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GEOMORPHOLOGICAL AND SOIL CONDITIONS OF THE VARIABILITY AND PERSISTENCE OF FOREST LANDSCAPE SINCE THE BEGINNING OF THE 19TH CENTURY IN THE LUBRZANKA CATCHMENT (THE HOLY CROSS MOUNTAINS, POLAND)

Abstract: The paper analyzes changes of forest cover in the Lubrzanka river catchment (the Holy Cross Mountains) in the years 1800–2011 in relation to the morphological characteristics of the terrain (altitude, slope gradients, and slope aspect) and genetic soil types, in relation to political and socio-economic factors. The source material consists of topographic maps from 1800, 1900, 1930 and 1983, thematic maps and Digital Elevation Model (DEM). GIS tools and algorithms were used to analyze the temporal and spatial forest cover changes. It was documented that the forest content was the largest at the beginning of the analyzed research period – in 1800 (46.7%) and the smallest in 1900 (24.3%). Subsequently, a slow but continuing increase in forest cover from 1900 to 2011 was demonstrated. An analysis of the persistence of the forest landscape in the context of the stability of its use was also carried out. In the Lubrzanka catchment, permanent forest use in the period 1800–2011 covered 48.9 km^2, which accounted for 19.2% of its total area.

Key words: forest cover, forest landscape, morphological characteristics, comparative cartography, the Holy Cross Mountains, Poland

INTRODUCTION

The forest is an important component of the mountain and upland landscape, as it significantly increases its view and ecological attractiveness. Changes in forest cover have a major impact on the course and dynamics of hydrological processes, including surface runoff, erosion and soil degradation (Ciupa 2008; Bryndal et al. 2010; Kroczak et al. 2022), also in the Małopolska Upland (Kowalski 1990; Ciupa 2001). Processes such as the one mentioned

above can consequently reshape river flooding parameters (Bryndal et al. 2006; Ozga-Zielińska et al. 2011). Changes in the forest area in various spatial and temporal scales in the mid-latitude zone have been the subject of numerous publications: in the world (Wilson 2005; Wulf et al. 2016; Bolliger et al. 2017; Sütő et al. 2017; Camarretta et al. 2018; Yang 2022), and in Poland (Szymański 1993; Kozak et al. 2007, 2018; Kozak 2010; Szymura et al. 2010; Gielarek et al. 2011; Pieńkowski, Kupiec 2015; Ostafin et al. 2017; Sobala et al. 2017; Szymura et al. 2018; Dobosz et al. 2019; Majewski, Marszałek 2020; Pieńkowski et al. 2020). The analysis of the presented publications shows that the process of deforestation reached its apogee in the 19th century, and in Southern Europe it continued until the 1970s for various environmental, social and economic reasons. In the Holy Cross Mountains, this issue was tackled in the works of T. Ciupa et al. (2015, 2016). In most of the aforementioned studies, broad access to archival cartographic materials made it possible to analyze the changes using comparative cartography methods (Jankowska, Lisiewicz 1998; Plit 2008, 2016; Nita, Myga-Piątek 2012). The rapid development of GIS technology produces tools that allow identifying historical changes in forest boundaries (Terefenko, Furmańczyk 2005; Kozak et al. 2008; Skalos et al. 2012; Kuna 2015; Kałamucka et al. 2016; Zgłobicki et al. 2016; Sobala, Rahmonov 2020). Moreover, access to high-quality Digital Elevation Models (DEM) also creates new opportunities for analyzing forest cover changes in the context of morphological conditions which in association with other thematic maps (e.g. soil) enable for more comprehensive analysis of related to environmental conditions of the forest. A special role in the landscape is played by the areas with high persistence of forest areas understood as the stability of their use (Degórska 2015; Plit 2016). They are characterized by high ecological resistance to multidirectional anthropopressure and quickly return to their original state (Richling, Solon 2011). To verify the persistence of forest patches, it is important to determine spatially unchanging forest areas within a period covering even several hundred years. On this basis, permanent habitats and ecological corridors can be identified, especially in natural taxonomic units such as river catchments.

The aim of the study was then to analyze spatial and temporal changes in the forest cover in the last 200 years in the Lubrzanka catchment, located in the central part of the Holy Cross Mountains, and to relate them environmental (altitude, slope gradients, slope exposure, genetic soil types) and socioeconomic factors affecting those changes.

STUDY AREA

The Lubrzanka river catchment (4th stream order), with an area of 254.6 km^2, is located in the central part of the Holy Cross Mountains (Poland) at an altitude of 235.3 m a.s.l. up to 611 m a.s.l. (Łysica), in the Nida basin. The northern part of the analyzed catchment covers the Klonowskie and Łysogórskie Ranges, which are located largely within the Świętokrzyski National Park. Masłowskie Range (from the west) and the Kraiński Ridge (from the east) encroach towards the center of catchment area. Between these ranges the gorge of the Lubrzanka River is situated – the most famous one in the Holy Cross Mountains (Kowalski 1992). In the lower part of the catchment run the Mójczański Ridge and the Otrocz Group. Between the above mountain ranges, there are extensive tectonic depressions with flat bottoms, without hypsometric diversity, called here valleys: Wilkowska and Kielecko-Łagowska (Ludwikowska-Kędzia 2021). The soils in the studied area are of a mosaic nature, mainly due to the complex geological structure of the area, as well as other environmental conditions. In the upper parts of the mountain ranges, skeletal soils of mountainous areas occur, and below them, rendzina and fertile soils formed on loess, clay and alluvial dust deposits. Podzol and marshy soils lie in the bottoms of the valleys (Musierowicz 1961). The eastern outskirts of Kielce are located in the south-western part of the Lubrzanka catchment (Fig. 1).

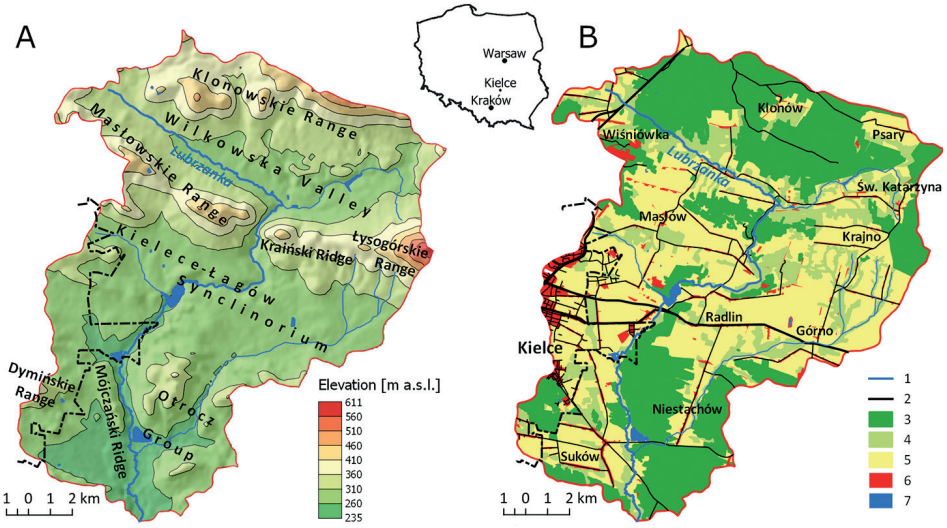

Fig. 1. Location (A) and landuse (B) of the Lubrzanka river catchment (1 – watercourses, 2 – roads, 3 –forests, 4 – meadows and pastures, 5 – arable land, 6 – buildings and anthropogenic grounds, 7 – water reservoirs). Source: Topographic Data Base – BDOT10k

The beginning of deforestation in the area covered by the Lubrzanka catchment was already associated with the development of ancient ore mining and iron metallurgy (1st century BC – 4th century AD) based on the exploitation of wood from the original Puszcza Świętokrzyska forest (Bielenin 1992). Large changes in the forest landscape of the analyzed area occurred over a period of over 100 years (1815–1918) related to the predatory exploitation of wood in the entire area of the Russian partition (Plit 2016; Janicki 2018).

MATERIALS AND METHODS

Historical maps that were used for the forest change analyses included: Map of Western Galicia by Anthony Mayer von Heldensfeld in the scale of 1:28,000 (issued in 1801–1804), Map of Western Russia (Karte Des Westlichen Russlands – KDWR) in the scale of 1:100,000 (1914–1915), Tactical Map of the Polish Geographic-Military Institute (WIG) in the scale of 1:100,000 (1931 and 1934), the Polish General Staff Map in the scale of 1:50,000 (1985–1988) and the Polish Sozological Map in the scale of 1:50,000 (2011). Interpretation of changes in the forest area, taking into account the validity of the above-mentioned maps, was carried out for four periods: 1800–1900, 1900–1930, 1930–1983, 1983–2011.

Historical maps were scanned in high resolution and georeferenced. A detailed description of the calibration methods used for the archival maps was presented in an earlier publication (Ciupa et al. 2016). The forest boundaries were digitized by on-screen vectorization to the shapefile format, starting from the latest to the oldest map, according to the comparative cartography methods of retrogression and elimination (Wilson 2005; Podobnikar 2010). The forest signatures are different in each map series, but all of them are easy to distinguish and allow to accurately determine the area of the forests. Methodological issues related to the analysis of forest cover based on historical maps were described in detail, e.g. in the publications of M. Wulf et al. (2010), M. Kunz (2012), T. Ciupa et al. (2016).

The morphological analysis was based on the Shuttle Radar Topography Mission (SRTM3) Digital Elevation Model in raster format with 90 m resolution (Farr et al. 2007). This image was converted to Polish State Coordinate System (PUWG-92) and was used to separate eight altitude ranges with a contour cut of 50 m (235–260, 260–310, 310–360, 360–410, 410–460, 460–510, 510–560, 560–611 m a.s.l.), five slope gradient categories (0–3°, 3–6°, 6–10°, 10–15°, >15°) and four exposure ranges (315–360 and 0–45° – sector N, 45–135° – E, 135–225° – S, 225–315° – W). On the basis of a soil map at a scale of 1:300,000 (Musierowicz 1961), five genetic soil types were distinguished in the research area: podzols, brown, skeletal, rendzina and marshy.

Within all the above-mentioned ranges and subdivisions, changes in the absolute forest area were examined and forest cover indicators were determined for each studied time period. The obtained results made it possible to capture the trends of forest cover changes in the catchment area, which became the basis for calculating the mean annual index of forest cover change between the analyzed time intervals. A map of the persistence of forest patches from the beginning of the 19th century was also developed, adopting the names of forest use divisions (permanent – forest marked on five analyzed maps, dominant – 4, majority – 3, alternating – 2, occasional – 1) based on J. Plit (2016). For this purpose, the study area was divided into individual fields with an area of 1 ha and a comparative analysis of the occurrence of forest within them was conducted in the selected multi-year periods.

The GIS analysis were carried out using Quantum GIS 3.16 and SAGA GIS 7.2 geoinformation software.

RESULTS AND DISCUSSION

The area of forests in the Lubrzanka catchment was the largest at the beginning of the study period (ca. 1800) and amounted to 119 km^2, which constituted 46.7% of the entire catchment (Fig. 2). The relatively high degree of deforestation in these areas resulted from the development of settlements and agriculture which dating back to the early 11th century (Mójcza, Krajno, Górno, Radlin, Masłów). Further deforestation was caused by the direct vicinity of the glass industry (16th–18th century), which consumed large amounts of beech wood (Żabko-Potopowicz 1954). In 1900, the forest area in the catchment decreased to 61.9 km^2 (forestation – 24.3%). This demonstrates that within 100 years there was an almost two-fold decrease in forest cover and it was greater than that found within the entire area of the Holy Cross Mountains (Ciupa et al. 2016). The average annual rate of deforestation in the catchment in this period was 0.57 km^2·year^{-1}. It should be emphasized, however, that in the first half of the 19th century, this process was not as intense as after the January Uprising (Miklaszewski 1928). In the first period of the Russian partition, rational forest management was being applied (Błaszczyk 1959; Nyrek 1997), despite the high demand for wood in the Staropolski Industrial District (Kasprzyk 1961). Those restrictions resulted in a slight decrease in forest cover observed until the second half of the 19th century. A significant decrease in the forest cover took place only after the fall of the January Uprising. On the one hand, the reason was the repressive policy of Russification consisting in, among others, granting or selling part of forest areas to people of Russian nationality, meritorious in suppressing the Uprising. A merciless felling of the stand without regeneration was then noticed. This process was

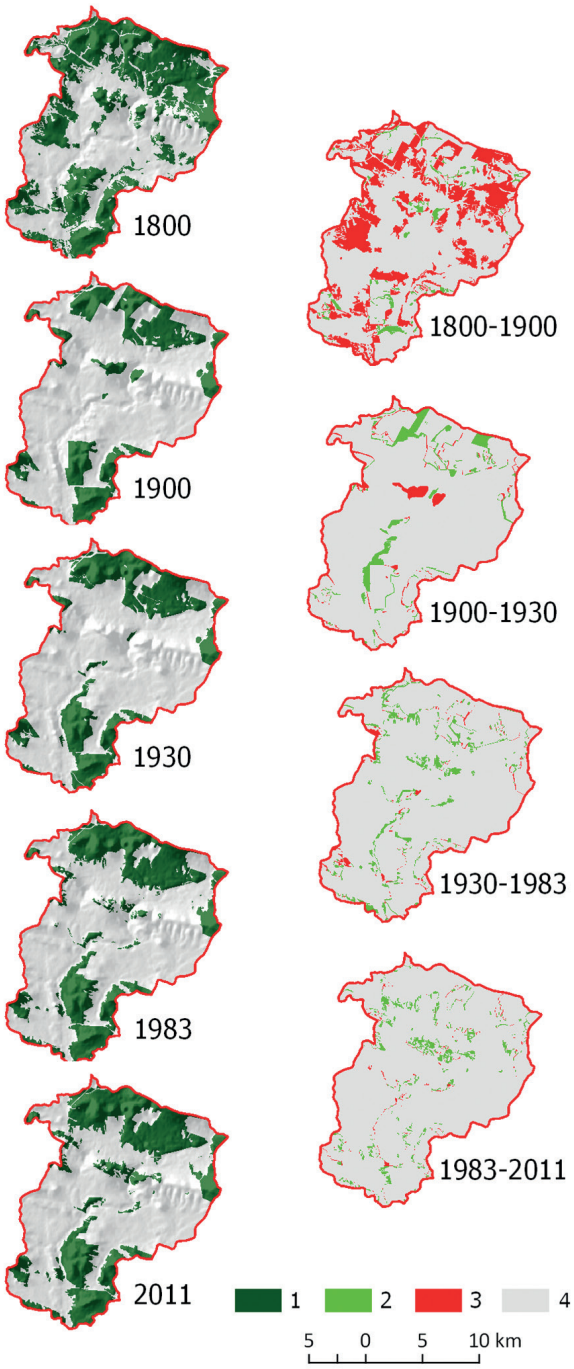

Fig. 2. Forest cover area in the Lubrzanka catchment since 1800 and its changes in four periods: 1 – forest, 2 – afforestation, 3 – deforestation, 4 – non-forest

deepened by the enfranchisement of peasants and the collapse of metallurgy in Zagłębie Staropolskie, which also caused an increase in interest in agriculture and, consequently, a shortage of land in the countryside (Szymański 1983). The thinning of forests took place near rural settlements, where the inhabitants used wood for fuel (Guldon 2000). In the Lubrzanka catchment, the effects of e.g. intensive deforestation were the increase in the frequency of floods and the processes of water erosion of soils on the slopes, in the bottom of the Lubrzanka valley, the increased accumulation of flood facies sediments (Kowalski 1992). The process of deforestation in the 19th century had a much wider range, as documented by J. Plit (2016) and W. Zgłobicki et al. (2016) in the Lesser Poland Upland, T. Ciupa et al. (2015, 2016) – in the Holy Cross Mountains, J. Miklaszewski (2010) – in the Carpathians, and T. H. Szymura et al. (2010, 2018) – in the Karkonosze Mountains.

Since 1900, in the Lubrzanka catchment, a slow recovery of the area occupied by forests has been observed (Fig. 2). In the literature on the subject, it is indicated that this process took on a larger scale only after the end of World War I and Poland reaining independence, when forest renewal took place as a result of artificial plantings (Szymański 1983), and in the entire region of the Holy Cross Mountains only after 1930 (Ciupa et al. 2016). In 1930, the forest cover in the studied catchment was 27.2% (69.2 km^2), and the growth gradient in the period 1900–1930 reached 0.24 $km^2 \cdot year^{-1}$. In 1983, forests in the catchment occupied 30.7% (78.3 km^2), and the average annual increase in forest area in the years 1930–1983 was only 0.17 $km^2 \cdot year^{-1}$. In the period 1983–2011, this process accelerated, and the average annual rate reached 0.27 $km^2 \cdot year^{-1}$.

Similar directions of changes show: for Europe – P. Piussi (2000), for Poland – M. Polna (2005), A. Ciołkosz and Z. Poławski (2005), J. Siuta and B. Żukowski (2011), in Bory Tucholskie – T. Giętkowski (2009). Therefore, in 2011 the total area of forests in the Lubrzanka catchment reached the value of 85.9 km^2, which constituted 33.7% of the entire catchment area. However, forests have not yet reached the area they were covering at the beginning of the 19th century (Fig. 2). Currently, the forest cover in the catchment is almost identical to that in the Holy Cross Mountains (33.9%) (Ciupa et al. 2016).

Therefore, the question arises: whether and how have environmental conditions influenced changes in the forest area in the last 200 years in the Lubrzanka catchment? In the 19th century, deforestation in the Lubrzanka catchment occurred in the altitude ranges up to 510 m a.s.l. (Fig. 3). It reached the highest value of 260–310 m a.s.l. zone (10.4% of the entire catchment), and then decreased with increasing altitude to 0.1% (410–460 m a.s.l.). In turn, in the Holy Cross Mountains, the largest decrease in forest cover was documented in the range of 350–400 m a.s.l. (Ciupa

et al. 2016). After 1900, in all analyzed altitude ranges, an increase in the forest cover indicator was demonstrated, while in the Holy Cross Mountains, the forest cover in the lowest-lying areas (up to 300 m a.s.l.) decreased until 1930 (Ciupa et al. 2016). In the period 1900–1930, the areas located at an altitude of 260–310 m a.s.l., i.e. areas where the greatest degradation of forests occurred in the 19th century, were the most preferred for afforestation. In the last two periods considered, the increase in forest area was the highest in the altitude zone of 260–360 m a.s.l. Minimal afforestation or natural succession occurred in the areas located below 260 m a.s.l. (Fig. 3).

In the 19th century, the deforestation process covered all the analyzed ranges of slope gradients in the Lubrzanka catchment area, but it reached the largest extent in the areas with the lowest slope gradient (0–3°), i.e. 14.4% of the entire catchment area (Fig. 4). These were the areas most accessible and valuable for agricultural production, and at the same time the least threatened by surface water erosion. The scale of this process is confirmed by the results for the Holy Cross Mountains (Ciupa et al. 2016). The analysis carried out in the Lubrzanka catchment showed that in the 20th century, the increase in afforestation took place in virtually all ranges of slope gradients, with the highest change rate achieved in the areas with low values (up to 3°), which in the catchment occupied the greatest areas above sea level (Fig. 4).

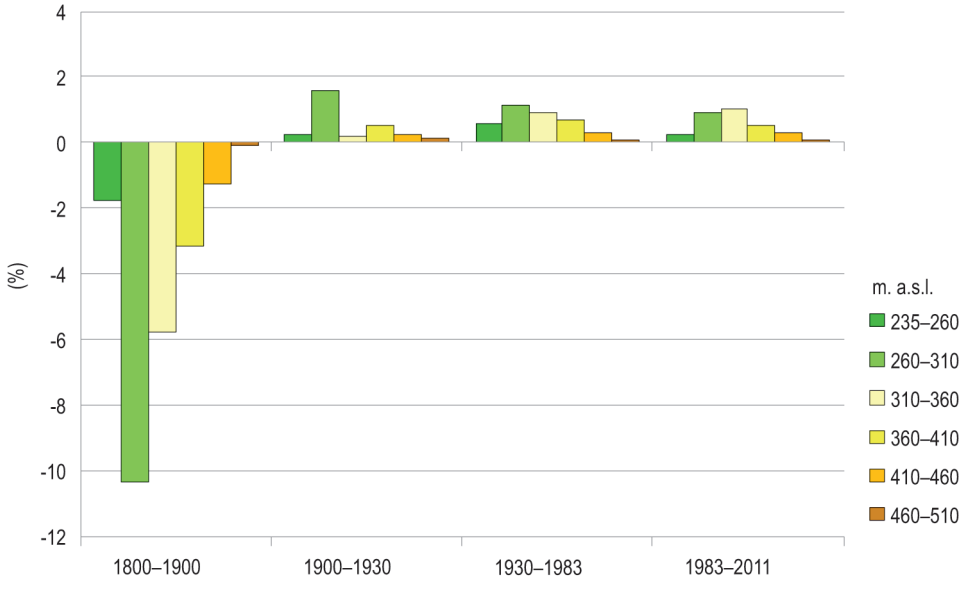

Fig. 3. Forest cover changes (%) in the Lubrzanka catchment with an increase of altitude (m a.s.l.) in the years 1800–2011

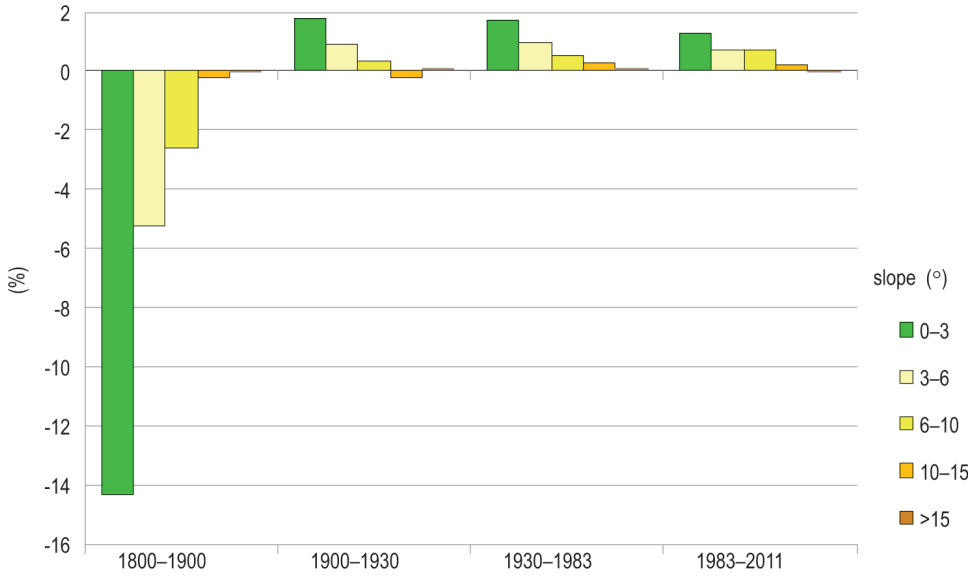

Fig. 4. Forest cover changes (%) in the Lubrzanka catchment with an increase of terrain slope (°) in the years 1800–2011

The largest deforestation in the Lubrzanka catchment in the 19th century covered slopes with southern exposure (S) (azimuth 135-225°) covering a total of 23.7 km^2 (9.3% of the entire catchment) (Fig. 5). These areas are characterized by better insolation, and therefore more favorable thermal conditions, which is important for agriculture, especially in upland and mountain areas.

Almost all the time since the beginning of the 20th century, forest area revival process has been observed, as in the case of the analyzed altitudinal zones and slopes. It is particularly visible on slopes with northern exposure, where in the period 1930–2011 the forest area increased by a total of 5.5 km^2, which means an increase in forest cover in this exposure sector by 2.1%.

Another critical component of the natural environment included in the analysis was the soil cover. Podzol soils occupy the largest area in the Lubrzanka catchment – 116.8 km^2 (45.9% of the total catchment area), followed by brown soils developed on loess and clay – 98.7 km^2 (38.8%), skeletal soils – 28.5 km^2 (11.2%), while rendzina and marshy soils together reach 10.7 km^2 (4.1%) (Table 1).

The process of deforestation (19th century) and then afforestation (20th–21st century) clearly refers to the agricultural suitability of particular genetic soil types. Forests in 1800 occupied the largest absolute area on brown soils (48.6 km^2) while the largest forest cover was observed on skeletal soils (78.6%).

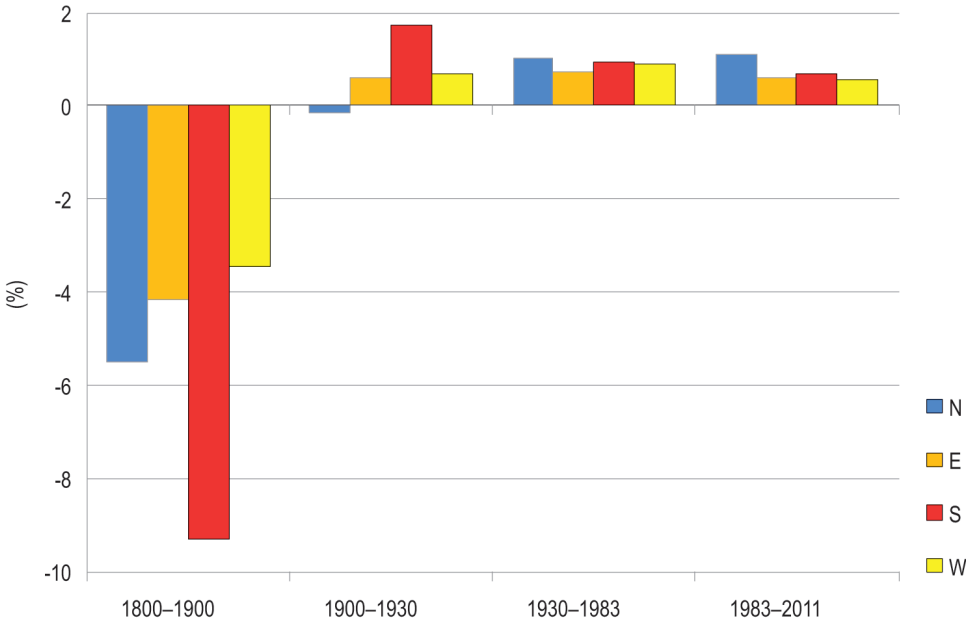

Fig. 5. Forest cover changes (%) in the Lubrzanka catchment in relation to terrain aspect in the years 1800–2011 (azimuths and slopes: N – 0–45° and 315–360°; E – 45–135°; S –135–225°; W – 225–315°)

During the 19th century, intensive deforestation took place mainly within soils with the most favorable conditions for farming. Among them, the most desired were brown soils developed mainly on loess, lying on the slopes of the mountain ranges (Masłowskie Range and Kraiński Ridge) and podzols – occurring in lower morphological levels (in the area of Masłów and Domaszowice) (Table 1). The documented forest cover in 1900 was of 21.2% and 18.6%, respectively. The most negligible loss of forest cover in the 19th century occurred on skeletal soils (from 78.6% to 63.9%). At the same time, it is worth noting that on the rendzinas the forest cover decreased by more than five times (from 41.7% to 8.0%).

On the other hand, in the period over 100 years (1900–2011), almost all considered types of soils (except for skeletal) demonstrated an increase in the area of forests. The largest afforestation in this period were observed in areas of brown soils (from 20.9 km^2 to 31.9 km^2) – developed within loess covers of small thickness, which were degraded here during over 100 years of their use. Reducing the production value of these soils, and thus profitability, contributed to the partial abandonment of cultivation on arable land in the vicinity of Klonów and Psary Kąty, as well as agricultural activity (meadows and pastures) in the bottoms of the Lubrzanka and Warkocz valleys. For comparison, the decrease in forest cover within most soil types (except for marshy,

Table 1.
Forest cover changes (%) in the Lubrzanka catchment within individual soil types in the years 1800–2011

Soil type	Total soil area	Forest area									
		1800		1900		1930		1983		2011	
	(km²)		(%)	(km²)	(%)	(km²)	(%)	(km²)	(%)	(km²)	(%)
podzols	116.77	43.4	37.2	21.7	18.6	25.8	22.1	29.2	25.0	30.9	26.5
brown	98.69	48.6	49.2	20.9	21.2	24.3	24.6	28.2	28.6	31.9	32.3
skeletal	28.50	22.4	78.6	18.2	63.9	17.7	62.1	19.2	67.4	21.1	74.0
rendzina	6.23	2.6	41.7	0.5	8.0	0.5	8.0	0.5	8.0	0.5	8.0
marshy	4.45	2.0	44.9	0.6	13.5	0.9	20.2	1.3	29.2	1.5	33.7

skeletal and rendzina soils) continued throughout the Holy Cross Mountains until 1930 (Ciupa et al. 2016).

The above-discussed changes in the forest area in the Lubrzanka catchment in the 19th century are confirmed by the calculated values of the average annual deforestation rate which reached 27.7 ha·year^{-1} for brown soils and 21.7 ha·year^{-1} for podzol soils (Fig. 6).

From 1900 until recently (2011), there has been a significant increase in the afforested area of podzol soils (8.3 ha·year^{-1}) and brown soils (9.9 ha·year^{-1}), and since 1930 – also skeletal (4.2 ha·year^{-1}). It is worth noting that no new afforestation nor natural succession occurred in rendzinas, and in the entire period of 1900–2011 this rate reached only 0.8 ha·year^{-1} on marshy soils.

The analysis shows (Fig. 7) that permanent forest land use in the Lubrzanka catchment in the period 1800–2011 covered a total area of 48.9 km², which was 19.2% of its total area. These areas constitute only 41% of the space occupied by forests in the period of their maximum extent, i.e. at the beginning of the 19th century. They overgrow the top and upper parts of the slopes of the Łysogórskie, Klonowskie, Dymińskie Ranges and Otrocz Group (Fig. 7).

The establishing of the Świętokrzyski National Park (1950) in the part of Łysogóry and the Klonowskie Range and the Chęciny-Kielce Landscape Park covering the Dymińskie Range was of great importance for the preservation of forests in the Lubrzanka catchment area. It was also favored by poor accessibility to the areas located in the northern part of the catchment. Occasional forest areas (documented only on one map) were found at the foot of the mountain ranges, in the Kielecko-Łagowska and Wilkowska valleys and in the Lubrzanka valley and its larger tributaries. They cover a total of approximately 49 km², which is slightly more than 19% of the area of

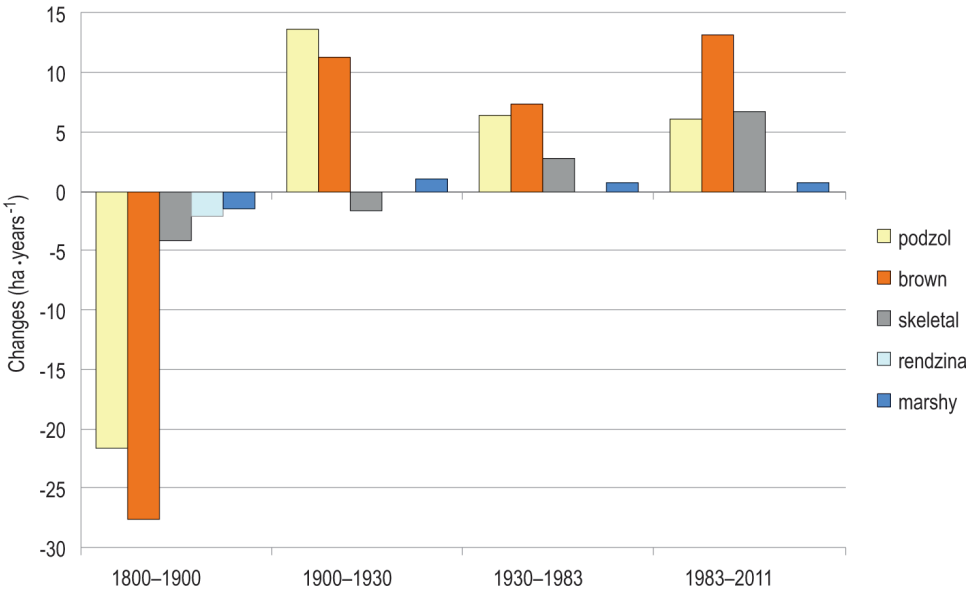

Fig. 6. Changes in the annual rate of deforestation (–) and afforestation (+) in the Lubrzanka catchment within individual soil types in the years 1800–2011

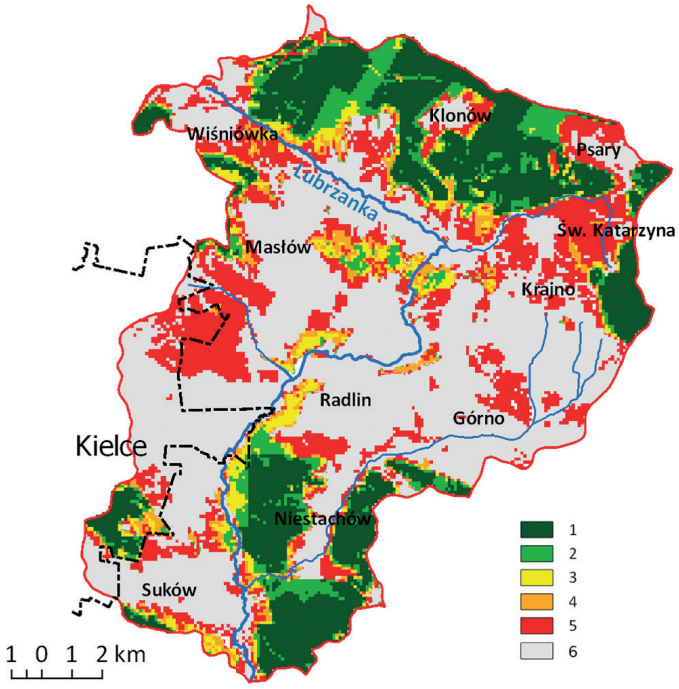

Fig. 7. Persistence of the forest patches in the Lubrzanka catchment landscape from the beginning of the 19th century. Persistence: 1 – permanent (unchanged forest cover), 2 – dominant, 3 – majority, 4 – alternating, 5 – occasional; 6 – non-forest

the studied catchment. The largest compact patches of this type are located in the north-eastern part of Kielce and in the vicinity of the villages of Wilków and Krajno. Other categories of persistence (dominant, majority and alternating) occur, among others: in the area of the Lubrzanka Gorge through the Masłowskie Range and the western part of the Kraiński Ridge (Radostowa Moutain) and near the compact forest patches.

CONCLUSSION

The conducted research showed that changes in the forest cover in the Lubrzanka catchment after 1800 were similar to those in the Holy Cross Mountains, as well as in other mountain and upland regions of Poland. The process of deforestation continued in the analyzed area until the end of the 19th century. The forest cover decreased from 46.7% to 24.3% within a century and was conditioned by the combined impact of socio-economic and natural factors. The most important reasons for the decrease of the forest cover in this period include the high demand for agricultural land, predatory forest management, as well as the beginning of industrialization. Deforestation took place within the land with the most favorable conditions for farming, which was shown by the analyzes of forest area in relation to the absolute height of the terrain, its gradient and exposure of the slopes. This process also clearly refers to the agricultural suitability of particular soil types. It is worth emphasizing that the beginning of the 20th century became a turning point from which the increase of forest cover began, as a consequence of the abandonment of areas with degraded soils and the ongoing natural succession of forests. In the second half of the 20th century, these factors also overlap with the migration of rural residents to cities and the inclusion of valuable natural areas under legal protection. The increase rate of forest cover in the Lubrzanka catchment, similarly to the Holy Cross Mountains and throughout Europe, is much lower than the rate of deforestation in the 19th century. As a result, the forest cover in the studied catchment has not yet reached the level from 1800 and amounts to 33.7%.

The analysis showed that permanent forest land use persists in the upper parts of the mountain ranges. They cover 41% of the area occupied by forests in the period of their maximum extent in the analyzed period (i.e. at the beginning of the 19th century). Nowadays, they are covered by various forms of nature protection. In turn, the largest occasional compact forest patches were found mainly in the north-eastern part of Kielce and in the area of the villages of Wilków and Krajno.

Intensive deforestation and then progressing afforestation of the catchment probably influenced the formation of surface runoff and floods. However, this is a separate issue that will be the subject of subsequent studies using hydrological modeling methods.

The authors are fully aware of the limitations of their research, which used historical maps made in different scales (degree of cartographic generalization), coordinate systems and using different measurement techniques. These conditions influenced the generation of certain errors (relatively small), e.g. related to georeferencing in GIS programs.

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