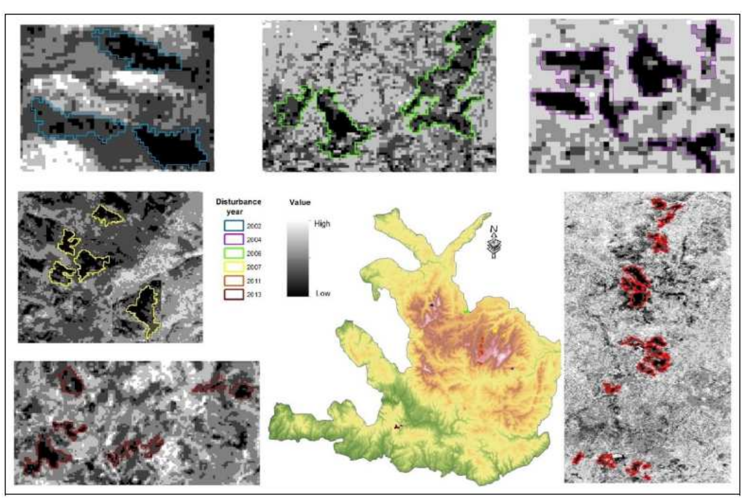

Figure 4: Windthrows area detected for 2000–2014 period.

events, (Fig. 2).

The co-occurrence filters were used to generate, based on disturbed area vegetation indices value, features for each disturbed area. The relationships between the images for before and after windthrow were "texturally" distinct when the disturbance occurred. Therefore the images were classified in three classes constant forest, disturbed area and constant other classes. Spectrally two stands can be confused, but the difference in structure and the resulting texture by applying a filter allow distinguishing between them. This filter includes mean, variance, homogeneity and correlation. Monotonic relationships were observed between the variable for these filter and vegetation indices (Fig. 3).

The synchronicity of each windthrow detected was evaluated by consulting the meteorological information to confirm the occurrence of a storm in the area and by consulting forest company archives.

4. CONCLUSION

Through analysis of multi-temporal Landsat data, we found evidence of systematic change in forest ecosystem from Apuseni Mountains. The similarities of the vegetation indices in near-infrared limit the ability to distinguish between windthrow area and harvest, therefore the windthrow area have been established by using forestry and meteorological data.

The approach described in this paper demonstrates that Landsat data can be used operationally for assessing forest cover changes analysis after a windthrow occurrence but the local knowledge and available ancillary data about windthrow occurrence are required in order to fully understand the nature of these trends.

Further investigations are, still, required into how the relationship can be modeled between the disturbance probability values obtained from this approach and the results obtained from forest monitoring on ground truth data.

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