

# MORPHOLOGICAL AND SOIL DETERMINANTS OF FOREST COVER CHANGES IN ŚWIĘTOKRZYSKI NATIONAL PARK AND ITS BUFFER ZONE IN THE LAST 200 YEARS

TADEUSZ CIUPA, ROMAN SULIGOWSKI, GRZEGORZ WAŁEK

Institute of Geography, Jan Kochanowski University in Kielce, Poland

Manuscript received: 14 May 2014

Revised version: 31 December 2014

CIUPA T., SULIGOWSKI R., WAŁEK G., 2015. Morphological and soil determinants of forest cover changes in Świętokrzyski National Park and its buffer zone in the last 200 years. *Quaestiones Geographicae* 34(1), Bogucki Wydawnictwo Naukowe, Poznań, pp. 55–63, 1 table, 5 figs. DOI 10.1515/quageo-2015-0005, ISSN 0137-477X.

**ABSTRACT:** The research described in the paper utilized GIS methods and comparative cartography in order to analyze changes in forest cover in the period 1800–2011 in the Świętokrzyski National Park (76.26 km<sup>2</sup>) and its buffer zone (207.86 km<sup>2</sup>). The research was done for predefined elevation intervals, slope gradients, and genetic soil types. Source materials included historical maps as well as a digital elevation model. Changes in forest cover were noted in spatial and temporal terms and were usually linked to morphology and soil type. While the 19th century was characterized by intense deforestation, this process reversed starting in the early 20th century. Nevertheless, forest cover in the study area has still not returned to its state from 1800.

**KEY WORDS:** forest, elevation, slope gradient, soils, Świętokrzyski National Park

*Address of the corresponding author: Tadeusz Ciupa, Institute of Geography, Jan Kochanowski University in Kielce, Kielce, Poland, e-mail: tciupa@ujk.edu.pl*

## Introduction

Forest cover change is a global problem, and was tackled in many papers. In Europe these studies were undertaken i.a. in Germany (Wulf et al. 2010), Italy (Di Fazio et al. 2011, Puddu et al. 2012), and the Czech Republic (Skalos et al. 2012). The mentioned authors indicated that changes in forest cover are an effect of a number of environmental, sociological, and economic conditions. The contemporary Polish research literature also includes many papers describing the analysis of forest cover changes at various spatial and temporal scales (Więcko 1986, Ciołkosz, Poławski 2005, Markuszewska 2005, Polna 2005, Giętkowski 2009, Kozak 2010, Gielarek et al. 2011, Kunz 2012, Macias, Szymczak 2012). The cited papers are

based largely on cartographic materials which have become a key feature of scientific papers on this topic starting from the period 1918–1939. Szymański (1979) presents a wide variety of cartographic sources and papers for Poland.

Forests in the Świętokrzyskie Mountains in central Poland have been studied by many researchers since the 19<sup>th</sup> century (Barański 1972). A review of the research literature on spatial forest research from the last 200 years reveals three main areas of interest: (1) Degree of economic use of forests found in the region, including those in the Świętokrzyski National Park (Połujański 1854, Aleksandrowicz 1880, Szafarkiewicz 1885, Błaszczyk 1959, Kasprzyk 1961, Krysztofik 1976, Krysztofik, Zieliński 1976, Plan ochrony... 2000), (2) Changes in the extent of forest cover driven by

historical, economic, and political determinants (Romanowska 1934, Więcko 1948, Zaręba 1958, Szymański 1978, 1983, 1993, Malczyk, Świeżak 2008, Siuta, Żukowski 2011), (3) Morphological and soil determinants of the forest cover in a given region. The third area of interest is, however, relatively poorly covered by the research literature of the region (Reniger 1956, Kowalkowski 2000).

Hence, the Świętokrzyskie Mountains, including the Świętokrzyski National Park (ŚNP), are the only mountain range in Poland without the forest cover having been analysed in the context of environmental determinants including relief and soil cover.

The purpose of this paper is then to analyze the changes in the forest cover over the last 200 years in the area within contemporary borders of the Świętokrzyski National Park and its buffer zone. The analysis includes factors such as elevation, slope gradient, and genetic soil type.

The development of new GIS technologies in recent years and an increasing access to archived cartographic materials have made it possible to detect and track changes in the forest cover for selected periods of time (Terefenko, Furmańczyk 2005, Kozak et al. 2007a, b, 2008, Wulf et al. 2010, Skalos et al. 2012). Newly available digital elevation models (DEM) help to analyze changes in the forest cover by including elements such as local morphology. DEM analyses concerning forest cover research were conducted in Europe by Hörsch (2003) for the Swiss Alps and by Geri et al. (2010) for Tuscany. In Poland, Kozak et al. (2007b) carried out a DEM analysis for the Carpathian Mountains, while Szymura et al. (2010) did it for the Sudety Mountains. These studies demonstrate the significant meaning of morphological determinants such as elevation, slope gradient and aspect for forest cover changes in mountain areas.

## Study area

The Świętokrzyski National Park (76.26 km<sup>2</sup>) and its buffer zone (207.86 km<sup>2</sup>) are located in the central part of the Świętokrzyskie Mountains (Fig. 1). The concept of a national park in this region emerged in the early 20<sup>th</sup> century and was finally realized in 1950. It was the first national

park to be established in Poland after World War II (Ćmak 2000).

The area is characterized by virtually parallel lines of ridges generally following a WNW-ESE geometry, associated with regional lithology and tectonics. Expansive valleys characterized by flat floors and small height differences can be found between the lines of hills (Kowalski 2000). Elevation in the Park and its buffer zone varies from 210 to 612 meters above sea level, while local slope gradients reach 20°. The Park features its own distinct climate relative to neighboring areas (Kłysik 1974). Precipitation totals are higher at summit elevations by an average of 200 mm per year and the air temperature is lower by an average of 1.5°C relative to adjacent valleys (Olszewski et al. 2000).

The soils in the study area are characterized by a mosaic pattern determined by a variety of environmental factors, while their relationship with forest type has already been shown by Kowalkowski (2000). Summit areas in the Park are dominated by skeletal mountain soils, while lower elevations and the Park's buffer zone are characterized by soils formed on loess, clay and alluvial dust deposits. Valleys in the study area feature marshy soils and alluvial soils.

## Research materials and methods

Source materials included high resolution scans of maps produced over the course of two centuries: (1) Map of Western Galicia by Colonel Mayer von Heldensfeld – scale: 1:28 800 (five sheets issued in the period 1801–1804), (2) Map of Western Russia – scale: 1:100 000 (two sheets issued in 1914 and 1915), (3) Tactical Map of Poland produced by the Military Geographic Institute – scale: 1:100 000 (two sheets issued in 1931 and 1934), (4) General Staff Map produced by the Polish Army – scale: 1:50 000 (four sheets issued in the period 1985–1988), (5) Environmental Map – scale: 1:50 000 (four sheets issued in 2011). Old maps were published on the basis of field mapping which could have been performed years before map's publication. Regarding the timeliness of the data presented on the above-mentioned maps, the following years were used in the analyses: Map of Western Galicia – 1800, Map of Western Russia – 1900, Tactical Map of

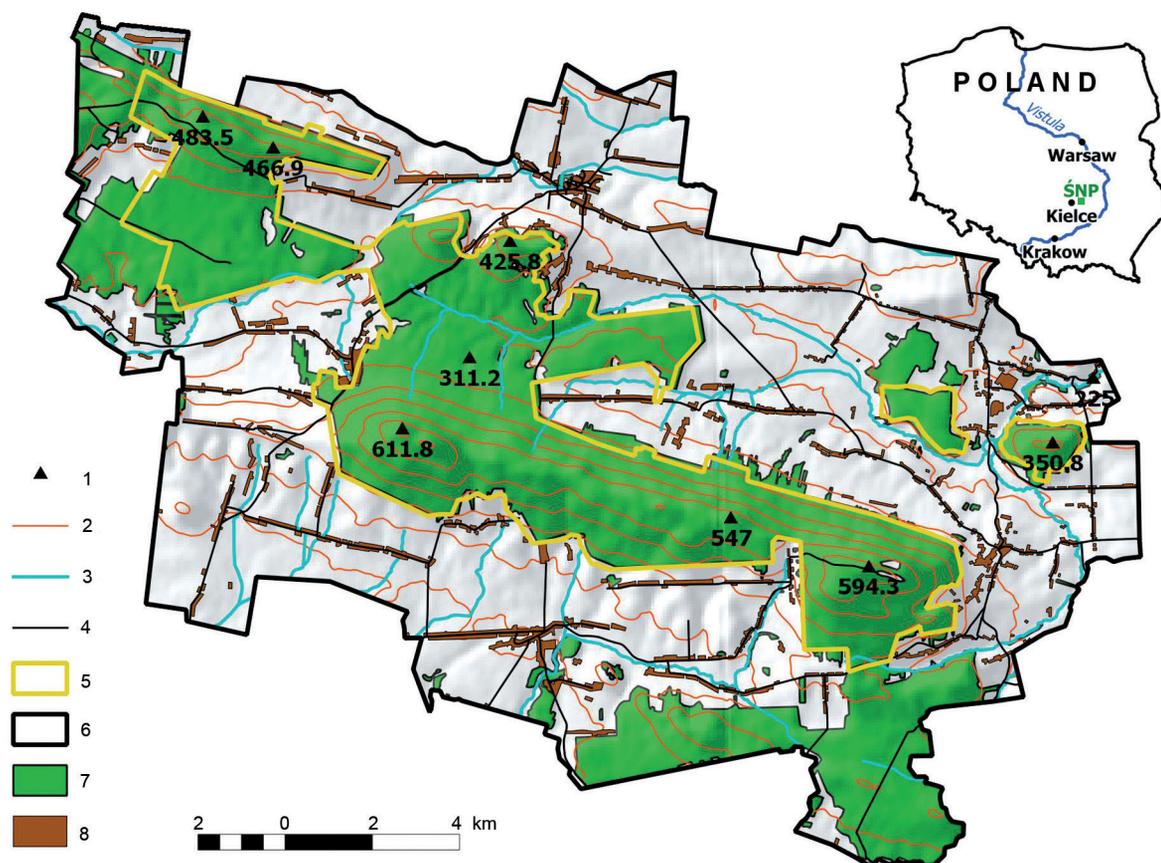


Fig. 1. Location of the Świętokrzyski National Park and its buffer zone

1 - summits, 2 - contour lines, 3 - rivers, 4 - roads, 5 - park boundary, 6 - boundary of the buffer zone, 7 - forests as of 2011, 8 - built-up areas

Poland - 1930, General Staff Map - 1983, Environmental Map - 2011. Timeliness of the two oldest maps has been estimated according to the literature (Słomczyński 1934). In the case of the three other maps it is directly marked on the sheets, therefore the timeliness of the oldest map in the series was taken into account. Those years make frames of the time periods used in the forest cover change analysis: 1800-1900, 1900-1930, 1930-1983, 1983-2011. A Soil Map of Poland from 1961 in the scale of 1:300 000 was used to determine the spatial dimensions of genetic soil types (Musierowicz 1961). Morphometric analysis was performed with the use of the SRTM3 digital elevation model (Shuttle... 2004).

The analysis was performed using Quantum GIS 1.8.0 and SAGA GIS 2.0.2 software. The first part of data was prepared with Quantum GIS in which scanned topographical maps were georeferenced to the European Terrestrial Reference System (ETRS) 1989/Poland CS92. Then forest areas were digitalized by on-screen vectorization method to the shapefile format, starting from the

latest to the oldest map, according to the comparative cartography methods of retrogression and elimination (Stevens, Tree 1951, Jankowska, Lisiewicz 1998, Wilson 2005). After these operations, the forest areas were calculated in the attribute table. Similar data preparation methodology was used to prepare digital data from the soil map. SAGA GIS software was used to analyze SRTM3 digital elevation model and delineate elevation and slope gradient classes. Finally, map overlay methods (difference and intersect) were used to analyze forest cover changes between the analyzed time intervals in elevation, slope gradient and genetic soil type classes. For every soil group, the mean annual index of forest cover change ( $\text{ha}\cdot\text{year}^{-1}$ ) for each studied time period has been calculated with the use of a spreadsheet.

## Results

Changes in the forest cover were studied separately for the Świętokrzyski National Park and

its buffer zone with respect to the morphology and soil cover.

Cartographic materials indicate that the forest cover in the study area was the greatest at the beginning of the study period – in the year 1800 – and amounted at 134.0 km<sup>2</sup>, which constituted 47.2% of the study area (Table 1, Fig. 2A).

The forest cover in the study area decreased to 94.8 km<sup>2</sup> by the year 1900 (Fig. 2B). In the Świętokrzyski National Park, the forest cover decreased from 70.0 km<sup>2</sup> in 1800 to 65.3 km<sup>2</sup> in 1900, while in its buffer zone, the forest cover decreased from 64.0 km<sup>2</sup> to 29.5 km<sup>2</sup> during the same time period. Hence, 13.8% of the entire study area was affected by deforestation, with deforestation of 6.2% in the National Park and 16.6% in the Park's buffer zone (Table 1). The mean annual rate of deforestation in the period 1800–1900 was 39.2 ha·yr<sup>-1</sup>. In the Park itself, the rate of deforestation was 4.7 ha·yr<sup>-1</sup>.

The forest cover has been increasing steadily since 1900 in the area of the Świętokrzyski National Park, but not in its buffer zone, where deforestation continued until 1930. In 1983 the forest cover in the study area increased to 100.8 km<sup>2</sup> (35.5%) and the rate of growth was 7.9 ha·yr<sup>-1</sup>. The annual rate of growth after 1983 increased to 19.6 ha·yr<sup>-1</sup> across the entire study area. By 2011, forests accounted for 37.4% (106.3 km<sup>2</sup>) of the study area (Fig. 2C). The forest cover increased by 11.5 km<sup>2</sup> in comparison to 1900, with 6.3 km<sup>2</sup> of a new forest in the National Park itself. As a result of that, the contemporary forest cover area in the ŚNP is larger than in 1800. Nevertheless,

the forest cover in the entire study area (the ŚNP and the buffer zone) has still not returned to its state as from 1800.

A digital elevation model was used to analyze the influence of geomorphological factors on the forest cover changes across the study area. The model was used to identify six distinct elevation categories (expressed in meters above sea level): 210–250, 250–300, 300–350, 350–400, 400–500, 500–612, which extent results from the elevation histogram natural breaks analysis. This also allowed for a better comparison of the classes areas.

The research has shown that the largest deforestation in the 19<sup>th</sup> century occurred at the elevations between 400 and 500 meters above sea level – a decrease of 5.4 km<sup>2</sup> (16.3%). Two lower elevation intervals were also characterized by deforestation of more than 15%: 350–400 meter interval and 300–350 meter interval. Both elevation zones featured large woodland areas suitable for agriculture and settlement. Finally, summit areas found at 500 meters above sea level or more experienced the lowest deforestation (Fig. 3).

Areas, already highly deforested in 1800 (forest cover: 14.2%), found at elevations of less than 250 meters continued to undergo deforestation until 1930. The forest cover decreased here to 1.2% by 1930. A similar pattern of deforestation was noted for the 250–300 meter elevation interval (Fig. 3). Research showed that the forest cover began to increase in virtually every elevation interval starting from the early 20<sup>th</sup> century. In 1930 the largest rate of increase was noted for the 400–500 meter elevation

Table 1. Forest data for the Świętokrzyski National Park (ŚNP) and its buffer zone (BZ) for the period 1800–2011

Characteristic		Year				
		1800	1900	1930	1983	2011
Area of forest (km <sup>2</sup> )	NP	70.0	65.3	68.2	70.2	71.6
	BZ	64.0	29.5	28.4	30.6	34.7
	Total	134.0	94.8	96.6	100.8	106.3
Forest cover (%)	NP	91.8	85.6	89.4	92.1	93.9
	BZ	30.8	14.2	13.7	14.7	16.7
	Total	47.2	33.4	34.0	35.5	37.4
		Period				
		1800–1900	1900–1930	1930–1983	1983–2011	
Mean annual rate of change (ha·yr <sup>-1</sup> )	NP	-4.7	+9.7	+3.8	+5.0	
	BZ	-34.5	-3.7	+4.1	+14.6	
	Total	-39.2	+6.0	+7.9	+19.6	

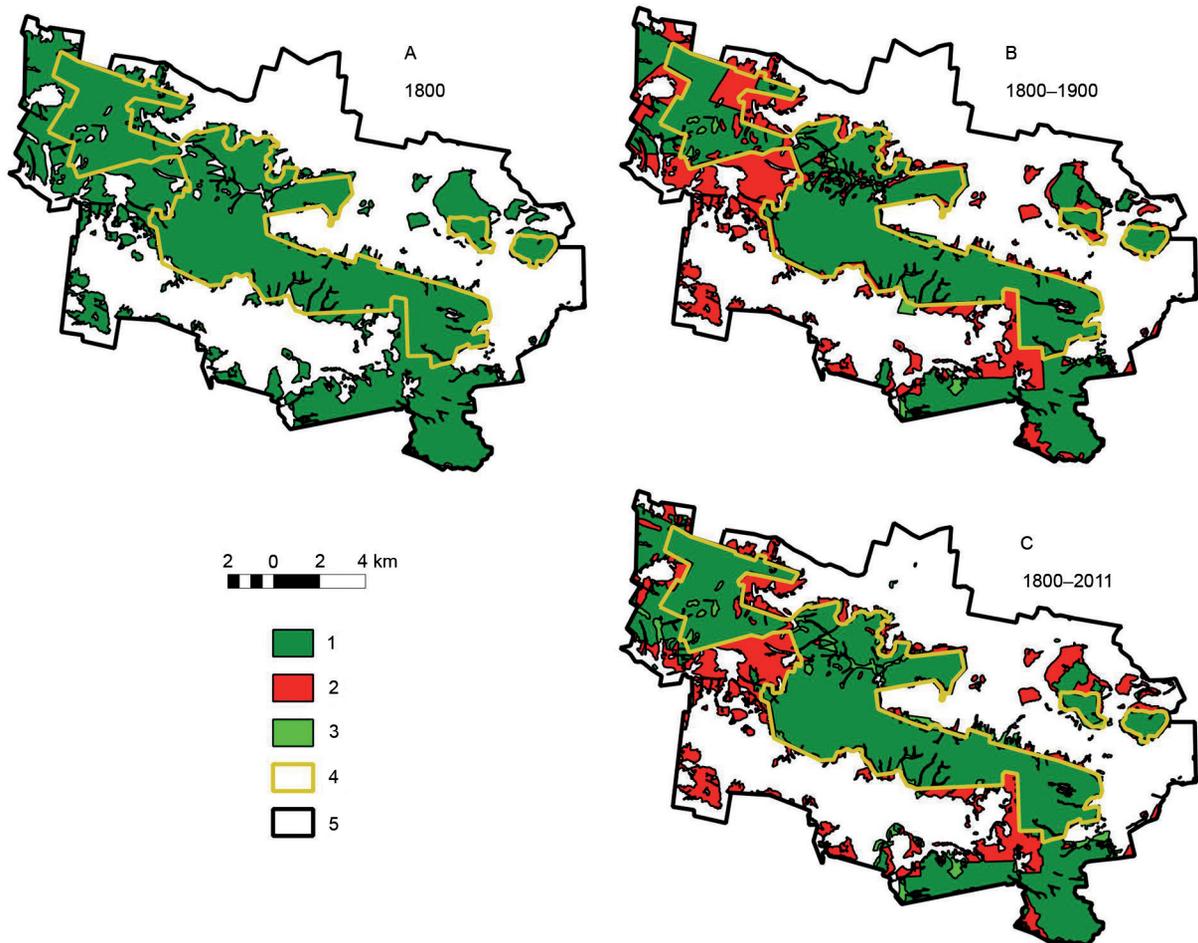


Fig. 2. Forest cover in the Świątokrzyski National Park and its buffer zone in 1800 (A) and subsequent changes in the periods 1800–1900 (B) and 1900–2011 (C)  
1 - forests, 2 - deforestation, 3 - reforestation, 4 - park boundary, 5 - buffer zone boundary

interval. This particular interval is of negligible agricultural importance. Finally, the period 1983–2011 was characterized by significant economic changes in Poland and in other parts of Central and Eastern Europe. The highest rate of new forest growth in the study area during this time was noted for the three lowest elevation intervals considered in this paper. Some of the reasons for this included intentional reforestation and natural succession across unused agricultural lands.

Changes in the forest cover in the Świątokrzyski National Park and its buffer zone were also analyzed in relation to slope gradient. Five slope gradient categories were identified: 0–3, 3–6, 6–10, 10–15, >15° according to the mechanism of surface water erosion processes in Poland (Józefaciuk, Józefaciuk 1996). All analyzed slope gradient categories were characterized by deforestation in the 19<sup>th</sup> century (Fig. 4). However, the largest rates of deforestation were noted for the

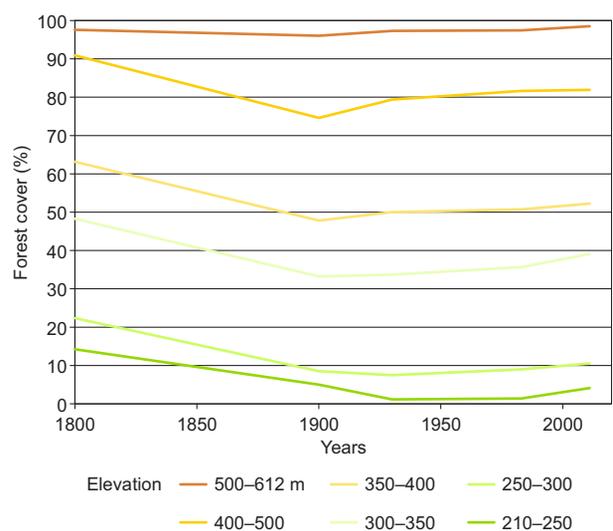


Fig. 3. Changes in the forest cover for selected elevation intervals in the Świątokrzyski National Park and its buffer zone since the year 1800

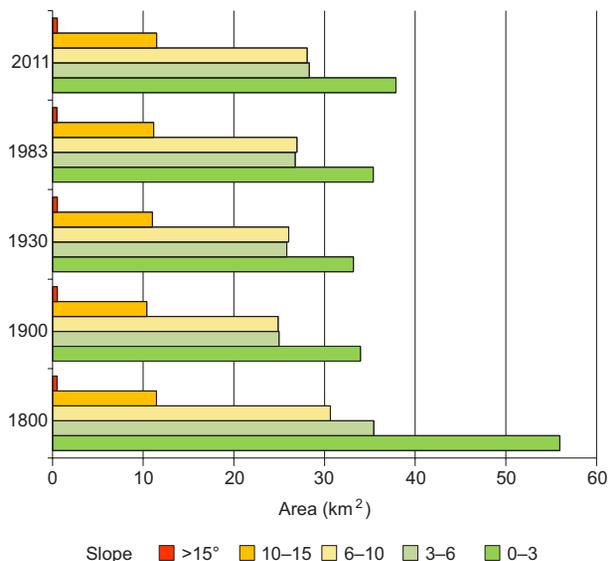


Fig. 4. Changes in the forest cover for selected slope gradient intervals in the Świętokrzyski National Park and its buffer zone since the year 1800

areas with the smallest slope gradients (0–3°). This category includes 39.3% of the study area and is characterized by the best conditions for agriculture and the lowest susceptibility to surface water erosion. Increases in forest cover have been noted for virtually every gradient category since the early 20<sup>th</sup> century. In one exceptional case, reforestation began to increase in the 0–3° category in 1930 (Fig. 4).

The Soil Map of Poland was used to create the following soil categories for the study area: (1) sand-based – 5.7% of the study area, (2) clay – 19.2%, (3) loess – 54.5%, (4) alluvial dust deposits – 9.1%, (5) marshy and alluvial soils – 0.7%, (6) rocky and skeletal soils on non-carbonate rocks – 10.8%. The forest cover (area and percentage) was calculated for each analyzed soil type and for each studied time period, and used to identify change patterns in the Świętokrzyski National Park and its buffer zone. Mean annual changes in the forest cover were also calculated for each studied time interval. Figure 5 shows the results for the periods 1800–1900 as well as for 1930–2011. The mean annual index of forest cover change calculated herein was negative for the period 1800–1900, which indicates deforestation across all soil types. Deforestation was greatest in the case of loess-type and clay-type soils – about 14 ha·yr<sup>-1</sup>. The highest deforestation rate in the 19<sup>th</sup> century was noted for the areas characterized by the best soil conditions for agriculture in a time of rising demand for farmland. Deforestation continued to occur across loess-type and sand-type soils in the study area until the early 20<sup>th</sup> century, while areas characterized by other soil types had already entered the reforestation stage at the time.

On the other hand, the forest cover increased between 1930 and 2011 for every soil type (Fig.

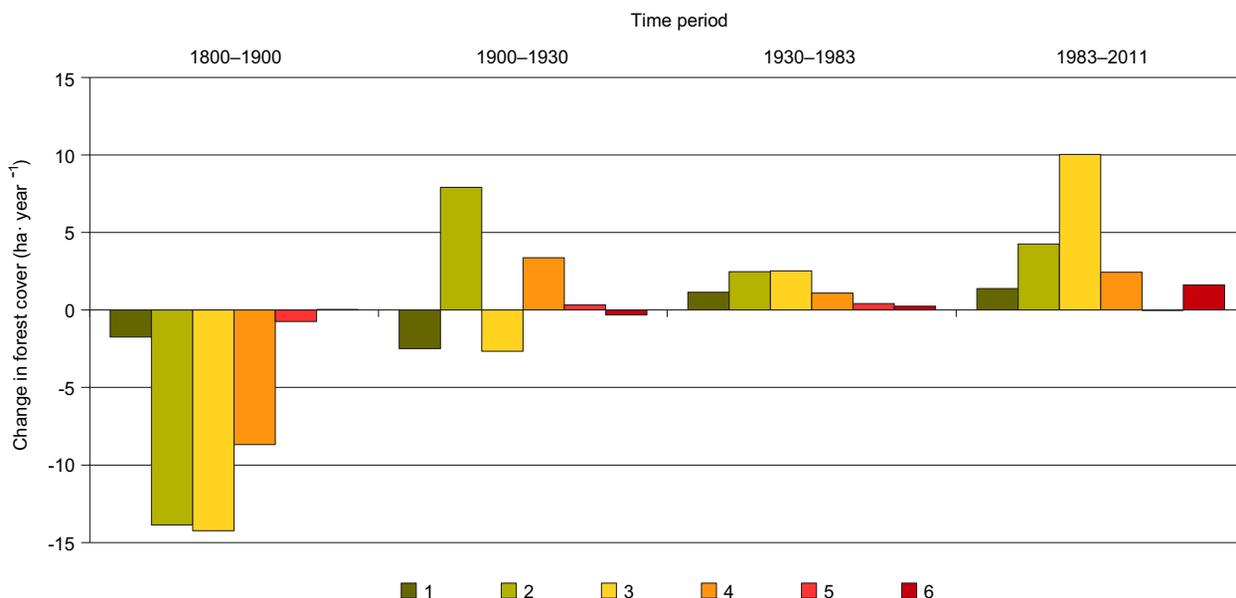


Fig. 5. Changes in the forest cover for selected soil types found in the Świętokrzyski National Park and its buffer zone since the year 1800  
Soil types: 1 - sand-based, 2 - clay-based, 3 - loess-based, 4 - alluvial dust deposits, 5 - marshy and alluvial soils, 6 - rocky and skeletal soils.

5). Today, increases in the forest cover are particularly visible in the case of loess-type soils (approx. 10 ha·yr<sup>-1</sup>).

## Discussion and conclusions

The paper attempts to show the significance of morphological and soil-based factors in the forest cover changes in the Świętokrzyski National Park and its buffer zone during the last 200 years.

The rate of deforestation in the National Park was quite low in the 19<sup>th</sup> century compared with that in the Park's buffer zone. In the Świętokrzyski National Park the process of deforestation was documented from 1800 to 1900, whereas in the buffer zone it lasted until the 1930. After the turning points in the mentioned years, afforestation began and it continues until present. Despite ongoing afforestation, the forest cover in the analyzed area has not returned to its state from the year 1800. A similar deforestation-afforestation trend was observed throughout Northern Europe until the mid-19<sup>th</sup> century. In Southern Europe, deforestation continued until the 1970s (Rudel et al. 2005).

Regarding the forest cover changes in elevation and slope categories, deforestation was observed everywhere, from the most to the least accessible parts of land, reaching high elevations and steep slopes in the National Park in 1900 and in the Park's buffer zone in 1930. After 1900 and 1930 continuous afforestation could be noted, covering at first the least accessible areas (ongoing to the 2011), while the areas of good agricultural suitability (in morphological context) kept being covered with the forest. This process is reinforced by additional nature preservation measures introduced in the area: since the mid-20<sup>th</sup> century – the Świętokrzyski National Park and – since the beginning of the 21<sup>st</sup> century – PLH260002 Łysogóry are a part of the pan-European Natura 2000 system. Deforestation and following afforestation have been observed for all elevation and slope gradient intervals.

Forest cover changes analysis, in addition to genetic soil types, showed a tendency similar to the one of the morphological determinants. At first, deforestation occurred on the soils best for agricultural purposes, then it covered less fertile and usable areas. After 1900 and 1930 affores-

tation did not follow such a clear pattern but it also seemed to be connected with soils fertility. Surprisingly, in the periods 1930–1983 and 1983–2011 the highest afforestation concerned loess soils. Those areas were used intensively for agricultural purposes for more than a century. For this reason, the soils in the ŚNP buffer zone became less fertile over the years and consequently less profitable for farmers who have largely abandoned the buffer zone in the recent years.

In the 19<sup>th</sup> century, environmental conditions were the most important for agricultural production led by local populations. However, in the 20<sup>th</sup> century, the key issues were economics and politics instead of local soil type and relief. This could partly explain afforestation on fertile soils. Broad description of such patterns can be found in a number of papers analyzing forest cover and its relationship with elevation, natural succession and human impact in Europe (Didier 2001, Hörsch 2003, Kozak 2005, Kozak et al. 2007b, Geri et al. 2010). Also the relationship between the forest cover and soil types in mountain areas, and indirectly with the agricultural potential, was studied by MacDonald et al. (2000) and Wulf et al. (2010). Szymura et al. (2010) analyzed the impact of relief and non-environmental factors on the forest cover in the 19<sup>th</sup> and 20<sup>th</sup> centuries in the context of pan-European trends, showing strong relationship between the forest cover and two variables: elevation and slope gradient.

The economic and political situation in Poland in the period 1800–1930 resulted in a significant decline in forest cover. Some of the reasons for deforestation included shortage of farmland in rural areas, lack of appropriate legislation, lack of local government oversight, and increasing industrialization in the region (Szymański 1978, 1983, 1993). In addition, small forests found near villages served as sources of firewood for home heating purposes. On the other hand, the 20<sup>th</sup> century was characterized by afforestation due to widespread abandonment of overused farmland, migration of rural residents to cities, as well as the introduction of environmental protection laws (Szymański 1993). Natural succession in the last several decades was documented earlier in other temperate forests throughout Europe (Piussi 2000, Kozak et al. 2007b, Baumann et al. 2012, Bose et al. 2014).

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