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Landscape structure characterization with the application of NDVI and fractal dimension of remote sensing imagery in Zabory Landscape Park

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ABSTRACT: The Zabory Landscape Park is part of the Bory Tucholskie Forest, one of the largest forest complex in Poland. This area has very interesting history recorded in a collection of old cartographic data as well as more contemporary and nowadays airborne and satellite imageries. Human economic activities, e.g. cutting primary forests, agricultural use through few centuries of the some areas, and restoration of forest on former fields, heathlands and poor pastures especially utilized by sheep, have influenced the contemporary structure of dominating forest landscape. The most intensive rate of changes in the exploitation of this area took place in the second part of 19 and beginning of 20 century, when large agricultural areas were afforested. There were many reasons for those changes, ecological, economical and political. On the basis of preliminary observations, contemporary structure of forest landscape was defined as quite homogeneous. A clear-signed analysis of vegetation and estimations based on satellite imagery shows greater heterogeneity, which expressed the most important changes having take place during the last 200 years. Contemporary plant cover in the Zabory Landscape Park is the resultant of : 1 – spatial variability of natural ecological factors, 2 – changes in the use of the area in the past, 3 – contemporary spatial distribution of economic processes mainly in forestry. The influence of the last group of factors is considerable because of its location in the research area near managed forests, many natural reserves and the "Bory Tucholskie" National park, which was founded in the southern part of the Zabory Landscape Park in 1995. The aim of the project is to define the influence of two groups of anthropogenic factors from point 2 and 3 on spatial variability of the value of Normalized Differential Vegetation Index and fractal dimension analysed on the basis of NDVI map in different parts of the Zabory Landscape Park. This analysis took place in GIS technology which enabled integration of data from cartographic materials, phytosociological ground research and satellite remote sensing.

1 INTRODUCTION

The deforestation and transformation of forest ecosystems into non-forest one make considerable changes in the structure of soil. They are especially substantial when a forest is transformed into an intensively explored field, and after this intensive exploitation it is reforested. Changes in sylvicultural soils which are temporary used for farming exist long after the reconstruction of the reforested ecosystem. They can be seen in the variable structure of tree stands and the rest strata of the forest. Considering trees, structural variability may cover species composition as well as biomass, in it green biomass of assimilative organs of trees. In remote sensing one of the most often used index of the assimilative apparatus of phytocenosis is NDVI. The map of spatial variability of this index can be the basis for estimation of mosaic landscape which is the result of overlapping natural variability of plants made by variability of habitation and economic processes realised by man. In the forest landscape the most important anthropogenic factor is forest economy.

The characteristic of spatial landscape pattern which is the result of plant variability, can be made with many indices describing among others fragmentation, variability and the amount of patches.

For many years NDVI and structural index have been used to monitor the state of forest ecosystems in the Zabory Landscape Park. The parts in which economic forests are dominating were especially analysed (Kunz and Nienartowicz 1999; Kunz et al. 2000, Nienartowicz et al. 2001) is project considers the creation of NDVI and indices of the landscape structure pattern of the part of the landscape park in which the National Park has been founded and be-

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cause of it economic activities have been stopped. In the past, northern and southern part of the area belonged to different administrative units. Because of it the area was used in different way. The aim of this research carried out with the financial support of Polish Research Committee No 6 P04F 04321 was to define the influence of area exploitation history before the creation of the park on NDVI, and indices characteristic for landscape structure.

2 STUDY AREA

Founded in 1985 the Zabory Landscape Park (Fig. 1) is situated in the southern part of Pomorskie voivodship , on the west from Brusy city and about 5 kilometres from Chojnice city. Its area is about 38 000 ha. Forest ecosystems dominate in the Park, and they cover about 80% of its area. Considerable area is covered by lakes (15%), and the biggest of them – Charzykowskie lake has the area of 1440 ha. Other big lakes are Karsinskie and Ostrowite. Brda the biggest river of this region flows through Charzykowskie lake and Karsinskie lake. The river also flows through many smaller lakes: Łackie, Witoczne, Dybrzyk, Kosobudno. The most important Brda's tributary is the picturesque Zbrzyca river crossing the northern part of the Landscape Park. In physic-geographic regionalization the park is localised on the Charzykowska plain (Kondracki 1982), and taking into account division obligatory in sylviculture it belongs to Bory Tucholskie District (Trampler et al. 1992). The area substratum is a vast outwash plain crossed by rivers and lake channels. There are also many melting lakes and many of them are lobelia lakes. The elevated, sand area is covered on considerable territory by one-species pine forests, mainly fresh and dry. Forests in the northern part of the park belong to Przymuszewo Forest Inspectorate, and in the southern part to Rytel Forest Inspectorate. The forest area is divided into regular figures of pine tree stands. On each of these territories there are trees of the same age. Small territories are covered by wet forests on mineral ground, and swampy forests on moors. Leafy forests exist only in river valleys and around lakes. In their trees there are mainly a black alder *Alnus glutinosa* and a downy birch *Betula pubescens*. The main additional species in dry and fresh forests is a silver birch *Betula pendula*. It is often grown along roads and near dividing lines creating fire belts. In the northern part of the park considerable additional species is a European beech *Fagus sylvatica*. Beech forests cover very small areas in river valleys, especially in Kulawa's valley which is an inflow of the Zbrzyca river, and on sides of lake channels. Fertile oak-hornbeam forests are on very small areas only in the northern part of Milachowo lake. In the past they covered bigger territories; however, after the introduction of planned forest economy leafy tree stands were cut and the areas were afforested with pines (Hjelmroos-Ericsson 1982). Today, in the area of those forests there are monocultures of a Scotch pine with the specific undergrowth where grass *Deschampsia flexuosa* is dominating or combination of species *Pteridium aquilinum, Hieracium lachenalii, Holcus lanatus,* etc.

The "Tuchola Forest" National Park was founded in 1995 in the northern part of Zabory Landscape Park. It covers the area of 4 794 ha. Fresh and dry forests are dominating, here. The park is situated in the eastern part of Charzykowskie lake near Charzykowy, which is a recreation area for inhabitants from Chojnice and other parts of Poland. Ostrowite lake is in the eastern part of the National Park, and Krasinskie lake is in the northern part of the Park These are two big lakes. The central part of the Park is crossed by the small river which flows through eight lakes and falls into Charzykowskie lake. Today, it is one of the main natural values of the park. In the past, it was the border between territorial units, from 1308 in the Teutonic State, after 1454 in Royal Prussia which belonged to Poland, and after the first partition of Poland in 1772 in Prussian State.

The area belonged to different administrative units and it was exploited in different ways. On Schrötter-Engelhard Prussian map from the turn of the XIX century and also on the economic map of Prussian Forest Chotzen Mülle Inspectorate the area on the northern side of the river, between Zielone lake and Plesno lake was separated and built over. On the southern side of the river which belonged to the Klosnau Forest Inspectorate there was a forest. Today both areas are covered with pines.

When the National Park was founded forest economy in this area was limited and changed, among others cuttings were decreased and it made the age and biomass of tree stands higher than in forests surrounding the National Park. This started the increase in homogeneity of the landscape. On the other hand, last cuttings took place on the edge of the Park with the use of ecological technologies, clumps of old tree stands were left and more leafy species were introduced, e.g. surficial, congeneric plantings of birches or mix of more than one leafy species of an oak, beech, birch. This contributed to the increase in forest landscape mosaic.

In economic forests around the Park wood harvest was much more intensive than in the area of the National Park during the last years. Bigger number of logged areas increased the mosaic of the landscape. However, here also the new rules of sustainable forestry were employed. The areas of cuttings were smaller, and some tree stands were left, areas were reforested after half-year resting, and leafy species were introduced, group and multiply fallings took

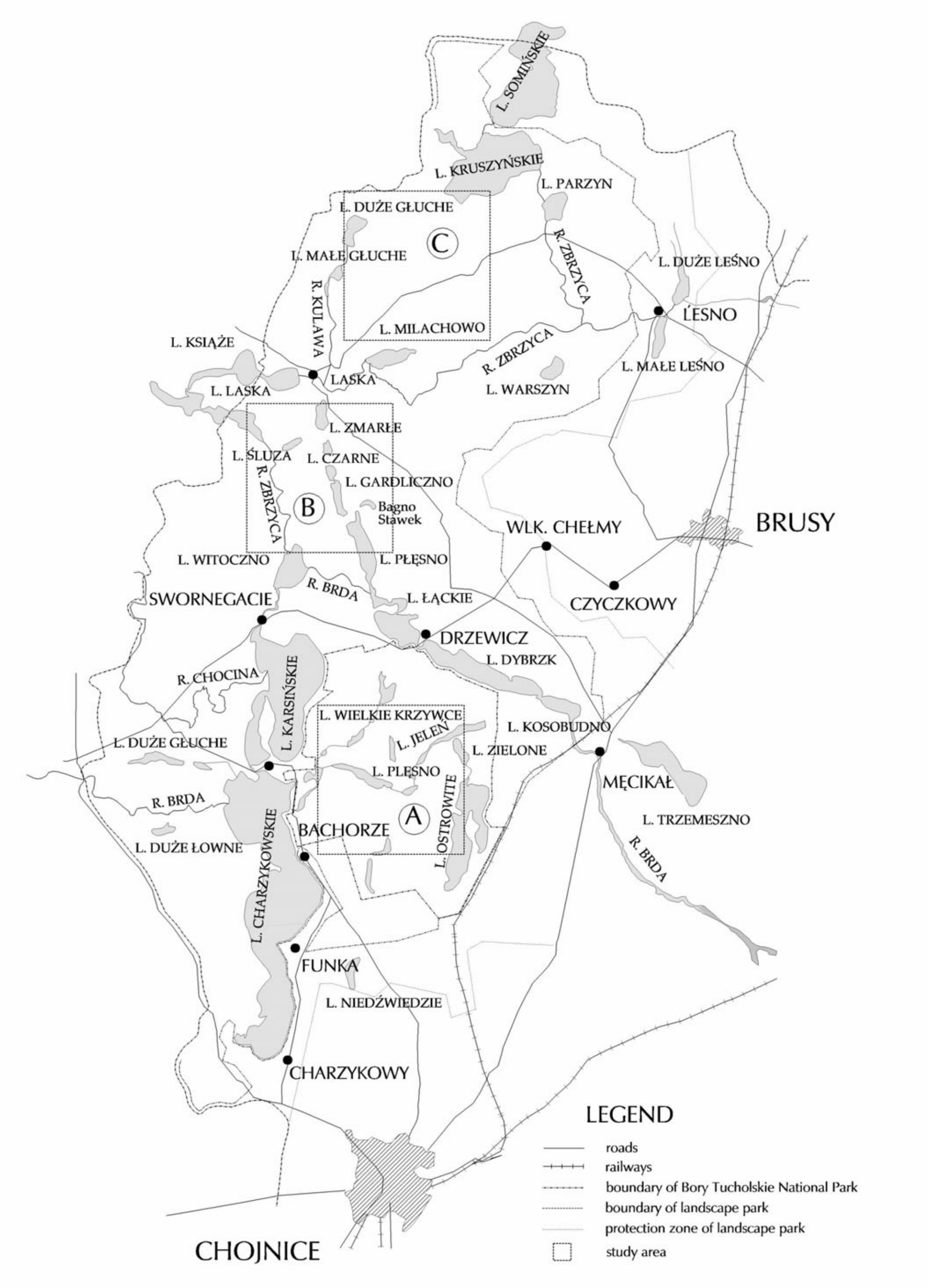

Figure 1. Situation of study area

place and the cutting age of tree stands was increased. These activities differentiate contemporary forest economy in the whole area of The Zabory Landscape Park from the economy realised here 30-50 years ago. Then, large-area cuttings took place and they were reforested with a pine very quickly. The cutting age of trees was much lower than today, stump wood and resin was harvested very intensively.

To establish the influence of past use of the area and changes in technology used in forestry on NDVI and forest landscape structure, three sample areas (each area is 2540 ha) have been chosen, one in the "Bory Tucholskie" National Park and two outside of it. Area A was localised in the Bory Tucholskie National Park, where according to maps from XVIII and XIX century the area was a forest. Area B was localised in the northern part of this National Park, and in 18-20 century there was a forest according to above mentioned maps. Area C was established in the northern part of the Zabory Landscape Park, near Kruszynskie Lake, to the east from Kulawa's valley. Additionally, within each biggest area A, B and C sample plots have been chosen and they have 300x300 meters each. These sample plots have pine forests of different age.

3 METHODS

Spatial change of landscape pattern was analysed on the basis of Landsat ETM+ satellite imagery made on 5 May 2000, with 30 meter resolution. ArcView Image Analyst and Idrisi-32 software was used in image analysis.

The indices have been used for quantity estimation of plant biomass and spatial variability of its resources which are NDVI and FD. The second index has been calculated by the Triangular Prism Method (TPM) (Altobelli at al. 2001, de Jong and P. Burrough 1995).

For each of sample areas (5040m x 5040m) the normalised difference vegetation index of separate pixel was counted according to the formula:

$$NDVI = [IR - RED] / [IR + RED],$$

where RED and IR are reflectance values equivalent to Thematic Mapper (ETM+) Bands 3 (RED, 630-690 nm) and 4 (IR, 780-900 nm).

Mean value of NDVI, range of its changes, and standard deviations were also defined. Total theoretic range of change NDVI from –1 to +1 was graduated into 256 classes which had numbers from 1 to 255. Frequency and percentage of pixels in each class were defined, histograms were prepared.

Additionally, diversity and fragmentation of sample areas were calculated by marking in their areas squares covering different number of pixels. Three sizes of squares comparing 3x3, 5x5 and 7x7 pixels were used in analysis.

Diversity was calculated using Shannon's formula:

$$H = - \sum_{i=1}^{n} p_i \ln p_i,$$

where p_i is share of i – th is class pixel (i = 1, 2, 3, ..., n), n – number of pixel categories in a square.

Fragmentation was calculated according to the formula:

$$F = (n - 1)/(c - 1),$$

where n states, as in the previous formula, number of pixel categories, and c – number of pixels in a square (9, 25 or 49).

Each area was characterised by average H and F values. This was arithmetic average from values calculated for a square group the middle area of which was one by one each pixel of the sample plot. Working according to this schema for pixels at the borders of analysed plot chosen squares 3x3, 5x5, 7x7 covered also pixels out of the sample plot. To preserve the same calculation formula for all squares of sample plots in diversity and fragmentation analysis, three additional ranges of pixels being out of each border of analysed area were taken into consideration.

Such activity was according to suggestions concerning the above method, which were stated by Upton and Fingleton (1985), Hauser and Mucina (1991).

The same indices were also calculated for small research territories of 300 x 300 metres which represented tree stands of different age: 60-80 years, 80-100 years and over 100 years.

With the use of GIS technology the distribution of patches marked on satellite imagery was compared with the structure of land cover defined on the basis of historical cartographic materials.

4 RESULTS

The variety of forest habitats in the area of the contemporary Bory Tucholskie National Park can be seen very well on satellite imagery - Landsat ETM+ from 5 May 2000.

In satellite imagery there are considerable differences in Normalized Differential Vegetation Index (NDVI) between the part of the Park which is to the north from Seven Lakes Stream and the part to the south from this stream. This notice is in accordance to the map of real plants of this area on which in the northern part there are more dry forests *Cladonio-Pinetum* and subset *cladonietosum* of fresh forest

Leucobryo-Pinetum, and in the southern part from Seven Lakes Stream there are more typical fresh forests.

On the basis of comparisons, it was stated that areas localised in the Bory Tucholskie National Park were characterised by higher NDVI values than other areas (Tab. 1)

Table 1. Changes of NDVI and fractal dimension in sample areas.

	A	B	C
NDVI	0,3097	0,3086	0,2949
FD	2,5003	2,4526	2,5492

In the area of higher preservation statutes, NDVI exceeded a little 0.3 value. In the area covering secondary pine forests in which intensive wood production took place, average NDVI value did not exceed that value.

However, the area above the Bory Tucholskie National Park, which in the past was also forest territory, has very similar NDVI. Little difference appeared especially because of preservation status of area A.

Spatial distribution of normalised vegetation index for three described areas is presented on Figures 2-4.

Different distribution is characteristic for fractal dimension index calculated with the method of the Triangular Prism Method (TPM). The index reaches the highest value in the area C localised in northern part of Zabory Landscape Park, and the lowest in the area B. These are 2,54 in the area C and 2,45 in the area B.

Comparing other indices of landscape pattern (Tab. 2) there should be noticed the increase in fragmentation and variability in the research area C with dominating poor pastures. This fact is influenced by economic activities which take place in the areas outside of preserved territory.

Table 2. Changes of landscape pattern indices for different kernel size on sample areas.

Study area	**landscape indices**	**mean value / kernel size**		
		3x3	5x5	7x7
A	fragmentation (F)	0,7781	0,6532	0,5470
	diversity (H)	1,8694	2,5517	2,8752
	Dominance (H_{max}-H)	0,0548	0,1577	0,2586
B	fragmentation (F)	0,8043	0,6957	0,5972
	diversity (H)	1,9061	2,6161	2,9610
	dominance (H_{max}-H)	0,0480	0,1535	0,2427
C	fragmentation (F)	0,8228	0,7028	0,5973
	diversity (H)	1,9541	2,6678	3,0078
	dominance (H_{max}-H)	0,0463	0,1414	0,2378

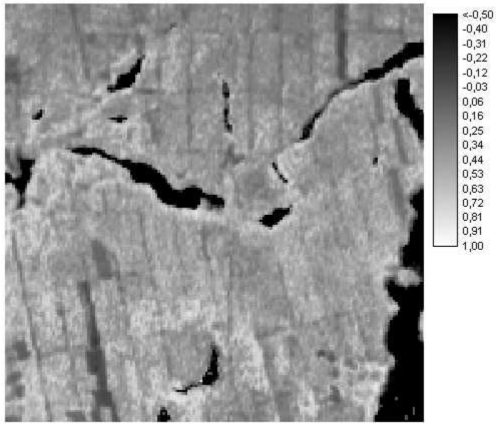

Figure 2. Spatial changes of NDVI on sample area A

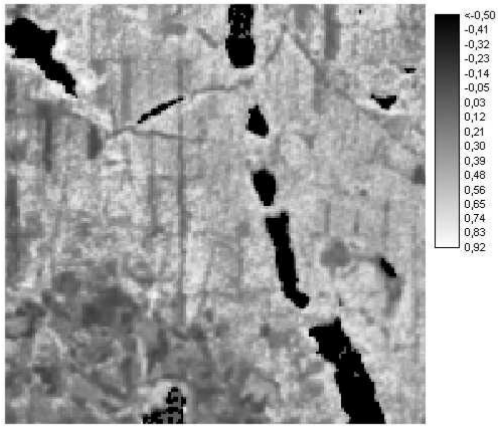

Figure 3. Spatial changes of NDVI on sample area B

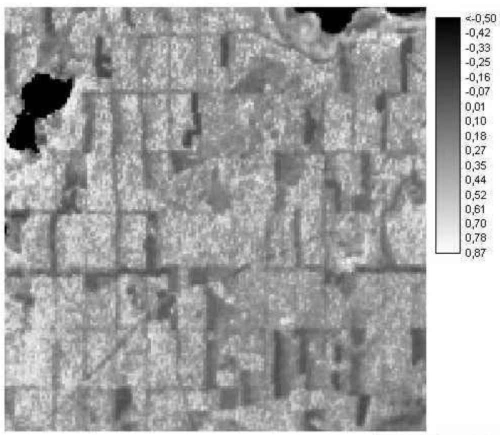

Figure 4. Spatial changes of NDVI on sample area C

From the analyses of result presented in Table 2 it was also concluded that when the area of a square was enlarged (one after the other 9, 25 and 49 pixels) there was the increase in diversity and in dominance and decrease in fragmentation.

Comparing NDVI in age classes it should be stated that the difference is especially considerable in 60-80 years age class (from 0,3368 in the area C to 0,5547 in the area A). In the following age classes of pine tree stands this tendency is preseved, but differences are not so considerable.

5 DISCUSSION AND CONCLUSIONS

From the comparisons of ranges and average index values of vegetation on separate areas and historical cartographic materials it was concluded that NDVI corresponded with the way the land was used. The similar effect is characteristic for fractal dimension.

The value of NDVI in this part of the Bory Tucholskie National Park is also higher than the value characteristic for areas around the Park. Spatial differentiation of spectral answer of plants in this region corresponds with spatial and time distribution of various natural ecologic factors and it is the place for the realization of main economic processes in the past.

On the forest areas situated in northern part of the Zabory Landscape Park where C area was defined, there was more pine forests restored on post-agricultural areas. Considering species composition they related to dry forests. This similarity resulted mainly from smaller share of dwarf shrubs, and high frequency and cover of overground lichens. Substantial area of this part of the landscape park was covered by *Pinus-Calluna* community marked by Boiński (1988). Heath forests were created mainly because of reforestations of poor pastures between XIX and XX ages. In this community besides common heather, moss and lichen were very important. Other forest groups dominated in southern part of the analysed area, which was the place where the National Park was created. Because this area was not agricultural in the past, and degeneration of forest communities was connected mainly with the introduction of pine monocultures for clear cutting, today fresh pine forest were dominating here, and they were classified as *Leucobryo-Pinetum* As it was presented by Barcikowski (1996), those forests were characterised by higher level of green biomass and chlorophyll content than dry forests. It was connected not only with mature treestands, but also with all analogical development phases in secondary forest succession in those habitats. Because of lower green biomass and lower chlorophyll content in one area unit, noticed in forests similar to dry forests, NDVI in formerly arable complexes, in which such phytocenoses were dominating, was lower. It was established with remote sensing methods and described in separate paper by Kunz et al. (2000).

Achieved average NDVI values are approximate to data given for plantations of other pine species in different parts of the world. Values gained for Zabory Landscape Park are approximate to 0.3 – 0.5 values, which were presented for *Pinus densiflora* plantations in Japanese mountain regions by Lee and Nakane (1997). Gholtz et al. (1997) analysing spectral answer of *Pinus elliotti* var. *elliotti* in Florida, USA, gained higher values 0.55-0.66. So high NDVI values in Zabory Landscape Park are reached only by forests with older treestands, and big density in fresh pine forest habitat.

The dependance among NDVI and fractal dimension, and fragmentation and variability should be noticed. When NDVI increase some other indices decrease. Moreover, the changes of these indices along with kernel size increase is also noticed.

The high value of fractal dimension in the area with agricultural and pasture past results from considerable age variablility of trees stands.

To compare landscapes a satellite image from 2000 was used. The foundation of the National Park 5 years earlier has influenced landscape structure, but these changes will be more visible on satellite imageries prepared later and in imagery detected with better resolution. This will make it easier to perceive economic activities which take place in the area of the National Park, mainly leafy platings which lead to changes in pine monocultures.

On the basis of analysis of satellite imagery it was stated that three sample plots were different in the spectral respect and the results are indices of changes which took place in these parts of the park during the last 200 years.

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