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Spatial pattern changes in Bory Tucholskie forest landscape

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ABSTRACT: The fast transformation from agricultural into forest landscape took place in considerable areas of Bory Tucholskie District (Pomerania Province) at the end of 19th and the beginning of 20th century. The reasons of those changes were economical and political factors, i.e. wood price increase and purchase of Polish land estates by Prussian government. On the basis of analyses concerning area research results, historical cartographic materials (Schrötter-Engelhardt Maps from 1796-1802; Messtischblatt from 1870-1910), forest inventory books, aerial photographs and Landsat TM and ETM+ imagery (from 1990 and 2000) made with GIS technology in the area of Zabory Landscape Park, there was established the influence of previous land utilization and afforestation on the following parameters of landscape pattern and texture: NDVI, diversity, fragmentation, fractal dimension, number of different classes, class area and some other structural characteristics such as number of patches and mean patch size. On the basis of the first image analysis it has been stated that landscape with intensively exploited forests on former agricultural soils was characterized by lower values of NDVI and higher values of diversity and fragmentation in comparison to those with sustainable forest management. By comparing two satellite images it has been stated that changes in forest technology in Poland during the last decade intensified differences between areas. The present work demonstrates the application of remote sensing methods to define the influence of political factors and economical activities, which took place in forestry during the last two centuries on habitat equality and a landscape spatial pattern.

1 INTRODUCTION

Two opposite human activities have changed the forests within the considerable area of north-western part of Bory Tucholskie during the last one thousand years. The first were clear cuttings which lasted with short breaks from the 9th to the 19th century. The second process was the recreation of secondary forests taking place from the 1980s until today. Particularly intensive cuttings took place in the Middle Ages, especially in the 13th and 14th centuries which was the period of the rapid colonization development considering the creation of cities and villages in this area. The second period of cuttings lasted from the middle of the 15th century to the end of the 17th century, caused by wood burning and potash production. Considerable demand for this product and its good price started the export of this salt produced in Bory Tucholskie from the port in Gdansk. Intensive cuttings took place during the Napoleonic wars, after the introduction of this area to Prussia as a result of the second partition of Poland. During the 20s and 30s Prussia paid its war debts with wood, which caused some forest areas to disappear. Heathlands and poor sheep pastures started to develop in these areas. Cultivation existed in the smaller territories.

Considerable degradation of soils and ecosystems made the Prussian government renovate forest ecosystems. This program was realised especially after the Prussian-French war. It considered repurchase of private properties especially those that belonged to Polish people. This last process was realised within the framework of Kulturkampf policy, started by Bismarck in the second half of 19th century. In the purchased areas, Prussian national forest inspectorates were created which started afforestation of pastures, heathlands and soils temporarily used for cultivation. The second stage of afforestation started after World War I, when in 1920 this area was introduced to the II Republic and the Polish government began to create the basis of forest economy. After damages of forests during World War II there was the next stage of afforestation in the area. In this case it was done within the framework of so called agricultural reform realised by the Polish communist government. It consisted in the nationalisation of big land properties which in most cases were afforested directly after their introduction to national forests. Intensive production of wood and side-products, timbering such as resin and stump wood took place

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in those forests. Timbering was done by clearcuttings in big territories. They also initiated changes in the structure of landscape and especially its fragmentation. During the last twenty years further increase in woodiness of the described region was caused by economy. Unprofitable agriculture made farmers resign the lease of small inner-forest fields, meadows and pastures, which were gradually afforested, at the same time changing the structure of landscape. Other reasons for changing the structure of forest landscape in north-western part of Bory Tucholskie was the change of political and economical Polish situation and the change of ecological policy which was based on the introduction of stable and balanced economy to Polish forestry. Regular group fellings and complex clearing for the acquisition of wood and reconstruction of forests, leaving clumps of old trees on cuttings and also reduction of clear cuttings range decreased the number of non-forest patches in the forest landscape.

A considerable amount of the above mentioned forest range and area cultivation in the history of Bory Tucholskie were recorded on old and contemporary maps. The most useful source of information about rapid changes of landscape structure were the Prussian Schrötter-Engelhardt maps from 1796-1802 and the set of Messtischblatt maps from 1870-1910. Frederick the Great of Prussia initiated the creation of the first documents. Prussian and Polish forest economic maps and topographic maps created for the armies of both countries were the basic source of information concerning forest range in those years. Aerial photographs were an important source of information about changes in landscape structure of this forest region from the 1960s, and satellite imagery from the 1970s.

The aim of this research carried out with the financial support of Polish Research Committee No 6 P04F 04321 was to define changes in landscape structure in this interesting region with the help of prevailing ecological indicators. Two sources of information concerning area exploitation were used in the document – historical, contemporary maps and satellite images which were analysed with GIS technology and the method of satellite imagery interpretation. Indicators were calculated with the conviction that their value and connections with other data describing the state of environment could make it easier to take proper decisions connected with preservation of biological diversity and rational economy of natural resources.

2 STUDY AREA

The study concerned a square c. 6 km. The area is now within Zaborski Landscape Park. Following the latest administrative division of Poland, the Park now finds itself in the Province of Pomerania. To the north of Chojnice and the north-west of Brusy (Fig. 1). In 1996 the "Bory Tucholskie" (Tuchola Forest) National Park was established in the southern part of the Zaborski Landscape Park. The extensive forest complexes in the area under study are part of Przymuszewo Forest Inspectorate, which is subordinate to the Regional State Directorate of Torun.

According to the physico-geographical partitioning of Poland after Kondracki (1978), the area under study is part of the macro-region of the South-Pomeranian Lakeland and the meso-region of the Charzykowy Plain. From the geobotanical point of view, the study area is in the Pomeranian Lakeland and Kartuzy District (Szafer & Zarzycki 1972), while hydrologically it is in the drainage basin of the Zbrzyca, and of its tributaries the Kulawa and the Klonecznica. Two big lakes Milachowo and Kruszynskie are situated near the southern and northern borders of the research area. Parallel to its western border there is the Kulawa river which flows across two small lakes Gluche Duze and Gluche Male.

Settlements are situated mainly in river and lake valleys. The largest villages are Rolbik, Widno and Laska on the Zbrzyca as well as Kruszyn situated by lake Kruszynskie. Some of the settlements and villages existing here in the second half of the 19th century became depopulated and their terrain was later afforested. Such settlements as Zielonki, Lisewo, Polaszek, Belfort and Kramarska have disappeared. At the end of 19th century, the area under study became part of the Prussian Forest Inspectorate Zwahgshof. It was set up in 1890, following the purchase of some landed estates by the Prussian government. Half of their area was fallow lands and glades. The 612 ha of the land estate Widno owned by Konstanty Przytarski was situated in the middle-southern part of the area under study. Milachowo lake created the southern border of this estate. In 1894 the terrain was sold to the Prussian government and became part of the Forest Inspectorate Zwangshof. The area in the north of Widno estate, which stated so called Gemarkung Kruszyn and situated between Kruszynskie and Duze Gluche lakes, was afforested later, mainly after World War I. Part of the old property was still private and the second part of it entered the Przymuszewo Forest Inspectorate created in the 1920s. The area to the east from Milachowo lake was part of the Rolbik and Kaszuba estates. They were nationalised after World War II, introduced to national forests, and afforested. Small private farms were created on part of the previous estates. A small inner-forest island of previously ploughed lands on the western side of the Milachowo lake has been afforested during the last ten years. After World War II this area was introduced to national forests and for over 30 years it was leased and cultivated by employees of the Przymuszewo Forest Inspectorate.

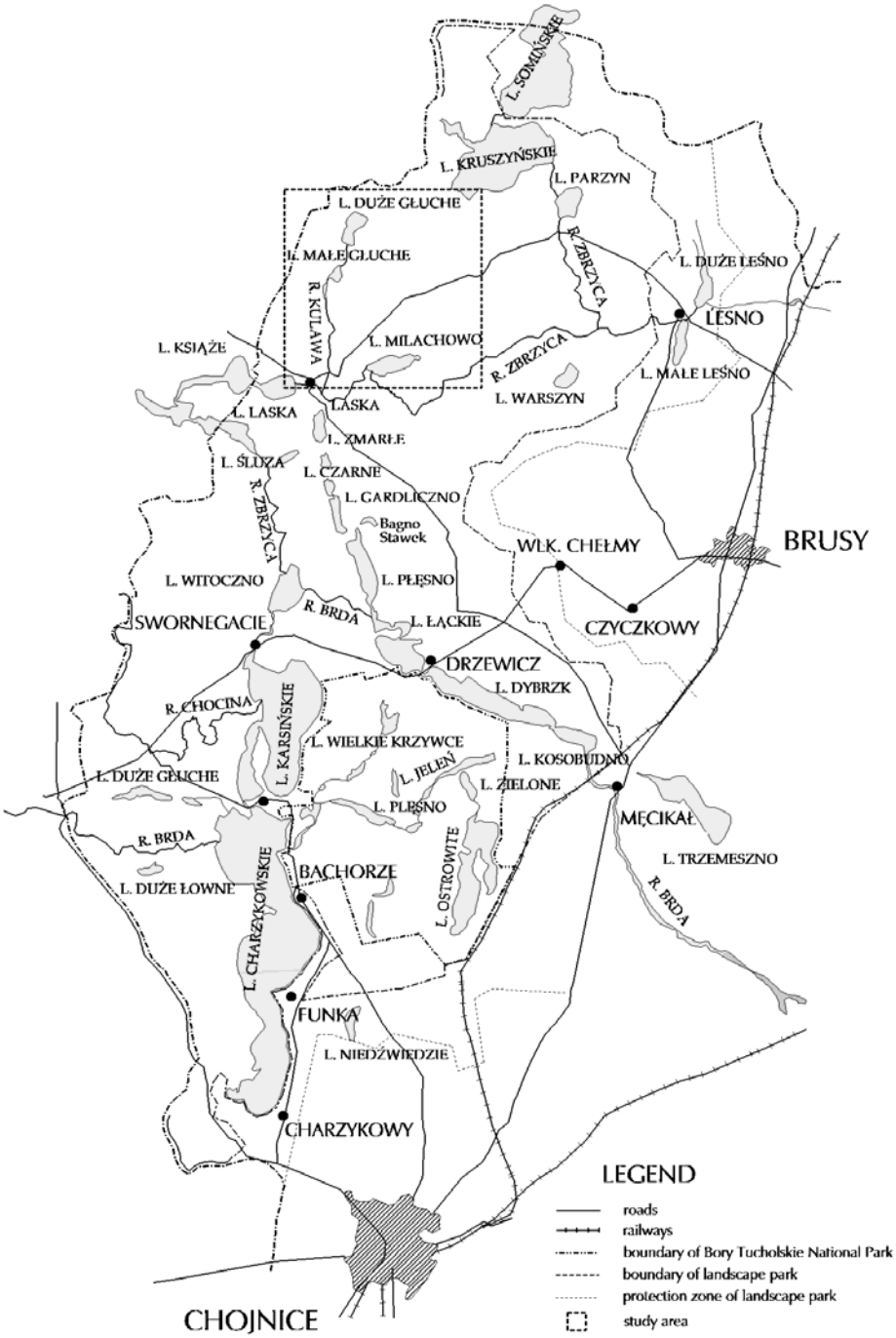

Figure 1. Situation of study area

Most of the forests in the area under study are state-owned now. Small-scale agricultural and forest ownerships are only found in the Zbrzyca valley. During the last few years they are purchased by people living in cities and transferred into recreational fields. Larger privately-owned farms with more intensive agricultural production are found by Lake Ksieze, in nearby Lesno, and in Duze Chelmy and Male Chelmy, i.e. agricultural area called the Brusy island bordering to big forest complex of the Landscape Park.

Heathlands, swards with *Festuca ovina* and dunes with *Corynephorus canescens* dominated in the 19th century in the research area. Today fresh (*Leucobryo-Pinetum*), dry (*Cladonio-Pinetum*) and heathland (*Calluno-Pinetum*) pine-forest of different ages are the dominating plant communities, especially on the broad plateau. Smaller territories are covered by wet and swampy forests. Scotch pine *Pinus sylvestris* is the dominating tree species in the whole area. Only very small fields are covered with exotic species such as *Pinus strobus* and *Pinus nigra* introduced by Prussian foresters. A large area covered by pine forests in the northern part of the research area is crossed by a fire belt which is partly without trees and partly covered by a birch *Betula verrucosa* protection line.

Broad leaved forests with Alnus glutinosa and Salix sp. cover small areas in valleys of rivers and lakes. An oak-hornbeam forest (Galio-Carpinetum) is situated in the small area on a steep slope on the north side of the Milachowo lake. Beech forest (Luzulo pilosae – Fagetum) exists in the close neighbourhood of this complex and on valley slopes of the Kulawa river. The forest of this kind grew in the considerable area of Kruszynskie lake according to the description of royal properties in Pomorze voivodship from 1564

Deciduous species of trees, especially birch, beech and oak, are more often used in recently created forest plantations on previously ploughed lands than during the past activities of Prussian and Polish forest inspectorates. Such species were grown during the afforestation of fallow lands in Widno village on the eastern side of Milachowo lake.

3 METHODS

Changes in the forest range and structure of the landscape were defined using old topographical maps from 1799 and 1874 and forest management maps from 1894 and 1998. The scale of the first map was 1:50 000, and the rest were 1:25 000. Forests range in the kernel chosen on those maps 6 x 6 km were compared using GIS technology, by scanning forest maps from each period as separate information layers. Microstation/J and MicroStation During analysis three categories of the land use were considered, which were forests, water ecosystems and all other forms. Colourful maps of different patches distribution, created on the basis of cartographic materials, were analysed with FRAGSTATS and IDRISI32 software. They were also used to analyse afforestation changes during the last decade on satellite imagery (Landsat TM from 28 July 1990 and Landsat ETM+ from 5 May 2000). For the research area in both periods the Normalized Difference Vegetation Index (NDVI) was calculated according to the formula: NDVI = [IR – RED] / [IR + RED], where RED and IR were reflectance values equivalent to Thematic Mapper bands 3 (RED, 630-690 nm) and band 4 (IR, 760-900 nm).

For maps presenting patches distribution in 1799, 1874, 1894 and 1998 the following parameters concerning landscape structure were calculated using FRAGSTATS software: patches number of each category, average patches size and total area of the separate form for the land usage. After the creation of spatial differentiation maps for NDVI in 1990 and 2000, on the basis of satellite imagery in 1990 and 2000, with the use of the IDRISI32 program within shifted in the range of the research area kernels covering 3x3, 5x5 or 7x7 pixels, six other indices defining pattern and texture of landscape were calculated: Number of Different Classes (NDC), Relative Richness (R), Diversity (H), Dominance (D), Fragmentation (F) and Fractional Dimension (d). The following formulas were applied in calculations:

1) NDC = number of different classes in each 3 x 3, 5 x 5, or 7 x 7 neighbourhood pixels (ranges from 1 – 9, 1 – 25, 1 – 49)
2) Relative richness R = n / nmax * 100, where n = number of different classes present in the kernel, nmax = maximum number of classes in entire image
3) Diversity $H = - \Sigma p_i \ln p_i$, where p_i is share of i-class pixels (i = 1, 2, 3, ..., n), n – number of different classes present in the kernel.
4) Dominance D = Hmax – H, where H = Diversity, Hmax = maximum diversity = ln (n), n = number of different classes present in the kernel
5) Fragmentation F = (n – 1) / (c – 1), where n = number of different classes present in the kernel, c = number of pixels (cells) considered (9, 25, or 49)
6) Fractional Dimension d = log (2) / log (2) + log [sin (180 – slope) / 2], where slope means the regression between perimeter and area of patches.

Details concerning the calculation of those indicators can be found in papers by Eastman 1985; O'Neill 1988; Turner 1989; Nienartowicz et al. 2001).

4 RESULTS

On the basis of those calculations it was stated that the area of forests in the analysed square was 14.8297 km^2 in 1799 and 7.8468 km^2 in 1874, which was twice as small (Table 1). In 1894, i.e. soon after the creation of the Prussian Forest Inspectorate Zwangshof the forest area increased three times in comparison to the state from twenty years before, and it reached 20.8530 km^2. After 104 years in 1998 the forest area increased to 33.0540 km^2, which was 91.8% of the total area (36km^2) presented on maps.

The opposite dependence between the forest area and the number of forest patches was stated. In 1874 when the forest area was the smallest the number of patches was 59. In 1998 when the forest area was the largest only three big forest patches were defined (Table 1, Fig. 2). In 1799 and 1894 the number of forest patches was 39 and 22 respectively. The opposite dependence between the number of patches and their areas was also observed. In 1874 the average area of 59 patches was 0.133 km^2, and the average area of 3 patches in 1998 was 11.018 km^2.

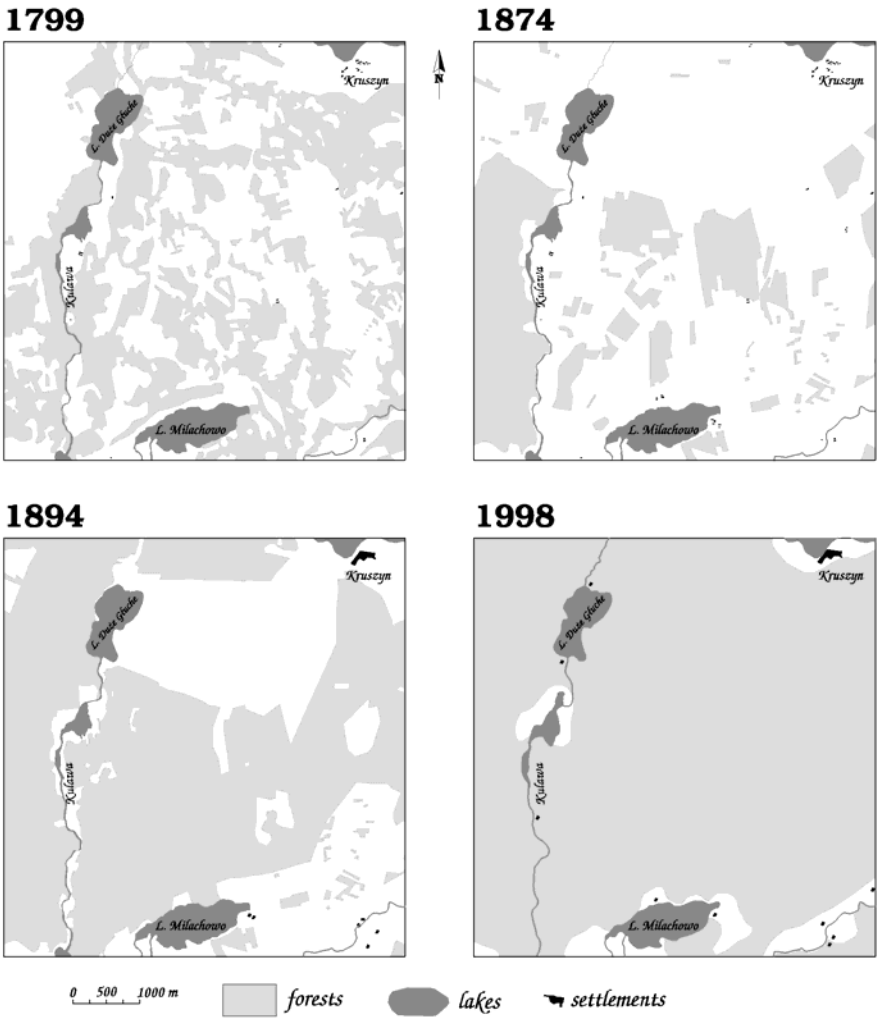

Figure 2. Forest range in 1799, 1874, 1894 and 1998

Table 1. Changes in forest area and spatial structure between 1799 and 1998 described on the basis of historical and contemporary cartographic data.

Year	Number of forest patches	Mean size of forest patches in km^2	Total area of forests in km^2
1799	39	0.3802	14.8297
1874	59	0.1330	7.8468
1894	22	0.9479	20.8530
1998	3	11.0180	33.0540

Although changes of forest area from 1799 to the present covered first its decrease and then regular increase for all indicators defining pattern and texture of landscape, the regular decrease of its value was observed (Table 2). The most considerable decrease of its value appeared between 1799 and 1874. The biggest changes were recorded for indicators of fragmentation, diversity and domination. The smallest number of changes during this time was typical for fractional dimension from 2.0063 in 1799 to 2.0018 in 1998.

Table 2. Changes of landscape pattern and texture indices (for kernel size 5 x 5) during the last two centuries in North-Western part of Tuchola Forest evaluated from cartographic data.

Year	Number of different classes NDC	Relative richness R	Diversity H	Dominance D	Fragmentation F	Fractal dimension d
1799	1.2920	43.0546	0.1479	0.0528	0.0123	2.0063
1874	1.1377	37.9180	0.0737	0.0208	0.0059	2.0040
1894	1.1232	37.4475	0.0657	0.0179	0.0054	2.0036
1998	1.0597	35.3552	0.0350	0.0055	0.0025	2.0018

The value decrease for the considerable majority of indices defining pattern and texture of landscape was also recorded in the analysis of satellite imageries from the beginning and the end of the last decade. Only the dominance index showed the opposite trend and increased from 0.2127 in 1990 to 0.2302 in 2000 with diversity index 1.9579 and 1.6855 respectively (Table 3). The bigger value of NDVI (Fig. 3) in 2000 was observed in comparison with 1990 (average NDVI values 0.4698 and 0.2887 respectively).

Table 3. Changes of NDVI and landscape pattern and texture indices (for kernel size 5 x 5) during the last decade in North-Western part of Tuchola Forest evaluated from Landsat TM satellite data.

Year	Mean value of NDVI	Number of different classes NDC	Relative richness R	Diversity H	Dominance D	Fragmentation F	Fractal dimension d
1990	0.2887	9.1504	22.8761	1.9579	0.2127	0.3537	2.3082
2000	0.4698	7.3874	18.4686	1.6855	0.2302	0.2776	2.2292

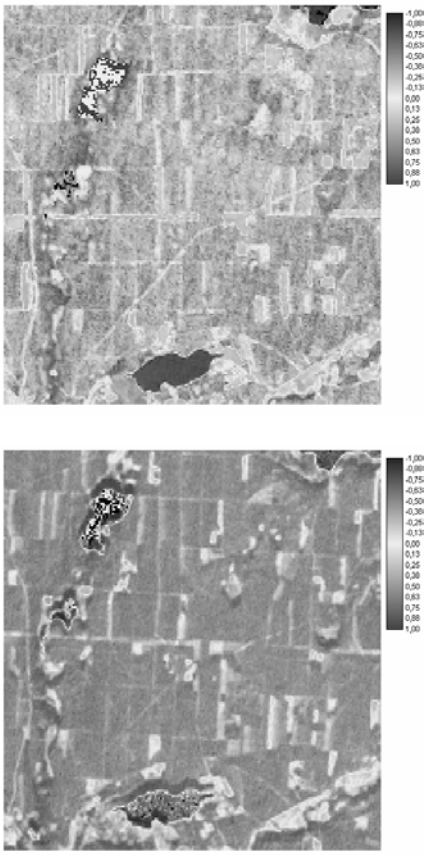

Figure 3. Spatial variability of NDVI in 1990 (upper) and 2000 (lower)

5 DISCUSSION

Ecological analyses revealed that political and economical factors influenced considerably the forest range and landscape structure in the area under study. The decrease in afforestation after the Napoleonic wars had a big influence here and it could be observed as differences in forest range in 1799 and 1874. An important influence on the range of forests, however, concerning their area, was the policy of the Prussian government which was based on purchasing land estates and creating national forest inspectorates in their place. Changes in afforestation during other periods were much smaller and were recorded clearly on smaller fragments of the territory, presented on aerial photographs or maps created at a smaller scale.

Differences in fragmentation and other indices of landscape structure on satellite imageries were the result of changes introduced recently to forest management in Poland. Especially smaller cutting areas, clumps of trees left on cutting areas caused smaller fragmentation of landscape. Moreover, the introduction of a larger number of broad leaved species and closed canopy on bigger areas created higher value of NDVI in 2000 in comparison to 1990. The dependence of NDVI and indices of landscape structure from such parameters were defined by Franklin and Forman (1987), Mladenoff et al. (1993) and Gamon et al. (1995). However, differences in the value of NDVI presented in this paper resulted from the fact that the images analysed were taken in different months, which were July and May. Climate factors and the phenological state of plants had a significant influence on the value of the indicator. A technical factor which could influence the value of estimated factors was the fact that a map from 1799 was created on 1:50 000 scale, and the other maps on 1:25 000 scale. It could influence the number of patches marked on maps. It may be suspected that precision of area projection on maps prepared at the turn of the 18th and 19th centuries and in the 19th century was different than on the ones prepared according to technologies used in cartography during recent years.

Analogical tendencies concerning the increase in area afforestation presented in this paper have been presented very often in ecological literature recently (e.g. Iverson 1988; Turner and Ruscher 1988; Kienast 1993; Jenkins and Parker 2000; Ripple et al. 2000). In other of our works (Wilkon-Michalska et al. 1999; Kunz et al. 2000; Nienartowicz et al., (in press), the influence of afforestation presented here on the distribution of rare and preserved plant species is analysed and its influence on carbon sequestration on the landscape level in the Tuchola Forest.

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