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ORIGINAL PAPER

Reconstruction of forest areas on post-agricultural land in selected forest districts of State Forests in Poland based on archival maps

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ABSTRACT

According to the State Forest Information System (SILP), 22.7% of forest area in Poland is located on post-agricultural land. This data includes almost exclusively areas afforested after World War II and only first generation stands on non-forest land. It does not include all previously afforested areas, stands that formed naturally through succession on post-agricultural land, and stands that were planted on post-agricultural land after decay due to the activity of root rot fungus *Heterobasidion annosum* (Fr.) Bref. The aim of the study was to analyze the changes in forest cover in five selected forest districts of Polish State Forests based on available historical maps and to determine the post-agricultural origin of the soils in their current distribution area. The study covered the territory of five forest districts of the State Forests including Bielsk, Bircza, Bolewice, Nidzica and Miastko (Fig. 1). Both forests owned by State Forests and those with other forms of ownership were analyzed.

The study methodology was conducted based on the following steps: search on map portals and in library databases for cartographic material for the above-mentioned forest districts; review of the selected maps in terms of their suitability for forest cover analysis; georeferencing of selected maps; digitization of maps from different time periods; comparative analysis of forest cover areas from the layers created using geoprocessing tools in the GIS software; and calculations and comparison of forest areas from different time periods for the selected forest districts. From the available historical cartographic materials, only the topographic maps are suitable for analysis of forest areas with the oldest maps dating back to 1780. After reviewing the acquired material based on the above steps, the maps were selected for analysis.

The study found that the actual area of forest stands on former agricultural land in the five forest districts is greatly underestimated. Based on the map analysis, the actual share of forest stands on former arable land in the total forest area in the forest districts is significantly higher than the data in the State Forest Information System (available from SILP in the year 2020) with the following results: Bielsk – 91.8% (according to SILP: 60.7%), Bolewice – 74.2% (according to SILP: 45.5%), Bircza – 61.8% (according to SILP: 37.2%), Nidzica – 84.6% (according to SILP: 60.9%), Miastko – 87.5% (according to SILP: 60.6%).

It would be advisable to change the State Forest Information System so that information on agricultural land use is available for each forest generation. Knowing which areas are post-agri-

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cultural is critical for choosing the right silvicultural and protective measures, maintaining stand stability, and reducing stand degradation due to root rot fungus which can also be active in second and third generation forests on post-agricultural land. Analysis of archival mapping material is, in many cases, the only way to obtain information on the origin of stands.

KEY WORDS

afforestation, change, cover, topographic

Introduction

Historical maps contain valuable information about changes in vegetation cover including the spatial occurrence of forests. By analyzing the information contained within them for comparison with current conditions, it makes it possible to determine changes in forest cover during a specific time scale. This information can be used for planning silvicultural measures and protective actions in forest areas. Specialized information tools can be used to interpret and compare cartographic archival materials. As a result of various processes including agricultural development, the Industrial Revolution and wars, the areas and locations of forests have changed significantly. According to current knowledge, 22.7% of forest area in State Forests (SF) are located on former agricultural land (SILP, 2020). This data includes only land that was afforested after World War II and only being first generation stands on non-forest land. It does not include all areas that were previously afforested, stands that occurred naturally through succession on post-agricultural lands, or stands that were planted on post-agricultural lands after dieback due to root rot fungus damage. Such discrepancies can be addressed in forest management plans. For example, the new forest management plan for the Wielbark Forest District (PUL, 2021) which has an area of about 8,000 hectares of first-generation stands on former cropland, but soil surveys have revealed features indicative of cropland on more than 20,000 hectares (about 90% of the forest area in the district).

The State Forest Information System (SILP) provides information on forests on post-agricultural land only in the first generation. There is no information in the system for second generation stands even if the first generation was removed by sanitary cuts due to root rot fungus damage. In many cases, the effects of agriculture can still be seen in the second and even third generations of the forest due to the reduced stability of the stands (Sierota *et al*., 2018).

The objective of this study is to analyze the changes in forest cover of five selected forest districts of SF in Poland based on available historical maps and to determine the post-agricultural origin of the areas within their current areal extent.

Historical background

Old topographic maps are a valuable source of information about the geographical space of the past (Pasławski, 1967; Krassowski and Tomaszewska, 1979; Plit, 1994, 2006; Konias, 2010; Faluszczak, 2011; Kuna, 2015; Panecki, 2017; Lieskovský *et al*., 2018) as the variety of information encoded on maps by cartographic signs is higher than on any other analog medium (Kudriawcew, 1955; Plit, 2014). Moreover, official documents (civil or military), which have been repeatedly verified in the phases of surveying, creation and reproduction, have given them a high degree of reliability (Knowles, 2002; Szady, 2013b). Using old topographic maps to track changes in geographic space requires the proper selection of cartographic materials, standardization of mathematical principles, and correct interpretation of the old topographic map's content (Nieścioruk, 2006; Kuna, 2014a). When searching for suitable cartographic materials, it is necessary to become

familiar with the history of the mapping of a given area and the studies of published topographic maps (Kuna, 2015). The degree of generalization of old topographic maps differs from that of modern maps (Kuna, 2014b), and the degree of cartographic generalization is the commonly accepted degree of simplification of a map drawn at a certain scale (Ostrowski, 2008).

One of the achievements of geoinformatics, which began in the 1960s, was the mapping of cartographic coordinates (georeferencing) to raster map images. Rectification gives the matrix cells of a digital map image a new set of coordinates that match the coordinates of the layout used on a specific reference map, and therefore enabling the use of computers on available archival analog maps. The ability to use a variety of source data, create arbitrary conversion algorithms, and display the results in real units has contributed to the spontaneous development of geographic information systems and the growth of map-based quantitative analysis (Macioch, 2006).

In georeferencing, a map is adjusted to a contemporary coordinate system in a Geographic Information System (GIS) program using adjustment points (topographic objects) identified on the old and current maps. This procedure allows virtual overlaying of maps created in different systems, scales and mapping. It is also possible to compare the content between different maps as well as a contemporary map. The cartographic coordinates of the map pixels registered in the parent coordinate system are transformed into the corresponding geographic coordinates and then transformed again into the corresponding coordinates of the coordinate system of the target map (Affek, 2012). In order to obtain correct transformation results of raster map images, the mathematical principles (ellipsoid parameters, cartographic mapping parameters) must be determined in precise detail (Panecki, 2014).

Modern GIS programs allow map transformation such as the temporary unification of the mathematical basis of a map or transformation into another cartographic representation. A problem arises when the parameters of the cartographic image of one of the calibrated maps are not known or determining them is not precise enough (*e.g.*, there is no information about the position of the initial ellipsoid in relation to the present WGS 84 ellipsoid). Giving a spatial reference to a topographic map with unknown or unreliable spatial reference parameters is only possible by matching the raster image of the map with other georeferenced spatial data (Affek, 2012). Matching a former topographic map with the reference material in GIS software requires marking a certain number of corresponding points on all available cartographic material. The selection of point pairs is based on the identification of stable points, *i.e.*, topographic objects whose locations have not changed during the historical period under study (Guerra, 2000; Nieścioruk, 2006). The transformation of old topographic maps into properly digitized layers of spatial databases described by coded attributes greatly facilitates the use of old topographic maps for the study of historical variability of geographic space components (Jaskulski *et al.*, 2013; Szady, 2013a).

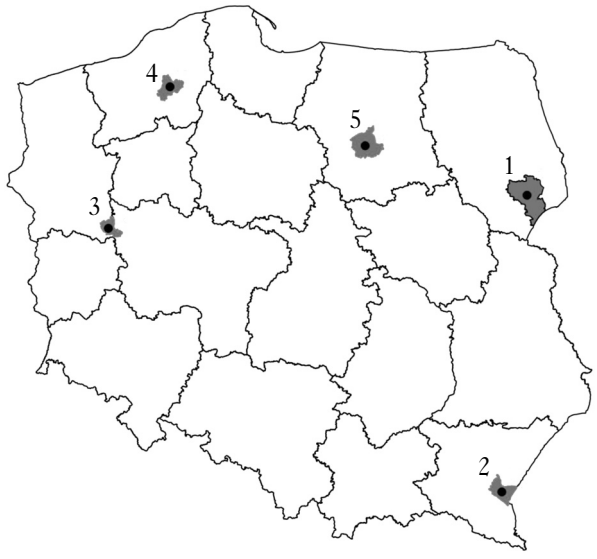
At the turn of the 18th and 19th centuries, cartographic work in the Polish territories increased when the annexing states of Prussia, Russia and Austria occupying new territories began to develop their own accurate maps for those territories. This was a time of great political change and massive military operations that required highly detailed knowledge of the tactical and operational features of the terrain. Triangulation work was followed by detailed field surveys, and the survey matrix was condensed and improved. In the second half of the 19th century, a topographic steering wheel with a vertical wheel and a rangefinder was introduced into survey work which allowed the topography of the earth's surface to be drawn more accurately using contour lines (Dzikiewicz, 1960).

Nowadays, archival topographic maps, especially from the 19th and 20th centuries, have acquired new value and play an increasingly important role in the study of changes in the geographic environment. The use of 18th century maps based on field reconnaissance, but lacking geodetic warping, present significant difficulties. Older maps that are not based on field surveys are fundamentally unsuitable for providing reliable information on the state of the geographic environment (Czerny, 2015). Geographic analysis of such sources is not a simple matter of processing of their content using the tools of GIS but instead a labour-intensive reinterpretation. Maps from the 16th and 17th centuries can be used to reconstruct elements of the geographic environment (*e.g.*, forests or lakes), but the results of such analyses are uncertain and must be verified against other source materials (Plit, 2012, 2014).

Materials and method

The study covered the areas of five Polish SF forest districts: Bielsk, Bircza, Bolewice, Nidzica and Miastko (Fig. 1). The selection of forest districts for analysis in each of the five regional directorates of SF was determined by the large proportion of forests on former farmland and the occurrence of root diseases. Forests under the management of SF as well as forests with other forms of ownership were analyzed. Data on forests not managed by SF were incomplete due to the lack of simplified forest management plans and the fact that land registry databases are often outdated. The work was carried out in the following phases:

1. Searching map portals and library databases for cartographic material for the aforementioned forest areas.
2. Review of maps found suitabile for forest cover analysis.
3. Georeferencing of the selected maps.
4. Digitization of maps from different time periods.
5. Comparative analysis of created forest cover layers using geoprocessing tools in GIS software.
6. Calculation and comparison of forest areas from different time periods for the selected forest districts.



1 – Bielsk – Regional Directorate of State Forests (RDSF) Białystok
2 – Bircza – RDSF Krosno
3 – Bolewice – RDSF Szczecin
4 – Miastko – RDSF Szczecinek
5 – Nidzica – RDSF Olsztyn

Fig. 1.
Location of the forest districts covered by the survey

Of all the available historical cartographic materials, only topographic maps were suitable for forest area analysis. Since such maps were not produced until the late 18th century, earlier publications were excluded. It was assumed that the scale of the maps should not be smaller than 1:200,000 since the degree of cartographic generalization, *i.e.*, the accepted degree of simplification of a drawn map at a given scale, is too high. After reviewing the selected materials, the maps summarized in Table 1 were selected for analysis.

Georeferencing was done manually when no frame of reference was available or by using the geographic grid of the map when a frame of reference was known. Georeferencing consisted of adjusting the map to the modern coordinate system in a GIS program using adjustment points (topographic objects) identified on the historical and modern maps. Manual georeferencing was performed for the oldest maps because they generally did not have a coordinate system grid. The condition of the copies of these maps was also significant. Maps more than 200 years old showed significant deformation of the paper on which they were produced. Churches and intersections of main roads were usually used as reference points. Previously calibrated maps with a known ellipsoids and known cartographic parameters were chosen as comparative maps. Due to major changes in the landscape, maps from the early 20th century were usually used as comparison maps.

Manual calibration was performed for the following maps:
- Textor-Sotzmann map from 1798 for the forest districts of Bielsk and Nidzica,
- Reymann's map from 1840 for the forest districts of Bielsk and Miastko,
- Schroetter map from 1800 for the forest district of Nidzica.

The following reference maps were used:
- a biverst map from 1915 for the Bielsk Forest District,
- Messtischblätter map from 1936 for the forest district of Miastko,
- KDR (Karte des Deutschen Reiches) from 1893 for the forest district of Nidzica,
- some of the maps from the Military Geographical Institute produced in the 1930s also had to be calibrated manually.

Maps of the Kingdoms of Galicia and Lodomeria (Josephinian image) and Galicia and Bukovina (Franciscan image) were obtained from mapire.eu which provides maps (with georeferencing already assigned) from the Austrian State Archives for a fee. The Web Map Service (WMS) of the National Geoportal was used to analyse the topographic maps of the General Office of Geodesy and Cartography (GUGiK). The other maps were calibrated by entering coordinates at the corners of the maps. Georeferencing was performed using QGIS version 3.14. Digitization of the forest areas was done for all maps by manually creating a polygon layer. The data was saved in ESRI shapefile format. ETRS89/Poland CS92 (EPSG:2180) was chosen as the project coordinate system. Geometric attributes were added to the created layers (containing the forest area from the year of the reference map) to obtain the current forest areas. Current layers of SF areas from the Forest Data Bank (post 2020) were used for the analysis. Data on forests not managed by SF and forests on former agricultural lands were obtained from SILP (numerical forest map).

The data from the Forest Data Bank contained the total area of forested and non-forested subcompartments, so it was necessary to separate the layers of these areas from the database. In doing so, some information related errors may have occurred as some land uses, such as those for succession or ecological use, may be both forest and non-forest land. However, the areas of such subcompartments were small and didn't affect the overall results of the analysis. The forest areas that were compared may differ slightly based on the source of data collection whether from BDL

Table 1.
Summary of historical maps used in the study

Year map created	Map name	Country of origin
	Bielsk Forest District	
1798	Topographisch-Militärische Karte von vormaligen Neu Ostpreussen oder dem jetzigen Nordlichen Theil des Herzogthums Warschau nebst dem Russischen District 1:152500 (1808), Karte von Neuostpreußen, Textor-Sotzmann' map	Prussia
1840	Topographische Spezial-Karte von Central-Europa Reymann's Spezialkarte 1:200000. The southern part of the forest district lying outside the border of Prussian annexation	Prussia
1866	Military topographical map of European Russia (Voenno-Topografičeskaâ Karta Evropejskoj Rossii) 1:126,000. The map was made between 1845 and 1889; the three-verst map (Bartnik, 2015)	Russia
1915	New topographic map of west Russia (Novaâ topografičeskaâ karta Zapadnoj Rossii) 1:84000, the biverst map (Matuszkiewicz *et al*., 2017)	Russia
1937	Tactical Map of the Military Geographical Institute, 1:100000 (Matuszkiewicz *et al*., 2017)	Poland
1972	Head Office of Geodesy and Cartography (GUGiK) topographic maps in 1965 layout	Poland
	Bircza Forest District	
1780	Map of the Kingdom of Galicia and Lodomeria, Mieg's map, 1:28800 (1779-1793), Karte des Königreichs Galizien und Lodomerien. Galizien und Lodomerien – First Military Survey (Bukowski and Janeczek, 2013)	Austria-Hungary
1862	Topographical map of Galicia and Bukovina. The second photo, so-called Franciscan, 1:28800 (1861-1864) (Bukowski, 2013)	Austria-Hungary
1937	Tactical Map of the Military Geographical Institute, 1:100000	Poland
1964	Head Office of Geodesy and Cartography (GUGiK) topographic maps in 1965 layout	Poland
	Bolewice Forest District	
1810	Map of Gaul/Raczynski, 1:75000 (1807-1812) (Panecki, 2015)	Poland
1893	Messtischblätter 1:25000 (1875-1915), [MTB] (Panecki, 2017)	Germany
1936	Tactical Map of the Military Geographical Institute, 1:100000	Poland
1977	Head Office of Geodesy and Cartography (GUGiK) topographic maps in 1965 layout	Poland
	Nidzica Forest District	
1800	Karte von Ost-Preussen nebst Preussisch Litthauen und West-Preussen nebst dem Netzdistrict 1:150000 (1802-1812), map of Schrötter-Engelhardt (Grabowski, 2005)	Prussia
1808	Topographisch-Militärische Karte von vormaligen Neu Ostpreussen oder dem jetzigen Nordlichen Theil des Herzogthums Warschau nebst dem Russischen District 1:152500 (1808), Karte von Neuostpreußen, map of Textor-Sotzmann Map of J.C. Textor under the title New East Prussia from the years 1795-1800 (Lankamer, 1967).The southern part of the forest district	Prussia
1893	Karte des Deutschen Reiches 1:100000 (1878-1945), [KdDR] (Panecki, 2017)	Germany
1930	Tactical Map of the Military Geographical Institute, 1:100000	Poland
1956	US AMS (Army Map Service), East Prussia 1:50000 (M752), 1956, Poland 1:50000 (M751-M753), 1956-1984 (http://polski.mapywig.org/)	USA

Table 1. continued

Year map created	Map name	Country of origin
	Miastko Forest District	
1850	Topographische Spezial-Karte von Central-Europa Reymann's Spezialkarte 1:200000 (wikipedia.org.pl)	Prussia
1893	Karte des Deutschen Reiches 1:100000 (1878-1945)	Germany
1936	Messtischblätter 1:25000	Germany
1976	Head Office of Geodesy and Cartography (GUGiK) topographic maps in the 1965 layout	Poland

(Forest Data Bank), SILP or forest management plans. This could not be avoided because the data was updated at different times and forest areas and ownership change dynamically.

Results

Bielsk Forest District. The forest cover of Bielsk Forest District changed slightly from the year 1798 to the beginning of the 20th century and amounted to about 16% (Table 2). After World War I, there was a further decrease in forest area probably as a result of wars and deforestation. After World War II, the forest area has been gradually increasing until the current reference period as a result of afforestation programs and natural succession on uncultivated agricultural land. Bielsk Forest District differs from the other study areas in terms of ownership structure as about half of all forests are not managed by SF. According to the analysis of the SF forest area, where there is a forest currently and there was no forest at least once in the past, it appears that actual post-agricultural forests account for as much as 91.8% of the Bielsk Forest District forest area. On the other hand, according to the data from SILP (2020) the share of forest area on post-agricultural land in 2020 in relation to the forest area in Bielsk Forest District is lower by about 30%. Of the forests not managed by SF, the majority in the current territory of the Bielsk Forest District are forests on former agricultural land. The actual share of forests compromising all forms of ownership on post-agricultural land in 2020 is about 93% in the current territory of the Bielsk Forest District which was calculated on the basis of map analysis and having appeared at least once as non-forest areas on the analyzed historical maps.

Bolewice Forest District. At the beginning of the 19th century, the forest area in the present territory of Bolewice Forest District was about 12,000 hectares which represented 39.2% of the territory (Table 3). During the course of the 19th century, as a result of the Industrial Revolution, the increased demand for wood and a rural exodus lead to a gradual deforestation of the area. It should be noted that throughout the period, parts of the area were deforested and reforested although not always the same areas. The history of the forest area of the forest was described by Anders (2018). Intensive afforestation and recognition of natural succession of non-agricultural land occurred until the 1970s and currently amounts to 65.1% (Table 3). The area of forests not managed by SF is very small with forests under SF management (Bolewice Forest District) on post-agricultural land make up 45.5% of all SF forests according to SILP data (2020). According to the analysis, the share of forest area in non-forest areas is higher by about 30%. Non-SF forests, in the current territorial range of Bolewice Forest District, are located mainly on post-agricultural land. The actual area of forests compromising all forms of ownership on post-agricultural land in 2020, calculated on the basis of the analyzed maps, is 75.6% which appeared at

Table 2.

Summary of forest areas in the current territorial range of Bielsk Forest District according to SILP and BDL data from 2020 and historical data (results of map analysis), as well as the results of calculations of the actual area of forests on post-agricultural lands since 1798

		Absolute values [ha]	In relation to territorial coverage (to line 8) [%]	In relation to the area of forests of all forms of ownership (to line 7) [%]
1	Bielsk Forest District area (BDL, 2020)	21183	14.90	49.48
2	Forest area of Bielsk Forest District (BDL, 2020)	20913	14.71	48.85
3	Non-forest area of Bielsk Forest District (BDL, 2020)	269	0.19	0.63
4	Area of non-SF forests in the territorial range of Bielsk Forest District (SILP, 2020)	21895	15.40	51.15
5	Forest area on post-agricultural land of Bielsk Forest District (SILP, 2020)	12850	9.04	30.02
6	Forest area on forest lands of Bielsk Forest District (SILP, 2020)	8329	5.86	19.46
7	**Area of forests of all forms of ownership in the territorial range of Bielsk Forest District (sum of lines 2 and 4)** (SILP, 2020; BDL, 2020)	**42809**	30.10	100.00
8	**Territorial range of Bielsk Forest District** (BDL, 2020)	**142200**	100.00	
	Forests in the current territorial range of Bielsk Forest District (results of analysis)			
9	**in 1798**	22320	15.70	52.14
10	**in 1866**	22811	16.04	53.29
11	**in 1915**	23719	16.68	55.41
12	**in 1937**	18495	13.01	43.20
13	**in 1972**	24097	16.95	56.29
	Actual forest area on post-agricultural land in 2020 which appeared as non-forest land at least once on the analyzed historical maps (results of analysis)			
14	Forest area on-post agricultural land under the management of SF	19192	13.50	44.83
15	Forest area on post-agricultural land not under SF management	20572	14.47	48.06
16	Area of all forests on post-agricultural land	39764	27.96	**92.89**
17	Share of forest area on post-agricultural land in Bielsk Forest District in 2020 in relation to the forest area of SF (result of analyses) [%]	**91.77**		
18	Share of forest area on post-agricultural land in Bielsk Forest District in 2020 in relation to the forest area of SF (SILP, 2020) [%]	**60.67**		
19	Share of forest area on non-SF managed post-agricultural land in 2020 in relation to non-SF managed forest area (results of analysis) [%]	**93.96**		

Table 3.

Summary of forest area in the current territorial range of Bolewice Forest District according to SILP and BDL data from 2020 and historical data (results of analysis), as well as the results of calculations of actual forest area on post-agricultural land since 1810

		Absolute values [ha]	In relation to territorial coverage (to line 8) [%]	In relation to the area of forests of all forms of ownership (to line 7) [%]
1	Bolewice Forest District area (BDL, 2020)	18947	61.95	95.17
2	Forest area of Bolewice Forest District (BDL, 2020)	18316	59.88	92.00
3	Non-forest area of Bolewice Forest District (BDL, 2020)	631	2.06	3.17
	Area of non-SF forests in the territorial range of Bolewice Forest District (SILP, 2020)	1593	5.21	8.00
5	Forest area on post-agricultural land of Bolewice Forest District (SILP, 2020)	8621	28.19	43.30
6	Forest area on forest lands of Bolewice Forest District (SILP, 2020)	10323	33.75	51.85
7	**Area of forests of all forms of ownership in the territorial range of Bolewice Forest District (sum of lines 2 and 4)** (SILP, 2020; BDL, 2020)	**19909**	65.09	100.00
8	**Territorial range of Bolewice Forest District** (BDL, 2020)	**30587**	100.00	
	Forests in the current territorial range of Bolewice Forest District (results of analysis)			
9	**in 1810**	11996	39.22	60.25
10	**in 1893**	9677	31.64	48.61
11	**in 1936**	10353	33.85	52.00
12	**in 1977**	17278	56.49	86.79
	Actual forest area on post-agricultural land in 2020 which appeared as non-forest land at least once on the analyzed historical maps (results of analysis)			
13	Forest area on-post agricultural land under the management of SF	13597	44.45	68.29
14	Forest area on post-agricultural land not under SF management	1458	4.77	7.32
15	Area of all forests on post-agricultural land	15054	49.22	**75.61**
16	Share of forest area on post-agricultural land in Bolewice Forest District in 2020 in relation to the forest area of SF (results of analysis) [%]	**74.23**		
17	Share of forest area on post-agricultural land in Bolewice Forest District in 2020 in relation to the forest area of SF (SILP, 2020) [%]	**45.51**		
18	Share of forest area on non-SF managed post-agricultural land in 2020 in relation to non-SF managed forest area (results of analysis) [%]	**91.52**		

least once on the analyzed historical maps as non-forest areas in the current territorial area of Bolewice Forest District.

Bircza Forest District. The forest cover of Bircza Forest District has always been quite high compared to other regions of the country. At the end of the 18th century, it was about 41% and then in 1862 it decreased by about 5% as a result of the Industrial Revolution (Table 4). After World War II, as a result of the massive resettlement of the local population and afforestation programmes for former agricultural lands, forest cover gradually increased. Based on this historical context, it can be seen that afforestation and recognition of the resulting natural regeneration on abandoned former agricultural land in Bircza Forest District occurred mainly in the short period after World War II. The ownership structure of forests account for about 90.2% managed by SF as related to the area of all forests in the current jurisdiction of the forest district. The area of forests on former agricultural lands according to SILP data is about 25% less than shown in the comparative analysis of archival maps The share of forest area on farmland not managed by SF is even higher. This data is consistent with the research results of the FORECOM project according to which the forest cover in the forest district increased from 35.2% in 1860 to 69.9% in 2013 (Kozak and Kaim, 2016). Calculated on the basis of map analysis, the actual forest area compromising all forms of ownership on post-agricultural land in 2020 is 64% in the current territorial area of the Bircza Forest District which appeared at least once as non-forest land on the analysed historical maps.

Nidzica Forest District. The development of forest stands in the 19th century, within the territory of present day Nidzica Forest District, is similar to the development of other forest districts located in Prussia. Even before the development of industry, the forest cover of the area was low but especially during the Industrial Revolution (1893) (Table 5). Currently, the forest cover of the territory of the Nidzica Forest District is 33.2% (SILP, 2020; BDL, 2020). The area of forests compromising all forms of ownership after World War II had doubled by 2020, from which can be deduced the share of forests on post-agricultural land (Table 5). Forests not managed by SF account for 12.8% of all forests. Unfortunately, it was not possible to obtain a spatial level for forests of this ownership type, therefore analysis of arable land was not performed for them. Only the total area of these forests was available. According to SILP (2020) datasets the share of forests within SF Nidzica Forest District on arable land is about 24% smaller than shown in the analysis.

Miastko Forest District. In the 19th century, the forest area in the present day territory of Miastko Forest District changed similarly to other forest areas of Prussia, and at the end of the 19th century the forest area was about 13.7% (1893) (Table 6). The low forest cover in this area was influenced by the fact that it was the 'granary of Prussia' and until World War II did not exceed 20%. The greatest increases in forest area occurred till the 1970s. Presently, the share of forest in the territory of Miastko Forest District is about 50%. The areas of forests not managed by SF are very small and located almost exclusively on former agricultural land. According to SILP (2020), forests on former agricultural land account for 60.6% of the total forest area managed SF in Miastko Forest District. A comparative analysis of archival maps shows that the actual arable area of forests managed by SF is about 27% higher.

To better illustrate the results of the study figures 2-6 illustrate the five analyzed forest districts areas of forests on forest and post-agricultural land under PGL LP management as verified by archival mapping material.

Table 4.

Summary of forest areas in the current territorial range of Bircza Forest District according to SILP and BDL data from 2020 and historical data (results of analysis), as well as the results of calculations of the actual area of forests on former post-agricultural land since 1780

		Absolute values [ha]	In relation to territorial coverage (to line 8) [%]	In relation to the area of forests of all forms of ownership (to line 7) [%]
1	Bircza Forest District area (BDL. 2020)	29822	59.23	96.92
2	Forest area of Bircza Forest District (BDL. 2020)	27754	55.12	90.20
3	Non-forest area of Bircza Forest District (BDL. 2020)	2067	4.11	6.72
4	Area of non-SF forests in the territorial range of Bircza Forest District (SILP. 2020)	3016	5.99	9.80
5	Forest area on post-agricultural land of Bircza Forest District (SILP. 2020)	11077	22.00	36.00
6	Forest area on forest lands of Bircza Forest District (SILP. 2020)	18718	37.18	60.83
7	**Area of forests of all forms of ownership in the territorial range of Bircza Forest District (sum of lines 2 and 4)** (SILP. 2020; BDL. 2020)	**30770**	61.11	100.00
8	**Territorial range of Bircza Forest District** (BDL. 2020)	**50349**	100.00	
	Forests in the current territorial range of Bircza Forest District (results of analysis)			
9	**in 1780**	20502	40.72	66.63
10	**in 1862**	17974	35.70	58.41
11	**in 1937**	18588	36.92	60.41
12	**in 1964**	29356	58.31	95.41
	Actual forest area on post-agricultural land in 2020 which appeared as non-forest land at least once on the analyzed historical maps (result of analyses)			
13	Forest area on-post agricultural land under the management of SF	17160	34.08	55.77
14	Forest area on post-agricultural land not under SF management	2534	5.03	8.24
15	Area of all forests on post-agricultural land	19694	39.12	**64.00**
16	Share of forest area on post-agricultural land in the Bircza Forest District in 2020 in relation to the forest area of SF (results of analysis) [%]	**61.83**		
17	Share of forest area on post-agricultural land in the Bircza Forest District in 2020in relation to the forest area of SF (SILP, 2020) [%]	37.18		
18	Share of forest area on non-SF managed post-agricultural land in 2020 in relation to non-SF managed forest area (results of analysis) [%]	**84.03**		

Discussion

Analysis of historical map materials showed changes in the forest landscape over a long period of time, and the results are consistent with historical events. At the beginning of the 19th century forest cover was low. Contributing factors were earlier overexploitation of forests, burning of forests for low-yield agriculture, and high demand for wood tar which Poland's production played a leading role.

Table 5.

Summary of forest area in the current territorial range of Nidzica Forest District according to SILP and BDL data from the year 2020 and historical data (results of analysis), as well as the results of calculations of actual forest area on post-agricultural land since 1800

		Absolute values [ha]	In relation to territorial coverage (to line 8) [%]	In relation to the area of forests of all forms of ownership (to line 7) [%]
1	Nidzica Forest District area (BDL. 2020)	24130	29.80	89.73
2	Forest area of Nidzica Forest District (BDL. 2020)	23439	28.95	87.16
3	Non-forest area of Nidzica Forest District (BDL. 2020)	691	0.85	2.57
4	Area of non-SF forests in the territorial range of Nidzica Forest District (SILP. 2020)	3452	4.26	12.84
5	Forest area on post-agricultural land of Nidzica Forest District (SILP. 2020)	14691	18.14	54.63
6	Forest area on forest lands of Nidzica Forest District (SILP. 2020)	9430	11.65	35.07
7	**Area of forests of all forms of ownership in the territorial range of Nidzica Forest District (sum of lines 2 and 4)** (SILP. 2020; BDL. 2020)	**26892**	33.21	100.00
8	**Territorial range of Nidzica Forest District** (BDL, 2020)	**80972**	100.00	
	Forests in the current territorial range of Nidzica Forest District (results of analysis)			
9	**in 1800**	13220	16.33	49.16
10	**in 1893**	8537	10.54	31.74
11	**in 1930**	13009	16.07	48.38
12	**in 1956**	13289	16.41	49.42
	Actual forest area on post-agricultural land in 2020 which appeared as non-forest land at least once on the analyzed historical maps (results of analysis)			
13	Forest area on-post agricultural land under the management of SF	19833	24.49	73.75
14	Share of forest area on post-agricultural land in Nidzica Forest District in 2020 in relation to the forest area of SF (result of analyses) [%]	**84.61**		
15	Share of forest area on post-agricultural land in Nidzica Forest District in 2020 in relation to the forest area of SF (SILP, 2020) [%]	**60.91**		

Table 6.

Summary of forest areas in the current territorial range of Miastko Forest District according to SILP and BDL data from 2020 and historical data (results of analysis), as well as the results of calculations of the actual area of forests on post-agricultural land since 1850

		Absolute values [ha]	In relation to territorial coverage (to line 8) [%]	In relation to the area of forests of all forms of ownership (to line 7) [%]
1	Miastko Forest District area (BDL. 2020)	23010	48.50	101.92
2	Forest area of Miastko Forest District (BDL. 2020)	21732	45.80	96.26
3	Non-forest area of Miastko Forest District (BDL. 2020)	1278	2.69	5.66
4	Area of non-SF forests in the territorial range of Miastko Forest District (SILP. 2020)	844	1.78	3.74
5	Forest area on post-agricultural land of Miastko Forest District (SILP. 2020)	13941	29.38	61.75
6	Forest area on forest lands of Miastko Forest District (SILP. 2020)	9053	19.08	40.10
7	**Area of forests of all forms of ownership in the territorial range of Miastko Forest District (sum of lines 2 and 4)** (SILP. 2020; BDL. 2020)	**22576**	47.58	100.00
8	**Territorial range of Miastko Forest District** (BDL. 2020)	**47447**	100.00	
	Forests in the current territorial range of Miastko Forest District (results of analysis)			
9	**in 1850**	8590	18.10	38.05
10	**in 1893**	6493	13.68	28.76
11	**in 1936**	9164	19.31	40.59
12	**in 1976**	19962	42.07	88.42
	Actual forest area on post-agricultural land in 2020 which appeared as non-forest land at least once on the analyzed historical maps (result of analyses)			
13	Forest area on-post agricultural land under the management of SF	19007	40.06	84.19
14	Forest area on post-agricultural land not under SF management	832	1.75	3.68
15	Area of all forests on post-agricultural land	19838	41.81	**87.87**
16	Share of forest area on post-agricultural land in Miastko Forest District in 2020 in relation to the forest area of SF (results of analysis) [%]	**87.46**		
17	Share of forest area on post-agricultural land in Miastko Forest District in 2020 in relation to the forest area of SF (SILP. 2020) [%]	**60.63**		
18	Share of forest area on non-SF managed post-agricultural land in 2020 in relation to non-SF managed forest area (results of analysis) [%]	**98.47**		

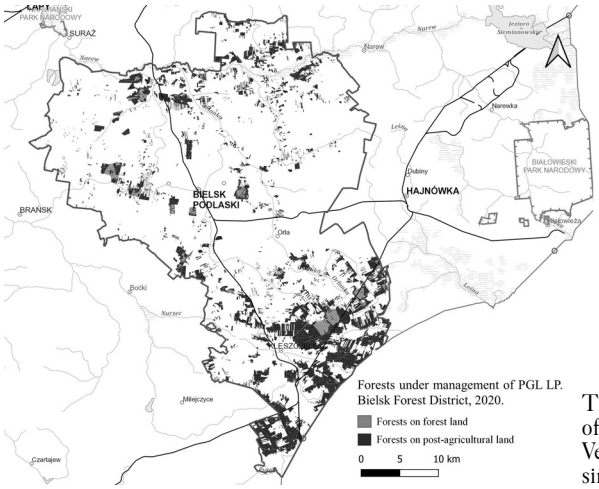


Fig. 2.
The area of forests under the management of PGL LP. Bielsk Forest District, 2020. Verified based on forest cover analysis since 1798

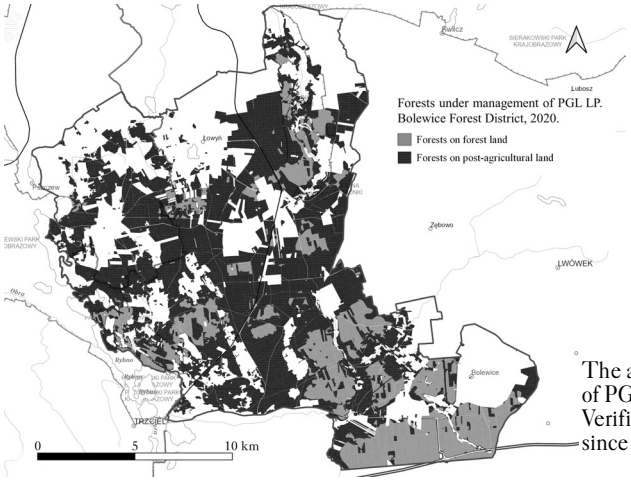


Fig. 3.
The area of forests under the management of PGL LP. Bolewice Forest District, 2020. Verified based on forest cover analysis since 1810

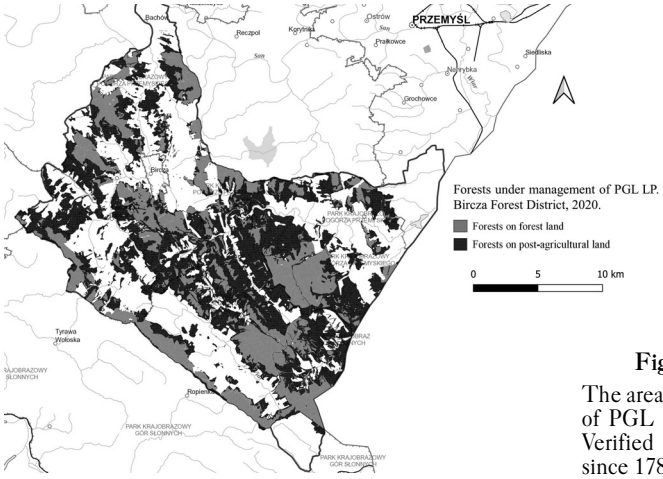


Fig. 4.
The area of forests under the management of PGL LP. Bircza Forest District, 2020. Verified based on forest cover analysis since 1780

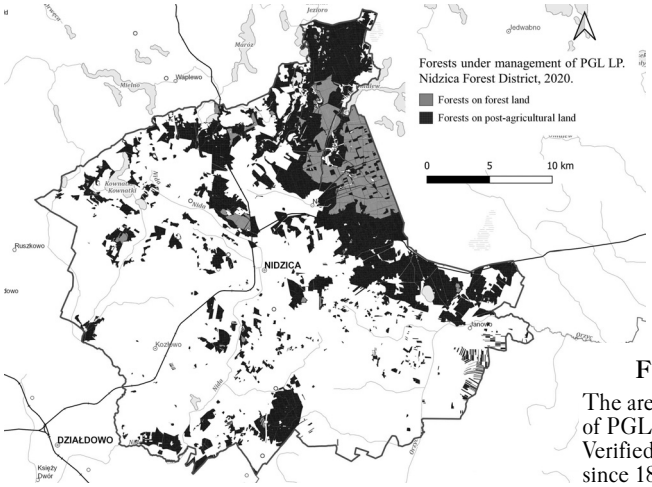


Fig. 5.

The area of forests under the management of PGL LP. Nidzica Forest District, 2020. Verified based on forest cover analysis since 1800

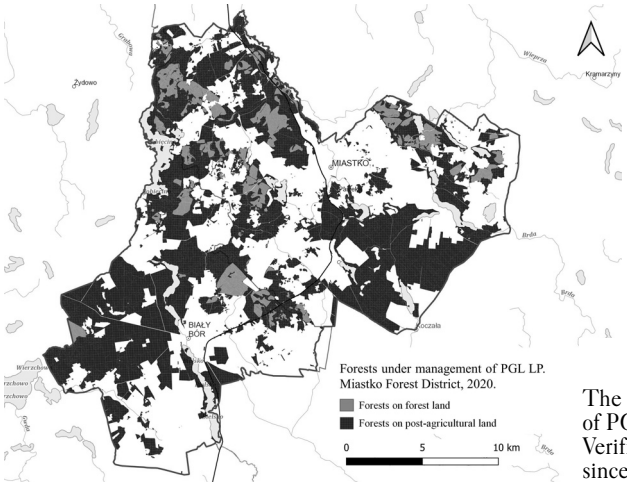


Fig. 6.

The area of forests under the management of PGL LP. Miastko Forest District, 2020. Verified based on forest cover analysis since 1850

In the middle of the 19th century, the demand for wood increased significantly as a result of the Industrial Revolution. After World War II forest area gradually increased which was due to the implementation of programs to increase forest area as well as natural succession in fallow areas left behind. For example, part of the FORECOM project (Kozak and Kaim, 2016) showed that forest cover doubled from the mid-1800s to the early 21st century for Bircza Forest District area from 35.2% in 1860 to 69.9% in 2013. Old maps were also analyzed by Matuszkiewicz *et al.* (2017) which depict historical changes in forest cover in the Mazurian-Kurpie border area in terms of sustainable landscape development.

Descriptions of forest stands in the SF Information System includes information on agricultural use only in the first generation of the forest. However, the impact of agriculture is observed in the second and even in the third generation on post-agricultural lands. This is especially true for sanitary cuttings as a result of root rot fungus activity and damage from primary and secondary pests due to stand weakening and overexposure. Analysis of old maps shows that the area of post-agricultural land is greatly underestimated in SF databases. It is often difficult to know the history of silvicultural activities and the origin of forest stands, even after World War II, and SILP has only been in place since the 1990s. Forest districts have often changed their territorial

extent, therefore making it difficult to retrieve data from old management plans. The analogous form of old management plans does not facilitate data retrieval. Older forest stands were often established on post-agricultural land in the interwar period and before World War I. Data on various forms of forest ownership before War II are nonexistent or very rare in most current forest districts. Information on the agricultural history of soils in forests is important for implementing appropriate silvicultural and conservation measures to ensure stand stability for the full regeneration of forest ecosystems. Often, the only way to obtain information on the increase of forest cover is through the analysis of cartographic archival material supported by GIS software.

Conclusions

- Full restoration of forest ecosystems in forests on agricultural land depends on many factors, especially the duration and intensity of agricultural use, and may take up to several stand generations (300-500 years). Information on agricultural land use in forests is important for selecting the right silvicultural and conservation measures that will ensure stability and limit stand decomposition by root rot fungus which can be active even in second- and third-generation forests on non-agricultural land.
- Based on map analysis, it was observed that the actual area of stands on former agricultural land in the studied forest districts is greatly underestimated with differences ranging from about 24% to 31% depending on the forest district.
- It is advisable to modify the SF Information System so that the information on the agricultural history of soils is available for each generation of forests on these lands.
- Analysis of archival mapping material is one of the most efficient ways to obtain information about the origins of forest stands.
- It might be advisable to conduct similar analyses for other forest districts with a high proportion of former agricultural land, poor forest habitats, or with disease symptoms characteristic of former agricultural lands.

Authors' contributions

J.Ł. – research concept, data analysis, manuscript preparation and corrections; Sz.K. – data analysis, creation of maps.

Conflicts of interest

The authors declare no conflicts of interest.

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STRESZCZENIE

Lasy na gruntach porolnych w wybranych nadleśnictwach Lasów Państwowych w Polsce odtworzone na podstawie map archiwalnych

Pełny powrót ekosystemów leśnych na grunty porolne w lasach zależy od wielu czynników (w tym głównie od okresu i intensywności użytkowania gleb przez rolnictwo) i może trwać nawet kilka pokoleń drzewostanów (I, II, a nawet III generacja). W porównaniu z drzewostanami na gruntach leśnych drzewostany na gruntach porolnych są szczególnie wrażliwe na negatywne czynniki abiotyczne i biotyczne. Z tego powodu wiedza o porolności gleb na terenach leśnych jest dla hodowli i ochrony lasu niezmiernie istotna. W Lasach Państwowych (LP) 22,7% areału lasów położone jest na gruntach porolnych (SILP 2020). Dane te obejmują prawie wyłącznie powierzchnie zalesione po II wojnie światowej i tylko drzewostany w pierwszym pokoleniu na gruntach nieleśnych. Nie są zarejestrowane wszystkie powierzchnie zalesione wcześniej, drzewostany powstałe naturalnie w wyniku sukcesji na gruntach porolnych i często drzewostany, które posadzono po rozpadzie w wyniku aktywności korzeniowca wieloletniego *Heterobasidion annosum* (Fr.) Bref. na glebach porolnych. W wielu przypadkach skutki „porolności" widoczne są jeszcze w drugim, a nawet w trzecim pokoleniu lasu w obniżonej stabilności drzewostanów (np. huba korzeni).

Celem opracowania była analiza zmian lesistości wybranych nadleśnictw Lasów Państwowych w Polsce na podstawie dostępnych map historycznych oraz ustalenie porolnego pochodzenia gruntów leżących w ich obecnym zasięgu terytorialnym. Badaniami objęto teren 5 nadleśnictw LP: Bielsk, Bircza, Bolewice, Nidzica oraz Miastko (ryc. 1). Analizowano zarówno lasy w zarządzie LP, jak i lasy innych form własności. Prace zrealizowano w następujących etapach: wyszukanie na portalach mapowych oraz w bazach danych bibliotek materiałów kartograficznych dla wymienionych wyżej nadleśnictw; weryfikacja wyszukanych map pod względem ich przydatności do analizy lesistości; wykonanie georeferencji wybranych map; digitalizacja map z różnych okresów; analiza

porównawcza utworzonych warstw zasięgów drzewostanów z wykorzystaniem narzędzi geoprocessingu w oprogramowaniu GIS; zestawienie tabelaryczne oraz porównanie powierzchni gruntów leśnych z różnych okresów dla wybranych nadleśnictw.

Spośród dostępnych historycznych materiałów kartograficznych do analizy lesistości przydatne są jedynie mapy topograficzne. Z uwagi na to, że takie mapy wykonywano dopiero od końca XVIII wieku, odrzucono starsze publikacje. Przyjęto, że skala map nie może być mniejsza niż 1:200 000. Na mapach o małej skali stopień generalizacji kartograficznej, czyli akceptowany poziom uproszczenia rysunku mapy w danej skali, jest zbyt duży. Po weryfikacji pozyskanych materiałów wybrano do analiz mapy zestawione w tabeli 1. Najstarsza z nich pochodziła z 1780 roku. Georeferencję wykonano ręcznie (w przypadku braku zdefiniowanego układu odniesienia) bądź z wykorzystaniem siatki układu geograficznego mapy (w przypadku znanego układu odniesienia). Georeferencja polegała na dopasowaniu mapy do współczesnego układu współrzędnych w programie GIS za pomocą punktów dostosowania (obiektów topograficznych) zidentyfikowanych na mapie dawnej i współczesnej. Ręczną georeferencję wykonano dla map najstarszych, ponieważ na ogół nie miały one siatki układu współrzędnych. Do prezentacji map topograficznych GUGiK wykorzystano usługę WMS geoportalu krajowego. Pozostałe mapy kalibrowano przez wpisywanie współrzędnych z narożników map. Georeferencji dokonano, wykorzystując oprogramowanie QGIS w wersji 3.14. Digitalizację obszarów leśnych dla wszystkich map wykonano, tworząc ręcznie warstwę poligonową. Dane zapisano w formacie ESRI Shapefile. Jako układ współrzędny projektu przyjęto ETRS89/Poland CS92 (EPSG:2180). Utworzonym warstwom (zawierającym powierzchnię leśną z roku podkładu kartograficznego) dodano atrybuty geometrii, co umożliwiło poznanie powierzchni lasów w danym okresie. Do analizy wykorzystano również współczesne warstwy powierzchni Lasów Państwowych pozyskane z Banku Danych o Lasach (dane aktualne na 2020 rok). Dane lasów niebędących w zarządzie Lasów Państwowych oraz lasów na gruntach porolnych pozyskano z SILP (leśna mapa numeryczna).

Stwierdzono, że rzeczywista powierzchnia drzewostanów na gruntach porolnych w analizowanych nadleśnictwach LP jest mocno niedoszacowana. Na podstawie wykonanych analiz map wyliczono rzeczywisty udział lasów na gruntach porolnych w całkowitej powierzchni lasów w nadleśnictwach, przekraczający znacząco dane z systemu informatycznego Lasów Państwowych dostępne w 2020 roku:

– Bielsk – 91,8% (według SILP 60,7%) (tab. 2, ryc. 2),
– Bolewice – 74,2% (według SILP 45,5%) (tab. 3, ryc. 3),
– Bircza – 61,8% (według SILP 37,2%) (tab. 4, ryc. 4),
– Nidzica – 84,6% (według SILP 60,9%) (tab. 5, ryc. 5),
– Miastko – 87,5% (według SILP 60,6%) (tab. 6, ryc. 6).

Wskazana jest adekwatna zmiana w Systemie Informacji Lasów Państwowych, aby informacja o porolności gruntu była obecna w przypadku każdego pokolenia lasu. Należy zastanowić się nad wykonaniem analiz podobnych do przeprowadzonych w ramach projektu dla nadleśnictw o dużym udziale gruntów porolnych, z ubogimi siedliskami lub z występowaniem symptomów chorób charakterystycznych dla gruntów porolnych. Analiza archiwalnych materiałów kartograficznych jest w wielu przypadkach jedynym sposobem dotarcia do informacji o pochodzeniu drzewostanów.