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THE USE OF REMOTE SENSING METHODS FOR ASSESSING FOREST STAND CONDITION IN NORTHERN POLAND

Zastosowanie metod teledetekcyjnych do oceny zdrowotności lasów w Polsce północnej

The influence of chemical and physical stresses on health condition of three forest complexes was analysed. The first study area consisted of managed forest situated in the vicinity of ANWIL Nitric Company in Włocławek subjected to strong NO_x stress. The second complex is a reserve Las Piwnicki situated near the city of Torun. For the last 20 years old pines and oaks in the reserve have been observed to die as a result of natural processes and chemical stress emitted by town. The third site consists of pine plantations in Zabory Landscape Park. A large part of the study area is covered by the secondary forest restored at the end of 19th century on land temporarily used for farming. Coloured and panchromatic aerial photographs were used to assess the range of NO_x emission effect and the extend of injuries suffered by tree crown in the surroundings of nitrogen works as well as to assess the dying rate of the pines and oaks in the reserve Las Piwnicki. The assessment of the condition of forests in Zabory Landscape Park was based on the NDVI obtained from the analysis of Landsat TM satellite data. The zone of very intensive influence of gas emission on forests growing near the nitrogen works was described on the basis of aerial photographs. It was found that changes in the structure of the upper layer of trees have considerably increased around 1985 in the reserve Las Piwnicki. The pine forests growing in places continuously afforested for the last several centuries have a higher NDVI value than secondary forests restored on former agricultural soils in Zabory Landscape Park. Those secondary forests have been referred to syntaxons *Cladonio-Pinetum* and *Calluno-Pinetum*. Fire risk in those forests is much higher than in the remaining forest types occurring in the park.

1. INTRODUCTION

The structure of forest community is conditioned by the natural process of succession, forest utilisation in the past, and the current anthropogenic factor. The effective tool for discovering and monitoring changes of forest communities within the time and space under the influence of those factors is the analysis of aerial photographs and identification of satellites imagery. That technology has been adopted to the analysis of development and health state of three forest complexes situated in northern Poland (Fig. 1). Those were: I - forests situated in the

neighbourhood of ANWIL Nitric Company, II - forest reserve Las Piwnicki, in which there are extinct pine-trees introduced in the past on the habitat of lime-oak-hornbeam forest, III - secondary forests restored on the areas used for a few centuries as ploughland, infertile meadows, and sheep-runs.

On the first of the sites mentioned above there is the need to monitor the forest health because of chemical company development and changes in technology. The factor which creates the danger for the forest is the emission of NO_x and dust, and also it can be the decrease in ground water level cause by its exploitation by the company for technologic processes. Stand of trees monitoring is very important in Las Piwnicki because of the role of this complex in ecological research. Ecological Station of Nicholas Copernicus University is the part of national monitoring network and it is localised in the Las Piwnicki reserve. Las Piwnicki is a reference point for the estimation of health and development state of managed forests which surround it.



Fig. 1. The Location of study areas: I – ANWIL Nitric Company, Włocławek, II – Las Piwnicki, III – Zabory Landscape Park

The third complex is a part of Przymuszewo Forest Inspectorate, which is in Zabory Landscape Park. In that forest inspectorate forests on previous agricultural fields constitute nearly 50% of its area. The present composition and pattern of forests in the area under study are closely related to previous human activity. On sandy soils exploited through intensive farming, occurs today dry pine forest *Cladonio-Pinetum*. Places occupied in the past by poor pastures, where sheep were grazed and later private forest were planted, are now overgrown with the community *Pinus-Calluna*. In places where forest existence was interrupted only by timber fellings, and the clear-cuttings were soon reforested there are now a fresh pine forest, *Leucobryo-Pinetum*. Syntaxons *Cladonio-Pinetum* and *Pinus-Calluna*

existing on formerly arable lands, and pastures are exposed to the invasion of parasitical fungus, noxious insects and fire. Because the danger is serious the test was made for identification of those communities with a satellite imagery.

The aim of the research, which took place with financial support by grant from the Polish Committee for Scientific Research (KBN P04F 01313) and partly from grant of Nicholas Copernicus University (445-G), was the comparison of different degeneration or regeneration processes of forest communities and identification by Normalised Difference Vegetation Index (NDVI) for forests restored on post-agricultural areas and those growing on lands where the existence of a forest was stopped by clearings and then reforestation took place soon.

2. STUDY AREA

ANWIL Nitric Company is situated about 8 kilometres in north-western direction from the center of Włocławek. On the northern, western and southern side it is surrounded by the complex of forests (Fig. 2). In the near neighbourhood of the company there are abandoned farmlands of previous villages Rózinowo, Leopoldowo and Krzywa Góra. On the eastern side of the company there exists flood terrace of the Vistula valley with a purification plant. There are also a road and railway which belong to the main communicational ways in Poland. The biggest area of the researched land are covered by podzolic soils formed from loose sands or clay sands. In the direct neighbourhood there are river muds and sands. In the wet depressions soils exist created from low peats.

Climate of the described area is characteristic with its weather changes and the lowest amount of rain in Poland – below 500 mm. Most of winds are western and north-western. Periods of silence and weak winds are also often observed, which is the advantage for the concentration of polluted air.

The researched area is covered by the dense pine-forest complex with small enclaves of bog-alder forest and ash-alder flood plain forest. The poorest habitats of fresh pine forest *Peucedano-Pinetum* are covered by mono-cultures *Pinus sylvestris* with intensive developed brushwood of *Padus serotina*. More fertile ground weak clay sands are covered by oak-pine mixed forests classified to *Quercus roboris-Pinetum* association. They exist in big areas. Their stand of trees is not very much differentiated because the introduction of a pine-tree. There are also habitats of thermophilous oak forest *Potentillo albae-Quercetum*, covered also by pine-trees. On the flood terrace of the Vistula there exists big concentrations of ash-alder flood plain forest *Circaeo-Alnetum*, bog-alder forest *Carici elongatae-Alnetum*, and willow thickets from *Salicetea purpurae* class.

The company started production in the second half of 1972. It produces liquid ammonia and carbon dioxide, nitric acid, ammonium sulphate, alkali lye, caustic soda, and polyvinyl chloride. Its divided into four complexes: chemical fertilizers, polyvinyl, chloride and energy complex. Main compounds emitted by the company are nitric oxide, ammonium sulphate as dust and spray, sulphur dioxide, vinyl chloride, hydrocarbons and carbon dust. Other substances, as ammonia, methane, and carbon dioxides was emitted only periodically during in the past damages.

ANWIL Nitric Company take part in the Polish-Norwegian Environmental Project “Clear Production”.

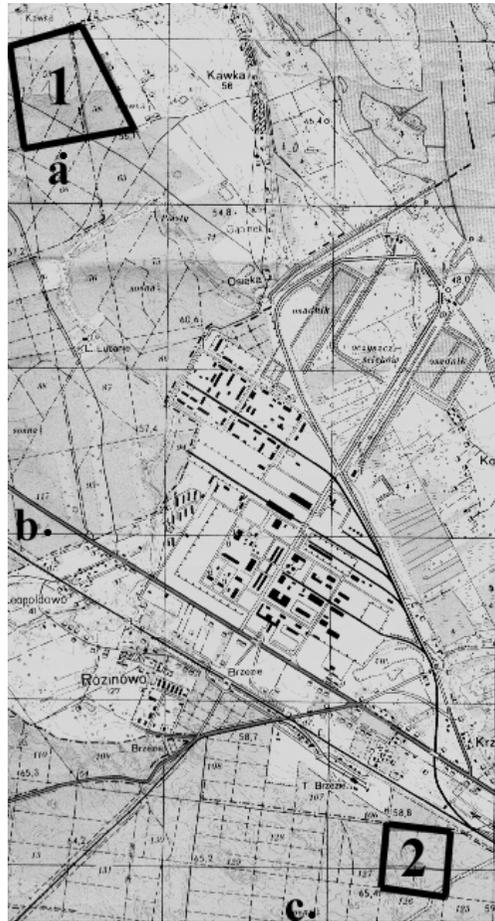


Fig. 2. Location of permanent plots in the vicinity of the Nitric Company, Włocławek.
 1 and 2 – areas over 50 ha, a - c - relevés areas 20x20m in
Peucedano-Pinetum (a) and in *Quercu roboris-Pinetum* (b and c)

Woodland called Las Piwnicki was accepted as a reserve in 1956. However, Wodziczko (1925) writes that this area was treated as protected as early as in twenties. Las Piwnicki reserve is situated just beyond the northern administrative border of Toruń, about 9 kilometres from the town centre. It is on the upper terrace of the Vistula valley. On the northern side the reserve is close to the edge of a 80 metres high moraine upland. The southern border of the reserve is the Struga Łysomicka river. Total area of the reserve amounts now to 37.27 ha.

The reserve is on fields with the smallest yearly amounts of rain in Poland (470 mm). Rusty brown soils, rusty-podzolized, and the complex of mucky and podzol-mucky soils dominate in the area of the reserve.

Stand of trees in the reserve is characteristic because there are many species and it has a stratified vertical structure. Top layer, i.e. overstory is formed mainly by a pine-tree *Pinus sylvestris*, which share in all the trees a short time ago amounted to 60-80%, and recently it has decreased. Besides pine-trees there are also oak-trees *Quercus robur* and *Q. sessilis* and sometimes hornbeams *Carpinus betulus* in the top layer. The lower layer – understory is formed by hornbeams and oak brushwoods. Apart from those basic species there is also a black alder *Alnus glutinosa*, a birch and silver birch *Betula pubescens* and *B. verrucosa* and rarely an aspen *Populus tremula*, a small-leaved lime *Tilia cordata*, a Norway maple-tree *Acer platanoides* and a sycamore *Acer pseudoplatanus*.

The age of the main trees which are Scots pines is about 200 years. Structures of age and diameter in breast height (DBH) in such species is not very much differentiated (Biały, 1972). Trees from higher classes of DBH dominate. Advanced age of a Scots-pine tree is the reason for its weak health and poor biological hardiness (over 90% of trees are invaded by a fungus *Trametes pini* and by bark beetles). Recently, mass extinction of the species has been observed. Because a pine brushwood does not exist in the area it is gradually replaced by a hornbeam. One-age stand of trees and lack of a brushwood prove that a pine-tree was introduced artificially to the area of the reserve. Besides a pine-tree, there were also other conifer-trees introduced, however on the smaller scale: a spruce and a European larch. The age of the oldest oaks is around 250-310 years. Considerably bigger share has a peduncle oak (about 70% of the total oak amount) in the creation of the stand of trees. Extinction and many windfallen of those trees has been observed recently. Younger trees of both oak species existing in the lower tree layer develop slower.

Basic phyto-sociological units of the reserve are a lime-oak-hornbeam forest *Tilio-Carpinetum* association and an oak-pine mixed forest *Pino-Quercetum* association (Fig. 3). On especially wet habitats there are fragments of bog-alder forest *Carici elongatae-Alnetum* and a ash-alder flood plain forest *Circaeo-Alnetum*. The preserved fragment of a bog-alder forest covers the depression of the area, near Struga Łysomicka. An ash-alder flood plain forest, which also develops only in fragments, covers area depressions along Struga Łysomicka.

Lime-oak-hornbeam forest *Tilio-Carpinetum* is divided into three sub-associations *Tilio-Carpinetum stachyetosum*, *Tilio-Carpinetum typicum* and *Tilio-Carpinetum calamagrostietosum*. The distribution of forests growing on dry ground is closely connected with rusty soils, and their classification into sub-associations is connected with depth of ground water level.

Tilio-Carpinetum typicum is dominating form of a lime-oak-hornbeam forest in the reserve. There is two-layer stand of trees. In the overstory there is more peduncle oak, and understory *Carpinus betulus* dominates. Undergrowth is created mainly by the brushwood of a hornbeam. According to Rejewski (1977) *Tilio-Carpinetum typicum* is a primary forest community in the area of the Las Piwnicki reserve. He states that if the development of forest communities takes place without drastic man influence and ground water economy does not become worse, reconstruction of this

natural forest should take place on the whole area of the reserve (apart from depressions).

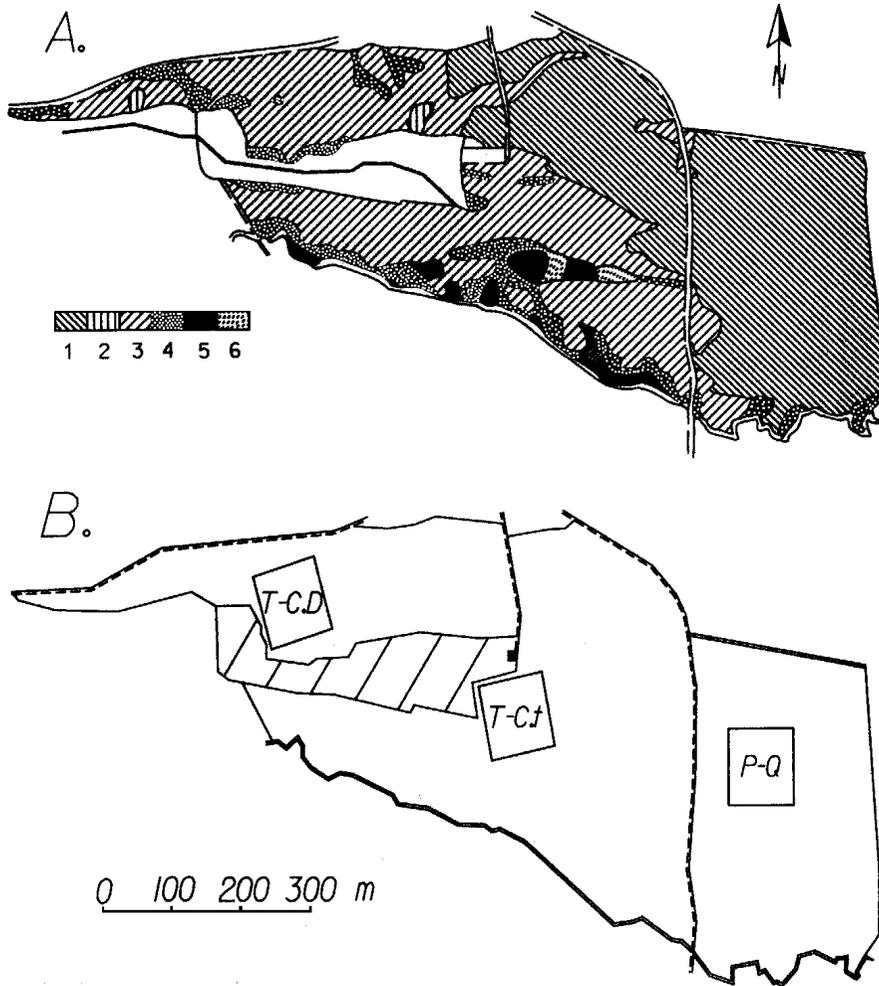


Fig. 3. Distribution of plant communities and permanent plots in Las Piwnicki reserve (A) and locality of permanent plots 1 ha (B): 1 – *Pino-Quercetum*, 2 – *Tilio-Carpinetum calamagrostietosum*, 3 – *Tilio-Carpinetum typicum*, 4 – *Tilio-Carpinetum stachyetosum*, 5 – *Circaeo-Alnetum*, 6 – *Carici elongatae-Alnetum*, T-C.D, T-C.t, P-Q – 1 ha areas in *Tilio-Carpinetum* on a dune, *Tilio-Carpinetum typicum* and *Pino-Quercetum*, respectively

There is two-layer stand of trees in typical form of lime-oak-hornbeam forest. Top layer is created by a peduncle oak and Scots-pine trees. A hornbeam dominates in a lower layer.

Oak-pine mixed forest is connected mainly with podzolic soils, and it covers north-eastern part of the reserve with the deepest level of ground water. Overstory is created by a Scots-pine and a peduncle oak. A hornbeam dominates in understory, and it grows together with two species of an oak which are a peduncle oak, and a non-peduncle oak.

Besides typical forms of plant communities in the area of the reserve, there are also different degeneration forms of forest phytocoenoses. They developed as the result of the introduction of new tree species, i.e. the conifers, a horse-chestnut (*Aesculus hippocastanum*), and bushes (*Sorbaria sorbifolia*, *Spirea salicifolia*, *Symphoricarpos albus*).

The study area in Tuchola Forest is situated north of the town of Chojnice and west of the town of Brusy. It is belonging to Zabory Landscape Park, inside which the Bory Tucholskie National Park was set up in 1995. According to Kondracki's (1978) physic-geographical partitioning of Poland, the area under study is part of the macroregion of South-Pomeranian Lakeland and of the mesoregion Charzykowy plain. The study area lies in the catchment area of the river Zbrzyca and its tributaries, the Kulawa and the Kłonecznica. The river Zbrzyca flows through a number of eutrophic lakes and into the river Brda. In the area under study there are also some *lobelia*-type lakes and several nature reserves.

Vast forest complex in the area under study are part of Przymuszewo Forest Inspectorate, which is subordinate to the Forestry Commission in Toruń. The afforestation of soils used for a time for farming was done here mainly by Prussian government at the end of 19th and the beginning of 20th century, partly within the framework of „Kulturkampf”. It consisted in buying out large numbers of Polish privately owned land estates and setting up state-owned forest cultures. Some farming areas were afforested by landowners, both before World War I and between the two World Wars, when the area under study was part of the restored Polish state. The forest area was extended also shortly after the Second World War, when the big estates were reforested in political action of Polish government called agricultural reform.

The settlements are situated mainly in river and lake valleys. The largest villages in that area are those lying on the Zbrzyca: Kaszuba, Rolbik and Laska, as well as Kruszyn situated by lake Kruszyn. Part of the settlements and villages existed there in the second half of 19th century became depopulated and their terrains were later afforested. Such settlements as Zielonki, Lisewo, Polaszek, Piecki, Nowa Laska, Belfort, Kramarska have disappeared.

At the end of 19th century the area under study became part of the Prussian Forest Inspectorates Zwangshoff and Laska. The former was set up in 1890 following purchase by the Prussian government of a large land estate. Half of it was fallow land and glades. The Prussian Forest Inspectorate Laska was set earlier. In the mid-nineties of 19th century both inspectorates were about 10,000 ha in area. In the years 1894-1920 the Prussian administration purchased yet another 1788 ha, mainly farming land belonging to the largest land estates in Pomerania. Further extension of forest areas came after 1920, i.e. after incorporation of the area into Polish Republic II and after 1945, following the agricultural reform. Several land estates, situated by lake Kruszyn and in the Zbrzyca valley, near the village

Kruszyn, Kaszuba and Rolbik, were then nationalised. Afforestation of farming land meaning turning cropland into mainly dry coniferous forest still continuous. The afforested areas are mainly small fields, rented until recently forest workers.

Most of the forests in the area under study are state-owned. Larger privately owned farms are found by the lake Księżę, in the nearby Leśno, in Duże Chełmy and Małe Chełmy, i.e. in the agricultural area called „Brusy island” bordering on the forest complex under study.

A pine-tree dominates in the stand of tree on the researched area. Other species as *Pinus strobus* and *Pinus nigra* dominate on small areas. From board-leaved trees a black alder creates close stand of trees only on the bottom of peated valleys of rivers and lakes, and a beech-tree does it on slopes of their valleys. Other species as verrucose birch-tree, small-leaved lime-tree exist as an addition in pine stand of trees.

A dry forest *Cladonio-Pinetum* and a fresh forest *Leucobryo-Pinetum* are dominating forest types in Przymuszewo Forest Inspectorate and the Zabory Landscape Park. The considerable variability of the fresh pine forest depends to large extend on the relief, i.e. the height, the slope and the exposure of the terrain (Sokołowski, 1965). Small fragments of lime-oak-hornbeam and beech forests survived on the sides of river and lake valleys, not fir for cultivation or grazing in place were board-leaved forests have been superseded by pine forests and on brown soils previously used for farming the community *Pinus sylvestris-Deschampsia flexuosa* is now developing.

3. METHODS

The influence of ANWIL Nitric Company on the neighbouring forest has been recognised on the basis of colour aerial photographs taken in 1997. Two areas were marked on pictured and their covered over two forest sections, which is the area over 50 ha. Area 1 was localised in north-western direction from the Nitric Company and it was situated near the border of forest complex with agricultural fields (Fig. 2). Area 2 was situated on north-eastern side, and with the domination of western winds it was more the subject of direct activity of emitted gases than area 1.

Besides the estimation of health of the trees on the basis of aerial photographs the changes of stand of trees structures was researched taking into consideration two series of phyto-sociological records (relevés) published by Kępczyński and Załuski (1988, 1991) made from 1973, which is the moment the company started production, to 1988 on permanent plots 20x20 m. localised on west from the Nitric Company (1200 m) on the habitat of fresh pine forest *Peucedano-Pinetum* (plot a) and oak-pine mixed forest *Quercus roboris-Pinetum* (plot b). Four relevés of the plot b were compared to the series of relevés made every year within 3 years on the area of 20x20 m located in the same type of a forest but in the bigger distance (about 5000 m) from the source of NO_x emission (plot c). Relevés were done using the Braun-Blanquet method. Preparing data for calculations the transformation of Braun-Blanquet cover-abundance scale into scale of Jenssen (1975) and van der Maarel (1979) took place.

Indirect gradient analysis was made for data sets using correspondence analysis method (Hill, 1973). Package of MVSP (Kovach, 1993) programmes was applied to calculations. All sets of relevés were analysed twice. In the first analysis the data concerning only features relating to the layer of trees, brushwood and undergrowth were used. In the second analysis the data which were taken into consideration concerned apart from the above mentioned forest layers also the layers of herbs and ground lichens, and bryophytes.

Changes in a tree-layer structure in Las Piwnicki reserve was estimated on the basis of panchromatic and colour aerial photographs made in 1960-1997. Stand of trees structure was additionally defined by the comparison of the amount of dead trees which belong to *Pinus sylvestris* and genus *Quercus* on three permanent 1 ha study areas (Fig. 3). They were localised on a dune in the western part of the reserve, where considerable amount of Scots-pine exist on the habitat of lime-oak-hornbeam forest (plot T-C.D), and it develops in a typical form of lime-oak-hornbeam forest (T-C), and in oak-pine mixed forest *Pino-Quercetum* (P-Q).

Changes in forest range in Zabory Landscape Park were defined using old topographical maps of 1875 and 1921 and land-use maps of 1894, 1926, 1947, 1953, 1966, 1976, 1988. To characterise the reflectance of forests on post-agricultural and not post-agricultural soils in this study area satellite imagery was used created by Landsat TM on 28.07.1990. With the support of image processing and GIS (Geographic Information System) software three-colour compositions were created and the NDVI was counted for the whole area of Zabory Landscape Park, according to the following formula:

$$\text{NDVI} = [\text{IR} - \text{RED}] / [\text{IR} + \text{RED}],$$

where RED and IR are reflectance values equivalent to Thematic Mapper (TM) Bands 3 (RED, 630-690 nm) and 4 (IR, 760-900 nm).

The map of spatial variation of NDVI was also prepared for the quarter with a 10 km side covering the area presented on one sheet of Prussian topographic map from 1875. Spatial variation of NDVI was additionally calculated for four areas inside this quarter which differentiate distinctly by the way the land was utilised in the past (Fig. 4). Symbols and history of the forests on those areas are as follows:

- a) the area situated on the highland on the northern side of Laska lake, where the area was not agriculturally utilised in the past,
- b) the area situated lower nearby Zmarle and Piecki lakes, where the development of a forest was interrupted only by clearings and not by longer agricultural utilisation,
- c) the area on the highland between Duże Gluche and Kruszyńskie lakes, where agricultural fields existed before it was reforested at the beginning of 20th century,
- d) the area where wet pastures existed before reforestation.

The size of each area was about 135 ha, which means each of them covered about 1500 pixels. During the preparation of maps the scope of NDVI index from -1.0 to +1.0 was divided into 20 classes which had colours used during maps creation.

Using the forest inventory book and information about cultivation activities and achieving wood, the share of forests and other types of plants, the age both structure of stand of trees and forest habitat structure were calculated on comparable areas. After the creation of the spatial NDVI variation map, histograms of index value were prepared, and the average value and standard deviation on each area was calculated.

Differences between the researched areas taking into consideration the value of NDVI index was defined by the numeric classification method. Features of the separate areas was pixels frequency used in the analysis of classes from NDVI scope. As a dissimilarity measure the Euclidean distance was chosen. Dendrogram was made by average variance clustering method (Orlóci, 1978). Moreover for characterisation of NDVI variability on each area for pixels frequency in histograms Shannon-Wiener's diversity index was used and evenness. In calculations of those indexes and for dendrogram preparation the MVSP program was used (Kovach, 1993).

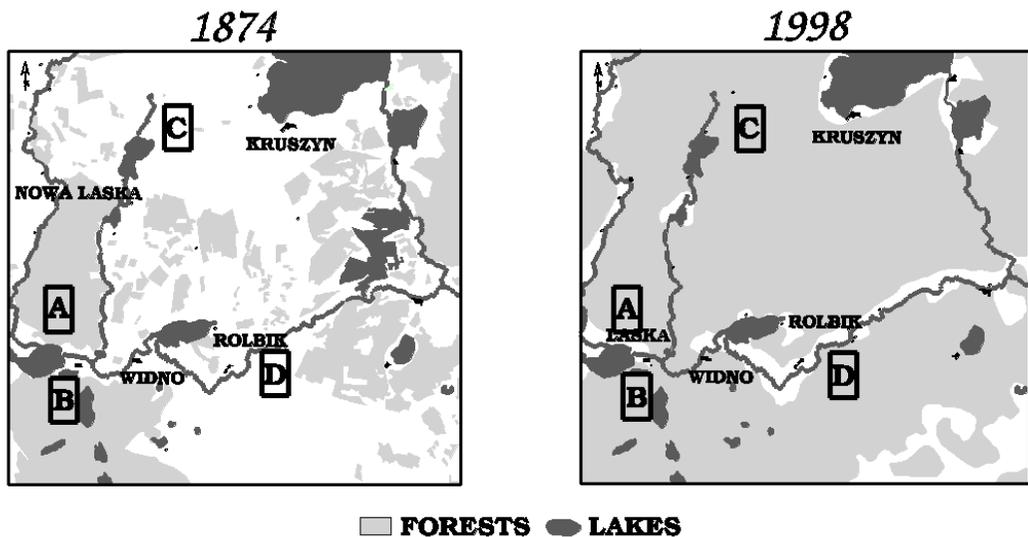


Fig. 4. Forest ranges on Zabory Landscape Park area in 1874 and 1997.
A, B, C, D – location of study areas

4. RESULTS

Aerial photographs analysis from the neighbourhood of the Nitric Company showed that area 1 is not very much damaged. The damages of top-trees on this plot are only on 15% of its area. On area 2 damages amount to 80% (Fig. 5). Stand of trees are considerably thinned out. Many trees area died, and those which remained alive had considerably small crowns and damaged assimilative apparatus.

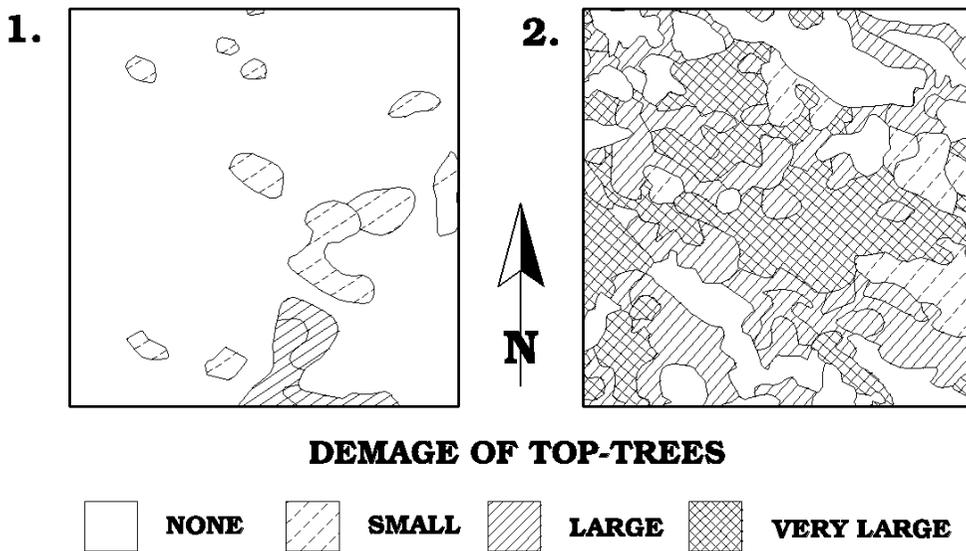


Fig. 5. Map of top-tree damages on fragment of areas 1 and 2 in the vicinity of the ANWIL Nitric Company, Wloclawek

Changes which took place in fresh pine forests included into *Peucedano-Pinetum*, and in oak-pine mixed forests *Quercus roboris-Pinetum* are presented in Fig. 6. It is concluded that taking into consideration all phytocoenosis layers differences between photos are more clear than during analysing only tree layers and undergrowth.

In case of the first forest associations there was a decrease in density of top-trees, in the undergrowth there was a decrease of plant cover and some species completely disappeared, e.g. heather *Calluna vulgaris*. Changes in oak-pine mixed forests *Quercus roboris-Pinetum* were very similar. A mixed forest near the Nitric Company was considerably different from a forest situated in bigger distance from the source of pollution (Fig. 6). The first one had smaller density and cover of top-trees and lower number of undergrowth species.

Multitemporal aerial pictures of Las Piwnicki reserve showed that most important changes in the stand of trees structure intensified in eighties. The stand of trees is dense on the photo of the reserve from 1976. Bigger gaps exist only in its northern part and there is a clearing with growing bushes *Sambucus nigra* and *S. racemosa* and grass *Agrostis vulgaris*. The gaps in stand of trees are bigger on photos from 1985 and 1997. There exists considerable diminution of trees, especially in the eastern part of the reserve on the habitat of *Pino-Quercetum* (Fig. 7). From the comparison of data it is concluded that the biggest changes took place on area P-Q. There was no dead trees in 1970 there. The smallest extinction of Scots-pine and oak trees appeared on area T-C.t which is lime-oak-hornbeam forest *Tilio-Carpinetum*. There was fifty such trees in 1985, and in 1999 already as much as 78. The number of dead trees of both *Quercus* species in 1985 on areas T-C.D and P-Q were 2 and 7, respectively (Barcikowski et al., 1991).

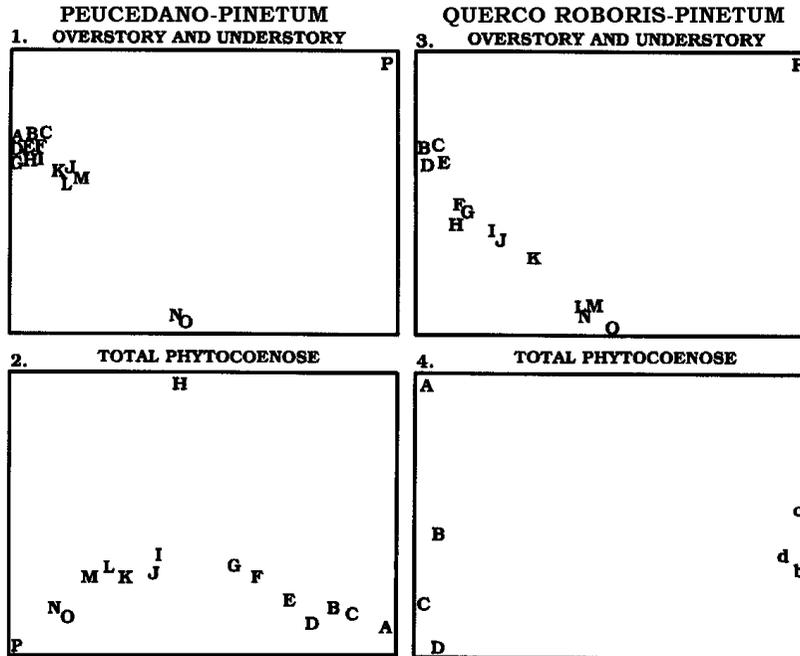


Fig. 6. Ordination of relevés from 1972 – 1988 in the neighbourhood of the Nitric Company, Włocławek in a pine fresh forest (1 – analysis of overstory and understory structure, 2 – analysis of total structure of phytocoenoses) and in a oak-pine mixed forest (3 - relevés made from the distance of 1200 m, and 4 - from the distance of 5000 m from the source of emission). A-P – the relevés made in the following years between 1973-1988, respectively, capital letters – relevés in short distance, small letters – relevés in biggest distance from the Nitric Company

On the basis of data analysis in the Przymuszewo forest inventory book in Bory Tucholskie it was stated that on A area there dominate typical fresh pine forests and transitional phytocoenoses between fresh and dry pine forests. Forests on that area in most cases belong to the II age class, which means 20-40 years (43%). Forests which are 60-80 years old cover 13%, which are 100-120 years old 10%. On the area of B fresh forest is the only habitat type, and in the age structure of trees forests which are 20-40 years old (29%) dominate. However, there exist older stands of trees on this area. The share of forests which are 100-120 years old is 22%, and which are 120-140 years old 18%. On both areas covered by forests on post-agricultural soils C and D fresh pine forests dominate. Their share in the structure of habitats amounts to 98% and 100% respectively. In the age structure forests of II age class, which is 20-40 years, dominate on the C area covering 40%. Forests which are 60-80 years old covered 25%, and 80-100 years old 14%. The biggest part of the D area was covered by 80-100 years old forests 61%. Forests which are 60-80 years old are 7%, and 20-40 years old - 15%.

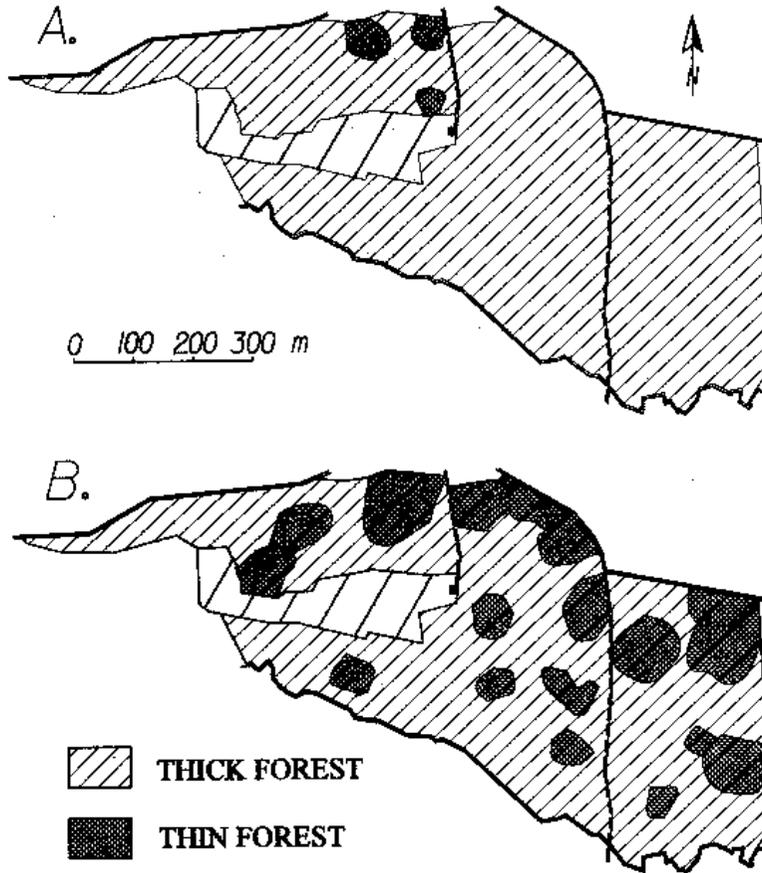


Fig. 7. Map of top-trees density in the Las Piwnicki reserve in 1960 (A) and 1997 (B)

According to Barcikowski (1992) and Barcikowski and Michalska (1988) fresh pine forests of Przymuszewo achieve the highest values of chlorophyll among all forest communities existing on that. It concerns older stand of trees as well as younger stage of secondary succession on that forest habitat. Chlorophyll index calculated into m^2 in fresh forests is higher than in forests on formerly arable fields, which are phytocoenosis *Cladonio-Pinetum* and *Calluno-Pinetum*, as well as in wet- and bog-pine forests and in stands which appeared after afforestation of pastures and pine forests with the domination of *Deschampsia flexuosa* created after the introduction of a pine-tree to the broad-leaved forests habitats. The situation is similar in secondary forests on former farmlands which have considerably smaller biomass than forests with stand of trees of the same age on permanently forested areas (Nienartowicz et al., 1998).

From value analyses of NDVI indexes on separate areas it is evident that the highest value of this parameter was achieved by B area, where the share of fresh pine forest was the highest, and where the oldest stands of trees exist (Fig. 8).

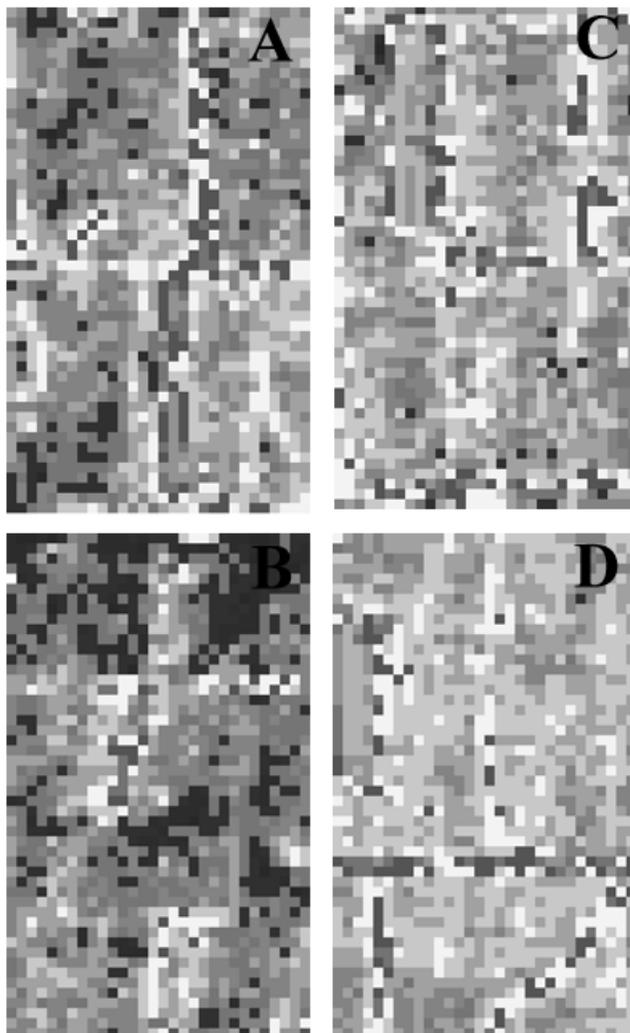


Fig. 8. Spatial variability of NDVI index on plots A – D in Zabory Landscape Park

The lowest value was achieved by D area, on which dry forest dominated. The average NDVI value on those areas amounted to 0.365 and 0.155, respectively. On A area where the existence of forests was not interrupted by agriculture activities NDVI value reached 0.262, and on the second post-agricultural area, e.g. C its value was 0.183.

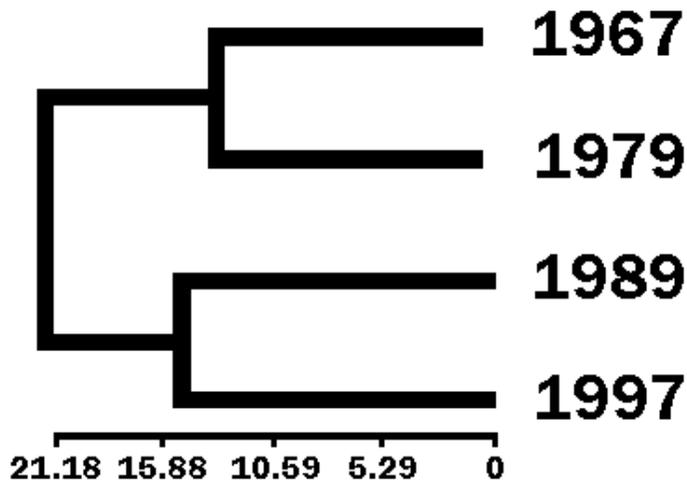


Fig. 9. Plots A – D classification on the basis of NDVI value

Separateness of forest area on post agricultural areas from lands with forests formerly not utilised agriculturally is showed on the dendrogram produced on the basis of pixels frequency in the separate parts of NDVI. Both pairs of area forming separate clusters (Fig. 9).

5. CONCLUSION

Analysis showed a considerable usefulness of aerial photographs and satellite imageries to the estimation of damages which appeared in forest communities under an influence of gases and dust emitted by the Nitric Company. They are also effective to detect transformations of tree layers structure under an influence on processes of natural succession. Observations revealed a significant sensibility of a pine-tree and hardiness of some leaved species as *Quercus rubra*, *Padus serotina*, *Salix sp.* on air pollution. Although pollution is not considerable, apart from emergencies, unfavourable influence of gas and dust on plants can be observed. The results of such influences are similar to the ones near other plants producing nitric oxide (Jakubczak et al., 1968; Kawecka, 1973). Damages in forests near Nitric Company's are caused not only by emission of NO_x but probably also by the decrease of ground water level which was the result of water exploitation by an industrial plant. However, as it is stated in reports concerning company influence on environment the use of water in technologic processes has decreased recently.

Changes caused by forest regeneration processes after the introduction of a pine tree to lime-oak-hornbeam forest habitat are very well visible on aerial photographs of Las Piwnicki. Analysis of stand of trees structure shows that in the near future hornbeam stand of trees will be formed in that forest complex. A hornbeam is a very

dynamic species which starts growing in all gaps which appear after the extinction of pine and oak trees. It is possible that extinction of oaks in the reserve is connected with an oak disease in whole Poland (Przybył, 1995), and it is caused by the decrease in ground water level or an attack of a parasitically fungus. SO₂ emitted by a heat and power generating plant, and industrial plants situated near Toruń undoubtedly contributes to the extinction of trees in Las Piwnicki.

On the basis of measurements done in Zabory Landscape Park it has been stated that there is a correlation between NDVI values and analysis results made with standard methods over the content of chlorophyll in phytocoenosis. It is concluded that satellite method can be used to discover areas covered today by dry forests, and which were arable some time ago. However the precise application of satellite methods needs further analysis concerning chlorophyll level in dry forests which appeared as a result of natural succession on formerly arable fields and fresh forests and phytocoenoses classified as *Pinus sylvestris-Deschampsia flexuosa* community created as the result of afforestation of formerly arable areas on fertile soil or as the result of afforestation of leaved forests with a pine-tree.

Results achieved are included into scopes presented for plantations of other kind of pine in different world regions. The highest accordance exists between NDVI values from Zabory Landscape Park and *Pinus densiflora* plantations on the mountain territory of Japan. Lee and Nakane (1997) propose NDVI values from 0.3 to 0.5 for those forests. Gholz et al. (1997) analysing reflectance of *Pinus elliottii* var. *elliottii* plantations on Florida, USA stated higher values, which are 0.55 - 0.66. Such NDVI values in Zabory Landscape Park are achieved only by the oldest stand of trees on the habitat of a fresh pine forest.

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STRESZCZENIE

Analizowano wpływ stresów chemicznych na zdrowotność trzech kompleksów leśnych. Pierwszy obszar badań, którym był las gospodarczy wokół zakładów azotowych ANWIL we Włocławku, podlegał silnemu oddziaływaniu NO_x. Drugim kompleksem był rezerwat Las Piwnicki zlokalizowany w pobliżu Torunia. Przez ostatnie dwadzieścia lat obserwuje się tu zamieranie starych sosen i dębów, jako następstwo skażeń chemicznych emitowanych przez miasto do atmosfery. Trzeci kompleks leśny obejmował plantacje sosny zwyczajnej w Zaborskim Parku Krajobrazowym. W tym obiekcie przyrodniczym znaczna część terenu pokryta jest lasami wtórnymi odtworzonymi w końcu XIX wieku na glebach czasowo użytkowanych rolniczo. Do oceny efektu emisji tlenków azotu w postaci uszkodzeń koron drzew wokół zakładów azotowych wykorzystano kolorowe i panchromatyczne zdjęcia

lotnicze. Z podobnych źródeł pochodziły informacje do oceny tempa usychania sosen i dębów w rezerwacie Las Piwnicki. Ocenę kondycji lasów w Zaborskim Parku Krajobrazowym oparto o analizę znormalizowanego różnicowego wskaźnika roślinnego (NDVI) pozyskanego ze zobrażenia wykonanego przez satelitę Landsat skanerem TM.

Na podstawie zdjęć lotniczych okolic Włocławka wyznaczono strefy oddziaływania emisji gazowych na lasy rosnące w pobliżu zakładów azotowych. Na podstawie serii zdjęć lotniczych Lasu Piwnickiego wykonanych w różnych latach stwierdzono, że zmiany w strukturze górnej warstwy drzew rezerwatu nasiliły się około 1985 roku. W wyniku analizy zdjęcia satelitarnego stwierdzono, że wskaźnik NDVI borów sosnowych rosnących na obszarach zawsze zalesionych w ciągu ostatnich kilku stuleci jest wyższy niż lasów wtórnych, odtworzonych na glebach użytkowanych rolniczo. Lasy te zaliczane są do syntaksonów *Cladonio-Pinetum* i *Calluno-Pinetum*. Występuje w nich znacznie wyższe zagrożenie pożarowe niż w pozostałych typach zbiorowisk leśnych wyróżnionych na terenie parku.

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