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# Classification System for Monitoring Historic Changes in Forest and Non-Forest Woody Vegetation—A Basis for Management

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Forest and non-forest vegetation fulfils many non-productive and productive functions. A good understanding of the trajectories and drivers of the woody vegetation change is necessary for the relevant management. Recently, the number of studies devoted to monitoring forest cover changes has increased. However, these works do not fully distinguish between different categories of forest and non-forest woody vegetation. The main aim of the study was to propose a classification system for monitoring historic changes of woody vegetation in the landscape. The period of the last 150 years was mapped through three time-lines (1842, 1953 and 2011). Data were obtained by interpreting historic maps (Stable Cadastral map of 1842) and historical (1953) and current orthophoto (2011) using ArcGIS tools. The classification was applied on the example of Sokolov region (57 km$^2$) located in western Bohemia. The result of the research is a proposal for classifying woody vegetation stands into four categories based on the structural and localisation criteria: (1) Line adjacent woodlands, (2) Landscape woodlands, (3) Settlement woodlands, and (4) Compact woodlands. Information on the woody vegetation development using the proposed classification system is important for understanding the patterns, pressures, and driving forces that led to the formation of the present-day forest and non-forest woody vegetation in the landscape. The results can also be applied as a basis for future forest management practice as they can be used in other different fields, e.g. history, archaeology etc.

*Keywords*: Forest Development; Forest and Non-Forest Woody Vegetation; ArcGIS; Sokolov Region

## Introduction

Apart from the productive roles, forest and non-forest woody vegetation has further non-production roles in the landscape (Ryszkowski & Kedziora, 2007), such as ecological, landscape-forming, eco-stabilising, and aesthetics (McCollin, 2000). Non-forest woody vegetation plays an essential ecological role, especially in intensively used landscapes (Bulíř & Škorpík, 1987). Erosion control function refers to a positive effect on the intensity of water runoff, therefore reducing the risk of soil erosion (Pattanayak & Mercer, 1997). It was recently confirmed that it is also important in mitigating climate change effects (Nair et al., 2009; Plieninger, 2011; Verchot et al., 2007; Manning et al., 2006). Small woodlands scattered in the landscape have become significant ecosystems that are important for biodiversity, both in agriculture (Manning et al., 2006) and in urban landscapes (Jim & Chen, 2009). Woody vegetation features in the landscape bear witness to the historical utilisation of the landscape (Krčmářová, 2012), thus playing an important role in the so-called memory or heritage of the landscape (Schama, 1995).

Forests in most European countries experienced fundamental

changes in the Holocene (Peterken, 1976; Hultberg, 2008; Ohlson & Tryterud, 1999; Mercuri et al., 2011). The present condition of the Czech forest landscape is the result of the long interrelation between men and the natural and cultural landscape. An important milestone in the human attitude to the forest in the Czech lands was the adoption of Forest legislation in 1754, which laid the foundations for forest management. Although the Neolithic period is regarded as a breakpoint in man's growing impact on the Czech landscape and forests, the fundamental changes have occurred over the past five thousand years (Svoboda, 1952; Nožička, 1975; Löw & Míchal, 2003; Sádlo et al., 2005; Ložek, 2007). The present methodology platform of historical geography (Semotanová, 2006) enables an extensive and complex analysis of transformations of the Earth's surface and its utilisation (changes in the so-called land cover/land use). There are recently published works that tackle transformations of forest cover (Brůna & Křováková, 2006; Mathys et al., 2006; Kozak et al., 2008; Brandt et al., 2012; Plieninger et al., 2012a, b; Skaloš et al., 2012; Peterken, 1976; Ohlson & Tryterud, 1999; Berg et al., 2008; Hultberg, 2008; Bollschweiler et al., 2008; Oosterbaan & Pels, 2007). Research studies performed by environmental archaeologists or historians help to integrate con-

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siderations on the natural forest dynamics and cultural history of a country (Beneš et al., 2002; Cílová & Woitsch, 2012). The identification and protection of natural or remnant patches of woody vegetation is an essential component of biodiversity conservation within these heavily transformed and managed agricultural landscapes. Remnant patches of vegetation may comprise important reservoirs of biodiversity and may contain biotic and structural legacies that are important for understanding and restoring native ecosystems (Lindenmayer & Franklin, 2002). Indeed, the overall contribution of these areas to habitat provision, biodiversity conservation, and the maintenance of key ecological processes is likely far in excess of that expected based on their proportional extent (Lindenmayer & Franklin, 2002; Schulte et al., 2006).

Apart from forest stands, the European landscape contains various types of non-forest woody vegetation, such as small landscape woodlots, adjacent linear woody vegetation along roads, streams, etc. (Auclair et al., 2000). Terminology related to woody vegetation features in the landscape is rather inconsistent (Forman & Godron, 1986; Bulíř & Škorpík, 1987; Ihse, 1995; Fjellstad & Dramstad, 1999; Sklenička & Lhota, 2002; Lindenmayer & Franklin, 2002; Schulte et al., 2006; Rayburn & Schulte, 2009; Kolařík et al., 2003; Součková, 2002; Sklenička et al., 2009; Skaloš & Engstová, 2010; Plieninger et al., 2012a). In the Czech Republic, the term "permanent greenery" is used to describe forests, non-forest woody vegetation (scattered landscape woodlands and adjacent linear woodlands), as well as orchards, vineyards, hop fields, meadows, pastures, and sparse wood elements. Scattered woody vegetation refers to individual trees, bushes, or small woodlands in the open landscape, either on agricultural land or on non-agricultural land. In the Land Register of the Czech Republic, these landscape segments are not registered as forest or agricultural crops since they have different origins, ground disposition, spatial form and species composition (Kolařík et al., 2003). The Land Register of the Czech Republic is a public data set about the real estates in the Czech Republic, including their description and a list of geometric and positional determination (ČUZK, 2013). Non-forest woody vegetation can be categorised according to location in the terrain, ground plan disposition, and priority function (Bulíř & Škorpík, 1987). According to the law (No. 289/1995 Coll.), a forest is a wood with its environment and land designated for fulfilling the forest's functions (the so-called PUPFL). In forestry, we can distinguish between a forest stand and a growth stand (Poleno & Vacek, 2007).

Fjellstad & Dramstad (1999) distinguished among coniferous, deciduous, and mixed woody growth in the landscape; Cousins & Ihse (1998), in contrast, paid detailed attention to the different age groups of the forest. Ihse (1995) recorded only shrubs, linear segments such as roadsides, stonewalls, ditches or water runs, or individual trees; this work also distinguished among point objects, such as solitary wood plants and pad objects. Strand et al. (2002) pursued only the development of shrubby vegetation, while Clare & Bunce (2006) focused on solitary wood plants. Oosterbaan & Pels (2007) presented a detailed methodology for monitoring small landscape elements, including solitary trees and lines of trees, but this study focused only on an evaluation of the current state of forests and their functions, and did not attempt to analyse the historical development of those elements. Sklenička et al. (2009), in a recent analysis of changes in the medieval agricultural land around villages, focused on the development of linear woody vegetation structures. An interesting category is referred to as "farm trees", which are identical with "solitary trees" (Arnold & Deewes, 1997; Van der Horst, 2006) or "trees outside forests" (FAO, 2001). This term has been defined by the FAO as "all trees not falling within the definition of non-forest woody growth and forest trees" (FAO, 2001). Non-forest woody growth can be subdivided into three categories: growth inside villages, scattered vegetation in the open landscape, and scattered roadside vegetation avenues (Skaloš & Engstová, 2010). Vláčilová (2011) divided woody growth into forest wood elements—scattered and lined; to analyse the development of these growth areas, however, she used only the old medium-scale maps and military mapping 1, 2 and 3. If they are further sub-categorized, the forests are divided only into coniferous, deciduous, and mixed.

Recently, several key studies have been devoted to monitoring forest or non-forest cover changes (Mathys et al., 2006; Kozak et al., 2008; Brandt et al., 2012; Plieninger et al., 2012a, b; Skaloš et al., 2012). However, certain deficits of methodological information on the historical development of forest and non-forest woods in the landscape are becoming evident. Namely, published works do not fully distinguish between forest and different categories of non-forest woody vegetation in the landscape (little landscape woodlands scattered in the landscape, adjacent linear woodlands along roads and streams), which is important for respecting the different dynamics and functional aspects of the mentioned different categories.

The main aim of the study lies in the methodological level. It aims to propose a relevant and common classification system for monitoring historic changes of all structural types of woody vegetation in the landscape. It should be also applicable to a variety of different source data, and for different localities characterised by differing landscape and forest types. This information is important for understanding the patterns, pressures, and forces that led to the formation of the present-day wood vegetation (Bürgi & Schuler, 2003). The study may provide new theoretical and methodology bases for further practical disciplines, such as forestry, history, landscape planning, land consolidation process, etc. (Lannér, 2003; Jordan et al., 2005).

## Material and Methods

### Study Area

The study area was 57 km$^2$ and included eight historical cadastres located in the Sokolov region in the west of the Czech Republic (**Figure 1**). This landscape has undergone significant and dynamic changes in the past 150 years mainly due to brown coal mining (Pecharová et al., 2011). However, there are also
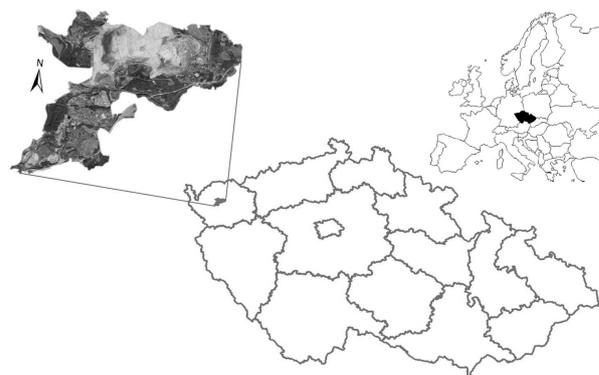
**Figure 1.**
Location of the area of interest in the Czech Republic (CENIA, 2011).

other factors that have had a significant impact on the study area landscape change (urbanisation, road construction, land consolidation process, natural succession, forestry etc.). These have become a substantial criteria for the choice of the study area. The first mining records date back to the 17th century, before which it had been a fertile agricultural area (Prokop 1994). The Sokolov Basin forms part of the Krušné Hory range of the Czech massif, and lies in the southwestern wing of the sub-Krušné Hory rift valley. The development of the rift was accompanied by volcanic activity and by the emergence the large sub-Krušné Hory lake that no longer exists (Toušek et al., 2005); the large Sokolov Basin was created from tertiary vegetation growth that continues to be mined for coal today. The coal is used by many associated industries in this area (e.g. the Tisová power plant and the Vřesová pressure gasworks).

## Source Data

### Stable Cadastre Maps (1842)

Imperial prints of a stable cadastre (ČUZK, 2010) contain valuable historical information about the land use of the area, and also the important spatial properties of the landscape. These maps were provided with parcel numbers and drawn in the scale of 1:2880. Mapping work in the Czech Republic was carried out between 1826 and 1842. The maps recorded the original state of the landscape without additional drawing of later amendments (Semotánová, 2002; Trpáková et al., 2009). Scanned map layouts of the study area with a vertical and horizontal resolution of 300 dpi were purchased (ČÚZK, 2010).

### Aerial Photographs

In the Czech Republic, as well as in many other countries (Ihse, 1995), a database of black and white historical aerial photographs from the 1930s onwards is available for landscape studies (Lipský, 2000; Lipský, 1995; Ihse, 1995; Fjellstad & Dramstad, 1999; Plieninger, 2011, Bürgi & Schuler, 2003). In the study, scanned and orthogonalised negatives from the growing season of 1953 were used (CENIA, 2010) giving information on the real woody vegetation structures in historic landscape.

### Present-Day Orthophotos

To obtain information on the present-day state of woody vegetation in the study area landscape, orthophotos from 2011 were purchased. They were obtained through the aerial photography process, which was undertaken during the growing season (the same as for the aerial photos of 1953) of 2011 (CUZK, 2008) with resolution of 0.5 m. The images were then photogrammetrically processed and transformed to the S-JTSK coordinate system. The average variation of the geodetically measured check points from the identical points on the orthophotomap was vy he0.36 m, vx i0.33 m. The identified lengths of the error vectors are not as large as a basic orthophoto pixel (Šíma, 2008).

### Processing the Data

Imperial prints of stable cadastre areas and historic aerial photographs were acquired as digital data in raster form in high resolution, Stable Cadastre maps of 300 dpi, historic aerial photo of 900 dpi (ČÚZK, 2010; CENIA, 2010). This high resolution enabled the detailed interpretation and provided the possibility to produce high quality layouts. While historic aerial photos were obtained as georeferenced (CENIA, 2010), Stable Cadastre maps were processed using ArcGIS 9.3 (ESRI) and

georectified in the S-JTSK_Krovak_East_North coordinate system using ground control points (objects or locations in the landscape where no spatial shift in the landscape is anticipated, e.g., churches, small religious architecture, road intersections); these points must be clear on both historic and present-day images. When errors occur in the transformation, the parameter used for estimating the accuracy of the transformation was RMS error (standard deviation). This adjustment was not necessary for the present-day orthophotos because IMS and WMS services allow georeferenced layers to be loaded. All base maps served only as a grid source for extracting data and for creating new vector layers.

## Interpretation of Old Maps, Aerial Photographs and Orthophotos

The interpretation and vectorisation of the Stable Cadastre maps as well as aerial photographs and orthophotos were executed in the GIS environment according to a suggested classification system. The scale of the vectorisation was 1:2000. In the study, only polygons were distinguished using the polygonisation (vectorisation) process using the basic polygonisation functions available within the ArcGIS (ArcView 9.3) software. The woody vegetation polygons in the study area were polygonised based on the visual interpretation of old maps, aerial photos, and orthophotos. While it is rather simple to identify woody vegetation on old maps based on the use of the map legend, it is more difficult on the basis of the aerial photos and orthophotos. As far as the landscape feature was marked by treetops or shrub crowns, it was classified as wood vegetation (forest, scattered wood element, accompanying element of roads and water runs). To each woody vegetation feature, the attribute table was added. This attribute table consisted of the data on the wood elements classification type and the area in hectares. This provided an opportunity to quantitatively analyse time and spatial changes of the wood elements.

## Typology of Woody Vegetation

This study focused on only woody vegetation in the landscape, which is a specific part of the previously defined term greenery. As different patches of woody vegetation are characterised by different dynamics, we distinguished between woody vegetation in the open landscape and woody vegetation in built-up areas. We classified woody vegetation into four categories based on the location, size, and shape of woody stand features captured from the various data sources (**Table 1**). However, the woody vegetation features consisted of patch, and also linear landscape structural features (Forman & Godron, 1986).

In this study, a decision on whether the woody vegetation element was classified as linear or patch was made by subjective estimation and no shape or perimeter-to-edge ratio were calculated. However, basic landscape ecology criteria defining basic landscape structural elements were applied, e.g. linear landscape features referring to those elements whose length substantially exceeds the width (Forman & Godron, 1986). Woodlands were classified as "settlement woodlands" in the event that the woody component followed directly on the built-up areas without interruption. Compact woodlands refer to those woody vegetation elements in the open landscape that are larger than 3 hectares, and are characterised by continuous forest cover. These woody elements mostly refer to the official forest land registered by the Land Registry, which is a functional category. However, the criteria applied here to differentiate woody vegetation resulted in

**Table 1.**

Detailed description of categories in different woody stands.

| Category | Description |
| --- | --- |
| Settlement woodlands | This category refers to woody stands located within the built-up areas. This refers to cities, towns, and villages, strip developments along transport infrastructures, and areas occupied by shopping centres, industrial and commercial complexes. Settlement woodlands are usually exposed to an intensive anthropogenic pressure as they are located within the built-up areas and fulfil many functions (mainly aesthetic, nature conservation, and partly productive). |
| Line adjacent woodlands | Line adjacent woodlands refer to linear landscape structural features in the landscape located along communication corridors (pathways, roads, motorways, train tracks), along watercourses or along elements that are linear-shaped in an open landscape (e.g. terraces). They provide mainly aesthetic and nature conservation functions. |
| Landscape woodlands | This refers to patches of woody vegetation in the open landscape that are smaller than 3 hectares and typically surrounded by agricultural land, or permanent grassland. These features can provide many different functions—primarily nature conservation, aesthetic and productive timber areas. |
| Compact woodlands | Compact woodlands are stands of woody vegetation in an open landscape. They typically are larger than 3 hectares and are characterised by continuous forest cover. These woody elements mostly refer to the official forest land registered by the Land Registry office, which is a functional category. They are primarily for timber production, but also provide nature conservation and aesthetic services. |

structural categories.

We classified woody vegetation into four following categories based on the location, size, and shape of features:

- Settlement woodlands,
- Line adjacent woodlands,
- Landscape woodlands,
- Compact woodlands.

## Observed Characteristics

For the purposes of this study, characteristics of the landscape macrostructure were calculated (Lipský, 1995) using hectares and a percentage to quantify changes trajectories of the woody vegetation categories (area in hectares, proportion in percentages). With the help of changes in these characteristics over time, it was possible to execute an analysis of the development of woody growth, and conduct a spatial-temporal analysis in ArcGIS.

## Spatial Analysis of Woodland Development

Old-growth ancient woodlands play an important role in nature conservation (Rayburn & Schulte, 2009). Given that these areas stand for the features of the landscape memory (Skaloš & Kašparová, 2012), they are valuable from the cultural heritage point of view as they bear information on the long-term relationships of our cultural landscape (Brandt et al., 2012). The analysis was performed in GIS, using the "intersection" function available in the ArcView 9.3 software. This analytical GIS tool allows the user to quantify and locate the temporal and spatial changes in the observed woodland patches resulting in quantifying and locating old-growth woodlands that have not changed over 50 years (between 1953 and 2011).

## Results

### Development of Wood Elements

Our results suggest that woody vegetation has changed considerably in the study region from 1842-2011 (**Table 2**, **Figures 2-5**). Specifically, in 1842 the most prevalent type in the area of interest was compact woodlands (1195 ha, 72.2% of the total area of the woody vegetation in the study area), followed by line adjacent woodlands (232 ha, 14.0%), landscape woodlands (208 ha, 12.6%), and finally settlement woodlands (20 ha, 1.2%) (**Figure 2**).
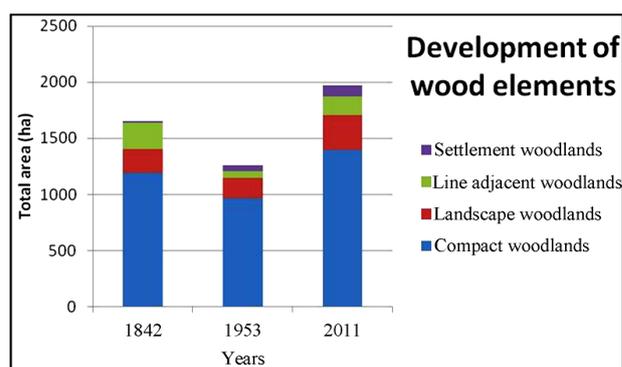


**Figure 2.**

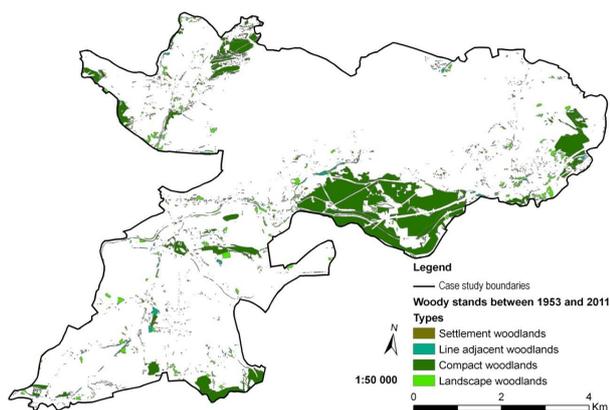Representation of individual woodlands categories.
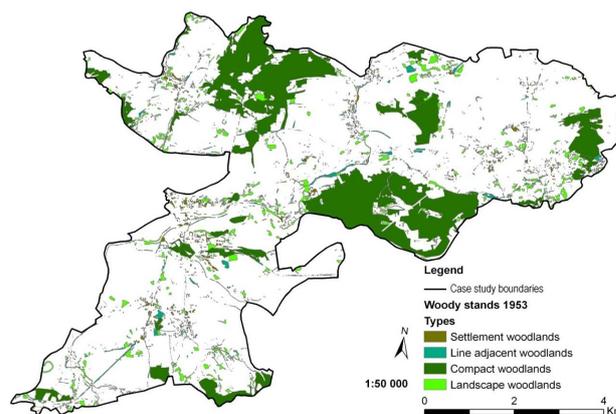


**Figure 3.**
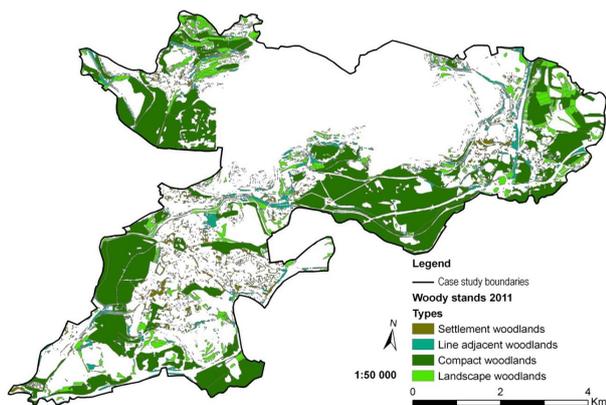
Distribution of individual woodlands categories in 1953.

Until 1953 (**Table 2**), the most prevalent category was still compact woodlands, but this category dropped to 963.3 ha (76.4% of the total area of the woody vegetation in the study area); this is a reduction in absolute area by 231.7 hectares. However, as the total area of woody vegetation decreased, the percentage of the compact woodlands increased up to 76.4%. The second most prevalent category in 1953 was landscape woodlands (180.1 ha, 14.3%). Here, too, there was a decrease in absolute area of 27.9 hectares, i.e. a decrease by 1.7%, which was followed by line adjacent woodlands (67.3 hectares, 5.3%). This category showed

**Table 2.**
Changes in different types of wood elements.

| | 1842 | | 1953 | | 2011 | |
|---|---|---|---|---|---|---|
| | Area (ha) | % | Area (ha) | % | Area (ha) | % |
| Line adjacent woodlands | 232 | 14 | 67.3 | 5.3 | 164 | 8.3 |
| Compact woodlands | 1195 | 72.2 | 963.3 | 76.4 | 1398 | 70.8 |
| Settlement woodlands | 20 | 1.2 | 49.8 | 4 | 104 | 5.3 |
| Landscape woodlands | 208 | 12.6 | 180.1 | 14.3 | 309 | 15.6 |



**Figure 4.**
Stability of the categories between 1953 and 2011.



**Figure 5.**
Distribution of individual woodlands categories in 2011.

a steep decline in absolute area by 164.7 hectares (8.7%). Settlement woodlands was the least represented category in 1953, with a total area of 49.8 hectares (4%), and the same was true in the earlier previous period. Settlement woodlands were the only category to record a positive growth trend; the increase in total area was 29.8 hectares, or an increase of 2.7% (**Figure 3**).

In the most recent reporting period (2011), there was typically an increase in the absolute area of all categories of woody vegetation. The most prevalent category was again compact woodlands (1398.1 ha, an increase by 203.1 ha over the value for 1842 and an increase by 434.8 ha in comparison with 1953), and the second largest category was landscape woodlands (309.2 hectares, an increase by 101.2 hectares in comparison with 1842

and an increase by 129.0 ha in comparison with 1953). In 2011, line adjacent woodlands covered 164 ha, representing a decrease in area by 68.1 hectares in comparison with 1842, but an increase by 96.6 hectares in comparison with 1953. Settlement woodlands covered 103.6 hectares in 2011, which means an increase of 83.6 ha in comparison with 1842, and an increase by 53.9 ha in comparison with 1953 (**Table 2**, **Figure 5**).

## Stability of the Categories between 1953 and 2011.

Between 1953 and 2011, 46.7% of the compact woodlands remained unchanged, i.e. an area of 450 ha. The second most stable category was woodlands in the open landscape, in which there were no changes in an area of 17.8 hectares (9.9%). Settlement woodlands remained unchanged on an area of 7.6 ha (15.2%). The least stable category was line adjacent woodlands, which remained preserved between 1953 and 2011 over an area of only 4.2 hectares (6.3%) (**Figure 4**).

## Discussion

### Driving Forces behind Woody Vegetation Change

Recently, much effort has been devoted to the analysis of the forest cover drivers (Bürg & Schuler, 2003; Kozak et al., 2008; Baumann et al., 2012; Brandt et al., 2012; Plieninger et al., 2012a, b). This study has analysed the dynamics of the development of different woody vegetation elements over a time period of 165 years. During this period, the development of woody vegetation segments were influenced by environmental factors as well as by economic and social factors (Bičík & Jeleček, 2001; Turner et al., 1996). In the landscape, there is a complex system that is structured not only by biological and biotic components, but also by a certain cultural layer and essence that plays a vital role in the relationship between the landscape and humans (Dneboská, 2006). When considering the formation of the landscape and woody vegetation structures of the study area presented in this paper, the political changes of the Czech Republic within the 165-year period under study should be taken into account. Also, the cultural context is to be taken into account when analysing landscape and woody vegetation historic changes (Lapka, 2008).

An important factor in the development of woody landscape segments in the area of interest is the worldwide phenomenon of urbanisation (Minghong et al., 2005; Arribas-Bel et al., 2011; Wang et al., 2012; Vermeiren et al., 2012; Míchal, 1994); by the 1960s, three-quarters of the inhabitants of the Czechoslovak Republic lived in towns (Blažek & Kubálek, 2008). Other important factors were collectivisation (from 1951) resulting in connecting small land plots into large arable blocks (Lipský,

1995; Jech, 2001). Second, the mining industry in the Sokolov area was expanded from the beginning of the 19th century (Skaloš & Kašparová, 2012). Forty years of Socialist governments that aimed to intensify all categories of manufacture. Before 1953, there were approximately 1,404,000 small farms in the Czech Republic; after the first wave of socialist collectivisation, this number fell to 78,000. In 1989, when socialist rule came to an end, only 2000 small private farms remained in the Czech Republic (Hájek, 2008). Various approaches to farm management connected with activities such as land consolidation, ploughing the edges of fields, and field road networks were limiting factors that made the greatest contribution to the changes in the size and location of the accompanying line of wood elements and wood elements in the open landscape, which is clearly reflected in their stability between 1953 and 2011 (Skaloš & Molnárová, 2012). The trend toward urbanisation, coupled with the extension of anthropogenic activities into the open landscape, e.g. mining and quarrying, road construction, commercial sub-urbanisation had a significant negative influence on the size and integrity of the compact woodlands (Keken et al., 2011; Anděl et al., 2005). Settlement woodlands remained unchanged between 1953 and 2011, with a total of 7.6 ha (15.2%).

Another limiting factor during the monitored period that influenced the dynamics mainly of the compact woodlands was the forest management practise as well as the management of non-forest areas (areas of land that are not designated to perform forest functions, but on which compact woody vegetation grows). When analysing the significance of driving forces of an environmental—economic or social nature—it is necessary to take into account the conflict between reducing the intensity of land use and the abandonment of agricultural land, leading for example to landscape vegetation overgrowing trees, and, on the other hand, intensification of farming in the landscape, such as in the case of forestry (Šlezingr, 2003). This is a general view and takes into account regional differences. Interpreting the occurrence of woody vegetation in the landscape in 1842, it is important to bear in mind that Stable Cadastre maps show the landscape at the time of the beginning of the period of the Industrial Revolution (Lipský, 1995; Sýkora, 1998; Semotánová, 2002; Low & Míchal, 2003). In this period, line adjacent woodlands covered the largest area (232 ha). Settlement and complex woodlands were spread fairly regularly in the landscape of 1842 due to the fact that surface coal mining had not affected the landscape by this year (Pecharová et al., 2011). The distribution of landscape woodlands and the line adjacent woodlands is primarily linked with a system of small fields with various methods of farming. Among other things, these elements fulfil the functions of highlighting land borders and eco-stabilisation (Sklenička, 2003; Löw & Michal, 2003; Lipský, 2000).

Between 1842 and 1953, the effects of urbanisation on woody vegetation began to become evident. Urbanisation stands for the strongest driving forces in shaping the landscape of the 20th century, including woody vegetation (Minghong et al., 2005; Arribas-Bel et al., 2011; Wang et al., 2012; Vermeiren et al., 2012; Míchal, 1994). The occurrence of the categories analysed here may significantly document the socio-political aspects of the periods associated with the two world wars. Environmental problems were increasingly caused by unintended consequences that were difficult to predict, but did not reduce the taste of society for risk (Lapka, 2008). It has been shown that ploughing the fields and industrial exploitation were accompanied by destruction of the woody vegetation in the open landscape (Harmer et al., 2001).

Between 1953 and 2011, it was mostly mining activities in the northern part of the area of interest, together with urbanisation, that completely transformed the structure and functions of the landscape and woody vegetation of the studied landscape (Pecharová et al., 2011) There was also an association between urbanisation and the development of linear structures, which significantly fragmented the compact habitat (Liu et al., 2008; Noss, 1993; Hlaváč & Anděl, 2001; Kušta et al., 2011). Roads have an obvious influence on the changes in ecosystems, especially on landscape structures (Liu et al., 2008). However, various compensatory measures have occurred to reduce the fragmentation and the barrier effect. With the growth of agglomerations of built-up areas, the sizes of settlement wood elements areas have grown as a substitute for natural spaces for the residents. The most recently observed period has produced a highly significant increase in wood elements across the landscape. This is primarily due to management aimed at stabilising the landscape that was damaged by mining, and secondly due to the process of natural succession (Uuttera et al., 1996; Koehler, 2000; Woziwoda & Kopeć, 2012).

## Discussion on Methodology

Recently, several papers dealing with methodology have focused on the analysis of forest or non-forest cover changes (Plieninger et al., 2012a; Pistorius et al., 2012; Achard & Estreguil, 2003; Mathys et al., 2006; Vogt et al., 2007; Kozak et al., 2008, Skaloš & Engstová, 2010; Lindberg & Hollaus, 2012). However, the common typological system enabling the monitoring historic changes in woody vegetation is lacking. The classification system presented in this study is complex and suitable for wide use in various types of landscapes. The disadvantage is the subjectivity of determining the linear and patch woody vegetation elements and relatively high labour intensity. In the case of the analysis, the research subjects are different structural categories of woody vegetation in the landscape. Because the analysis is retrospective, it is necessary to consider the different nature of the materials that are used. This has to be integrated, which leads to the possibility of a range of inaccuracies. A key problem with the use of different types of graphic source data (historic maps, aerial photos) in landscape change research is the compatibility data on landscape attributes obtained from different sources, which differ in character, scale, quality, and resolution (Timár, 2004; Boltižiar et al., 2008; Skaloš et al., 2011; Plieninger et al., 2012b).

A particular problem, which is necessary to take into account, is the different nature of historical cadastral maps (cadastral maps stable from 1842) and aerial photographs. While cadastral maps provide information on the ownership structure of the landscape, aerial images contain information about the actual physical structure of the landscape (Skaloš & Engstová, 2010). Data on the representation of linear and scattered woody vegetation on stable cadastre maps were distorted to some extent. The reason is that i.e. woody vegetation was only shown on some maps, and only in one area. Scattered vegetation was recorded only schematically. The solution to this problem may be to use the data correction and other documents, such as maps of the second Military mapping (Uhlířová, 2002).

## Management Links

Pursuing the research on landscape changes and history,

especially the relatively distant one, might seem a methodical or purely intellectual exercise. However, understanding the past is necessary for understanding the present and for right actions in the present (Bloch, 1952), and this is most apparent in case of changing landscapes.

Changing land use is held to be a crucial factor of global environment changes (Dale et al., 2000). The landscape change trajectories are often taken into account in conservation ecology when observing and predicting an influence of landscape changes on studied species. The woodlands being a highly important habitat type in landscape, fragmentation (Piquer-Rodriguez et al., 2012), connectivity (Theobald et al., 2011), habitat condition (Klenner et al., 2000) and other parameters are thoroughly studied as to their impact on selected species and their abundance.

Studying the historic changes in woodland condition can give a broader context to the development of management strategies. Knowledge of the native, old-growth forests functioning drawn from historic sources significantly helps with their restoration (Axelsson & Ostlund, 2001). Since the woodlands are also an important source of fuel biomass, the better understanding of their structure changes are necessary to plan the management strategies concerning the responsible energy policy of the region (Fiorese & Guariso, 2013), especially in the age of changing climate (Nitschke & Innes, 2008). In the contrary the existing strategies can be evaluated and compared by model scenarios methods as to their impact on landscape and its ecological functions (Gustafson & Crow, 1996), which can lead to reformulating of the management policy.

A detailed classification of woodland types is essential for determining the ecological and other environmental impacts of their changes. As Kadıoğulları (2013) in the study on Turkey sub-temperate forest fragmentation states the increase of total forested area does not always lead to enhancement of landscape functionality.

These few examples of many show that studies on landscape and woodland changes can help to better understanding of their dynamic and thus better design of planning strategies. However, to put the acquired information into practical life means to build and keep the strong connections between the research and stakeholder spheres and to present the results in clear way (Dale et al., 2000).

## Conclusion

The results of this study may further help to understand the long-term dynamics of the landscape change through learning the lessons of the history of the woody vegetation in the post-mining landscape in the north-western part of the Czech Republic. Here, the development of woody vegetation over the past 165 years has been very dynamic, and the extent to which each category was analysed fluctuated during certain periods, in direct relation with the political, social, economic or environmental development of the surveyed region. The results show that there has been an increasing trend since 1953 in the area of settlement woodlands. This can be explained as a way of offsetting the negative secondary effects of urbanisation that were rooted in industrial exploitation (brown coal mining) and that had a significant negative impact on the remaining categories of woody vegetation, mainly compact woodlands. The dynamics of the development of the line adjacent woodlands and landscape woodlands in all of the time periods studied here could docu-

ment the different approaches mainly to agricultural management that the landscape has undergone.

The greatest contribution of the work lies in the methodological level. Although the proposed methodology should be seen as an essential step in the initial results of the extensive research project, the main advantage of the proposed methodology is that it enables users to trace back the history of woody vegetation in separate categories (forest and non-forest woody vegetation) respecting the different change dynamics of different woody stands in the landscape. Non-forest woody vegetation may be further subdivided based on the structural criteria into settlement, landscape, and adjacent linear woodlands. This information will help to understand historic changes in woody vegetation in the landscape. The typological system presented in this study is unique for its complexity and the possibility for wider use in various types of landscapes. Unfortunately, the method is flawed, as it consists of applying subjective criteria in differentiating linear and patch woody vegetation elements and no landscape metrics were calculated. Therefore, the application of landscape metrics to objectivise the woody vegetation classification forms the basis for future research aimed at the automation and objectification of the processes of woody vegetation elements classification. The disadvantage of the method is that it is time-consuming as well as labour-intense. For the purpose of the improvement and correction of historical data regarding the status and changes in woody vegetation, it will be necessary to use other types of source data (e.g. Military Survey Maps) and remote sensing methods.

The results of this retrospective study can be used predominantly in forest management practice, but also in other different forms of landscape planning practice, e.g. territorial planning, post-mining landscape reclamation, or regional development policies that will set future trends in the development of areas from the perspective of woody elements in the landscape. The key starting point is the understanding of the historical context and the driving forces involved in its development. Methodological conclusions of the study are useful in other fields, such as history, geography, etc.

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