GeoInformation in Europe, M.A. Gomarsca (ed.)

Variation of NDVI in seminatural and secondary forests: a case study of Zaborski Landscape Park

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Keywords: NDVI, secondary forest, green biomass, landscape structure

ABSTRACT: The research on anthropogenic processes and natural factors was carried out in the Zaborski Landscape Park (the central part of the largest, dense forest complex in Poland – Bory Tucholskie). Three study areas 5040 × 5040 m of various human influences were designated in the park: starting from the area of intensive forestry to a legally protected area (the national park created within the landscape park in 1996), where forest management is very limited. Today, all study areas are dominated by forest ecosystems. Within each study area, 25 sample plots (squares with a side of 300 × 300 m) were selected for further analysis. These sample plots represent all age classes of treestands growing in habitats of fresh and dry coniferous forests, which are dominating in the study area. For those selected sample plots, temporal changes of the NDVI indicator were calculated on the basis of seven Landsat satellite imageries from the period of 1975 to 2003 (four imageries registered by MSS scanner, one by TM scanner and two by ETM +). Additionally, for one study area, a high-resolution IKONOS satellite imagery of 2004 was used. At the same time, applying the GIS technology, the history of afforestation in this area was reconstructed, starting from 1796, on the basis of available cartographic and topographic materials. Also, the data basis of subdivisions was created (the basic forestland unit on which forest management works are performed), which comprises information on the spatial structure, habitat, age and species composition of the forest stands.

1 INTRODUCTION

Satellite remote sensing is successfully used in studies on the present landscape structure and in the analysis of its former conditions. In forest areas, the technology using satellite imageries is often applied for the evaluation of landscape structure modified by cutting down of tree stands and the reconstruction of a forest. However, landscape conditions observed at the moment of satellite recording are not only the result of the present spatial structure of multi-aged treestands, but also of the former conditions of individual forest divisions and subdivisions. Anthropogenic factors are of great importance here, such as the number of tree generations introduced in the past during the forest regeneration or long-term deforestation to gain areas for agriculture, and duration of agricultural exploitation of a formerly forestland. Anthropogenic processes transforming the spatial landscape structure are compounded by natural factors e.g. terrain orography or the type and moisture of the soil.

The aim of the research was to define the spatial and time variation of NDVI in relation to former human management within the Zaborski Landscape Park with reference to the age structure of treestands defined in 20-year-old intervals, and the type of habitat overgrown with this forest stand. The performed research is mainly connected with the problem how to determine ranges of secondary forests occurring on formerly arable soils.

Additionally, within the selected sample plots, the evaluation of their variability was performed, which results from the intra-phytocenosis structure. In order to do that, dendrometric measurements of treestands were conducted in groups of nine squares, 30×30 m each. These measurements were done on five plots situated within the oldest pine forest stand, 87–127 years old, growing in the habitat of a fresh pine forest. They enabled to assess the biomass of conifer needle litter, and to define the relationship between the green biomass and the structure of the whole plant community described with the *relevé* method according to Braun-Blanquet, and with obtained NDVI values.

2 STUDY AREA

The research took place in the area of the Zaborski Landscape Park (ZLP) in the Bory Tucholskie natural district, covering one of the biggest forest complexes in Poland. The area is situated in Northern Poland in Pomeranian voivodship. By order of the administration, this is the area of Chojnice and Brusy communes, and it is situated respectively to the north and west from these cities. Today forests (71%) and aquatic ecosystems, mainly rivers and lakes (13%) are dominating in the area of the park. This area was finally shaped by the youngest Baltic glaciation. This is why very differentiated post-glacial forms of the sculpture of the Earth surface are also here as valleys, channels, and small lakes, which together with hummocks of dunes create fully differentiated landscape.

The spatial variability of landscape created by natural factors is covered by heterogeneity introduced by 130 years of intensive forest economy which took place in this area. Forests are managed by The Regional Management of State Forests in Torun. In spite of strong environmental changes of forest communities, the nature of this area is of such good values that in 1996 in the southern part of the landscape park the Bory Tucholskie National Park (BTNP) was created of the area of about 48 km^2. Except the national park, in the researched area there are six nature reserves.

Three study areas 5040×5040 m of different human influence were designated in the park: starting from the area of intensive forestry to legally protected area (the national park created within the landscape park in 1996), where forest management is very limited. Today, all study areas are dominated by forest ecosystems. Within each study area, 25 sample plots (squares with a side of 300×300 m) were selected for further analysis. These sample plots represent all age classes of treestands growing in habitats of fresh and dry coniferous forests, which are dominating in the study area.

3 METHODS

Multitemporal satellite imageries Landsat from 1975 to 2003 were used in the study. Only for the third study area – BTNP, IKONOS satellite imagery was used. Imageries were processed and maps were created with GIS technology with the use of ArcView program together with its extensions. In each of three study areas, 25 sample plots were chosen with the size of 300 $\times$ 300 m representing various age classes, types of forest habitat, and the history of its afforestation. The size of sample plots related to 16 pixels of satellite imageries Landsat MSS, 100 pixels of satellite imageries Landsat TM and Landsat ETM + and 5625 pixels of IKONOS imagery.

NDVI for the chosen sample plots was calculated according to the formula proposed by Rouse *et al.* (1973) (NDVI = (IR−R)/(IR + R), where IR means near-by infrared radiation, and R – red radiation).

By using other levels of information from created Geographical Information System (GIS) of the Zaborski Landscape Park (Kunz 1999) the history of this area afforestation was defined, and the dependence of spectral response on the age of treestands and the type of habitat were described.

The estimation of the range of inter-phytocenosis variability structure within one forest, the area covered with the same plant community – subocean fresh coniferous forest *Leucobryo-Pinetum*. Dendrometric measurements of a Scots pine were done on a few stands to assess the fresh biomass of Scots pine needles. Measurements concerning the tree stocking and spatial distribution were done in six forest subsections with pine treestands of a higher age class. Two subsections were situated in the Bory Tucholskie National Park, and other four in the Zaborski Landscape Park (two of them in Kruszyn and Laska study areas). Each sample plot consisted of 9 squares 30 $\times$ 30 m, creating a bigger square of 90 $\times$ 90 m, which relates to the area of 3 $\times$ 3 pixels for the imagery of Landsat TM and ETM + satellites. The size of the area was 8100 m^2. In the study concerning tree stockings, their spatial distribution in all sample plots, there was the total number of 1295 living pine trees and 201 cut tree stems. Both categories of trees were introduced as point elements on numeric maps to the GIS system.

4 RESULTS

The mean value of NDVI has been calculated for all sample plots distributed in the study areas on the basis of satellite imageries from 1975 to 2003. No correlation has been stated between the mean age of treestands and the mean value of NDVI, and this is the result of the fact that in following years in one area there were treestands of various ages. However, it was stated that sample plots in the area of a dry coniferous forest had a higher value of NDVI that sample plots localized in the area of a fresh coniferous forest.

In the Kruszyn area, the highest value of NDVI was noticed for a homogenous sample plot, taking into consideration its age, covered by pines in the third age class. The lowest value of NDVI was gained by a heterogenous sample plot, taking into consideration its age, with a forest field dominated by 7 years old pine. Their area share in the age structure of treestands reached 34%.

In Laska study area, there were two sample plots with treestands of the V age class, existing in the area of a dry coniferous forest and they had a higher NDVI values than some sample plots localized in the area of a fresh coniferous forest, but with a characteristic young treestands. The highest value of NDVI in the whole analised period was reached by a sample plot localized in the area of a fresh coniferous forest covered by 123 years old forest. In 2000, the highest value of NDVI was noted for a multi-aged sample plot of covered by the VII age class pines. The lowest NDVI value was on one age sample plot with 92 years old pine.

All sample plots within BTNP study area are covered by treestands of a higher age class in the area of a fresh coniferous forest, now. Sample plots which had been arable lands 200 years ago, had a lower NDVI values than the ones which had been covered by forest all the time. In 2000 the highest NDVI value was on a sample plot uniformly covered by 63 years old pines. The lowest NDVI level was characteristic for the area covered by multi-aged treestands with dominating 111 years old pine.

Analysing the spatial variability of NDVI indexes for all periods in relation to the forest extend in the past (1874), it can be noticed that study areas which had been all the time covered by a forest had higher NDVI values than study areas within formerly arable areas. Negative influence of past agricultural exploitation of the soil on the NVDI level of forest was characteristic for all analysed satellite imageries.

Analysing the record of treestands density, it should be stated that the biggest number of trees was noted in subsection 71a. On this stand there was a total number of 319 living trees with an mean breast height of 30.3 cm and 8 stems of cut trees. Graphical distribution of living trees and stems in this subsection is presented in Figure 1a. The smallest number of trees was noted in subsection 239d. There were only 169 trees and 61

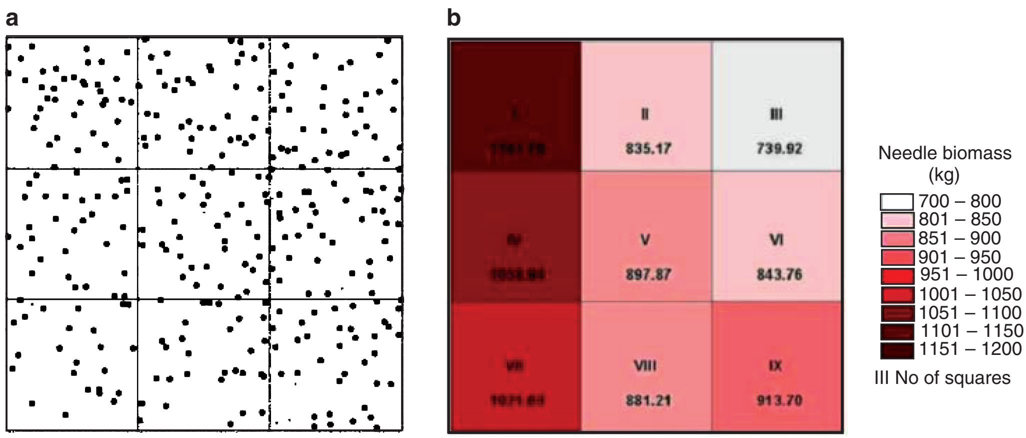

Figure 1. Trees distribution in subsection 71a in 30 × 30 m squares; grey colour shows stems (a), spatial variability of needle biomass according to squares in subsection 71a (b).

Table 1. Needle biomass in kg/square. ha and NDVI value in each forest subsection.

Section. subsection. localization	Plant community	Needle biomass in kg in 1 square (max. min)	Σ needle biomass in kg on whole area (8100 m^2)	biomass kg/ha	NDVI (mean)
173f BTNP	L-P	540.15–936.82	5934.49	8791.84	0.0772 ± 0.014
149a BTNP	L-P	784.46–942.36	2615.38*	9686.59	0.0745 ± 0.017
239d P	L-PCr	322.81–992.33	6214.33	7672.01	0.0741 ± 0.024
71a P	L-P	739.92–1161.70	8353.90	10313.46	0.0886 ± 0.020
79c L	L-P	886.92–1354.06	9464.56	11684.64	0.1216 ± 0.018
39a L	L-P	614.53–858.55	6748.16	8331.02	0.0901 ± 0.023
279d P	L-P			11572.85	0.1190 ± 0.024
144g P	P-C			3204.64	0.0673 ± 0.025
291f P	C-PVm			3883.50	0.0557 ± 0.021
327d P	C-P			2216.67	0.0457 ± 0.024

*Analysed area was 2700 m^2.

Symbols:

localization: BT NP – Bory Tucholskie National Park. P – Przymuszewo district. L – Laska district; plant community: L-P – *Leucobryo-Pinetum*. C-P – *Cladonio-Pinetum*. L-PCr – *Leucobryo-Pinetum* variant with *Cladonia rangiferina*. C-PVm – *Cladonio-Pinetum* variant with *Vaccinium myrtillus*. P-C – *Pinus-Calluna*.

stems. The biggest mean breast height was noted in the sample plot localized in subsection 239d with 107 years old pines. It was 35.9 cm. The smallest mean breast height was in the sample plot localized in subsection 39a covered with 91 years old pine. In this case the mean breast height was 28.4 cm.

The breast height of each tree was used in the calculation concerning the size of its assimilatory organs in a kilogram of the fresh mass of needles. To the calculation the boards of relations between breast height and needle biomass were used. They were made by Lemke (1975, 1988) for pine treestands with the higher density, growing on the habitat of the fresh coniferous forest. Using the map of trees, distribution biomass of pine needles was calculated in each of the nine squares, and then the total mass of needles in one bigger square 90 × 90 m (Table 1) was gained. The example of needle biomass distribution is presented in Figure 1b. The highest values were in squares I, IV, VII. Maximum needle biomass which was 1161.70 kg, was in square I, and the lowest value 739.92 kg was in square III.

In principle, in the presented diagram squares on the left side of the sample plot had considerably higher biomass than plots localized in its middle part and on the right side of the diagram. This was the result of the neighborhood of those squares with the section line, and in consequence there was the better light for trees and less internal competition of pines. More beneficial conditions for the development of pines gave higher needle biomass and higher NDVI value in the satellite imagery. To define the relationship between the size of assimilatory organs and NDVI, needle biomass in 1 hectare (Table 1) of forest was calculated. In the area of 90 × 90 m, on each stand the mean NDVI was calculated on the basis of Landsat satellite imagery from the one year study of the area (2000). The results and data from other studies were used (Kunz and Nienartowicz 2002).

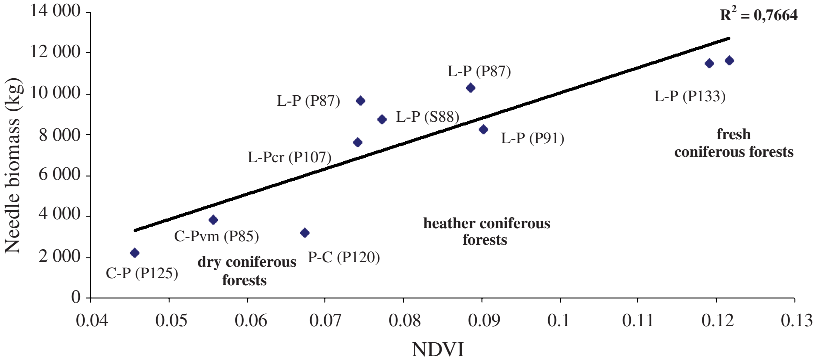

Figure 2. Relation between needle biomass and NDVI index in pine coniferous forests.

Symbols:

plant community: L-P – *Leucobryo-Pinetum*. C-P – *Cladonio-Pinetum*. L-PCr – *Leucobryo-Pinetum* variant with *Cladonia rangiferina*. C-PVm – *Cladonio-Pinetum* variant with *Vaccinium myrtillus*. P-C – *Pinus-Calluna;* in the bracket: P – pine, 87-age of treestand.

For data of various types of habitat quite considerable positive value of correlation factor $R^2 = 0.7664$ was gained (Figure 2). In the figure, there is a clear separateness of dry coniferous forests from fresh ones taking into consideration the size of assimilatory organs and NDVI. Phytocenoses of the first type have considerably lower values. Moreover, there is a big variability of both mentioned parameters within the area of one habitat of fresh coniferous forest. It seems that the age of phytocenosis has had an essential influence on them. Older treestands, 127 and 133 years old from the VII age class, reached considerable higher values of assimilatory organs and NDVI than younger ones from the V age class. Fertility and humidity of the habitat are also very important. This is the result of the fact that phytocenosis representing drier form of *Leucobryo-Pinetum* variant with *Cladonia rangiferina* with 107 years old pine treestands has lower needle biomass and NDVI than younger treestands in the habitat of a typical fresh coniferous forest.

Differences gained for five types of plant groups and communities on the basis of their assimilatory organs biomass and spectral response of their active surface, correspond with differences in species composition and level structure of compared natural objects, expressed in hierarchical method of a numerical taxonomy and presented by Wilkoń-Michalska *et al.* (1999).

5 DISCUSSION AND CONCLUSION

Comparative analysis of study areas made on the basis of satellite imageries has shown differences in spatial structure of landscape in these areas. Plant cover plays the most important part in the analysis of the landscape structure done on the basis of NDVI. The spatial variability index has not only been influenced by differences between separate communities reaching the level of plant formations or types of communities within the same formation, but also by changes within one plant community resulting from structural differences in its separate parts.

The comparison of mean NDVI values in separate areas and historical cartographic materials with NDVI values registered on present satellite imageries are determined by the way the area was used in the past. The analysis prove results of the earlier studies in this area, e.g. Kunz and Nienartowicz (2007, 2004) and Kunz *et al.* (2000).

In comparisons made in this paper satellite imageries from 1975 to 2003 were used. The contemporary state was researched from before and over 8 years after the foundation of the Bory Tucholskie National Park. After the foundation of the national park timber logging was considerably limited and clear cuttings have not taken place there at all. It will be worth to do the whole study once again in this area using similar methods after 2010. Additionally, the study should also be based on high-resolution satellite imageries.

In the study on relations between assimilatory organs biomass and NDVI for all forest habitat Lemke (1975, 1988) tables were used, in spite of the fact that they had been formulated only for fresh coniferous forests. This is why the results for a weaker habitat have some considerable errors. Because of the necessity of large area analysis of plant landcover structure such tables should be formulated also for other forest communities as soon as possible. In calculations of a correlation factor between green biomass and NDVI, only the needle biomass of a Scots pine was taken into account. Taking into consideration in the calculation of green biomass also other levels of a forest (undergrowth, brushwood and ground cover) would give more accurate analysis.

REFERENCES

Kunz, M. 1999. System Informacji Geograficznej (GIS) Zaborskiego Parku Krajobrazowego, In: Barcikowski, A., Boinski, M., Nienartowicz, A. (Eds.), Wielofunkcyjna rola lasu. Ochrona Przyrody-Gospodarka-Edukacja, Wyd. UMK, Torun.

Kunz, M., Nienartowicz, A. 2002. Remote sensing imagery in monitoring spatial pattern changes in forest landscape, In: *Observing our Environment from Space – New Solutions for a New Millenium*, A.A. Balkema Publishers, 391–398.

Kunz, M., Nienartowicz, A. 2004. Landscape structure characterization with the application of NDVI and fractal dimension of remote sensing imageries in Zaborski Landscape Park, In: *Remote Sensing in Transitio*n, Millpress Science Publishers, Rotterdam Netherlands, 435–441.

Kunz, M., Nienartowicz, A. 2007. The influence of past human activity gradient on present variation of NDVI and texture indices in Zaborski Landscape Park, In: *New Developments and Challenges in Remote Sensing*, Millpress, 171–184.

Kunz, M., Nienartowicz, A. & Deptula, M. 2000. The use of satellite remote sensing imagery for detection of secondary forests on post-agricultural soils: A case study of Tuchola forest, northern Poland. In: Casanova L. (Ed.), *Remote Sensing in the 21st Century: Economic and Environmental Applications*. JA.A. Balkema/Rotterdam/Brookfield, 61–66.

Lemke, J. 1975. Szacowanie ciezaru swiezego igliwia sosny zwyczajnej. Sylwan 119(6).

Lemke, J. 1988. Tabele do szacowania ciezaru igliwia i uiglonych gałazek sosny zwyczajnej. Sylwan 127(2).

Rouse, J.W., Haas, R.H., Schell, J.A., & Deering, D. W. 1973. Monitoring vegetation systems in the great plains with ERTS, *ERTS Symposium*. NASA SP-351 I: 309–317.
Wilkoń-Michalska, J., Nienartowicz, A., Kunz, M. & Deptuła, M. 1999. Old land-use maps as basis for the interpretaction of the contemporary structure of forest communities in Zabory Landscape Park. In: *Phytocenosis 11* (N.S.), *Supplementum Cartographiae Geobotanicae*, Geobotanical map in nature conservation, Warszawa-Bialowieza, Warszawa, 139–154.