

# Use of GIS-Supported Comparative Cartography and Historical Maps in Long-Term Forest Cover Changes Analysis in the Holy Cross Mountains (Poland)

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## Abstract

In recent years forest research benefits from access to archived cartographic materials and geographic information systems technology, which both allow to analyze the processes of forest cover changes over time. Available digital elevation models (DEMs) and soil maps make it possible to consider terrain relief and soils characteristics in the research. The present paper analyzes changes of forest cover in the Holy Cross Mountains (central Poland) within the period of 1800–2011 and they relation to altitude and slope gradient classes as well as to genetic soil groups. The source materials consist of topographic maps created in 1800, 1900, 1930, 1983 and thematic maps: Polish Sozological Map in 1: 50,000 scale from 2011, Soil Map of Poland in 1: 300,000 scale and SRTM3 digital elevation model. Scanned maps were georeferenced to metric coordinate system and then forest areas were digitalized by on-screen vectorization. Digital elevation model was used to delineate elevation and slope gradient classes. Finally, the overlay geoprocessing methods were used to analyze the areas of forest cover changes in time, also in addition to altitude zones, slope gradient and genetic soil type classes. Forest cover indicator (%) and mean annual index of forest cover change ( $\text{ha}\cdot\text{year}^{-1}$ ) have been calculated. Forest cover was the highest at the beginning of the study period in 1800 and the lowest in 1930. The decrease in forest cover in this period equaled 35.3 %. A slow process of recovery began in 1930 and continues till today. However, the coverage noted in 1800 has not yet been achieved. Also forest cover stability analysis has been performed. Today forest areas of very high stability cover about 21 % of the Holy Cross Mountains and 49 % of the area covered by trees in 1800. The present analysis has been performed with the use of GIS-supported comparative cartography and historical maps, which have significantly improved the investigations of long-term forest cover changes.

**Keywords:** forest cover changes, comparative cartography, relief, soils, central Poland

## Introduction

The identification of changes in forest cover is a key part of many environmental, sociological, and economic analyses the results of which could be applied in forestry. Numerous research publications of different topics have tackled this issue from various spatial and temporal perspectives. Recently, some important papers describing long-term forest cover changes have been published in different parts of Europe (i.a. Wulf et al. 2010, Puddu et al. 2012, Skalos et al. 2012). At the same time, the following papers have addressed the issue of forest cover change in Poland: the Polish Carpathian Mountains in period 1800–2000 (Kozak 2010); the Kalisz Plateau in 1830–1998 (Markuszczyńska 2005); the Northern Carpathians in 1930–1990 and 1987–2000 (Kozak et al. 2007a,b); Tuchola Pinewoods in 1938–2000 (Giętkowski 2009); the Western Bieszczady Mts. in 1854–2004 (Gielarek et al. 2011); West Pomerania in 1618–2006 (Kunz 2012); Krotoszyn commune in 1793–2005 (Macias and Szymczak

2012). The rapid progress of forest cover changes research is primarily due to recent development in geographic information systems (GIS). This makes it possible to perform accurate measurements using various source materials across a wide array of administrative, topographic and hydrographic regions, both large and small.

There are many research papers on forest cover changes that utilize historical maps and methods of comparative cartography (i.a. Więcko 1986, Kienast 1993, Petit and Lambin 2002, Kozak 2003, Skalos et al. 2012). The use of such cartographic materials in land cover research is well established because they are often the only source of long-term data on land cover, in particular from the last centuries. In Poland this type of research was conducted already in the 1930s and included the Holy Cross Mountains. A few decades later, a broad review of papers based on historical maps analysis was published (Szymański 1979). Forests in the Holy Cross Mountains sparked the interest of researchers already in the 19<sup>th</sup> century (Barański 1972). A review of papers written over the last

200 years has made it possible to identify two principal research approaches in the area of forest cover analysis. The first approach addresses forest cover changes in the context of historical, political, and economic conditions (Szymański 1993). The second approach addresses environmental determinants (Reniger 1956, Kowalkowski 2000). This environmental approach corresponds to the aim of the present paper.

The recent availability of digital elevation models (DEMs) has created further opportunities for the exploration of land cover changes in addition to terrain morphology. Papers that utilize DEM and its derivatives in forest cover analysis include: the Swiss Alps (Hörsch 2003), the Andes (Bader and Ruijten 2008), Tuscany (Geri et al. 2010), Simien National Park in Ethiopia (Wondie et al. 2011), the Carpathian Mountains in Poland (Kozak et al. 2007b), the Sudety Mountains in Poland (Szymura et al. 2010) and others. A number of researchers have studied forest cover and its relationship with altitude, natural succession, and human impact in Europe (Didier 2001, Hörsch 2003, Kozak 2003, Geri et al. 2010). The impact of relief and non-environmental factors on forest cover in the 19<sup>th</sup> and 20<sup>th</sup> centuries in the context of pan-European trends is one of the latest research topics (Kozak 2010, Szymura et al. 2010). Research has shown that forest cover changes in mountain areas are dependent on soil

types and resulting soil agricultural potential (MacDonald et al. 2000, Wulf et al. 2010). This problem is scarcely mentioned in forest cover change analysis but it has been decided to tackle this determinant by taking into account a large variety of soil groups of different fertility existing in the analyzed area of the Holy Cross Mountains.

The objective of this study is to analyze changes in the forest cover in the Holy Cross Mountains over the last 200 years in the context of spatial morphological determinants such as altitude and relief as well as soil-based factors, with the use of the comparative cartography methodology. The present paper tries to answer the following questions: What area was affected by changes in forest cover during each studied time interval? How did morphological and soil-based factors influence these changes? What advantages does the use of GIS-supported comparative cartography and historical maps bring into forest research?

**Materials and Methods**

The source materials used in the research consist of scanned maps, both new and historical: Map of Western Galicia by Anthony Mayer von Heldensfeld, Karte Des Westlichen Russlands, Tactical Map of Poland, Polish General Staff Map, Polish Sozological Map (Table 1). Old maps were published on the basis of field mapping, which

**Table 1.** Maps used to analyze the forest cover

Map	Year		Scale	Number of sheets	RMSE of GCPs location (m) min – max	Forest representation
	topicality	issue				
Map of Western Galicia by Anthony Mayer von Heldensfeld (source: Österreichisches Kriegsarchiv, Vienna)	1800	1801–1804	~1:28 800	16	–*	Coloured polygons filled with tree signatures
Karte Des Westlichen Russlands (Map Archive of Geographic-Military Institute)	1900	1914–1915	1:100 000	9	31,5 – 129,8	Polygons filled with tree signatures; dotted line boundaries
Tactical Map of Poland (Map Archive of Geographic-Military Institute)	1930	1931–1934	1:100 000	9	29,4 – 63,0	Polygons filled with tree signatures indicating deciduous, coniferous or mixed forest; dotted line boundaries
Polish General Staff Map (Archive of Institute of Geography, Jan Kochanowski University, Kielce)	1983	1985–1988	1:50 000	14	10,4 – 23,7	Coloured polygons with dotted line boundaries; text indication of forest species composition
Polish Sozological Map (Main Centre of Geodetic and Cartographic Documentation, Warsaw)	2011	2011–2012	1:50 000	14	–	Coloured polygons showing protected and other forests

\* – calculation was unnecessary because of the Thin Plate Spline transformation function used

could have been performed years before the map publication. On the basis of maps timeliness, forest cover was analyzed in the following years: 1800, 1900, 1930, 1983, 2011 and in the four time periods between them. Selection of the source material from the 19<sup>th</sup> century to the first half of 20<sup>th</sup> century was very limited and therefore the present study is based on the only map series available for the period and covering the area in question. It has been decided to use 1:50,000 scale maps for the two last time periods to allow the most reliable comparison. Therefore, taking into consideration their properties and the information about all the maps used taken from the literature, it can be stated that the general accuracy of the study is comparable to 1:50,000 scale map.

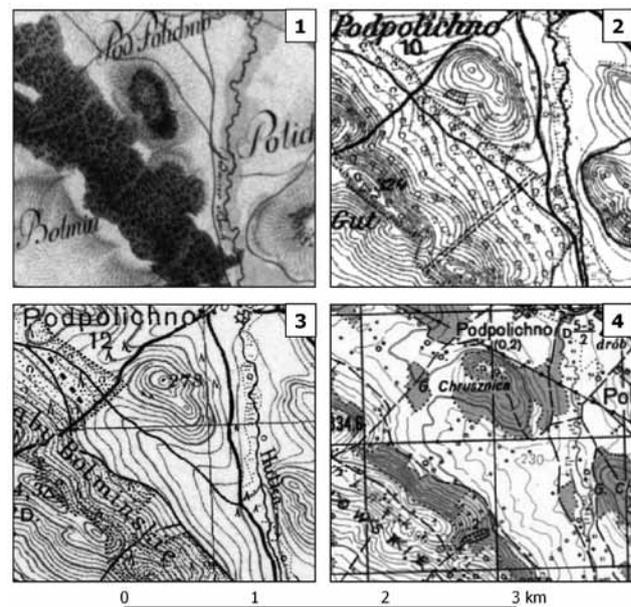
The fundamental step in data preparation was georeferencing of the maps images. In this process, scanned, high-resolution images of historical maps were transformed in GIS into metric coordinate system (Poland CS92). It was performed with the use of a transformation based upon identical ground control points (GCPs), which are stable in time and clearly defined objects or places marked as signatures on each map series. In the study, the following GCPs have been used: churches, crossroads, bridges and hilltops. The Karte Des Westlichen Russlands, Tactical Map of Poland and Polish General Staff Map were georeferenced using Helmert transformation method, with 14 to 18 GCPs distributed evenly on each map sheet. The root mean square error (RMSE) of GCPs location on the output maps did not exceed 130 m (Table 1). This was in the case of one map sheet of Karte Des Westlichen Russlands in the 1:100,000 scale. The oldest of the analyzed map series – Map of Western Galicia, as the one with the biggest possible errors resulting from the time of its production, was transformed with a nonlinear method called rubber-sheeting, using thin plate spline functions (TPS). This method is used for georeferencing of maps and other spatial data with potentially big and unevenly distributed localization errors (White and Griffin 1985) – such as those on the maps from the beginning of the 19<sup>th</sup> century. The effect of this method is that the GCPs on the output georeferenced map are situated exactly in the same place, where they are in reality, and the space between them is interpolated to fill all the area. In this case, calculation of RMSE of the resulting GCPs was unnecessary. Map sheets from this series have the biggest possible errors, even though they were made in the 1:28,800 scale. The Polish Sozological Map already had spatial adjustment in the desired coordinate system so we did not perform georeferencing for this data.

The signatures representing forests are different on each map series; however, all of them are easy to distinguish and allow to determine forest reach. An example of different cartographic signatures used to present forest on the maps is shown on Figure 1.

On the basis of georeferenced map images, 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 and Tree 1951, Wilson 2005, Plit 2008, Podobnikar 2010). Many publications describe similar methodological issues connected with forest cover analysis based on historical maps (i.a. Kozak 2003, 2010, Wulf 2010, Gielarek et al. 2011, Kunz 2012, Skalos et al. 2012).

The morphological analysis was based upon the SRTM3 DEM in raster format, created during the Shuttle Radar Topography Mission in three arcsecond (90 m) resolution (Shuttle... 2004, Farr et al. 2007). This DEM was converted into the Polish State Coordinate System 92 and used to identify six altitude zones (under 250, 250–300, 300–350, 350–400, 400–500, above 500 meters a.s.l.), designated by the elevation histogram analysis. As a result of slope map calculation (Zevenbergen and Thorne 1987), six slope gradient categories were identified: 0–1, 1–3, 3–6, 6–10, 10–15, >15° (all in degrees) according to the mechanism of surface water erosion processes in Poland (Józefaciuk and Józefaciuk 1996).

As far as soils are concerned, forest cover change analysis was based on the above listed soil types. Soil cover was mapped using the IUSS, ISRIC, and FAO (2006) classification systems. Seven generalized groups of soils (formed on carbonate rock, sand, clay, loess, alluvial dust deposits, boggy and alluvial deposits, non-carbonate rock



**Figure 1.** Examples of the historical maps used in the study along with the forest signatures: 1 – Map of Western Galicia by Anthony Mayer von Heldensfeld; 2 – Karte Des Westlichen Russlands; 3 – Tactical Map of Poland; 4 – Polish General Staff Map

and skeletal) were distinguished according to the parent material identified with the use of the Soil Map of Poland in the scale of 1:300,000 (Musierowicz 1961).

Finally, the overlay geoprocessing methods (difference and intersect) were used to analyze forest cover changes between the analyzed time intervals in altitude zones, slope gradients and genetic soil groups. For every soil group, the mean annual index of forest cover change (ha-year<sup>-1</sup>) for each studied time period has been calculated using a spreadsheet. Moreover, a compensating border effect error in calculation of the forests areas in different years has been assumed, taking into consideration large study area and many existing forest stands.

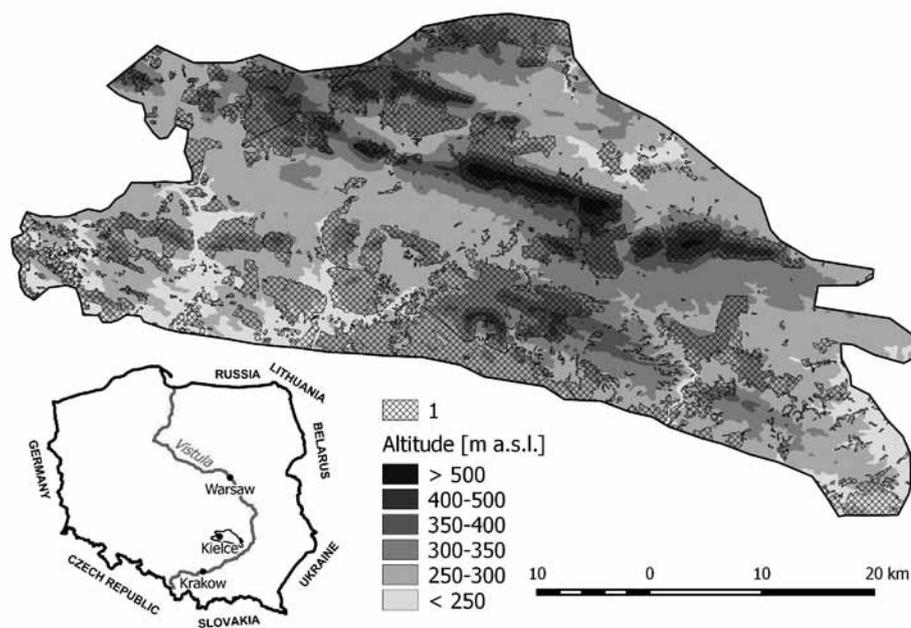
During the investigation of forest cover change processes over the last 200 years, a complementary analysis of forest cover stability has been performed. At first, forest areas in vector format were converted into the raster format with 100 m resolution, where raster cells values are an outcome of principle of the highest share between forested or non-forested areas. This helped to eliminate potential representation errors along forests borders. Then unique numerical identifiers were assigned to the forest cover from every time period. In the end, with the use of the map algebra operations (Tomlin 1990), spatial multiplication of the identifiers was performed and the result of this operation was categorized to create a forest stability map with five classes of forest cover. The value system used to create the map was the following: a unit area with forest on one of the five maps used was designated very low stability ( $f = 1$ ), while a unit area with forest on all of the five maps used was designated very high stability ( $f = 5$ ). All analysis was performed with the use of Quantum GIS 1.8.0 and SAGA GIS 2.0.2 software.

**Study area**

The Holy Cross Mountains (Polish: Góry Świętokrzyskie) in Central Poland are one of the oldest mountain ranges in Europe. The range was classified as a distinct physical geographic mesoregion (Kondracki 2011) covering the area of 1,825 square kilometers (Figure 2). The Holy Cross Mountains are part of a larger system of Polish Uplands and consist of virtually parallel belts of hills oriented in a general WNW-ESE direction. The orientation closely mirrors the local lithology and tectonics of the Paleozoic fundament. Expansive valleys lie between each mountain belt. The valleys are flat-bottomed and characterized by similar hypsometry. Local altitude ranges from 175 to 612 meters above sea level. The Holy Cross Mountains possess a rather unique climate in comparison to surrounding areas. The mean annual precipitation at the highest altitudes exceeds 820 mm, while the mean air temperature reaches 5.7°C. In valleys precipitation is lower by about 200 mm, and the air temperature by about 1.5°C (Olszewski 1992).

The soils in the study area follow a mosaic pattern mainly due to the complex geological structure of the area as well as to other environmental determinants. Top sections of hills are largely covered with skeletal mountain soils. Lower altitudes are characterized by fertile soils formed on loess, clay, and alluvial dust deposits. Finally, valleys are covered with boggy and alluvial soils (Musierowicz 1961).

Presently beech and fir forests cover the upper altitudes of the Holy Cross Mountains – above 350 meters on northern slopes and above 450 meters on southern slopes. Outside the analyzed region, this type of mixed forest can be found in Poland only in certain parts of the Ro-



**Figure 2.** Location of the Holy Cross Mountains. Legend: 1 – contemporary forests

ztocze hill range. The Latin name *Abietetum polonicum* emphasizes its endemic character. Beech and fir are the most important forest stands component in the Łysogóry Range, and are protected in the Świętokrzyski National Park (Danielewicz 2000), where they grow on the northernmost border of their natural range in Central Poland (Matuszkiewicz and Matuszkiewicz 1996). Below the borderline of *Abietetum polonicum*, forest areas of this region host all most important forest tree species in Poland. These lower altitudes are covered with pine forests as well as hornbeam and oak forests, while valleys feature submontane riparian forests (Trampller et al. 1990).

Significant human impact on forests in the Holy Cross Mountains dates back to Roman times. Ancient miners and ironworkers toiled in the region. Logging was a common practice (Orzechowski 1991). Permanent settlements emerged in the region in the Early Middle Ages and soon followed agriculture with deforestation in river valleys and on loess slopes. Glass was manufactured in the region between the 16<sup>th</sup> and 18<sup>th</sup> century, consuming large quantities of beech wood. This led to decreased biodiversity and a resurgence of fir in the forests of the Holy Cross Mountains (Wyrobisz 1966, Wijaczka et al. 2004).

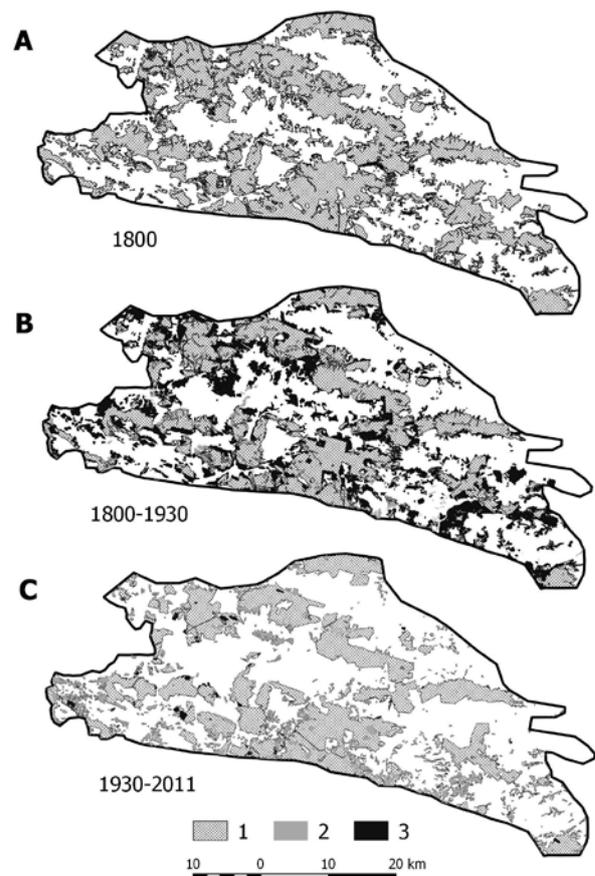
**Results**

Forest cover area in the Holy Cross Mountains was the greatest at the beginning of the study period (around the year 1800), 772.5 km<sup>2</sup>, which was 42.3 % of the total area of the region (Figure 3A, Table 2). This measurement was based on the map in the largest scale, therefore, the derived forest reach, in this paper treated as the forest cover changes starting point, could be considered as very reliable. Forest cover decreased to 510.8 km<sup>2</sup> by the year 1900, and 499.7 km<sup>2</sup> by 1930 (Figure 3B, Table 2). Hence, forest cover was reduced by 35.3 % between 1800 and 1930. The mean annual rate of deforestation in the period of 1800–1930 was -209.8 ha·year<sup>-1</sup>. A slow increase in forest cover was observed since 1930 (Table 2). Forest cover in the study area increased to 554.7 km<sup>2</sup> (30.4 %) by 1983. The rate of increase between 1930 and 1983 was 103.8 ha·year<sup>-1</sup>. After 1983 the rate of afforestation reached 230.4 ha·year<sup>-1</sup>. In 2011, in the Holy Cross Mountains for-

ests occupied 619.2 km<sup>2</sup> (33.9 %) (Table 2). Forest cover increased by 119.5 km<sup>2</sup> between 1930 and 2011, with a mean annual forest growth rate of 153.2 ha·yr<sup>-1</sup>. Therefore, forest cover in the study area has not returned to its state from the year 1800. For comparison, forest cover in Poland reached 29.3 % in 2011 and exhibits a growth trend (Forestry 2013).

**Morphological determinants**

Both deforestation and afforestation processes were identified for each studied altitude zone in the period of



**Figure 3.** Forest cover in the Holy Cross Mountains in 1800 (A) and changes in the periods 1800–1930 (B) and 1930–2011 (C). Legend: 1 – forests, 2 – afforestations, 3 – deforestations

**Table 2.** Selected characteristics of forest cover in the Holy Cross Mountains between 1800 and 2011

Year	1800	1900	1930	1983	2011
Forest cover (%)	42.3	28.0	27.4	30.4	33.9
Forested area (km <sup>2</sup> )	772.5	510.8	499.7	554.7	619.2
Period	1800–1900	1900–1930	1930–1983	1983–2011	
Mean annual index of change (ha·yr <sup>-1</sup> )		-251.7 (1800–1930: -209.8)	-37.0	+103.8 (1930–2011: +153.2)	+230.4

1800–2011. Deforestation was found to be the greatest in each altitude zone during the 19<sup>th</sup> century, with a maximum value of -16.9 % between 350 and 400 meters above sea level. The lowest rate of deforestation was noted over 500 m a.s.l. (-1.1%). Deforestation in other altitude zones ranged from -11.6 to -15.8 % between 1800 and 1900. The two lowest altitude zones (under 250 m and 250–300 m a.s.l.) experienced deforestation until 1930, reaching -18.7 % and -14.7 %, respectively, for the period of 1800–1930 (Figure 4).

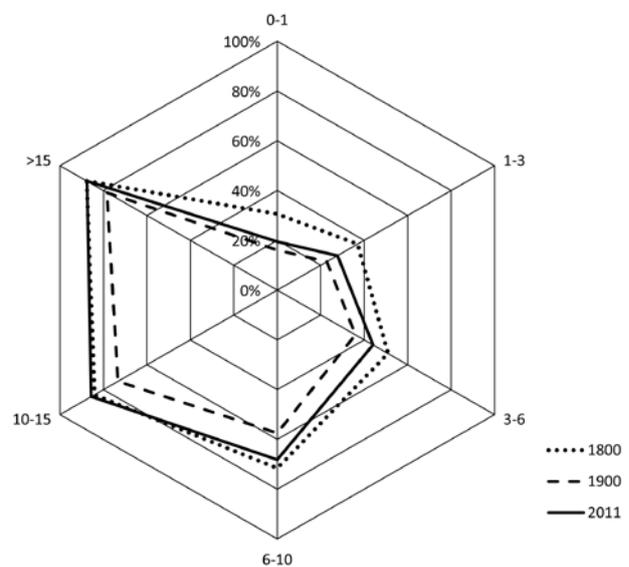
Above 300 meters of altitude, deforestation was halted by the year of 1900 and by 1930 afforestation permanently replaced deforestation in every altitude zone. This trend continued until the end of the study period in 2011. The greatest increases in forest cover occurred at the lowest altitudes: 175–250 m, 5.3 % (1930–1983) and 4.9 % (1983–2011). The lowest increases were noted over 500 meters above sea level: 1.3 % and 0.7 %, respectively. It is worth noting that the largest increases in forest cover were recorded for 350–500 m a.s.l. in the period of 1930–1983 and less than 350 m a.s.l. in the period of 1983–2011. Increases in the period of 1930–1983 were largely the result of the abandonment of overused and often poorly accessible farmland – especially this situated on higher altitudes. Between 1983 and 2011, afforestation was related to natural conditions, but simultaneously reinforced by Poland’s transition from socialism to capitalism in the early 1990s. Abandonment of farmland in the last three decades led to natural succession as well as to afforestation in some places, but was not clearly related to analyzed altitude zones.

Within the whole analyzed period, the largest forest share was observed in the areas with high slope gradients. In the year 1800 forest cover ranged from 30.6 % for 0–1° to 87.7 % for more than 15°, in the year 1900 – from 16.1 % to 78.4 %, while in 2010 – from 19.5 % to 87.6 %.

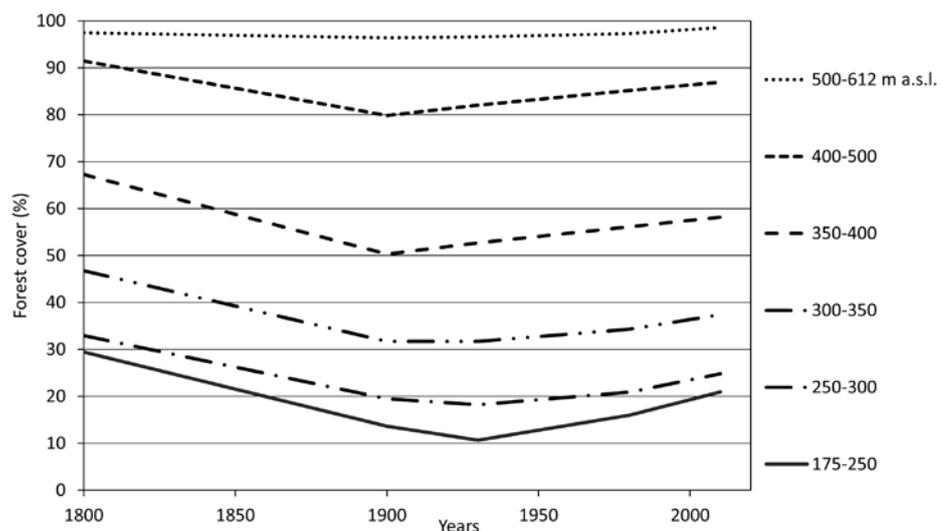
variable relief ranging from -9.3 % for more than 15° to -15.0 % for 3–6°. Deforestation was the greatest on slopes with a gradient of 1–3° (128.4 km<sup>2</sup>). The decrease in forest cover in this gradient interval ranged from 36.9 % to 22.8 % or 14.1 %. Areas of this type are almost ideal for agriculture, easily accessible, and relatively unaffected by surface water erosion. Deforestation continued to occur until 1930 only in the two lowest terrain slope intervals. All other slope intervals were characterized by afforestation (Figure 5).

*Soil determinants*

In the Holy Cross Mountains the most soils are formed on loess 33.4 %, while those formed on clay oc-



**Figure 5.** Forest cover (in percent) by terrain slope in six intervals (in degrees) for the Holy Cross Mountains in 1800, 1900, and 2011



**Figure 4.** Forest cover changes at selected altitude zones in the Holy Cross Mountains from 1800 to 2011

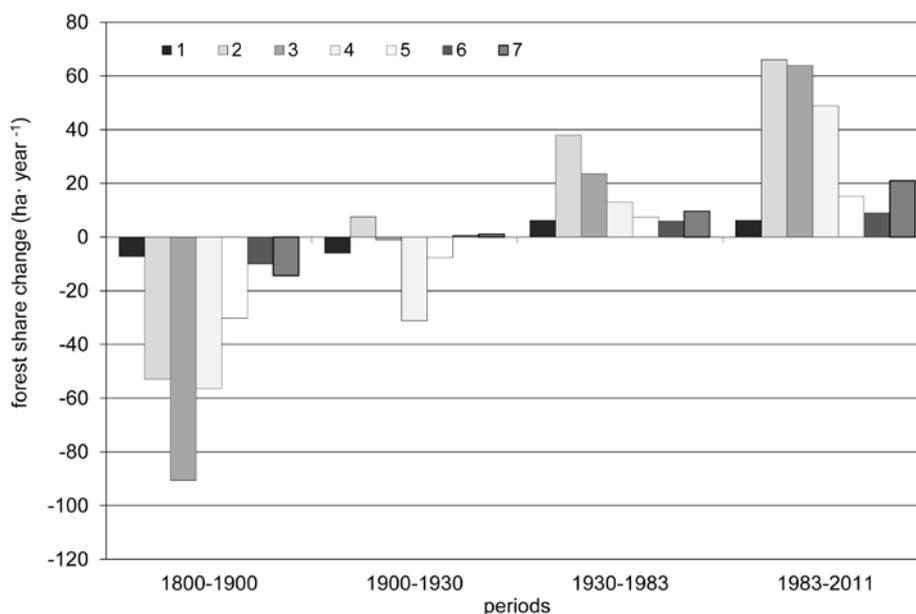
cupy 24.4 %, and on sand 19.3 %. Other soil types do not exceed 10 % of the total regions area (Table 3). Forest share was the largest in the areas featuring rocky and skeletal soil types during the 200-year study period and ranged from 83.2 % (1800) to 72.2 % (1900). Significant forest cover was also noted for soils formed of alluvial dust, ranging from 65.3 % in 1800 to 40.9 % in 1930. However, this type of forest cover occupied only about 14 % of the area of the Holy Cross Mountains. In 1800 the largest forested areas were noted for clay type soils (238.2 km<sup>2</sup>) and sand type soils (162.2 km<sup>2</sup>).

Only negative mean annual rates of forest change were noted for the period 1800–1900, for each soil group (Figure 6), the largest were noted for soils formed on clay (-90.6 ha·year<sup>-1</sup>) and loess (-56.5 ha·year<sup>-1</sup>). This was largely the result of high demand for fertile land needed for agricultural purposes.

The time period 1900–1930 was characterized by on-going deforestation in the areas with fertile soils including loess (-31.2 %), alluvial dust (-7.6 %), carbonate rock (-6.0 %), and clay (-1.1 %). However, forests growing on other soil types were already experiencing afforestation. This was especially true for sandy areas. Forest cover increased across all soil types after 1930, as measured by the mean annual index of change: 6.1 ha·year<sup>-1</sup> (carbonate rock soils), 38.0 ha·year<sup>-1</sup> (sandy soils) (Figure 6). The period 1983–2011 was characterized by even larger increases in forest growth in clay type soils (63.9 ha·year<sup>-1</sup>) and loess type soils (48.9 ha·year<sup>-1</sup>). As Poland made the transition from socialism to capitalism in the early 1990s, agricultural production decreased across large swaths of degraded soils that had been used for over 100 years.

**Table 3.** Changes in forest cover in the Holy Cross Mountains between 1800 and 2011 in addition to soil parent material

Soil type	Soil area km <sup>2</sup>	1800		1900		1930		1983		2011	
		km <sup>2</sup>	%								
carbonate rock	70.5	20.6	29.2	13.3	18.9	11.5	16.3	14.8	21.0	16.6	23.5
sand	352.2	162.2	46.1	109.3	31.0	111.6	31.7	131.7	37.4	150.2	42.7
clay	444.8	238.2	53.5	147.5	33.2	147.2	33.1	159.7	35.9	177.6	39.9
loess	654.6	141.2	21.6	84.7	12.9	75.4	11.5	82.3	12.6	96.0	14.7
alluvial dust	132.9	86.8	65.3	56.6	42.6	54.3	40.9	58.2	43.8	62.5	47.0
boggy and alluvial	40.8	15.7	38.4	5.7	14.0	5.9	14.5	9.0	22.1	11.6	28.3
non-carbonate rock and skeletal	129.6	107.9	83.2	93.5	72.2	93.9	72.4	99.0	76.3	104.8	80.9



**Figure 6.** Changes in forest share for selected soil types found in the Holy Cross Mountains from the beginning of the 19<sup>th</sup> century. Soils formed on: 1 – carbonate rock, 2 – sand, 3 – clay, 4 – loess, 5 – alluvial dust deposits, 6 – boggy and alluvial deposits, 7 – non-carbonate rock and skeletal

### Forest cover stability

The most stable forest areas that exist continuously since 1800 create a number of dense forest complexes that spatially correspond to the course of mountain ranges in the region (Figure 7). Their total area is 382,6 km<sup>2</sup>, which is 21 % of the total region area and 49 % of the area covered by trees in time of the maximum forest cover reach in the analyzed period – at the beginning of the 19<sup>th</sup> century. Permanently forested are tops and upper parts of slopes of the highest mountain ranges: Łysogórskie, Jeleniowskie, Masłowskie and Klonowskie. Very high stability ( $f = 5$ ) is also observed in a number of lower mountain ranges: Orłowińskie, Iwaniskie, Zgórskie, Poślowickie, Sieradowickie. As the distance from the stable areas increases, forest cover stability lowers. Forests with very low stability ( $f = 1$ ) were documented in the foothills of mountain ranges, in Kielce-Łagów and Wilkowska valleys. Their total area is of 269.5 km<sup>2</sup>, which is 14.8 % of the total Holy Cross Mountains area.

### Discussion and conclusions

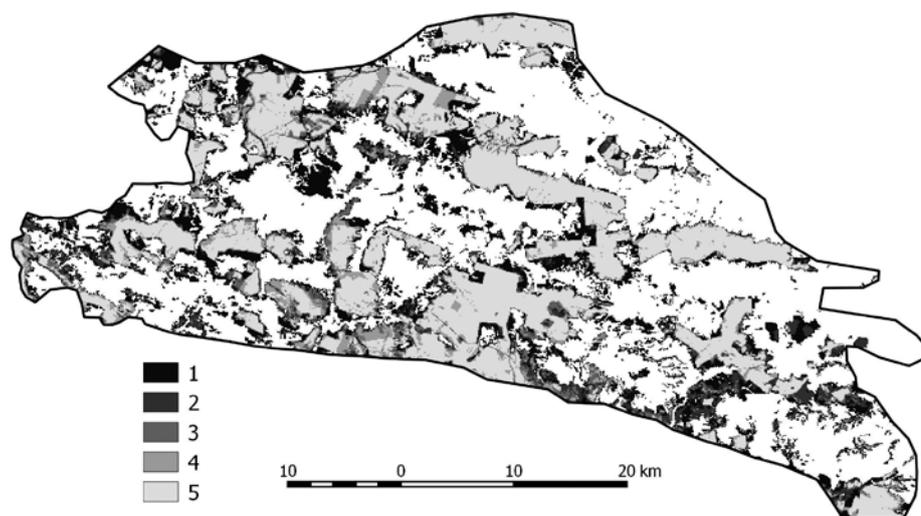
The research presented in this paper indicates that changes in the forest cover of the Holy Cross Mountains after the year 1800 followed a pattern similar to that in other parts of Poland and throughout Europe (i.a. Didier 2001, Hörsch 2003, Rudel et al. 2005, Kozak et al. 2007a, Macias and Szymczak 2012). Process of deforestation reached its peak in the Holy Cross Mountains in the 19<sup>th</sup> century and remained active until a turning point in 1930. A similar trend was observed throughout Northern Europe until the mid-19<sup>th</sup> century. In Southern Europe, deforestation continued until the 1970s for a variety of environmental, social and economic reasons (Rudel et al. 2005). Some of the reasons for deforestation in the Holy Cross Mountains included a shortage of farmland in the Polish

countryside, lack of environmental laws and regulations, lack of general government oversight, as well as an onset of industrialization. In addition, rural residents used wood to heat houses (Guldon 2000). All of the above factors produced abrupt changes in forest ecosystems by altering their initial state, leading to an overall decline in tree stand density. Other negative consequences included physical weakening of trees and a reduction in their longevity. It is important to note that the abandonment of farmland and the onset of natural succession in the last several decades were documented earlier in other temperate forests throughout Europe (Piuksi 2000, Kozak et al. 2007b, Bose et al. 2014). The rate of afforestation in the Holy Cross Mountains as well as throughout Europe is much lower than the rate of deforestation prior to each region's turning point. As a result, forest cover in Poland and in Europe has not returned to its state from the year 1800.

This work has attempted to show the significance of morphological and soil-based factors in changes of forest cover. Both types of factors were used to explain the process of deforestation in the 19<sup>th</sup> century and afforestation in the 20<sup>th</sup> century. The economic and political situation in Poland in the period of 1800–1930 brought about a significant decline in forest cover that occurred mostly on more fertile soils, not used so far for agricultural purposes, and also on higher altitudes with steep slopes. The period 1930–2011 was characterized by afforestation that could be explained by widespread abandonment of over-used farmland, migration of rural residents to cities, as well as the passage of environmental protection laws. It is noticeable that this process of afforestation begun at first on the areas with worse agricultural conditions than the others.

Areas featuring the largest forest cover stability directly correspond to a number of mountain ranges existing in the region. Natural conditions in those areas are the

**Figure 7.** Map of forest cover stability in the Holy Cross Mountains based on historical maps from 1800, 1900, 1930, 1983, and 2011. Stability: 1 – very low ( $f = 1$ ), 2 – low ( $f = 2$ ), 3 – moderate ( $f = 3$ ), 4 – high ( $f = 4$ ), 5 – very high ( $f = 5$ )



worst for agricultural purposes and because of that they were not deforested. Those stable areas could also indicate large number of old trees. In the study area they are usually protected by the law. This would be the Holy Cross National Park (Polish: Świętokrzyski Park Narodowy), five landscape parks and eight special protected areas, which are part of the pan-European Natura 2000 system of environmental protection (Council Directive... 1992).

The properties of the cartographical documents used, mostly the scale differences and resulting from them different cartographic generalization, caused some inaccuracies in comparing forest areas in the analyzed time periods. Some of these misinterpretations were minimized by choosing optimal georeferencing methods, some were impossible to correct. This is a known disadvantage of the historical comparative cartography (Kienast 1993). The metrical quality of the historical maps used was inhomogeneous because of different methods, techniques, resources and equipment used to produce old map series. Furthermore, generalization methods are unknown, following the fact that the location of features is less accurate in earlier map editions than today (Podobnikar 2010, Hodgson and Alexander 1990). Taking this into consideration, the authors of the present study had to be careful in preparation of digital spatial datasets based upon old cartographic documents. The quality of the results depends mainly on the quality of the maps used in the research.

Despite its drawbacks, GIS-supported comparative cartography still could have a big potential in forest research. Old maps – especially those published as large scale map series - are often the only reasonable source of data documenting forests spatial reach in the last centuries. European countries have long cartographic traditions. Depending on the availability of historical maps, in some parts of Europe, the analysis could reach back even to the second half of the 18<sup>th</sup> century.

It has been found necessary to apply the presented methodology in the investigation of long-term spatial forest cover changes in the Holy Cross Mountains. The use of GIS and comparative cartography enabled to expand the temporal and spatial reach of the forest cover change analysis. It speeded up the analysis, increased its accuracy and allowed for other spatial factors to be included in the research – such as morphological and soil determinants analyzed in the present study.

Additional data such as SRTM3 DEM and soil map have helped to extend the analysis by introducing natural environment determinants. They were found to be in relation with forest cover changes but these needs to be studied further, in a more detailed way.

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