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GEOECOLOGY

Forest cover changes over historical times in the area of Lake Jasień (northern Poland) recorded in slope sediments and archival maps – a case study

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Abstract. The subject of the study was to get an overview of the changes in forest cover in the last 1,500 years. The research covered an area of 4,250 hectares, the natural boundaries of which are determined by the lowering of Lake Jasień. The reconstruction of forest cover evolution in the older part of the studied period (5th/6th–17th centuries) was conducted on the basis of geological structure analysis of 9 landforms from which slope sediments were separated. The emergence of slope sediments was associated with deforestation and development of agricultural land use. The approximate age of these events was determined on the basis of 11 examples of radiocarbon dating of the material taken under the slope sediments and within their area. Changes during the younger period (1618–2017) were examined using large-scale cartographic materials and an orthophotomap as well as data from the Forests Data Bank.

It was found that from 5th/6th till the mid-19th centuries, forested area used to decrease, and deforestation grew in two periods. The first of them took place from the turn of the 5th and 6th centuries till the 9th century and the second between the 12th and the mid-19th centuries, when afforestation rate dropped to the lowest point ever, recorded of 20%. From the mid-19th century forest cover started to increase systematically. In 2017 forests covered 69% of the studied area and that was the highest value in more than 400 years.

Afforestation rate and the size of forest cover changes in the studied area over the past 400 years most often did not coincide with changes in Western Pomerania. This proves that local transformations of forests could have significantly differed from the general trend of much larger areas.

Key words: geography, land use changes, 5th–21th centuries, slope sediments, archival maps, northern Poland.

1. INTRODUCTION

Since the emergence of the first agricultural societies, the clearest change in the natural environment related to human activity has been deforestation combined with agricultural land use. Intensity of deforestation has varied in different periods. Until the 19th century deforestation generally increased, although with different dynamics, depending on the period, the location and the size of the area. Ongoing afforestation in central and western Europe since the 19th century has also significantly changed and shaped the landscape (Mather, 1992).

Reconstruction of afforestation changes in historical times is mainly based on old cartographic materials. In recent years, numerous works have been published on the issue of forest cover changes (Petek, 2002; Wulf et al., 2010; Opršal et al., 2013; Abadie et al., 2018), including areas of contemporary Poland (e.g. Więcko, 1986; Nyrek, 1997; Kozak, 2005; Kunz and Nienartowicz, 2006; Poławski, 2009; Macias and Dryjer, 2010; Gielarek et al.,

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2011; Kunz, 2012; Macias and Szymczak, 2012; Mikusińska et al., 2013; Ciupa et al., 2015; Degórska, 2015; Kaim et al., 2016; Plit, 2016; Zgłobicki et al., 2016; Majewski et al., 2018), based precisely on archival cartographic materials, supported to a greater or lesser extent by historical records. An undoubted drawback of this method is its limited time range, dating back only to about 17th century, i.e. the period from which the first maps necessary for a fairly accurate estimation of the forest cover are available (cf. Kunz, 2012; Plit, 2016).

Inferences about changes in forest cover area and land use structure in earlier centuries can be made, among others, on the basis of the analysis of slope sediments (cf. Henker et al., 2017) which fill drainless depressions or erosion-denudation valleys and form accumulation cones. This issue, however, was not usually the subject of detailed studies as it was only signalled on the occasion of researches related to broadly defined denudation (e.g. Borówka, 1992; Twardy, 1995, 2005; Dotterweich et al., 2003, 2014; Gábris et al., 2003; Sinkiewicz, 1998; Smolska, 2005; Szpikowski, 2010; Majewski, 2013; Baculа et al., 2014; Paluszkiewicz, 2016; Kappler et al., 2018; Kołodyńska-Gawrysiak et al., 2017). Obviously, the results gained by this method are not as accurate as those obtained through the analysis of old maps, but they enable researchers to make relatively precise distinction between periods of clear changes in land use in many specific areas (see Kaplan et al., 2009) and analyse practically any period of human history. Identifying land use transformations in the past, including forest cover, caused by human activity, is useful for assessing the extent of their impact on the natural environment and helpful for better understanding of the consequences of these changes. It can also be used to assess their environmental impact in the future.

2. RESEARCH AREA

The research was conducted in the tunnel valley of Lake Jasień located in northern Poland (Fig. 1), in the early post-glacial zone relief associated with the Pomeranian phase of the Vistulian glaciation (Kozarski, 1995).

The natural morphometric axis of the area is constituted by Lake Jasień, the water table of which is located at an altitude of 113 m above sea level. Along the shores of the lake, within lakeside flattening, accumulation cones have developed. Sandur levels, rising to a height of 140 m above sea level, adhere to the flattening (Majewski, 2013). Areas with altitudes above 140 metres above sea level are occupied by undulating moraine plateaus. Within the lakeside flattening, gley-podzols as well as peat and silt soils occur (Florek and Florek, 2001).

These areas are accompanied by small communities of riparian forests and fen and fen-bog transition mires (Majewski, 2013). Podzols, which have developed on sandur levels, are covered mainly with pine-dominated forests. Moraine plateaus correspond to cambisols with a predominance of folic cambisols while in wetland drainless depressions located within the plateaus soils with gley subtypes occur (Florek and Florek, 2001). Rusty soils are present in the plateau areas built of slightly loamy sands (Majewski, 2013). The highland is dominated by beech communities.

The relief of sandurs and plateaus is diversified by numerous drainless depressions and erosion and denudation valleys, perpendicular in their course to the longitudinal axis of the lake.

3. PURPOSE, SUBJECT AND METHODS OF THE RESEARCH

The main purpose of the study was to present changes in forest cover in historical times. In addition, for the last 400 years, the extent of forest cover changes of the studied area was compared with changes in north-west Poland. The subject of the study was the tunnel valley of Lake Jasień (northern Poland). The area of the research site, without the participation of lakes, is about 4,250 ha.

The time range of the study includes two periods: the first, lasting from the beginning of the Middle Ages till the 17th century; and the second – from 1618 to 2017. The division in the time axis adopted resulted from the varying degree of reliability and usefulness of the research methods used.

The reconstruction of the course of afforestation changes related to the first period was made on the basis of the investigation of the geological structure of land forms, and thus it refers to specific, smaller areas within the entire research site. The study uses data from the analysis of eleven test pits made in the area of four drainless depressions (Z-1, Z-2, Z-3 and Z-3′, Z-4) of four erosion-denudation valleys (D-1, D-2, D-3, D-4) and one accumulation cone (S-1 and S-1′) (Fig. 1). The transformation of forest areas into arable lands was recorded in the form of slope sediments, which accumulated during cultivation of the land in the relief depressions mentioned earlier or formed cones on the extension of the valleys. The approximate period of changes was determined on the basis of the age of organic sediments lying directly below or within the slope series. The age of sediments was determined using radiocarbon dating, carried out in Gliwice Radiocarbon Laboratory Silesian University of Technology (laboratory code Gd), the Museum of Archaeology and Ethnography in Łódź

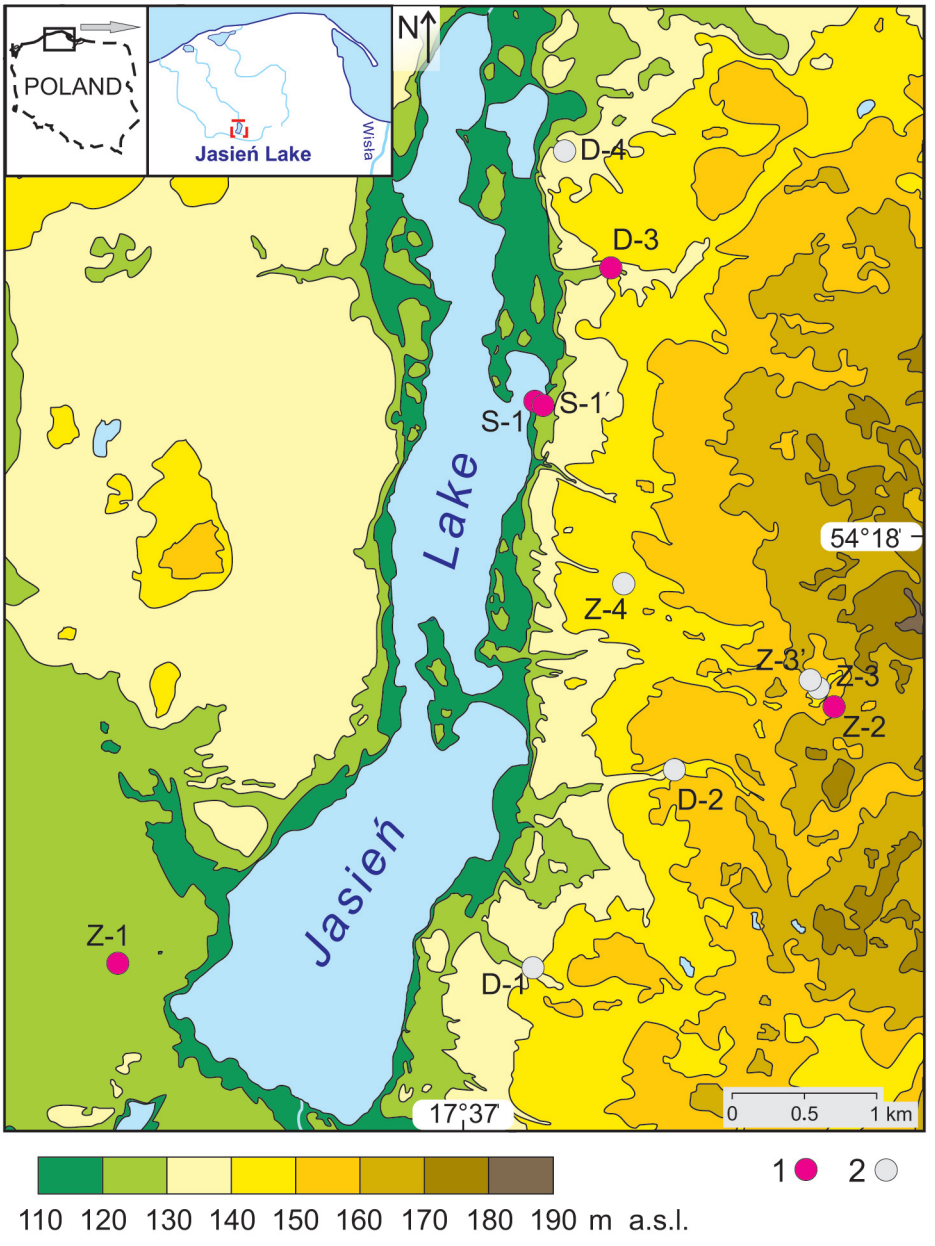

Fig. 1. Sketch of the research area with the location of sites with dated sediments: (1) 5th–9th centuries period; (2) 12th–17th centuries period.

(lab. code LOD), and in the Laboratory of Absolute Dating in Kraków (lab. code MKL). 11 dating examples were used in the study (calibrated dates).

The changes for the period 1618–2017 were traced using archival and modern cartographic materials as well as digital data. On their basis, land use was presented in graphical form and changes in the percentage share of selected land use forms were determined. The following cartographic materials were analysed and developed:

- a map by E. Lubben, 1618, Nova illustrissimi principatus Pomeraniae desriptos, scale 1 : 227,000;
- a map by D. Gilly, 1789, Karte des Königl. Preuss. Herzogthums Vor- und Hinter-Pommern, scale 1 : 180,000;
- General Karte von der Königlichen Oberförsterei Borntuchen 1843, scale 1 : 150,000;
- Topographische Karte, 1887, sheets Schwarz Damerkow and Jansen, scale 1 : 25,000;
- Topographische Karte, from 1939–1941 (hereinafter referred to as 1941), sheets Schwarz Damerkow and Jassen, scale 1 : 25,000;
- a topographic map of Poland, 1954, sheets N-33-72-Ab (Jasień) N-33-72-Aa (Jerzkowice), scale 1 : 25,000;

- a topographic map of Poland, cartographic elaboration 1989, sheets 324.121 Jasień and 314.343 Jerzkowice, scale 1 : 10,000;
- aerial photos and an orthophotomap from www.geoportal.gov.pl and the Forests Data Bank as of 2017;
- Archaeological Picture of Poland; sheets 12–34, 12–35, 13–34, 13–35; archaeological sites refer to both periods analysed.

In order to determine the size of the land surface based on the maps from 1789 and newer, the cartographic materials in the form of raster files and GIS software (Map Maker 3) were used.

4. RESULTS

The reduction of forest areas and their replacement with arable fields in the early Middle Ages (570–1250) is recorded in the sequence of sediments identified in the Z-1 depression, located in west of Lake Jasień (Fig. 1). At the bottom of the depression, a distinctive slash-and-burn level dated on 1260 ± 50 years BP (671–777 cal AD) was found covered with a series of slope sediments (Fig. 2).

The recognized level of slash-and-burn agriculture may be the result of burning forests that preceded grubbing up to obtain land for agriculture. Cultivation of soil in the water catchment area of the depression caused gravitational and mechanical movement of sediments and creating slope covers at the bottom.

In the tunnel valley of Jasień Lake, several Z-1-like sites have been identified and described, which testify to the reduction of forest areas in the period from 5th/6th to 9th centuries (cf. Majewski, 2013; Majewski and Drozdowska, 2017) (see Fig. 1, Table 1).

The distribution of areas indicating changes in the structure of land use in the 12th–17th centuries was identified in the slope sediment layers found in the test pits, covering the charcoal dated on the period between 1260 ± 50 BP and 315 ± 70 BP (Fig. 1, Table 2). The youngest recognized sediments (areas Z-4 and D-2) were covered by diluvia associated with human agricultural activity (Majewski, 2014).

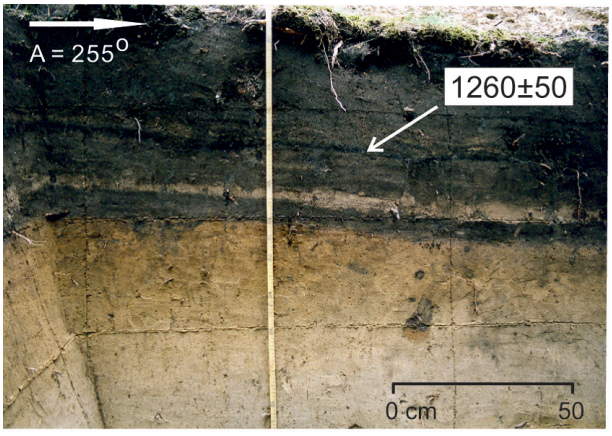

Fig. 2. Dated slash-and-burn level and series of slope sediments in the Z-1 depression.

The situation related to deforestation captured on the basis of the youngest dated sediments is confirmed by the view in the Lubben map. It can be seen that in the beginning of the 17th century, a significant part of the areas adjacent to Lake Jasień was devoid of forests. Based on the map, it can be estimated that at that time forests covered about 40% of the area of the research site (Fig. 3).

According to Gilly's map from 1789, it appears that forests covered only about 26% of the analysed area. It can be seen that the sectors located north of the village of Jasień and west of the southern part of Lake Jasień were devoid of forests (see Fig. 4), and the areas directly adjacent to the above-mentioned deforested depressions (e.g. Z-4, D-2) were then used as arable fields. This demonstrates continuity of agricultural development of that time of certain areas for over 150 years.

The decreasing trend regarding the area covered by the forests lasted till around the middle of the 19th century. According to the map from 1843 (General Karte von der Königlichen Oberförsterei Borntuchen), forests covered only about 20% of the area.

In 1877, forests covered 29% of the area, and their cover was strongly fragmented – 11 large and over 20 small forest areas can be distinguished (Fig. 5A).

Following decades (1877–1941) showed further and very significant increase in forest areas, up to the level of 49%. The largest growth occurred in the western part of the lake (Fig. 5B) and extended mainly over sandur areas.

In the first post-war years, despite political and ownership changes (areas were then within the borders of Poland), the research site was subjected to further afforestation. In the mid-1950s, forest cover increased already to 61% (Fig. 5C).

Today, forest cover in the tunnel valley of Lake Jasień (see Fig. 5D) slightly exceeds 69% (against 37% for north-western Poland).

5. DISCUSSION

Presumably, the first clear changes in forest cover of the analysed area, related to human activity, occurred already in the Neolithic Period, as evidenced by settlement traces of this era (Archaeological Photo of Poland), as well as an increase in the pollen content of nitrophilous synanthropic plants such as mugwort (*Artemisia*) and

Table 1. Summary of dated sediments from the 5th–9th centuries

Area symbol	^{14}C age, BP	Age range, 68.2%, cal AD	Age range, 95.4%, cal AD	Laboratory code
Z-1	1260 ± 50	671–777	664–880	LOD-1431
S-1	1480 ± 45	535–630	440–650	Gd-11685
S-1′	1440 ± 50	595–660	482–662	LOD-1345
Z-2	1600 ± 50	416–535	342–572	MKL-1620
D-3	1580 ± 50	420–540	380–610	LOD-1282

Table 2. Summary of dated sediments from the 12th–17th centuries

Area symbol	^{14}C age, BP	Age range, 68.2%, cal AD	Age range, 95.4%, cal AD	Laboratory code
D-4	900 ± 50	1119–1189	1024–1224	LOD-1429
Z-3′	600 ± 40	1315–1395	1300–1405	Gd-11698
D-1	530 ± 60	1391–1440	1295–1454	MKL-1621
Z-3	470 ± 70	1395–1491	1385–1528	MKL-1622
D-2	350 ± 40	1485–1612	1456–1638	Gd-11689
Z-4	315 ± 70	1495–1643	1453–1797	Gd-12524

Fig. 3. Lake Jasień region (Lupofske Lacus) with visible forest areas on the map of Lubben (1618) with marked location of the village of Łupawsko (thom Lupafsken).

sorrel (*Rumex*) to a total of 10% (see Miotk-Szpiganowicz, 1998). The intensification of deforestation took place in the late La Tène and Roman periods, when an increase in cereal cultivation (Miotk-Szpiganowicz, 1998) and metallurgical production occurred, which required large amounts of wood (Wielowiejski, 1981). Deforestation was so strong that it was recorded here by the development of slope processes that led to clear transformations of the relief (Majewski, 2013).

It can be assumed that during the migration period (~ 4th–6th centuries) the regeneration of forests in the studied area took place (cf. Latałowa, 1982; Tobolski, 1998) and the population that began to settle these areas at the beginning of the Middle Ages, i.e. in the 6th century, found fully regenerated forest areas. Settlement in the lake district zone was then accompanied by slash-and-burn economy consisting in cutting and burning of forests. These processes also included the tunnel valley of Lake Jasień, as

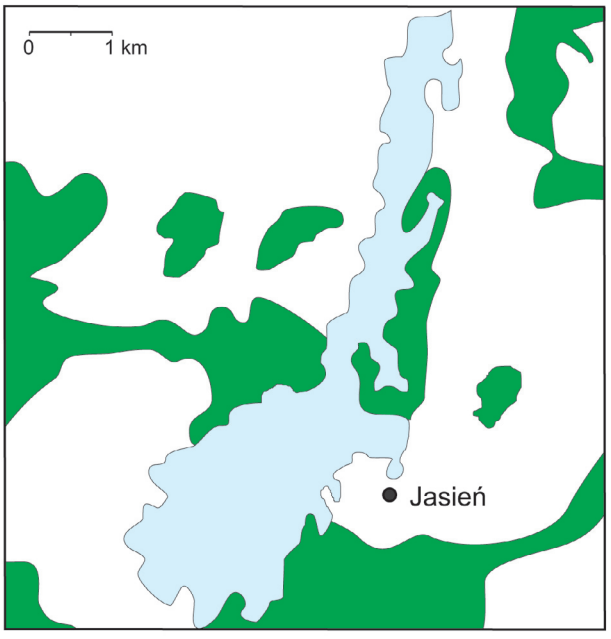

Fig. 4. Forest areas distinguished according to the map by Gilly (1789).

evidenced by the numerous archaeological sites identified here, associated with the period of the early Middle Ages (Archaeological Photo of Poland; Gerstmannowa et al., 1999) and the above-mentioned dating. A multitude of geological sites indirectly signalling changes in forest cover during the period of 5th/6th–9th centuries (Figs 1 and 6) allow us to estimate that this process intensified then, creating a distinguished phase of decline in forest cover, and could encompass areas constituting up to 10% (?) of the area of forests of that time. It should be noted that the vertical increase in slope sediments in depressions of the terrain and on accumulation cones most often indicates changes in afforestation not only at the site of the open pit, but also in the catchment area of the form.

It is difficult to unequivocally explain the small-time gap lacking the record of deforestation of new areas, and covering the 10th century. Most likely, this is the result of an insufficient number of dating samples or the lack of new major deforestations in that time.

The collected geological material shows that deforestation continued in the subsequent centuries, and intensified at the end of the Middle Ages and at the beginning of the modern period, creating another phase of deforestation, lasting from the 11th/12th to the 17th centuries (Fig. 6). It should be mentioned that it was the time of establishing and development of the surrounding villages: Jasień (from the fourteenth century), Jerzkowice (from the 15th century) and Łupawska (from the 17th century). Population growth resulted in an increase in demand for wood and the need to enlarge agricultural acreage.

Medieval and early modern deforestation led to a drop in forest cover area, which was around 40% at the beginning of the 17th century. However, this value is very high compared to the forest cover of the whole of Western Pomerania at the time – 16% (Kunz, 2012), or a smaller part of it, e.g. Sławieńska Land – 18% (Plit, 2016).

Over the next two centuries (from the beginning of the 17th till the end of the 18th centuries), afforestation fell to around 26%, and thus the forest cover level approached the average value for Western Pomerania, which was then 20% (Kunz, 2012). This can be explained by the above-mentioned further development of the surrounding villages and increasing arable land. In addition, based on the identified geological structure of the land forms (e.g. Z-4, D-2; Fig. 1), it can be seen that the areas considered deprived of forests at that time, coincide with woodless areas distinguished on Gilly's map (Fig. 4), which reinforces the premises regarding this issue from the analysis of the geological structure.

The first half of the 19th century turned out to be a significant period for the level of forest cover. It was the time when the forest cover of the area fell to the lowest level in history (about 20%) and the moment from which its rates have been constantly rising to the present day. Already in 1877, forest areas increased their acreage by nearly half that is from 20% to 29%. The forest borders were very irregular (Fig. 5A), which may indicate strong human impact (cf. Plit, 2016). A clear increase in the percentage of forest area in the period 1843–1877 can be associated with afforestation introduced by Prussian authorities at the turn of the 18th and 19th centuries – forests were renovated using Scots pine. The forest policy relied also on purchasing on behalf of the State damaged forest areas and wasteland for afforestation (Poławski, 2009).

In the years 1877–1941, a further increase in forest cover, up to 49% occurred. This process was undoubtedly the result of a favourable tax policy encouraging extensive afforestation of lands that were less suitable for agricultural purposes (cf. Nyrek, 1997; Wulf et al., 2010). Thus, the percentage of arable land decreased during this period from 61.6% to 42% (see Table 3). According to the map compilation (Figs 5A and 5B) deforestation at that time was of little importance and covered two small areas that were designated for arable land.

In the mid-1950s, the forest cover of the research area was almost twice as high as the forest cover level of the West Pomerania (cf. Kunz, 2012). The high increase was the result of almost complete afforestation of arable land in the immediate vicinity of the lake (Fig. 5C). These are sandur areas, i.e. those with the weakest soils in the region and soil depletion by agricultural activity, conducted at

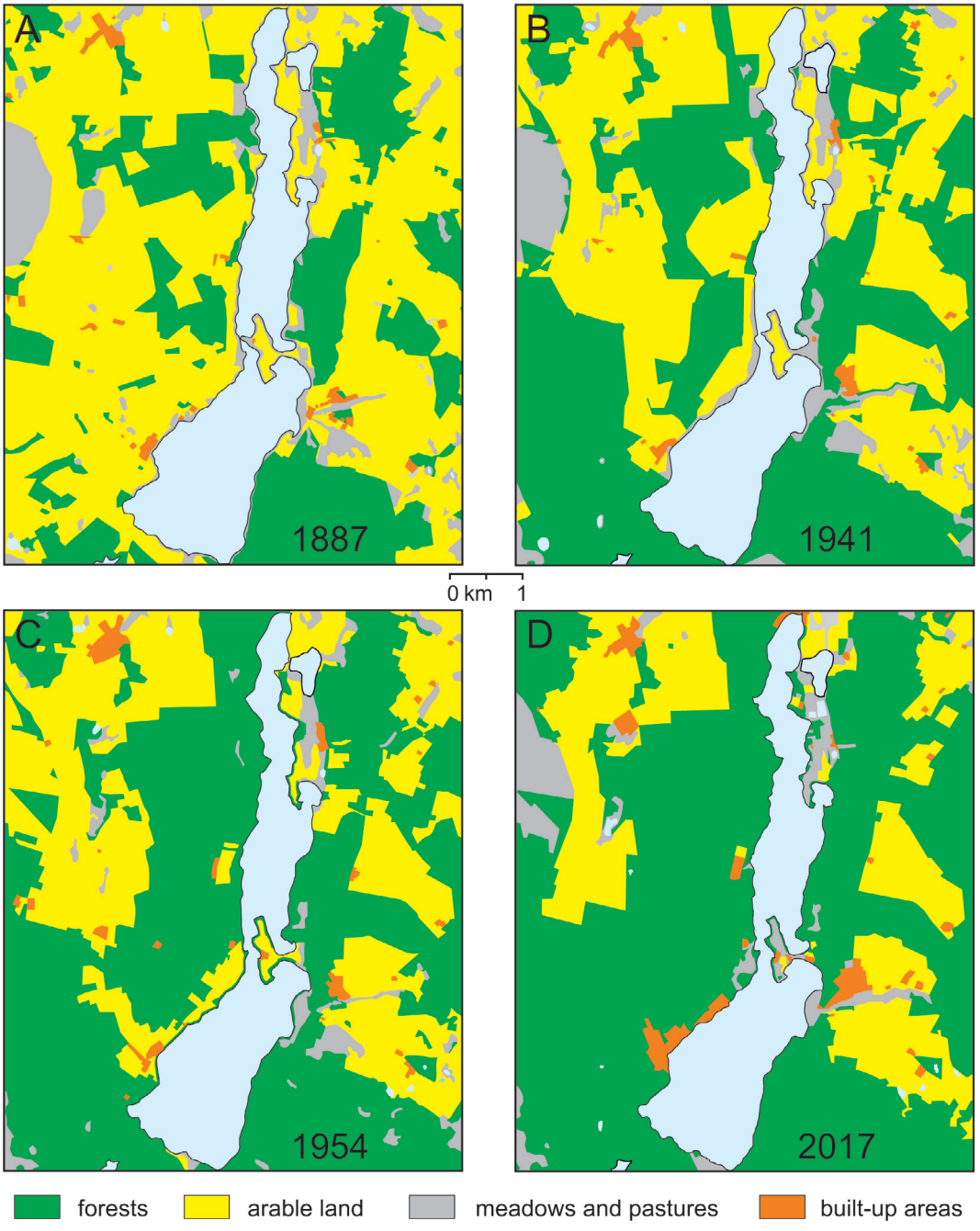

Fig. 5. The structure of land use in the studied area in the years 1877–2017.

Table 3. Size of changes in the structure of land use in the tunnel valley of Lake Jasień in the years 1887–2017

Type of land use	Year 1887	Year 1941	Year 1954	Year 2017
Forests	29.2%	49.1%	61%	69.2%
Arable land	61.6%	42%	33.8%	22.9%
Meadows, pastures and wetlands, with ponds	8.2%	7.9%	3.9%	5.7%
Densely built-up areas with orchards	1.0%	1.0%	1.3%	2.2%

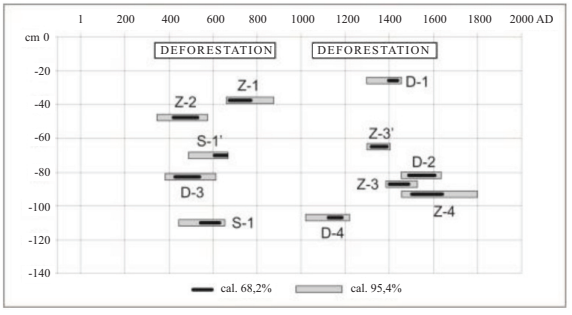

Fig. 6. Phases of deforestation distinguished on the basis of sediment age (calibrated dates); depth of dated material deposits (cm).

least since the 18th century. The drop in the percentage of arable land in 1941–1954 was also accompanied by a decrease in the area occupied by meadows (Table 3).

In the second decade of the 21st century, forest cover exceeded 69% and has been the largest of over 400 years. Forest areas create compact and continuous surfaces here (Fig. 5D) and the increase in the covered area has taken place in recent decades mainly at the expense of afforestation of arable land (see Table 3) which were not used for agriculture purposes after the collapse of nearby state-owned farms. It should be added that over the past 130 years, the area occupied by densely built-up areas constituted a negligible part of the research site.

6. CONCLUSIONS

Based on the geological structure of the land forms and the analysis of cartographic materials, changes in forest cover in the area of Lake Jasień are presented, including the period from the beginning of the Middle Ages to the turn of the 20th and 21st centuries. Deforestation occurring here in prehistoric times did not affect the level of forest cover on the threshold of the studied period due to regeneration of forests during the Migration Period. It was found that from the 5th century to the mid-19th century, forest areas were successively decreasing and the process was continuous, with two periods of intensification of the phenomenon. The first increase occurred between the turn of the 5th and 6th centuries and the 9th century, and was associated with settlement after a period of migration of peoples. The second clear rise in deforestation occurred in the period between the 12th and mid-19th centuries and was generally associated with the growing number of inhabitants and the development of surrounding villages. At the end of this period, forest cover of the studied area reached the lowest point in history, 20%. Since the second half of the 19th century, there has been a systematic increase in forest area up to 69% in 2017. The ensuing changes are the result of forest policy pursued by the German authorities, and by the Polish authorities after the Second World War.

The size of forest cover changes of the studied area over the last 400 years did not coincide with the changes in Western Pomerania. This indicates that the local transformation of forests, both the decreases and increases in the covered area, could clearly differ from the general trend for much larger areas, which makes them worthy of attention and detailed research. This indicates that case studies can provide valuable information on local long-term land use changes (cf. Flyvbjerg, 2006) and be a part of wider comparative research leading to the synthesis of data for larger areas.

By combining two research methods – geological structure analysis and cartographic materials, it is possible to track forest cover changes over the past several centuries to the present day. It gives insight into the assessment of changes in the environment in the past and can be useful in assessing their impact nowadays.

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