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ORIGINAL PAPER

Long-term changes in forest cover 1780–2007 in central Bohemia, Czech Republic

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Abstract Many studies have recently been devoted to the study of landscape change, and some have even focused on an analysis of the dynamics of forest cover change. However, few of the studies have worked on a methodology for making a detailed investigation of long-term forest change dynamics based on historic cartographic sources. The goal of this study is to further develop a method for analyzing long-term changes in forest cover on the basis of old maps and orthophoto maps in the GIS environment. The study area is located in Central Bohemia, to the east of Kutná Hora, a UNESCO World Heritage Site. The area consists of 21 cadastral units with a total area of 113 km^2. The maps of the First (1780), Second (1851) and Third Military Surveys (1877) and the present-day orthophotomap (2007) of the Czech Republic were used as data resources. Source data have been processed in GIS. Forest cover is the subject of our study. However, the term is perceived from a broader perspective. What we call forest cover in our study refers to forest wood elements and other wood species in the landscape. In this study, forest cover has been structurally considered as a whole, without dividing it into the two categories mentioned. We counted the extent of the forest cover in each particular time horizon in hectares and as a percentage of the area under study, also the absolute changes in forest cover between the individual time horizons in hectares as well as the intensity of the changes in forest cover in hectares per year. The spatial changes in forest cover were evaluated in a GIS environment using specialized features to analyze spatial variation. The forest cover occupied 16.60% (1,880 ha) of the total area in the First Military Survey (1780). In 2007, the proportion was slightly higher at 16.64% (1,884 ha). More than half of all forest land (53%) from the time of the Second Military Survey (1851) survived until 2007. Not only the information on absolute changes but also the information on the rate of change is of great importance. The old Military Survey maps and the orthophotomap enable us to carry out studies of long-term changes in forest cover. However, the geodetic inaccuracy of the First Military Survey maps precludes reliable and exact quantification of the landscape changes between the First Military Survey and the Second Military Survey, and also between the First Military Survey and present-day (orthophoto map). These maps cannot be used for evaluating forest cover changes on the level of individual plots. The method presented in our paper may contribute to a better understanding of the long-term dynamics of forest land, covering a period of more than 250 years. This knowledge can be applied in forest management planning procedures. Apart from their application

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in forestry, the methods presented in this study may be of interest for historians and biologists.

Keywords Forest cover change · Old maps · Orthophoto map · Czech Republic

Introduction

Forest cover has undergone radical changes in most European countries (Berg et al. 2008; Hultberg 2008; Ericsson et al. 2005; Ohlson and Tryterud 1999; Bollschweiler et al. 2008). The area of forest land in the Czech lands was on a low level at the end of the eighteenth century (Lipský 1998). This led to a reform of the forestry law, and to the establishment of a requirement for afforestation (Svoboda 1952). In the nineteenth century, "massive" deployment of spruce monocultures began and deciduous woods retreated (Lipský 2000). More trees were planted along existing roads and also along newly constructed roads (Štěpán 2001). The period after 1950 was characterized by fundamental, permanent and dramatic changes in the Czech countryside. An important factor that influenced the character of the landscape in the border areas of the Czech Republic was the post-war expulsion of the German community. This resulted in increased natural succession of the vegetation, with a gradual return to forest communities (Lipský 2000). High levels of industrial emissions were an ecological disaster for forest ecosystems and have had a significant impact on the quality of the forests (Löw and Míchal 2003). Increasing development of modern methods and practices in forestry, especially in the last 20 years, has placed increasing emphasis on environment-friendly forest management methods. The trend toward increasing the forest area has been maintained until the present time (Poleno and Vacek 2007).

Information about the history of a forest and its management is crucial for an understanding of its past, present and potential future characteristics (Bürgi and Schuler 2003). Studies of forest and landscape changes require relevant map sources. Comparative cartographic sources are considered very important source materials for studies of landscape changes also in the Czech Republic (Semotánová 2002). Monitoring changes in the development of landscape on the basis of data obtained from old maps is a widely used method, not only in the Czech Republic but also in other European countries (Breuste et al. 2009). In Switzerland, for example, the first topographic maps were established in the 1870s. Since then they have been issued every 10–20 years and every 6–8 years since the 1940s (Schneeberger et al. 2007). Hersperger and Bürgi (2009) used old topographic maps to make a comparison of landscape elements in different periods. In Estonia, old maps have been used for studying the landscape history of calcareous grassland. The oldest maps, on a scale of 1:5,000, were from 1705 (Pärtel et al. 1999). However, long-term studies on landscape changes are not necessarily always based on graphical sources. Statistical data can provide suitable information, e.g., data on artificial forest regeneration practices (Bürgi and Schuler 2003). In countries where detailed old maps are not available, various scenarios can be produced for modeling the landscape structure or land cover characteristics from history (e.g., the pre-colonial landscape in Northern America) (Scheller et al. 2008; Stoltman et al. 2007; Mladenoff 2004; Williams 2003). Even if close cooperation between landscape ecologists and historians is still rare (Bürgi and Russell 2001), some multidisciplinary approaches are now being started up. Ecosystem responses to land change are complex and interactive (Grimm et al. 2008). The most important driving forces for shaping landscape are economic and political. However, natural and spatial driving forces are not necessary important for agricultural intensification (Hersperger and Bürgi 2009).

The choice of which old maps to use for these evaluations depends on the date when they were drawn, their scale and the purpose of the study. Cadastral maps are reliable and detailed, and can be used for evaluating the landscape microstructure. Old medium-scale maps enable an evaluation of landscape changes over larger areas. The application of old medium-scale maps for observing landscape changes has been discussed by numerous authors (Vuorela et al. 2002; Pärtel et al. 1999; Walz 2002; Cajthaml and Krejčí 2008; Zimová et al. 2006; Eremiášová et al. 2007; Boltižiar et al. 2008; Brůna and Křováková 2006; Skokanová and Havlíček 2009). In the Czech Republic, the maps of the First, Second and Third Military Surveys represent the category of old medium-scale maps. The maps of the Military Surveys provide support for an investigation of changes in forest cover in the study area over a period of more than 250 years. With increasingly intensive landscape changes in the Czech Republic (Sklenicka and Šálek 2008), the military surveys provide a unique primary historical source that illustrates the dynamics of the changes in forest cover. These are medium-scale maps, and they are suitable for studies of larger areas. The use of maps together with GIS methods has been considerably broadened by digitization and by the general availability of these maps in electronic form. Numerous authors have written about ways of using these maps in the Czech Republic (Lipský 2002; Sádlo and Karlík 2002; Uhlířová 2002; Lipský 2000; Demek et al. 2007). Brůna et al. have done detailed work with military maps and with elaborating them in GIS (Brůna and Uhlířová 2000; Brůna et al. 2002). While there is a tradition going back about 30 years of ecological interpretation of old map sources, and the method has become relatively accessible, little work has been done on interpreting the written parts of the maps (Brůna and Křováková 2005).

Unlike the Second and Third Military Survey maps, the First Military Survey maps were not created using present-day standard geodetic methods. For most of the area that they cover, they have not been fully elaborated in GIS. Consequently, there is a lack of information that would enable us to evaluate the possibilities of using the old military maps for analyzing forest changes in the GIS environment over a period of almost 250 years. The main aims of our study are therefore to analyze and to assess long-term changes in forest cover. Another underlying goal of the study is to further develop a method for making a detailed analysis of forest cover changes based on old Military Survey maps and orthophoto mapping (orthophoto maps) through the use of GIS.

Study area

Localization and natural settings of the study site

The study was carried out as a case study in an area located in Central Bohemia, to the east of Kutná Hora (Kuttenberg), a UNESCO World Heritage Site (Fig. 1). The model area is situated in the lowlands. It is an intensively utilized agricultural landscape, formed by large-scale collective open fields with small patches of woodland and rural settlements. Although the area has been used for agricultural production since Neolithic times, a number of historical landscape structures from the fifteenth to nineteenth centuries, e.g., some relicts of the former landscape design, are among the characteristic landscape features that increase its cultural, aesthetic and natural values (Lipský et al. 2008). The area consists of 21 cadastral units, with a total area of 113 km^2. From the geological point of view, Quaternary fluvial deposits (clay, sand, gravel) cover most of the area; loess, loess loam and Aeolian sand are also found. With the exception of the Železné Hory Mountains (Iron Mts.), the area is flat, predominantly at an elevation of 200–230 m. Fluvial soils—bottomlands and gley bottomlands—are prevalent in the wide bottomlands along the streams, and cover a significant part of the area. In the southern and southwestern parts, and also at the foot of the Železné Hory Mountains, there are black soils (Chernozems). Brown soils (Luvisols to Cambisols) and slightly gleyed brown soils mainly occur in the southern part of the area. Loess, loess loam or mixed soils on the slopes are the most frequent soil substrates. In the area of the Železné Hory Mountains, on the mountain slopes, and also in the area of the Fačinský Hřbet range, cambisol is the main soil type (Novák et al. 1992). According to Quitt (1971), the area under study can be classified as a “warm area”. Intensively exploited agricultural, mostly arable, land is prevalent. Large orchards, predominantly of apples and cherries, can nowadays be found on the hillsides of the Železné Hory Mountains. Forests cover less than 20% of the area and have been preserved on less fertile Aeolian sands in a part of the Železné Hory.

Cultural settings

Czech society changed dramatically in the course of the nineteenth century. The industrial revolution started at the end of the eighteenth century, and it led to population

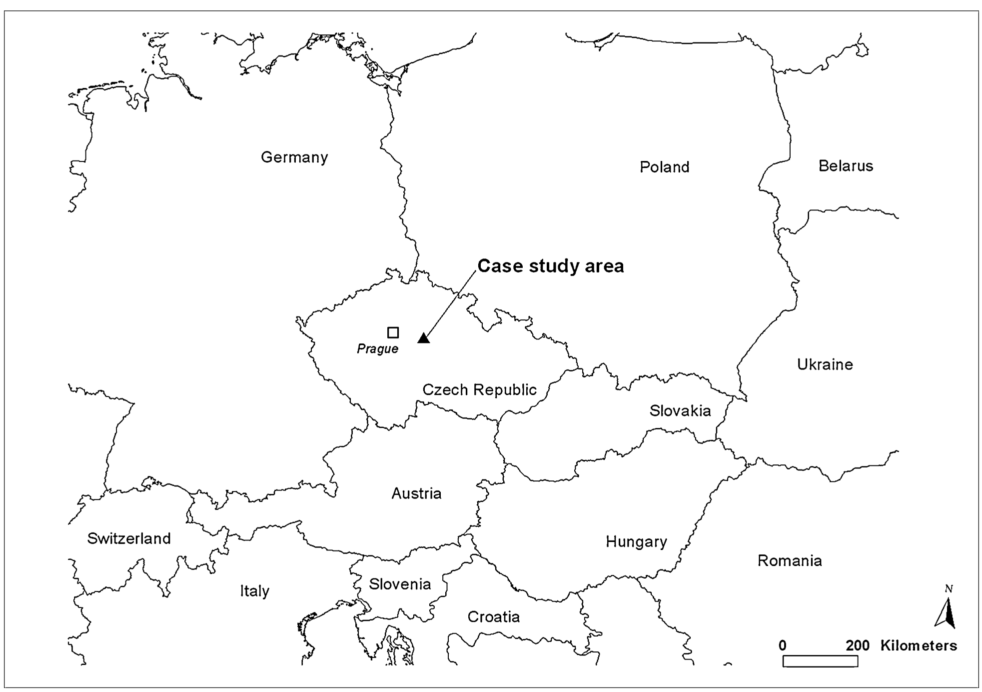

Fig. 1 Location of the Nové Dvory–Kačina study area (113.2 km^2) in Europe

growth and to dramatically increased urbanization (Bělina et al. 2006). The study area is a rural region that was influenced by these changes. New railway and modern road transport corridors were built (Novák 2001). Agriculture had to face up to these changes, which led to the use of new technologies and the spread of arable land (Lipský 2000). The landscape just before these changes is shown in the First Military Survey maps. There are forests on the slopes and in the wetlands that could not be cultivated using the technologies of that period. Hunting areas and pheasantries were also large forested areas. During the first half of the nineteenth century, almost all ponds and wetlands were dried out, and the forests and the shrubby vegetation around them were cut down. In the same period of time, many landscape parks were being built in the Czech lands and also within the study area (Kačina–Nové Dvory area, Žehušice area) (Novák 2001; Horký 1967). The countryside after the changes caused by industrialization and intensification is clearly shown in the Third Military Survey maps. The ponds and wetlands have been dried out, and the shrubby vegetation around them has been changed to arable land. The forests on the slopes have also mostly been cut down, and they have been replaced by orchards and fields. Large forests were the only designed landscape areas (Lipský 1998; Novák 2001). However, we should bear in mind that the microstructure of the landscape was completely different, and the fields were divided by strips of shrubs and grass that cannot be seen and measured in the Military maps (Petek and Urbanc 2004). The structure of the landscape that we can study using the Third Military Survey maps changed dramatically in the 1950s. Collectivization and industrialization of agriculture changed the landscape structure into collective open fields (Lipský 1998; Cuhra et al. 2006). Shrubby strips and grass strips disappeared. The tree vegetation lining streams, roads and paths was cut down. However, heavy machinery could not be used on steep slopes, so these slopes were reforested. Landscape parks mostly became nature reservations, and they received little care, so that the forest spread out over former meadows and small fields. In this way, the afforested area increased until it was similar to the amount of forested area in the First Military Survey maps. However, the structure of the forests has changed completely.

Materials and methods

Source materials and data processing

Old maps

The scale of the first Military Survey maps is approximately 1:28,800. The survey of the territory of the Czech lands was carried out within a period of just 20 years, from 1763 to 1783. The maps were made without any exact surveying or cartographic methods. Historical surveyors used the 1723 map of Bohemia by Müller on a scale of 1:132,000 to display important points, which were transformed to a scale of 1:28,800. Then they created a new map using the *à la vue* method—the surveyors simply observed the terrain and estimated the distances (Kuchař 1967). The survey was not based on a network of precisely defined triangulation points (Fig. 2).

The Second Military Survey of the Czech lands was made in the period between 1842 and 1852. The scale of the maps is 1:28,800. Unlike the First Survey, the Second Survey was based on a triangulation network, and used the maps of the Stable Cadastre on a scale of 1:2,880. The Second Survey is therefore of much higher accuracy. In fact, the content of the map sheets is identical with the previous set, but with the addition of triangulation points for elevation.

The Third Military Survey was carried out between 1869 and 1887. The maps of the Czech lands were created between 1874 and 1880. The basic map sheets are on a scale of 1:25,000. The collection of original basic map sheets is not complete. The content of the maps is more precise, mainly in the depiction of the relief (the contour lines are at intervals of 20 m) and in the depiction of roads. The maps of the Third Military Survey formed the basis for the creation of various maps that were in use until the 1950s.

The raster maps of the First Military Survey and the Second Military Survey were obtained by scanning color copies of them acquired from the Vienna Military Archive, on a scale of 1:1. The maps of the Third Military Survey were scanned directly from the originals on the premises of the Map Collection of Charles University in Prague. All the original maps, or copies, were scanned with density 400 dpi (dots per inch). All the raster maps were georeferenced using so-called ground control points that can be recognized on both the historical map and the present-day map and that supposedly cannot change their position over a long period of time, e.g., stream junctions, road intersections, churches and other sacred objects. The S-JTSK coordinate system has been used as a basis for georeferencing. The Military Survey maps were georeferenced with the help of ArcGIS 9.2 software, and we used the affinity type of georeferencing, which minimizes the distortion of angles and lengths. We achieved exceptionally good results. The polynomial order was chosen as the specific mathematical algorithm for the georeferencing of the Military Survey maps. The same method was applied for all three maps, i.e., the First, Second, and the Third Military Survey maps. Rubber sheeting is adopted for the geographic transformation.

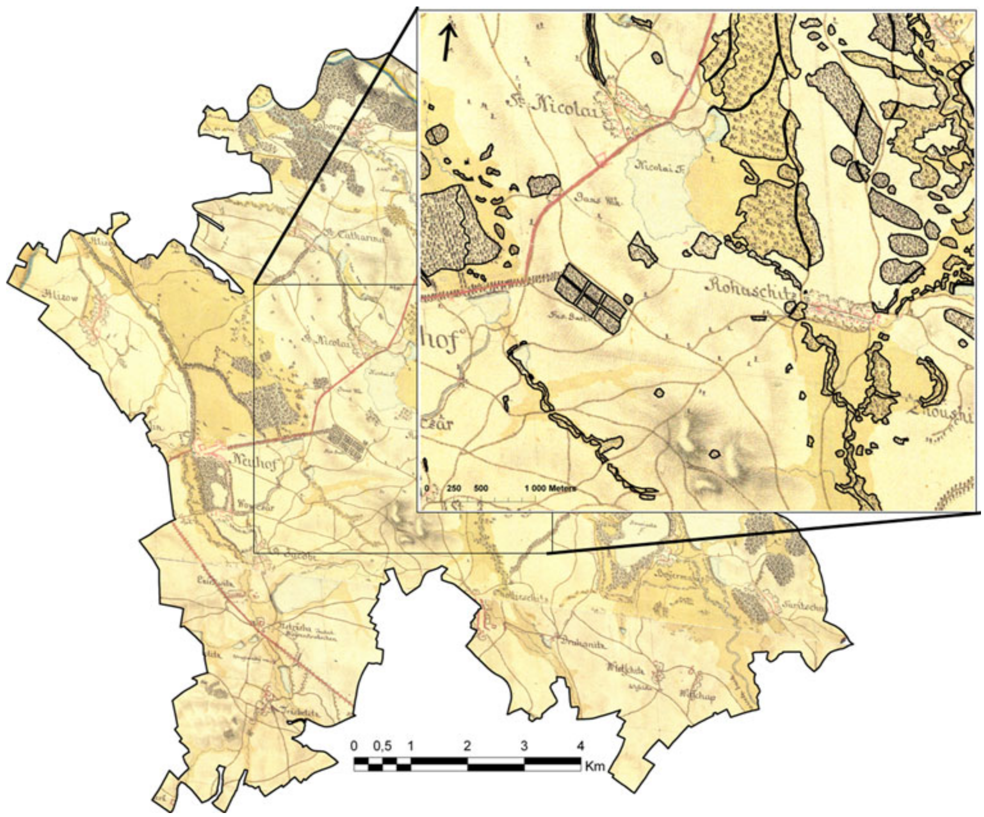

Fig. 2 Forest cover on the First Military Survey map of 1780

To analyze historic changes in the forest cover, we visually interpreted the forest cover area on the First, Second, and the Third Military Survey maps. The interpreted information in combination with written data and other archive sources provides a picture of the historical landscape and its utilization by human society. Written data and other archive sources refer to the text information related to forest area changes or forest management history involved in the broad spectra of references, e.g., journals, textbooks, and archive sources. Digitising is the most frequently used way of transforming spatial data from analogous maps to GIS. In our work, we used on-screen digitization, known as vectorizing, with the help of ArcGIS 9.2 software. We picked up polygons of forest land objects over the raster maps. In addition, GIS software is able to calculate the areas of these map objects, which provide the fundamental data for monitoring forest cover changes in landscape.

Orthophoto map

The present orthophoto map of 2004–2006 (CENIA 2009) is in the S-JTSK coordinate system. It presents a picture compounded of orthogonalized aerial survey photographs (ASP), and its accuracy and cartographic projection meet all the requirements for such a scale (Procházková 2007). The orthophotomap is seamless, with color correction, and is made on a scale of 1:5,000 (Šíma 2008). The method, in which positional data has been obtained from the orthophoto map, is the same as the method used with the old military maps. For the orthophoto map with resolution of 0.5 m, the average variation of the geodetically measured check points from the identical points on the orthophotomap is $v_y = 0.36$ m, $v_x = 0.33$ m. The identified lengths of the error vectors are not as large as a basic orthophotomap pixel. The interpretation and vectorization of the orthophotomap were executed in the GIS environment according to a set legend, on an operating scale of 1:10,000 with final generalization to a scale of 1:25,000. The scale of the vectorization itself was, however, of a higher order (1:2,000). ArcInfo 9.2 software, produced by ESRI, was used for processing, vectorizing, and analyzing the data. Although the original orthophoto maps date back to 2004–2006, the information on forest cover was verified in the field in 2007. Then, in the following work, forest cover data derived from the orthophoto is dated to 2007.

Forest cover classification scale, monitored characteristics

Forest cover is the subject of our study. However, the term is perceived from a broader perspective. What we call forest cover in our study refers to the following types of segments:

- *Forest wood elements*, i.e., patch landscape elements covered mostly by trees that form part of the administrative forest land.
- *Other wood species in the landscape*, i.e., patch landscape elements covered mostly by trees scattered in the open landscape or lining water courses or roads, and that are not part of the official category of forest land.

However, in this study, forest has been structurally considered as a whole, without dividing it into the two categories mentioned above. The main reason for this is that the current definition of forest land is governed largely administratively and by property criteria. Thus, the distribution of vegetation on forest land and other wood species in the landscape does not always take into account functional considerations. The underlying objective of our study is to analyze the change dynamics of all types of forest cover, so the forests are considered as a whole. Tree alleys are not the subject of our study.

The changes in forest cover in the area under study were monitored by quantifying and analyzing the following quantitative characteristics:

- The extent of the forest cover in each particular time horizon, in hectares and as a percentage of the area under study.
- Absolute changes in forest cover between the individual time horizons (in hectares).
- The intensity of the changes in forest cover (in hectares per year). This characteristic provides information on the area in hectares of the forest cover that has increased or decreased per 1 year in the course of the study period. This also refers to the rate of forest cover change. $I = {}_{\Delta}P/{}_{\Delta}N$, where I = intensity of changes in forest cover, ${}_{\Delta}P$ = difference in the forest cover area between two neighboring time horizons, ${}_{\Delta}N$ = number of years between two neighboring time horizons.

The spatial changes in forest cover were evaluated in a GIS environment using specialized features to analyze spatial variation (e.g., the CLIP function in the ArcGIS program). By overlapping the present and historic thematic layers, we can locate and quantify plots that are identical for both time horizons. In the case of forest cover, elements that have remained in the same location form the so-called time-constant landscape structure. This process enables the user to identify forests and other land cover types that have remained unchanged throughout the period of the study.

Tools utilized in the study

Several different tools have been utilized in the study. For the time–space analyses, we used ArcGIS tools, e.g., ArcView 9.2., with the CLIP function. As this function allows us to overlap forest cover layers from different time horizons, we can make analyses of time–space changes in the forest cover. Then we can answer research questions such as "What parts of the historic forest cover did not change location between 1780 and 2007?" In addition, the basic Microsoft Office tool was utilized to process the fundamental text or data procedures, e.g., Word and Excel.

Results

Changes in forest cover

In comparison with the historical situation shown in the First Military Survey of 1780 (Fig. 2), present-day forests cover a slightly larger proportion of the study area. The forest cover occupied 16.60% (1,880 ha) of the total area in the First Military Survey (1780). In 2007, the proportion was slightly higher at 16.64% (1,884 ha) (Figs. 3, 4).

In the First Military Survey map of 1780, some of the stands were concentrated in several small woodlots, while the remaining forests were concentrated in compact, larger forest plots. According to the 1851 map, the forest cover had increased by 1.4% between 1780 and 1851 from 16.60 to 17.98% (by 156 ha) of the total study area (Figs. 3, 4). The Second Military Survey map (1851) clearly identifies sites where there are new tree stands (Fig. 3). The Third Military Survey map (1877) shows that the acreage of forest cover dropped significantly between 1851 and 1877, by some 5.9% (663 ha) from 17.98 to 12.13% (Fig. 4). A decline in forest cover was recorded mainly in sites in the eastern part of the area (Fig. 3). The orthophoto map of 2007 records a 4.5% increase in forests (from 12.13 to 16.64%, by 512 ha), i.e., a return to the level in the eighteenth century (Fig. 4).

There has been only a minimal overall change in the area of forest cover over the entire study period. Nevertheless, the changes in forest cover between the different time horizons were quite dynamic. The trends in absolute changes in forest cover in hectares (Fig. 5) are identical with the trends in forest change intensity in hectares per year (Fig. 6).

The area of forest cover grew between the First Military Survey and the Second Military Survey, and also between the Third Military Survey and the present time, and the overall balance between 1780 and 2007 also grew; however, the largest increase in forest cover took place between 1877 and 2007 (Fig. 5). This period is also the time during which the most intensive extension of the forest area took place, by 4 ha per year, as compared to 2.2 ha per year between 1780 and 1851, and 0.02 ha per year between 1780 and 2007 (Fig. 6). The biggest absolute decrease in

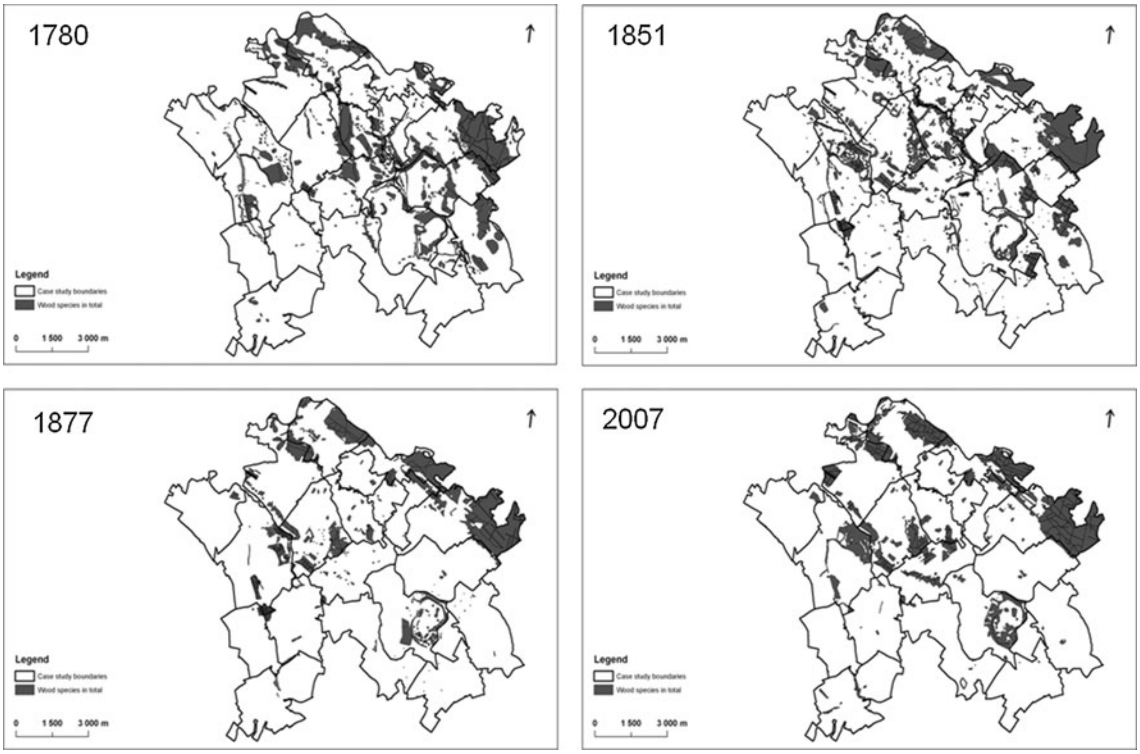

Fig. 3 Forest cover changes recorded in the Military Survey Maps (1780, 1851, and 1877) and in an orthophoto map (2007)

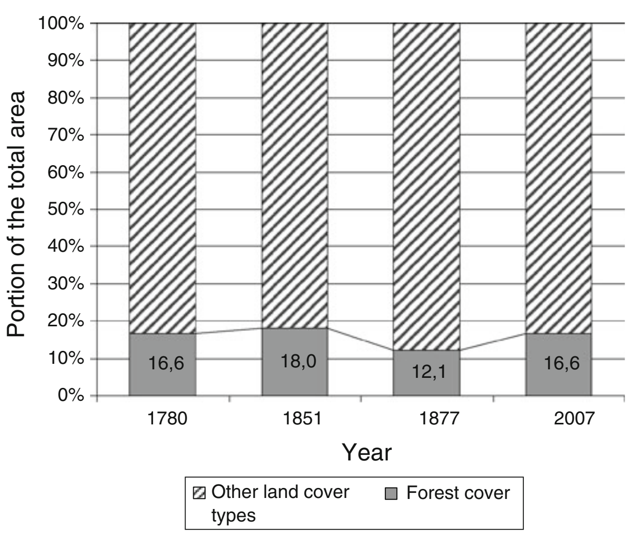

Fig. 4 Changes in the proportion of forest land between 1780 and 2007

forest cover took place between 1851 and 1877, by 663 ha (Fig. 5). During this period, the decline in forest cover area was also very intensive (26 ha per year) (Fig. 6).

Spatial changes in forest cover

More than half of all forest land (53%) from the time of the Second Military Survey (1851) survived until 2007. Within the period 1855–1877, only 47% of the wood stands shown in the Second Military Survey maps survived until the Third Military Survey (Figs. 7, 8). Figure 7 presents spatial changes in forest cover within the entire territory, with the forest cover in specific years (1851, 1877, 2007) marked with different types of hatching. Figure 8 provides the same type of information, but it gives more detailed information about the forest cover change in the area near Kačina Castle. Places where all the three types of hatching overlap indicate forest cover that remained unchanged on the site. These are the forest stands around Kačina castle and also some rather large forest areas on the steep slopes of the Železné Hory Mountains. Locations marked only in black indicate areas that were afforested only in 1851, but were then cleared of forest. These locations are found in the central and eastern part of the territory. New forest planted in the study landscape is marked by hatching with the lines going from left to right.

Discussion

Remarks on the development of forest cover

The study area has been an agricultural landscape since Neolithic times, with a growing tendency in the course of the monitored period for arable land to be the dominant

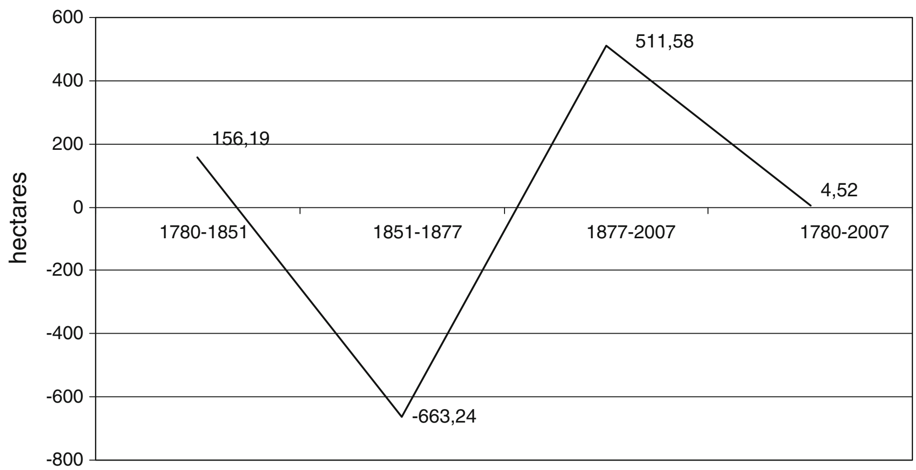

Fig. 5 Absolute changes in forest cover (in hectares between the source maps)

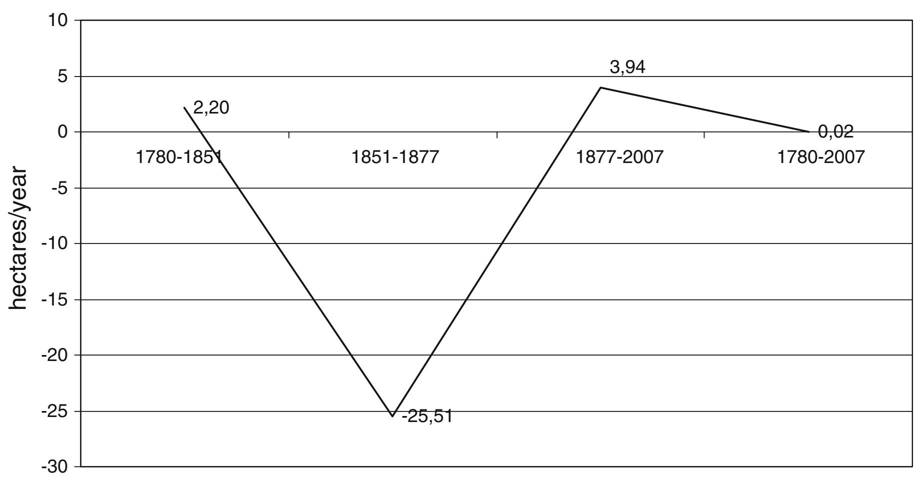

Fig. 6 Change intensity in forest cover (in hectares per year between the source maps)

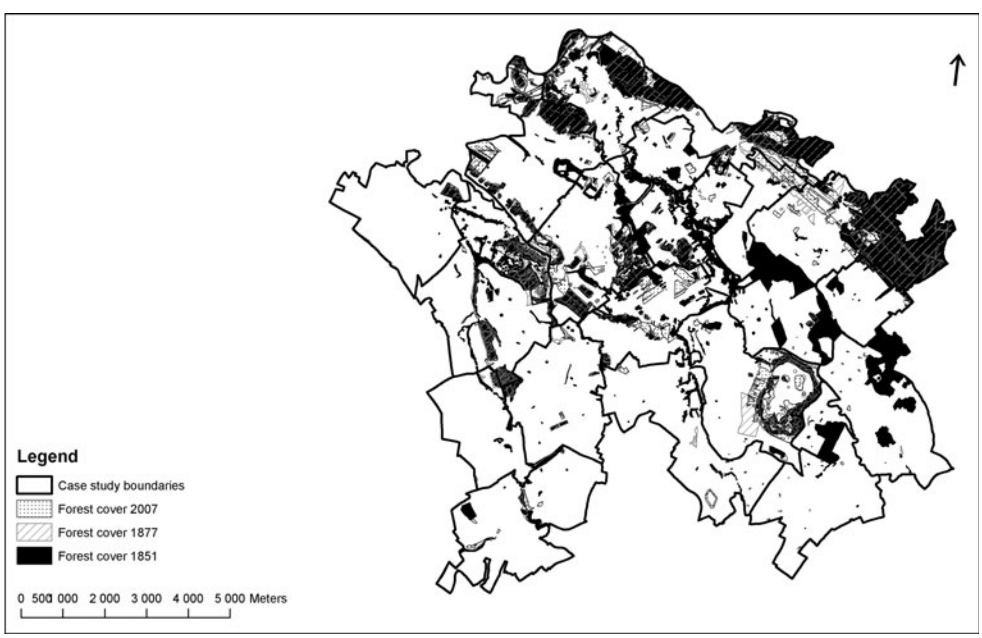

Fig. 7 Forest cover that survived from the Second Military Survey until 2007 (study area)

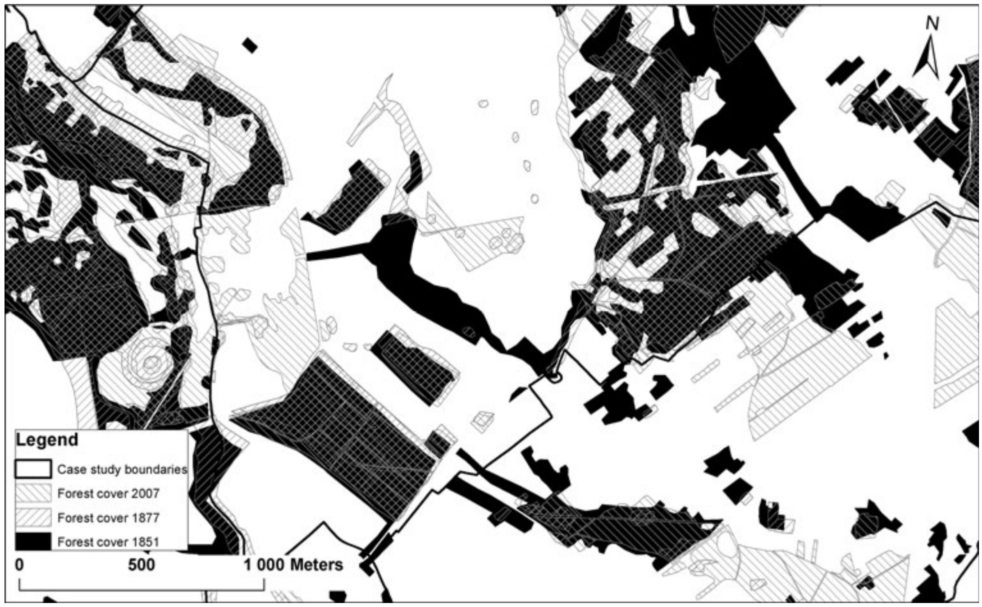

Fig. 8 Forest cover that survived from the Second Military Survey until 2007 (detailed view on the central part of the study area)

type of land use (Novák 2001; Skaloš et al. 2011). Forestry has had a secondary role in the area, though there have been important game reserves and, in some cases, forest management has made an important contribution to the public budget (Nožička 1961). Landscapes in the second half of the eighteenth century were characterized by small forest patches, woods or solitary trees and pastures or meadows with numerous scattered shrubberies (Lipský et al. 2008; Lipský 2002; Nožička 1961). At the time of the First Military Survey (1780), forest occupied almost 16.60% of the study area, which is the smallest area of forest coverage within the studied time span (1780–2007). This low level of forest coverage in 1780 is in accordance with the lowest forest coverage in Bohemia quoted by Nožička (1957). In comparison with the situation at the present time, based on visual observation of the original First Military Survey map, in 1780 significantly more trees grew along the rivers and in the alluvial plains, where there was a system of ponds at that time. However, this fact is not taken into account in the GIS analysis, since only patch elements have been considered and no linear elements (e.g., tree alleys) are analyzed.

A similar situation can be observed in the maps of the Second Military Survey (1851). The total forest cover had increased by almost 1.4% as a result of the conversion of hunting areas and pheasantries to landscape parks with forested areas (Novák 2001; Horký 1967). The tree cover persisted and the area of tree cover had continued to grow, also along the river banks. By the second half of the nineteenth century, the system of ponds had mostly disappeared, which may be one of the reasons underlying the decrease in forest cover. In that period, small woodlots still persisted on the permanent grasslands, together with scattered vegetation of various types. At this time, there were abundant but fragmented forests in the study area. The increase in the area of forest land may reflect the forestry reforms, especially the new forestry law for Bohemia and Moravia in 1754, for Silesia in 1756, and for Slovakia in 1769. In the nineteenth century, “massive” deployment of spruce monocultures began and deciduous woods retreated in Bohemia (Lipský 2000; Svoboda 1952).

The Third Military Survey (1877) revealed major changes in forest cover. The forest areas in our study area had decreased by almost 6% (Fig. 2). The biggest decrease was due to the transformation of smaller woodlands on arable land (Novák 2001). In the second half of the nineteenth century and in the first half of the twentieth century, the Czech landscape was strongly deforested due to the development of intensive agricultural production (Bicík et al. 1996; Novák 2001). Advanced technologies made it possible to drain wet meadows and to cultivate previously unusable lands (Lipský 2000; Sklenička et al. 2009). The proportion of forest cover in the study area grew in the second half of the nineteenth century. Small amounts of wood species elements returned to the Czech landscape, because crop fields were consolidated into large units suitable for heavy machinery, and ancient terraces, balks and fosses disappeared. However, places where heavy machinery could not be utilized, e.g., river banks, were left to natural development and were spontaneously overgrown by forest cover (Lipský 2000; Sádlo et al. 2005). In 2007, forests again occupied almost 17% of the study area, as they had at the end of the eighteenth century. The present-day forest coverage in the study areas is significantly below the national average of 33.5% (Statistics, Czech Republic 2010).

The basic trends, i.e., the lowest area of forest cover in 1780 and the increase in forest area between 1877 and 2007 comply with the overall forest cover changes in the Czech Republic (Bičík et al. 2001; Bičík 2004; Lipský et al. 2008; Skaloš 2007; Skokanová and Havlíček 2009, Statistics, Czech Republic 2010). The only difference is observed in the period between 1851 and 1877, during which the area of forest land decreased. There was no such trend in Bohemia as a whole (Nožička 1957).

Typology of forest stands

In many studies, forest cover is structurally divided into three main subcategories according to its specific dynamics (Fischer and Harris 1999; Skaloš and Engstová 2010): (1) forest land, (2) non-forest wood species scattered in the landscape, (3) non-forest wood species accompanying greenery (linear character, lining waterways, roads, etc.).

When evaluating changes in these stands, it is necessary to take into account the dynamics of all types of forest cover. However, in this study, the category of forest cover is tracked as a whole, as not all categories can be satisfactorily identified in the source maps, particularly due to the differences between the old military maps and the orthophoto map. Another pitfall is that while the present investigation may well identify the official category of forest land ("PUPFL" in Czech, land designated for forestry), the same approach and the same specific criteria cannot be used for identifying forest land in the earlier maps. The main reason is that when describing the historical forest conditions we are not able to apply and validate the criteria for the definition of forest land, because only a limited amount of information is available. For this reason, an analysis of changes in line forest cover based on the use of old maps and orthophoto maps is suitable for describing only the relative length of the characteristic elements of greenery.

Forest continuity

By overlapping forest layers from different time horizons, an analysis of the time–space changes in forest cover may provide data that enable us analyze so-called forest continuity. In this study, forest continuity refers to the ability of a forest stand to persist in time. The rate of such persistence can be analyzed by the occurrence of forestation on old maps and on the orthophotomap in different time horizons. In this study, the term "forest continuity" is closest to the term "stand continuity", used by Sklenicka and Charvatova (2003). In this concept, stand continuity is indicated as a relatively constant spatio-temporal factor in habitat quality. Unlike other studies, we do not refer to the continuity of particular tree species on the basis of a pollen analysis (Hultberg 2008; Ohlson and Tryterud 1999).

Forest stand continuity has been viewed from many different standpoints by other authors. For example, Kolb and Diekmann (2004) see forest continuity as habitat continuity for the distribution of herbaceous forest plant species in a fragmented landscape, based on redundancy analysis with variation. Fritz et al. (2008) studied the effects of forest continuity on a local scale in the framework of the investigation of red-listed and indicator species of epiphytic lichens and bryophytes in southern Sweden. Groven et al. (2002) focused on a historical reconstructions of past forest dynamics, and stand structures were used to establish reference conditions for managing present forest ecosystems. Groven et al. (2002) combined a suite of stand reconstruction techniques to describe past stand characteristics and also applied these stand histories in an evaluation of the relationship between wood-decay fungi and forest continuity.

Based on our study, some 53% of the forest stands marked in the First Military Survey remained until 2007. This information should be viewed critically, due to the differences in character between the two Military Survey maps and the present-day orthophoto map. The map of the Second Military Survey does not show some types of information that can be identified in the orthophoto map, e.g., small streams. There is also some undesirable distortion of the results. The real proportion of wood vegetation in the maps of the Second Military Survey must have been higher (e.g., the vegetation along small streams cannot be distinguished). The rate of surviving wood elements and forest plots in 2007 should therefore probably also be higher. The data based on a comparison of the Second and the Third Military Survey maps is more accurate, because the map sources that are being compared are more similar to each other. The forest cover layer from 1780 has not been used in the spatial analysis, as this information was elaborated on the basis of the geodetically inaccurate First Military Survey map. Little more than half of the forest cover from the Second Military Survey maps has persisted until the present time. This means that the overall absolute forest continuity is rather low. However, we have taken into account several features of the study that seriously affect what we refer to here as forest continuity. One of the features is the use of old military survey maps and the orthophotomap, with their specific content. We use the medium scale on which the old military maps were made. Although we use quite a wide spectrum of source data, there remain some time "gaps" in the study. This is due to the fact that we have source data strictly referring only to the horizons covered by the old maps and the orthophotomap. Thus, to indicate the forest change between the studied horizons, we are strictly limited to the absolute change between the two horizons. We have not made any attempt to learn about the real and exact changes that may have taken place within the studied time horizons (1780–1851, 1851–1877, 1877–2007).

It should be emphasized that the total surface areas of forest in our study area are now the same as at the end of the eighteenth century, but there have been considerable changes, mainly in the structure and distribution of forest plots and patches. We can identify stable forest plots that have changed in size but have never ceased to exist. There are two large stable forest areas on the slopes of the Železné Hory Mts. and another along the river. Both environments were unsuitable for agricultural machinery in the nineteenth century. The mountain forests were unsuitable because of the steepness of the terrain and the riverside due to waterlogging. They were therefore allowed to remain covered by forests. Other stable forest plots are set aside as game reserves or for pheasants. There is a major area of forest vegetation on the slopes of the Železné Hory Mts. This area was deforested in the first half of the nineteenth century, and fruit trees were planted there (Novák 2001).

Remarks on the use of a variety of data sources

The First Military Survey maps are less accurate than the maps of the Second Military Survey and the Third Military Survey (Cajthaml and Krejčí 2008). The inadequacies are due to the delineation technique that was selected, from a small scale into a larger scale, and not vice versa, and due to the absence of a consistent triangulation network (Paldus 1919). The planimetric content of the map sections of the Second Military Survey is absolutely reliable for the entire territory of the Czech Lands; it is based on triangulation (for the Czech lands in the Gustenberg system, for Moravia in the St. Stephen system). In terms of the planimetric exactness of the Third Military Survey sketches, some topographic sections are highly reliable, while others are less reliable.

However, the maps cannot be used for observing the landscape microstructure at the level of individual plots; only topographic-cadastral maps and orthophoto maps support such studies. This shortcoming can be overcome to some extent by using other archive sources and statistical data. From the point of view of how broadly they can be interpreted, the Military Survey maps are limited most of all by the fact that they were created for a specific military purpose, and by the methods used in elaborating them, which are the methods that were in use at the time when they were made. When studying old Military Survey maps, it is typically difficult to identify the boundaries of land cover categories, and this can lead to inaccuracies in the evaluation. The landscape display method is in accordance with the real situation at the time, when there were very often no sharp boundaries between biotopes. Therefore, particularly in the First Military Survey, we find forest stands with no clear boundaries, and so the delimitation of a specific boundary is often inevitably a subjective matter (Brůna et al. 2002; Brůna and Křováková 2006).

The low geodetic accuracy of the maps is another cause of complications, especially in the First Military Survey. Inaccuracies in georeferencing of the First Military Survey maps can lead to inaccurate analysis and misinterpretation of changes in forest cover. In this survey, it is not possible to make a precise distinction between arable lands and other agricultural lands, or to make a full-quality definition of the studied elements, e.g., forest composition, scattered green structure grassland characteristics, gardens, etc. These deficiencies can be compensated, to some extent, by knowledge of old farming methods and historical technologies.

The orthophoto map, however, provides highly accurate documentation of the current land use/land cover of the area, as it offers a current, non-generalized picture of the present-day landscape. The legibility and resolution of orthophoto maps depend on their total color interpretation, and also on the light conditions and the vegetative period at the time of scanning. Deep shades, and also low contrast, restrict identification and make it more difficult to define the exact boundaries of objects, e.g., forests. The way in which the land categories are interpreted can influence the size of the area accorded to a category in the area.

The use of two different sources (old maps and the orthophotomap) for studying changes in land cover required special attention when the compilers were working on processing and comparing the data. The category of forest land can serve as a good example. While it is relatively easy today to delimit the boundaries of forest land, it is difficult in the Military Survey landscape to identify growths that would meet the present-day definition of forest. The individual subcategories, such as forest wood elements and other wood species in the landscape, have therefore been associated into an overall category referred to as forest cover, though this will reduce the accuracy of the dynamic analysis category.

Implications of the study

Given the important ecological and economic functions of forests, it is important to monitor long-term changes using old maps and written sources, as this enables us to monitor trends and find causes of the current situation from a different time dimension. The method presented in our paper may contribute to a better understanding of the long-term dynamics of forest land, covering a period of more than 250 years. This knowledge may then serve as a basis for understanding the processes that have contributed to the creation of the present forest land structure. This, in turn, can be applied in forest management planning procedures in order to provide sound forest management in the future. Our study may also have implications for other spheres of research and for practical applications. Not only forestry researchers but also historians and biologists can apply the methods presented here. Especially methodological outcomes, such as the use of old military survey maps, can be applied in historical research. Biological researchers can also apply some aspects of the methods developed in this study and adapt them for their own purposes.

A great advantage of our study of forest cover dynamics lies in the length of the time period under study (from 1780 until 2007). It covers the period from the end of the eighteenth century until the twenty-first century, a period of more than 220 years. However, while the first half of the time period is described on the basis of three time profiles (the maps of the First, Second and Third Military Survey), we have no data from the twentieth century, and the last time point is 2007. This long gap in the time axis might be considered as a weak point in our study. However, our goal was to observe long-term changes in forest cover on the basis of the old military maps and to compare the state of forests in the eighteenth century and in the nineteenth century with the present-day situation. It was not our intention to make a study of twentieth century changes. There is therefore no reason to criticize this gap in the data. It would be possible to make a separate detailed study of landscape changes on the basis of the adequate number of twentieth century map sources that are available, supplemented by a series of orthophoto maps. Topographic maps, in particular, are direct successors of ancient military maps and show the landscape from a similar perspective (Mackovčin 2009).

Conclusions

- The forest cover in the area under study has undergone dynamic changes. There has been almost no change in the total area of forest cover between the beginning of the study period (1780) and the end of the study period (2007), but some remarkable changes have been recorded between the individual time horizons, showing the varying dynamics of forest cover very clearly. Not only the information on absolute changes but also the information on the rate of change is of great importance, as the rate of change differs according to the time horizon.
- The most intensive and most considerable changes in forest land were recorded in the period between the Second Military Survey (1851) and the Third Military Survey (1877). This was the period with the most significant decrease in forest cover, not only in terms of numbers of hectares, but also in terms of the fastest rate of change. On the other hand, the greatest and most rapid increase in the area of forest cover was between 1877 and 2007.
- There have also been notable changes in the structure and distribution of forest plots and patches. In the eighteenth century, there were a few large wood complexes and also a large number of small woods dispersed in the open landscape and along the watercourses and roads. In the twenty-first century, by contrast, the forest has tended to be consolidated into larger plots, and the number of smaller forest elements distributed in the landscape has decreased.
- The old Military Survey maps and the orthophotomap enable us to carry out studies of long-term changes in forest cover. However, due to the different interpretation capacity of these maps, the study has not dealt only with areas that are strictly speaking administratively official forest lands, but has included all species elements in wood patches in the landscape. This has enabled us to observe the complete dynamics of all wood stands in the landscape, regardless of whether they are large forest land complexes, scattered wood vegetation in the open landscape, or trees lining watercourses or roads.
- The geodetic inaccuracy of the First Military Survey maps precludes reliable and exact quantification of the landscape changes between the First Military Survey and the Second Military Survey, and also between the First Military Survey and present-day (orthophoto map). This is the main shortcoming of the old military maps. A further limitation of these maps is the deteriorated quality of the original graphic documents and the inaccurate delineation of the landscape elements. As a result, they cannot be used for evaluating forest cover changes on the level of individual plots.
- The method presented in our paper may contribute to a better understanding of the long-term dynamics of forest land, covering a period of more than 250 years. This knowledge may then serve as a basis for understanding the processes that have contributed to the creation of the present forest land structure. This, in turn, can be applied in forest management planning procedures, in order to provide sound forest management in the future.
- This study may also have implications for other research and application spheres. Apart from their application in forestry, the methods presented in this study may be of interest for historians and biologists. The methodological outcomes, e.g., the use of old military survey maps, are also applicable in historical research. Biological researchers can also apply some aspects our methods.

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References

Bělina P, Kaše J, Kučera JP (2006) The Czech lands in the history of Europe III, Paseka, Praha, Litomyšl, 408 s (in Czech)

Berg A, Östlund L, Moen J, Olofsson J (2008) A century logging and forestry in a reindeer herding area in northern Sweden. For Ecol Manage 256:1009–1020

Bičík I (2004) Long-term changes in landscape utilization within the Czech Republic. Environment 38(2):81–85

Bičík I et al (1996) Land cover (land cover) changes in the Czech Republic 1845–1995. Geografie Sborník ČGS 101(2):92–109 (in Czech)

Bičík I, Chromý P, Jančák V, Jeleček L, Winklerová J, Štěpánek V, Kupková L (2001) Land use/land cover changes in Czechia over the past 150 years: an overview. In: Himiyama Y et al. (eds) Land use/cover changes in selected regions in the world I. IGU—LUCC, Asahikawa, pp 29–39

Bollschweiler M, Stoffel M, Schneuwly DM (2008) Dynamics in debris-flow activity on a forested cone—a case study using different dendroecological approaches. Catena 72(1):67–78

Boltižiar M, Brůna V, Chrastina P, Křováková K (2008) Potential of antique maps and orthophoto maps for landscape changes assessment—an example of the High Tatra Mts. Ekológia 27(1): 65–81

Breuste J, Klozová M, Finka M (eds) (2009) European landscapes in transformation: challenges for landscape ecology and management. European IALE conference 2009, Salzburg (Austria), Bratislava (Slovakia)

Brůna V, Křováková K (2005) Stable cadaster as a source of information on landscape. In: Historická geografie 33. Historical Institute, pp 397–409 (in Czech)

Brůna V, Křováková K (2006) Exploitation of old maps of medium and large scale for an investigation of forest development. In: Neuhöferová P (ed) Forests history and development in the Czech countries. Srní, 17–18 Oct 2006, Department of Silviculture FLE ČZU, Prague, pp 111–117 (in Czech)

Brůna V, Uhlířová L (2000) Methodology for an approach to the interpretation of historical maps, with special reference to sustainability and recovery of ecologically stable landscapes, Prague, UJEP Ústi nad Labem, pp 1–17, 3 p attachments (in Czech)

Brůna V, Buchta I, Uhlířová L (2002) Identification of the historical network of landscape ecological stability elements in the military survey maps. Acta Universitatis Purkynianae, Studia Geoinformatica II, University of J. E. Purkyně, Ústí nad Labem, 46 p. CD ROM (in Czech)

Bürgi M, Russell EWB (2001) Integrative methods to study landscape changes. Land Use Policy 18:9–16

Bürgi M, Schuler A (2003) Driving forces of forest management—an analysis of regeneration practices in the forest of the Swiss Central Plateau during the 19th and 20th century. For Ecol Manage 176:173–183

Cajthaml J, Krejčí J (2008) Exploitation of old maps for landscape research, Ostrava. GIS, abstract of papers no. 18. gis.vsb.cz/GIS_Ostrava/GIS_Ova_2008/sbornik, pp 1–10 (in Czech)

Cuhra J, Ellinger J, Gjuričová A, Smetana V (2006) The Czech lands in European history IV. Paseka, Praha, Litomyšl, 360 s (in Czech)

Demek J, Havlíček M, Mackovčin P, Stránská T (2007) Brno and its surroundings: a landscape—ecological study. J Landsc Ecol 32–53 (in Czech)

Eremiášová R, Havlíček M, Mackovčin P (2007) Quantitative analysis of landscape development and mapping of drainage of the surroundings of Kašperské Hory (Czech Republic). Silva Gabreta 13(3):285–300 (Vimperk, in Czech)

Ericsson TS, Berglund H, Östlund L (2005) History and forest biodiversity of woodland key habitats in south boreal Sweden. Biol Conserv 122:289–303

Fischer AM, Harris SJ (1999) The dynamics of tree cover change in a rural Australian landscape. Landsc Urban Plan 45:193–207

Fritz O, Gustafsson L, Larsson K (2008) Does forest continuity matter in conservation? A study of epiphytic lichens and bryophytes in beech forests of southern Sweden. Biol Conserv 141(3):655–668

Grimm NB, Foster D, Groffman P, Grove JV, Hopkinson CS, Nadelhoffer KJ, Pataki DE, Peters DPC (2008) The changing landscape: ecosystem responses to urbanization and pollution across climatic and societal gradients. Front Ecol Environ 6(5): 264–272

Groven R, Rolstad J, Storaunet KO, Rolstad E (2002) Using forest stand reconstructions to assess the role of structural continuity for late-successional species. For Ecol Manage 164(1–3):39–55

Hersperger AM, Bürgi M (2009) Going beyond landscape change description: quantifying the importance of driving forces of landscape change in a Central Europe case study. Land Use Policy 26:640–648

Horký J (1967) Developing relationships within settlement units and country I. In: Proceedings of the Silva Taroucy Research Institute for Landscape and Ornamental Gardening, Public Research Institute, č. 4, s. 151–223 (in Czech)

Hultberg T (2008) Forest continuity and human impact-vegetation history of Torup forest, south-western Scania. Examensarbete nr 107, Swedish University of Agricultural Sciences, Institutionen för sydsvensk skogsvetenskap, Alnarp

Kolb A, Diekmann M (2004) Effects of environment, habitat configuration and forest continuity on the distribution of forest plant specie. J Veg Sci 15(2):199–208

Kuchař K (1967) Map sources for geography of Czechoslovakia. Acta Universitatis Carolinae Geographica, 2, č. 1, s. 57–97

Lipský Z (1998) Landscape ecology for students of geographical disciplines. Karolinum, Prague (in Czech)

Lipský Z (2000) Investigation of changes in cultural landscapes. Czech Agricultural University, Prague (in Czech)

Lipský Z (2002) Investigation of the historical development of landscape structures with the use of old maps. In: Němec J (ed) Landscape 2002. From investigation to integration, Ministry of Environment, Ústí nad Labem, Prague, pp 44–48 (in Czech)

Lipský Z, Skaloš J, Šantrůčková M, Weber M (2008) Novodvorsko and Žehušicko landscape changes. In: Venkovská krajina (rural landscape) 2008, Brno, CZ-IALE, s. 77–84 (in Czech)

Löw J, Míchal I (2003) Landscape character. Forestry Practice, Kostelec nad Černými lesy (in Czech)

Mackovčin P (2009) Land use categorization based on topographic maps. Acta Pruhoniciana 91:5–13

Mladenoff DJ (2004) LANDIS and forest landscape models. Ecol Model 180:7–19

Novák P et al. (1992) Synthetic soil map of the Czech Republic. MZe, MŽP, Prague (in Czech)

Novák P (2001) Novohradsko-Žehušicko Landscape Memory. Kuttna, Kutná Hora, p. 120 (in Czech)
Nožička J (1957) Development of our forests—review. SZN, Prague (in Czech)
Nožička J (1961) Forests on Novodvorské domain (near Kutná Hora) until 1850. Separate impression from proceedings of Czechoslovak academy of agricultural sciences, Prague. Forestry (Lesnictví) 7(34), N8, pp 771–782 (in Czech)
Ohlson M, Tryterud E (1999) Long-term spruce forest continuity—a challenge for a sustainable Scandinavian forestry. For Ecol Manage 124(1):27–34
Paldus J (1919) Die Militärischen Aufnahmen im Bereiche der Habsburgischen Länder aus der Zeit Josef II. Wien (in German)
Pärtel M, Mendla R, Zobel M (1999) Landscape history of a calcareous (alvar) grassland in Hanila, western Estonia, during the last three hundred years. Landsc Ecol 14:187–196
Petek F, Urbanc M (2004) The Franziscean Land Cadaster as a key to understanding the 19th—century cultural landscape in Slovenia—Franciscejski kataster kot ključ za razumevanje kulturne pokrajine v Sloveniji v 19. Stoletju. In: Adamič Orožen M (ed) Acta Geographica Slovenica—Geografski zbornik, roč. 44, č. 1, s. 89–112 (in Slovenian)
Poleno Z, Vacek S (2007) Silviculture II. Theoretical basis of silviculture. Lesnická práce, Kostelec nad Černými lesy (in Czech)
Procházková P (2007) Next survey of possibilities on usage of coloured digital orthophotomaps for evaluation of positioning accuracy of six feet maps in raster form before their vectorization. Diploma work, Department of mathematics, Faculty of applied sciences, The University of West Bohemia, Pilsen, 70 s (in Czech)
Quitt E (1971) Climatic areas of the Czechoslovakia. Studia Geographica, 16, Brno (in Czech)
Sádlo J, Karlík P (2002) Landscape-ecological interpretation of old maps through geoinformatics: an example of josephs' mapping. In: Němec J (ed) Landscape 2002. From investigation to integration, Ministry of Environment, Ústí nad Labem, Prague, pp 58–62 (in Czech)
Sádlo J, Pokorný P, Hájek P, Dreslerová D, Cílek V (2005) Landscape and revolution. Important turning points in the landscape development of the Czech countries. Malá Skála (in Czech)
Scheller RM, Van Tuyl S, Calrk K, Hayden NG, Hom J, Mladenoff DJ (2008) Simulation of forest change in the New Jersey Pine Barrens under current and pre-colonial conditions. For Ecol Manage 255:1489–1500
Schneeberger N, Bürgi M, Kienast PDF (2007) Rates of landscape change at the northern fringe of the Swiss Alps: historical and recent tendencies. Landsc Urban Plan 80:127–136
Semotánová E (2002) Landscape studies and comparative cartographic sources. Ústí nad Labem (in Czech)
Šíma J (2008) Orthophotomap as a contemporary tool for imaging of territorial reality. Geobusiness, 7, č. 6+7, s. 33–35 (in Czech)
Skaloš J (2007) Czech and Swedish intensively utilised agricultural landscapes—parallels and divergences during the last 300 years. J Landsc Ecol 0:135–162
Skaloš J, Engstová B (2010) Methodology for mapping non-forest wood elements using historic cadastral maps and orthophoto maps as a basis for management. J Environ Manage 91:831–843
Skaloš J, Weber M, Lipský Z, Trpáková I, Šantrůčková M, Uhlířová L, Kukla P (2011) Using old military survey maps and orthophotograph maps to analyse long-term land cover changes—case study (Czech Republic). Appl Geogr 31(2):426–438
Sklenička P, Charvatova E (2003) Stand continuity—a useful parameter for ecological networks in post-mining landscapes. Ecol Eng 20(4):287–296
Sklenička P, Šálek M (2008) Ownership and soil quality as sources of agricultural land fragmentation in highly fragmented ownership patterns. Landsc Ecol 23:299–311
Sklenička P, Molnárová K, Brabec E, Kumble P, Pittnerová B, Pixová K, Šálek M (2009) Remnants of medieval field patterns in the Czech Republic: analysis of driving forces behind their disappearance with special attention to the role of hedgerows. Agric Ecosyst Environ 129:465–473
Skokanová H, Havlíček M (2009) Long-term development of Czech landscape studied on the basis of old topographic maps. EGU General Assembly, Geophysical Research Abstract, vol 11, EGU 2009-2091-1
Štěpán L (2001) Chrudim region—creation of rural settlements in the Chrudim region. OkÚ, SokA Chrudim (in Czech)
Stoltman AM, Radeloff VC, Mladenoff DJ (2007) Computer visualization of pre-settlement and current forests in Wisconsin. For Ecol Manage 246:135–143
Svoboda P (1952) Living forest. SZN, Prague (in Czech)
Uhlířová L (2002) Contemporary estate of old maps utilisation for landscape changes research. In: Němec J (ed) Landscape 2002. From investigation to integration, Ministry of Environment, Ústí nad Labem, Prague, pp 93–95 (in Czech)
Vuorela N, Alho P, Kalliola R (2002) Systematic assessment of maps as source information in landscape-change research. Landsc Res 27:141–166
Walz U (2002) Historische Kartenwerke in Sachsen als Grundlage für Untersuchungen zur Landschaftsentwicklung, In: Němec J (ed) Krajina 2002. Landscape 2002. From investigation to integration, Ministry of Environment, Ústí nad Labem, Prague, pp 113–118
Williams JW (2003) Variations in tree cover in North America since the last glacial maximum. Glob Planet Change 35(1–2):1–23
Zimová R, Pestak J, Veverka B (2006) Historical military survey of the Czech lands—positional accuracy of old maps. GIM Int 20(10):21–23 (In Czech)

Old maps

Military maps of the 1st, 2nd and 3rd Military Survey, Austrian State Archive/Military
Archive, Vienna; Geoinformatics Laboratory, University of J. E. Purkyně, Ministry of the Environment of the Czech Republic (http://oldmaps.geolab.cz), Ministry of the Environment of the Czech Republic 2003, deposited at: VÚKOZ, v.v.i.; Map Collection of Charles University in Prague, Faculty of Science)

Orthophotomap

CENIA (2009) Czech Environmental Information Agency. (CENIA), 2009. Present aerial photographs available (online). Cited 15 Dec 2009. URL:<http://geoportal.cenia.cz>
Statistics, Czech Republic (2010) A database of statistical data for Czech Republic. Czech Statistical Office (www.czso.cz)