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**M U N I**

**HUMAN IMPACT ON FORESTS IN THE PAST  
MILLENNIUM**

HABILITATION THESIS

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BRNO 2026

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## Preface

This habilitation thesis summarizes my research carried out over the past sixteen years on the impact human societies had on forests in the past millennium in the Czech lands. The work is organized into four thematic parts, which follow the development, heyday, decline and rediscovery traditional woodland management through time. The first part (**papers 1-7**) discusses the history of traditional woodland management, especially coppicing, from the Middle Ages until the 20<sup>th</sup> century. The second part of the thesis (**papers 8-11**) addresses the non-timber uses and the multiple use of forests. The third part (**papers 12-14**) focuses on building timber: tree species used, geographic origins and the factors influencing building activity. The fourth part of the thesis (**papers 15-18**) describes the abandonment of traditional management, its negative consequences for biodiversity, as well as the rediscovery of traditional management and the current state of reintroduction efforts in the Czech Republic. The overall aim of this habilitation thesis is to provide a comprehensive summary of my research within the general framework of the state of the art and recent advances in interdisciplinary forest historical studies in Europe and elsewhere.

Many of the papers were written as part of research projects that I led, co-led or participated in throughout the years. The most significant of these was my ERC (European Research Council) Starting grant “Long-term woodland dynamics in Central Europe: from estimations to a realistic model” (LONGWOOD, Grant no. 278065, 2012-2016), which set the foundations for broad interdisciplinary cooperation between archaeologists, historians, geographers and ecologists. Other relevant projects include GAAV (Grant Agency of the [Czech] Academy of Sciences) “Lowlands woodlands in the perspective of historical development” (IAA600050812, 2008-2012), TAČR (Technology Agency of the Czech Republic) “Agroforestry – potential for regional development and sustainable rural landscape (TL01000298, 2018-2020), GAČR (Czech Science Foundation) “Humans as nature: anthropogenic legacy in temperate forest ecosystems” (GA17-09283S, 2017-2019), TAČR “Restoration of coppicing management: a way to diversification of the societal, economic and ecological use of the forest potential in Central Europe” (TL02000314, 2019-2022), TAČR “Application of traditional knowledge to halt biodiversity loss in woodlands” (TO01000132, 2021-2024) and TAČR “Center for landscape and biodiversity” (SS02030018, 2021-2026).

**Paper 1:**

**Szabó, P.** (2010) Driving forces of stability and change in woodland structure: A case-study from the Czech lowlands. *Forest Ecology and Management* 259: 650-656. [Q1 AIS on WoS]

**Paper 2:**

**Szabó, P.** (2010) Ancient woodland boundaries in Europe. *Journal of Historical Geography* 36: 205-214. [Q2 AIS on WoS]

**Paper 3:**

**Szabó, P.** (2024) It's a fair coppice: methodological considerations of the history of woodland management. In *Countryside History: The Life and Legacy of Oliver Rackham*, ed. I. D. Rotherham & J. Moody, pp. 258-270. Pelagic Publishing: London.

**Paper 4:**

**Szabó, P.** & Hédli R. (2013) Socio-economic demands, ecological conditions and the power of tradition: past woodland management decisions in a Central European landscape. *Landscape Research* 38: 243-261. [Q3 AIS on WoS]

**Paper 5:**

**Szabó, P.**, Müllerová J., Suchánková S. & Kotačka M. (2015) Intensive woodland management in the Middle Ages: spatial modelling based on archival data. *Journal of Historical Geography* 48: 1-10. [Q2 AIS on WoS]

**Paper 6:**

**Szabó, P.**, Šipoš J. & Hédli H. (2021) Standards versus underwood: historical patterns of tree taxon occurrence in coppice forests. *Journal of Vegetation Science* 32: e12963. [Q1 AIS on WoS]

**Paper 7:**

Müllerová, J., **Szabó, P.** & Hédli, R. (2014) The rise and fall of traditional forest management in southern Moravia: A history of the past 700 years. *Forest Ecology and Management* 331: 104-115. [Q1 AIS on WoS]

**Paper 8:**

Jamrichová, E., **Szabó, P.**, Hédli, R., Kuneš, P., Bobek, P. & Pelánková, B. (2013) Continuity and change in the vegetation of a Central European oakwood. *Holocene* 23: 46-56. [Q1 AIS on WoS]

**Paper 9:**

**Szabó, P.** (2023) The Horka litter raking incident: On foresters and peasants in nineteenth-century Moravia. *Environment and History* 29: 323-343. [Q2 AIS on WoS]

**Paper 10:**

**Szabó, P.**, Diniz, É. S. & Houška, J. (2024) Traditional agroforestry on forested land: a comprehensive analysis of its distribution pattern in the 19th century. *Agroforestry Systems* 98: 115-127. [Q2 AIS on WoS]

**Paper 11:**

Vild, O., Šipoš, J., **Szabó, P.**, Macek, M., Chudomelová, M., Kopecký, M., Suchánková, S., Houška, J., Kotačka, M. & Hédli, R. (2018) Legacy of historical litter raking in temperate forest plant communities. *Journal of Vegetation Science* 29: 596-606. [Q1 AIS on WoS]

**Paper 12:**

Kolář, T., Dobrovolný, P., **Szabó, P.**, Mikita, T., Kyncl, T., Kyncl, J., Sochová, I. & Rybníček, M. (2021) Wood species utilization for timber constructions in the Czech lands over the period 1400-1900. *Dendrochronologia* 70: 125900. [Q1 AIS on WoS]

**Paper 13:**

**Szabó, P.**, Dobrovolný, P., Kolář, T., Rybníček, M., Kyncl, J. & Kyncl, T. (2025) Local timber dominated pre-industrial construction: Insights from archival and dendrochronological data. *Dendrochronologia* 91: 126337. [Q1 AIS on WoS]

**Paper 14:**

Kolář, T., Dobrovolný, P., **Szabó, P.**, Mikita, T., Kyncl, T., Kyncl, J., Sochová, I., Flídr, A., Merta, D. & Rybníček, M. (2022) Effects of social and climatic factors on building activity in the Czech lands between 1450 and 1950: a dendrochronological analysis. *Journal of Quaternary Science* 37: 123-132. [Q2 AIS on WoS]

**Paper 15:**

Müllerová, J., Hédli, R. & **Szabó, P.** (2015) Coppice abandonment and its implications for species diversity in forest vegetation. *Forest Ecology and Management* 343: 88-100. [Q1 AIS on WoS]

**Paper 16:**

**Szabó, P.**, Gálová, A., Jamrichová, E., Šumberová, K., Šipoš, J. & Hédli, R. (2017) Trends and events through seven centuries: the history of a wetland landscape in the Czech Republic. *Regional Environmental Change* 17: 501-514. [Q1 AIS on WoS]

**Paper 17:**

**Szabó, P.** (2020) Traditional woodland management, forest legislation, and modern nature conservation in east-central Europe. In *Conservation's Roots: Managing for Sustainability in Preindustrial Europe, 1100–1800*, ed. Dowling A. & Keyser R., pp. 304-326. Berghahn: New York & Oxford.

**Paper 18:**

Kozdasová, A., Galčanová Batista, L., Hédli, R. & **Szabó, P.** (2024) Coppice reintroduction in the Czech Republic: extent, motivation and obstacles. *European Journal of Forest Research* 143: 305-317. [Q1 AIS on WoS]

## 1. Introduction

### *1.1. Human impact on forests: basic principles*

Human impact on forests can have many forms. The most direct and intentional anthropogenic impact is deforestation, when forests are destroyed and replaced by another land use type, such as arable or pasture (Williams 2003). At the other end of the spectrum are the unintended but equally significant effects of recent human activities, such as global warming or air pollution, on forests (Forzieri et al. 2022, Knutzen et al. 2025, De Marco et al. 2022). In between these extremes there is a myriad of ways in which people have been using and changing European forests for their own purposes for millennia: these form the subject matter of this habilitation thesis. The main motivation of people in most periods and places was the acquisition of firewood and building timber, but they also gathered various non-timber products (leaves, hay, mushrooms, edible plants etc.), and used forests as hunting ground (Shackleton et al. 2011, Allsen 2006, Dizard & Stange 2022, Bichel & Hart 2023). Although often these uses had a simple extractive character, in many cases people aimed to manipulate natural processes to achieve a particular type or a more stable flow of desirable forest products. Such human management of forests mainly focused on tree regeneration. Generally speaking, trees can regenerate in two ways: generatively or vegetatively. Generative regeneration refers to sexual reproduction, in which new trees get established from seed. In contrast, vegetative reproduction means that offspring arise from dormant buds on the stem, branches or root system of existing trees (Koop 1987). Vegetative reproduction is an ancient property of trees, which developed either as a reaction to disturbances (such as fire, grazing, trampling or windstorms) or in conditions, typically at the edges of the distribution range of particular tree species, where the chances of successful generative regeneration are low (Bond & Midgley 2003). It is important to notice that, with few exceptions, coniferous trees do not regenerate vegetatively.

Humans have intentionally modified both generative and vegetative natural regeneration for millennia. The former could be done by sowing tree seeds or planting young trees; the latter, by repeatedly cutting trees and leaving the stumps (called ‘stools’) in the ground to encourage the growth of young shoots, a management technique called coppicing. A range of further variables could also be modified to steer the regeneration process in a given direction, which led to considerable spatiotemporal variation in forest management in Europe. First, the length of the cutting cycle (for both seed-grown and coppiced trees) could be shortened or lengthened to influence the size of the final product. The ideal size of a tree always depended on its intended use, which in turn followed from local socioeconomic circumstances; a larger tree did not

always necessarily mean a more valuable tree. Second, the openness of forest stands could be modified. In much of temperate Europe, unmanaged forests tend to become more closed over time through a process called succession, which favours long-lived and shade-tolerant tree species with little undergrowth (Picket et al. 2011, Poorter et al. 2023, see also Vera 2000 for an alternative hypothesis). This could be seen as a negative process when, for example, pioneer tree species or coppice underwood were preferred. People therefore often kept forests relatively open and much early legislation was devoted to the right amount of seed-grown large trees over coppice stands, so that the former do not impede the growth of the latter (e.g. Keyser 2009). Third, people could interfere with the natural selection of trees. Forests are usually full of tree seedlings and saplings, of which only a few reach maturity, while the majority perish through natural competition for light and nutrients. People modified this process by selecting a preferred species or shape of tree (Vojta et al. 2023, Ruano 2013). Fourth, people also altered fire regimes, which are an integral part of the regeneration cycle especially in coniferous forests. This was particularly common in slash-and-burn agriculture, in which trees were cut down and burned to improve soil conditions in a shifting cultivation system (Emanuelsson & Segerstrom 2002, Drobyshev et al. 2024). People could also burn the vegetation to improve habitats for grazing animals and therefore for hunting, or, conversely, suppress natural fires to conserve timber (Pechony & Shindell 2010, Kaplan et al. 2016, Dietze et al. 2018).

### *1.2. Forest management types through history*

In accordance with the above basic principles, there have been historically two main types of managed forests in Europe: coppices and high forests (Fig. 1). In coppices, which were typical for lowland areas with broadleaved trees, vegetative tree regeneration dominated and the main product was firewood. As will be discussed later on, coppice cycles (the number of years between consecutive harvests of the same stand) were usually short (7-25 years) because young coppice shoots provided the ideal fuelwood: smallish branches that could be put on the fire with little further labour investment. Shoots were tied in bundles called faggots, which were often depicted in medieval and early modern illustrations (Fig. 2). A remarkable aspect of coppice management is that it was not confined to Europe. It was separately invented and used in Japan and China, and European colonizers introduced it in eastern part of northern America (Totman 1986, Whitney 1996, Saito 2009, Miller 2022).



**Figure 1.** The structure of high forest and coppice. In high forests (left) trees of seed-origin dominate and the main product is building timber, whereas in coppice woods (right) trees regenerate vegetatively and the main product is firewood. Photo by author.



**Figure 2.** Firewood was used for example to burn heretics. The wood in this picture comprises young coppice shoots (note the tree rings) tied up in faggots. Jan Hus at the stake in a 16<sup>th</sup>-century Hussite prayer book.

High forests consisted of trees of seed origin and their main product was building timber. Timber trees were larger than coppice firewood, but the principle that Oliver Rackham called “the smallest tree that would do the job” (Rackham 1980) was valid here as well: timber trees

were usually only as large as required by a given construction. For example, the dendrochronological analysis of more than 46,000 timber trees from Central Europe for the period AD 1050-1850 showed that the typical spruce or fir tree used in constructions was cut at ca. 60 years of age and 25 cm of diameter. In fact, size seemed to be the most important criterion for timber selection (Antoine et al. 2024). This significantly reduced labour and transportation costs. Outsize timber trees were used only in extraordinary circumstances, such as in castles or major ecclesiastical buildings (Prak 2011). A reduction in timber size could often be observed in different places and periods as the original forests were gradually replaced by managed stands (Muigg et al. 2025). The precise management methods of high forests before the 19<sup>th</sup> century are still relatively little known, with selective cutting as probably the most common traditional method (Savill 2015, Pommerening et al. 2025). In some regions, the combination of grazing by domestic herbivores and timber trees created a special kind of open, savanna-like high forest, which some consider a separate kind of wood-pasture vegetation, distinct from ordinary forests (Plieninger et al. 2015).

Coppice underwood could co-exist with timber trees in the system known as coppice-with-standards, in which some trees were left to regenerate from seed and remained standing through several coppice cycles to provide building timber. In many cases, standard trees were of a different species (typically oak)<sup>1</sup> than coppice underwood. In practice, coppice-with-standards were a sub-type of coppices, because the number of standards could greatly vary through time including periods with no standards at all. Coppices-with-standards were formalized as a separate management type through the efforts of Heinrich Cotta, one of the seminal figures of German forestry in the 19<sup>th</sup> century, who also invented the term *Mittelwald* (~middle forest, which found its way into several European languages, cf. Czech *střední les*, Hungarian *középerdő*). Such terminological developments could also shape actual forest landscapes (Bürgi 1999).

The proportion of coppices and high forests among all woodlands in any given region and historical period was driven by societal demand for woodland products and also by natural conditions. In coniferous regions, high forests were the only option. In broadleaved forests, coppices were more common, at least until the 19<sup>th</sup> century. This was based on the simple fact that firewood was usually needed in much larger quantities than building timber. There was

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<sup>1</sup> Throughout this thesis, I use common names for tree species or genera. These are oak (*Quercus* spp.), (Scotch) pine (*Pinus sylvestris*), (Norway) spruce (*Picea abies*), (European) larch (*Larix decidua*), (silver) fir (*Abies alba*), (European) beech (*Fagus sylvatica*), lime (*Tilia* spp.) and hornbeam (*Carpinus betulus*). In other cases, I will identify the species or genus with its Latin name at first use.

naturally much variation in Europe: more wood was needed in the cold north than in the Mediterranean; parts of northwestern Europe had vast deposits of peat as an alternative fuel source (Kander et al. 2013, McGrath et al. 2015). On the whole, however, firewood was the most important product. For example, according to Radkau (2012), nine tenth of all wood used in Germany until the 19<sup>th</sup> century was burned as fuel, and statistical data from the mid-19<sup>th</sup> century in Bohemia described similar proportions (Schnabel 1848). In addition, the coincidence of larger human populations in lowland regions with the distribution of broadleaved forests also reinforced the prevalence of coppice management. The dominance of firewood in everyday life has often been underappreciated in scholarly literature not least because timber features more extensively in the available source material, for example in royal legislation concerning shipbuilding timber (Eliasson & Nilsson 2002, Wing 2014). As an example, I may quote the discussion on the impact of Ottoman wars on Hungarian forests. The traditional narrative claimed that during 150 years of continuous warfare along the Ottoman-Habsburg frontier in the 16<sup>th</sup> and 17<sup>th</sup> centuries in what is today western and central Hungary, the construction and maintenance of timber fortifications used massive amounts of building timber and contributed to deforestation. A quantitative analysis, however, showed that a mere 625 hectares of high forest or 7,100 hectares of coppices-with-standards would have sufficed to satisfy the timber demand of all know fortifications in western Hungary in a sustainable manner. In contrast, the provisioning of firewood for the local population (including soldiers) required a 150 times larger forest area (Vadas & Szabó 2018).

### *1.3. Traditional woodland management versus scientific forestry*

With few and notable exceptions (such as the Nuremberg *Reichswälder* from the 14<sup>th</sup> century onwards: Radkau 2012), until the 18<sup>th</sup> century people relied on the natural ability of forests to renew themselves. As discussed above, regeneration processes were altered in a number of ways, but forest ecosystems remained natural in the sense that no non-native tree species or non-local specimens of native tree species were introduced into them. The other defining feature of traditional forest management was multiple use: in addition to wood extraction, forests were utilised for a number of other purposes, such as grazing or litter raking. Depending on socioeconomic conditions and the amount of available forests, non-timber uses could be more important for local populations than wood extraction. However, different uses often contradicted each other: for example, grazing animals were detrimental to tree regeneration, especially to coppice shoots. As a result, multiple-use forests were usually heavily regulated to



avoid potential conflicts or resource scarcity. The best known such regulation is the prohibition of grazing in young stands, but regulatory systems could be much more complex (Szabó 2013; Varga et al. 2020). Political relations always played a significant part, and more powerful parties often tried to prioritize their preferred product over the rights of less fortunate social groups. A typical example of this was the banning of goats (“the cow of the poor”) from French forests in the 18<sup>th</sup>-19<sup>th</sup> centuries (Matteson 2015).

As for regeneration, tree planting was a well-known activity in Europe since at least the Roman Period, but it was mainly restricted to fruit trees in orchards. John Evelyn’s famous *Sylva, or A Discourse of Forest-Trees and the Propagation of Timber in His Majesty's Dominions*, published in 1664, was significant in the sense that it urged land-owners to plant forest trees (Hemery 2014). However, even Evelyn had tree planting on non-forested land in mind: his goal was to increase the area of forests. The first author to consistently argue for the planting of forest trees *inside* existing forests as a means of regeneration was Hans Carl von Carlowitz. Although he is nowadays better known for ‘inventing’ sustainability (in his actual words ‘sustainable use’ – *nachhaltende Nutzung*) in forest management (Warde 2018), his ideas were in fact more ground-breaking as regards artificial forest regeneration (Warde 2013). Throughout the 18<sup>th</sup> century, more and more foresters propagated this new method. When artificial forest regeneration finally became a standard method during the 19<sup>th</sup> century, it truly signalled the beginning of the end of traditional forest management.

Tree planting in forests was just one, although the most readily identifiable, feature of a new management system that later literature named ‘scientific’ or ‘modern’ forestry. The development of scientific forestry is inseparable from the ideology of the Enlightenment and the emergence of modern states, which aimed at complete oversight of natural resources, including forests (Hölzl 2010a, Bonan 2022, Związek et al. 2024, Egry 2025). The above-mentioned Cotta defined the goals of scientific forestry in 1817 as such: „The main purpose of forestry is therefore this: to manage forests in such a way that the largest and most useful quantity of timber is cultivated and properly utilized in them at the lowest cost” (Cotta 1817). Georg Ludwig Hartig, the other towering figure of early scientific forestry, argued that “forestry science teaches us how to cultivate perfect forests in every respect with the least expenditure of time and money, how to protect and preserve already cultivated forests, how to determine the sustainable annual timber yield and the monetary value of the forests, how to make the best possible use of the forest products, and how to organize and direct the entire forestry operation appropriately” (Hartig & Hartig 1834). To achieve ‘sustainability’ (which in this period meant

not harvesting more wood than what would later regrow (Hölzl 2010b)), predictions about future harvests and yields needed to be made. These in turn were made possible by detailed surveys of forest stands, including current stock and growth rates based on site conditions (Dargavel & Johann 2013). Artificial regeneration (initially with the help of seed sowing, later on mainly by planting) fit into this system in the sense that it made regeneration much more predictable than natural processes would have allowed. As for the species of tree to be planted, especially conifers became popular all over Europe in the 19<sup>th</sup> and 20<sup>th</sup> centuries. These had the double advantage of being relatively undemanding with respect to climate and soil, and having long straight trunks along with a predictable growth pattern. There was a wide variety of favoured plantation trees in different regions ranging from non-native species (such as Sitka spruce [*Picea sitchensis*] in Great Britain), to common native species planted outside their native range (such as Scotch pine or Norway spruce in Central Europe), to very rare native species that became common through planting (such as European larch in the Czech lands) (Quine 2015, Dudová & Szabó 2022, Zin et al. 2025). Growing such trees instead of what would have grown in forests naturally also made it more feasible to translate yields into monetary units, a trend that became especially marked from the second half of the 19<sup>th</sup> century onwards (Lowood 1990).

A factor that played a major part in the spread and eventual dominance of scientific forestry over traditional management was the decreasing demand for firewood. First coal and later other fossils fuels gradually replaced firewood as the main source of energy in every European country (Sieferle 2001). This transition first took place in England in the 17<sup>th</sup> century and reached much of Europe by the 19<sup>th</sup> century (Kander et al. 2013). As a result, building timber rather than fuelwood became the most marketable forest product. The symbol of these changes was the railway – it made it possible to transport coal to large distances with low costs, but, at the same time, required millions of preferably coniferous timber trees as sleepers. These changes hit coppices especially hard, which suddenly lost their *raison d'être* but were often too small or in unfavourable locations to be suitable for scientific forestry operations. The result – as will be shown on Czech examples – was the mass abandonment of coppices.

With its focus on timber production, scientific forestry also strongly disapproved of the multiple use of forests. This became a major source of conflicts in the mid-19<sup>th</sup> century, when growing rural populations intensified non-timber uses in forests that were – according to the foresters – already overused (Popek 2025). Many formerly tolerated activities became illegal and prosecuting them was bureaucratized leading to, for example, over 180,000 documented

offences against forest regulations per year in the 1830s and 1840s in Bavaria (Hölzl 2011). In the long run, not least because chemical advances made many non-timber products (such as leaf litter) redundant, scientific forestry achieved its goals and non-timber uses have become very rare or outright banned in many European countries (Varga et al. 2020).

#### *1.4. Motivation and research questions*

Whereas until the turn of the millennium much was already written about the development of modern forestry, far less attention was paid to traditional management. The prevalent opinion of the latter was still negative, especially when compared scientific forestry. This followed from the narrative of modern forestry itself, which blamed what it saw as an imminent danger of wood scarcity on earlier management (or lack thereof). Many forest historians searched for the origins of scientific forestry before the 18<sup>th</sup> century, and, when such could hardly be found, argued that traditional management was primitive and devastated forests, leading to a general scarcity of wood with catastrophic consequences. Such teleological “histories-of-progress” (Whited 2000) are rather problematic from an epistemological point of view: here I concur with eminent historian Chris Wickham that it is important to realize that “historical development does not go *to*; it goes *from*.” (Wickham 2016, p.1, italics in original). For forest history in particular, the teleological narrative was first questioned by Joachim Radkau in the 1980s, who argued that ‘wood scarcity’ was essentially a social construct which served the needs of emerging scientific forestry itself (Radkau 1983, 1986). This naturally met with much scholarly resistance and a fierce debate ensued, which now has its own historiography (Schmidt 2000). In any case, it appeared to me more meaningful to try to understand traditional forest management, and, by implication, human impact on forests in the long period before the emergence modern forestry within the context of its own time, assuming that in that context it was as rational as any other type of economic and land management activity. In this framework, scientific forestry was not a better or more advanced version of forest management but rather a new system that stemmed from and adapted to quickly changing socioeconomic circumstances in the 18<sup>th</sup> and 19<sup>th</sup> centuries.

As regards methods, there was little cooperation between individual disciplines that, one way or another, all dealt with historical human impact on forests: history, palaeoecology, geography and archaeology. The most significant early effort to combine them was the work of Oliver Rackham in the 1970s and 1980s, which set the grounds for much later work including mine

(Rackham 1975, 1976, 1980, 1989). Historical geographers were also actively seeking ways to provide a more complex understanding of the relationship between human societies and forest ecosystems. For example, Michael Williams published a vast volume on the deforestation of the Earth (Williams 2003) and Charles Watkins co-edited an interdisciplinary collaborative volume on forest history (Kirby & Watkins 1998).

Last but not least, the application of research results in forest management and conservation was very rare. This was to a large extent due to the lack of communication on both sides. Foresters were unaware of how historical knowledge – other than relatively recent information on forest conditions recorded in forest management plans – could be useful for them, and academic researchers made little effort to reach out to them. Especially traditional management seemed moot, as it was virtually extinct in much of western and central Europe.

My research originally intended to address some of the challenges outlined above. It also formed part of a general European trend that took off in the early 2000s. On the one hand, there was a renewed interest in the history of forests not least because of its connections to global change (Agnoletti & Anderson 2000). On the other hand, forest conservationists realized that traditional management – and, more generally, human impact – sometimes contributed to the creation of valuable forest ecosystems, which were degrading or disappearing along with the abandonment of earlier management forms. However, there was little understanding at that point of how traditional management actually worked outside a few better-known areas, or even what methods can be used to study it. One of the first attempts to bring together scientists from various disciplines to discuss the uses of historical knowledge in forest conservation on a European scale was an edited volume that grew out of a IUFRO (International Union of Forest Research Institutions) conference in 2003 (Honnay et al. 2004). Further similar volumes followed, some of which offered a truly comprehensive picture (e.g. Kirby & Watkins 2015).

In view of the above, I structured this thesis around four key research questions:

1. How did traditional woodland management, especially coppicing, function in the study area from the Middle Ages until its abandonment in the 20<sup>th</sup> century?
2. Which were the most important non-timber forest uses, how were they organized and distributed? How did multiple use influence forest ecosystems?
3. What kinds of building timber were used and where were they sourced from? How did socioeconomic processes, weather events and climate influence the use of timber?
4. When, why and how was traditional management abandoned and later rediscovered?

## 2. Study area and period

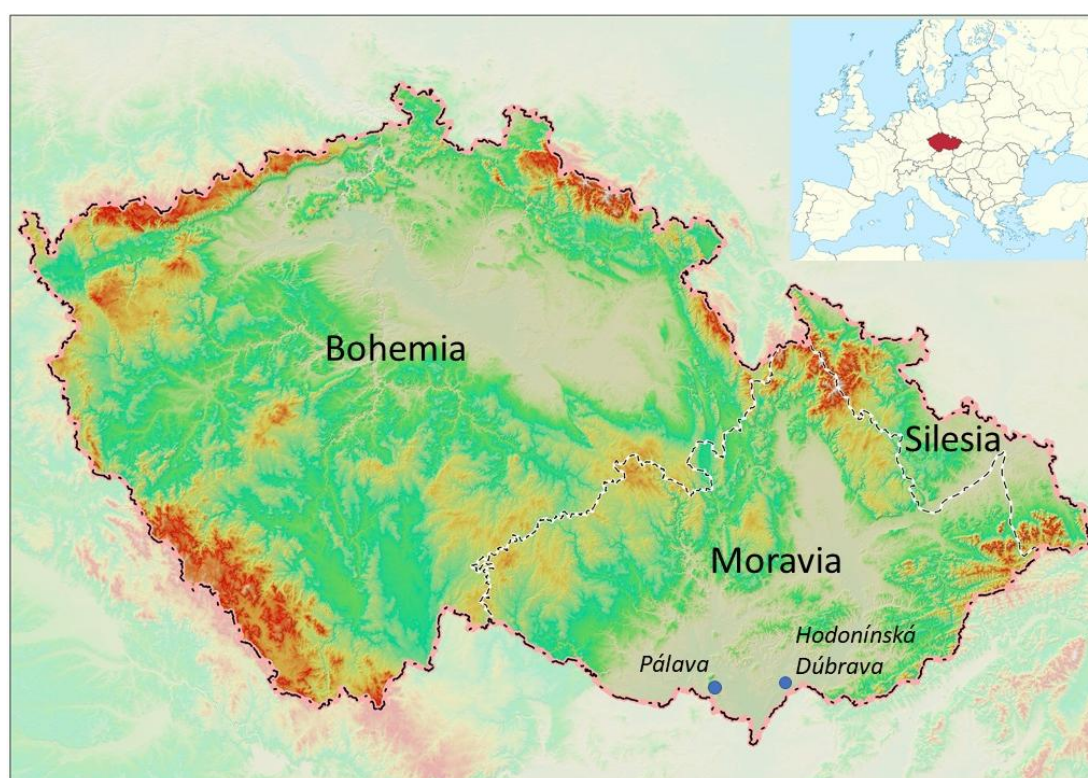
The individual papers in this thesis concern the whole or part of the territory of the Czech Republic in various spatiotemporal resolutions (Fig. 3). For a number of reasons, the Czech Republic appeared to be an excellent ‘laboratory’ to study the research questions. It has had a long history of human settlement with a correspondingly significant anthropogenic influence on forests. Because of cultural developments after the High Middle Ages, the area is rich in forest-related archival sources, especially when compared to countries in the eastern parts of Europe. At the same time, forest cover never sank to levels seen in north-western Europe, therefore more places are available to study the effects of past human activities on existing forests. In addition, because of social structures present in the whole of east-central Europe towards the end of the Early Modern Period, traditional forest management lingered on longer here than in many western European countries.

Humans have been present in what is nowadays the Czech Republic since the Palaeolithic, and their population rapidly increased after the onset of the Neolithic in ca. 5500 BC. Lowland areas have been relatively densely settled ever since, but there was significant variation in population dynamics in geographically more marginal regions (Kolář et al. 2022). The current settlement network mostly originated in the Middle Ages. From this period until the 20<sup>th</sup> century, the area comprised three polities: Bohemia, Moravia and Silesia. These were connected under the Bohemian crown since the 14<sup>th</sup> century and had varying degrees of autonomy. While Bohemia and Moravia were territorially relatively stable over the long run, most of Silesia was conquered by Prussia in 1742. The remaining smaller part is usually referred to as Austrian or Czech Silesia. After the 16<sup>th</sup> century, the Czech lands formed part of the Habsburg monarchy in its various manifestations until the end of World War I.

Geographically, the area is quite varied, including agricultural lowlands around major settlements in river valleys, extensive highlands especially between Bohemia and Moravia, and mid-sized mountains (highest peak at 1603 m a.s.l.) on the edges. Potential natural vegetation comprises oak-hornbeam forests in the lowlands, beech and fir-beech forests in the highlands with oak-pine forests in the southwest of Bohemia, and spruce forests at the highest elevations (Chytrý 2017). However, humans have co-existed with and modified vegetation for millennia. Vegetation without human influence has hardly existed in the current climatic phase of the Holocene (the past ca. 4200 years) except in inaccessible regions, which makes any large-scale statements about natural vegetation somewhat hypothetical. In any case, quantitative pollen

reconstructions indicated that the existing vegetation was closest to a hypothesized natural version in the Early Middle Ages (Abraham et al. 2016).

As for the study areas of individual papers (except for those with a more theoretical focus: **papers 3, 17**), three main levels can be distinguished: national, regional and local (Table 1). Three papers focus on the entire country (**papers 12, 14, 18**), and five papers deal with the region of Moravia and Czech Silesia (**papers 5, 6, 10, 11, 13**). These were conducted in high spatial resolution using the existing 3567 townships (cadastral areas) as basic geographic units. Local studies centred around the two sites of Hodonínská Důbrava (**papers 8, 16**) and Pálava (**papers 1, 7, 15**), complemented by a comparative study of the two sites (**paper 4**) (Fig. 3).



**Figure 3.** The study area with regions and specific study sites

Hodonínská Důbrava is a large (ca. 3300 ha) subcontinental oakwood in the alluvium of the Morava river in southern Moravia lying on 150-200 cm thick Quaternary blown sand deposits (Novák & Pelíšek 1943). Its climate is warm and relatively dry with ca. 9°C average annual temperature and 500–550 mm of annual precipitation (Tolasz et al. 2007). Elevation ranges from 164 to 242 m a.s.l., the terrain is generally flat with numerous sand dunes and shallow depressions. The vegetation is very rich with more than 650 plant species identified, which led to some of the forest being protected on an EU level as a Site of Community Importance

(CZ0624070 – Hodonínská doubrava) and under Czech legislation as a National Nature Monument (NPP Hodonínská Dúbrava) (Roleček et al. 2017). Pálava is a Protected Landscape Area (CHKO Pálava) ca. 30 km to the west of Hodonínská Dúbrava. It includes two forest complexes: the larger Milovice Wood (ca. 2500 ha) and the smaller Děvín Wood (ca. 400 ha). The climate of the site is similar to that of Hodonínská Dúbrava. Milovice Wood is a subcontinental oakwood on an undulating loess plateau (180–324 m a.s.l.); Děvín Wood comprises mesophilous oak-hornbeam and ravine lime forests on steep limestone slopes (260–550 m a.s.l.). Hodonínská Dúbrava and Pálava are connected by their long history of intensive human use, which included coppicing, forest grazing, litter raking and hay cutting. However, much of their area can still be considered natural in the sense that it was never commercially logged, ploughed and replanted. Finally, two further papers concern other areas: one deals with the phenomenon of woodbanks on a European level with a case study from the Czech karst region (**paper 2**), and the other discusses litter raking at a locality near the town of Olomouc in central Moravia (**paper 9**).

As for the study period, a few papers include prehistory, while the majority focus on the past seven centuries. A multicentennial scale dominates, with eleven papers dealing with at least five centuries. The time period since the 14<sup>th</sup> century is evenly covered except for the 19<sup>th</sup> century, which was included in sixteen papers. This follows from the exceptional richness of archival sources for this century (Table 1).

**Table 1.** Study areas and time periods covered in the papers

| paper | chapter & topic                      | study area |          |          |       | time period covered: century |    |    |    |    |    |    |    |    |    |    |
|-------|--------------------------------------|------------|----------|----------|-------|------------------------------|----|----|----|----|----|----|----|----|----|----|
|       |                                      | local      | regional | national | other | 11                           | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 1     | 4.1. Traditional management: coppice |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 2     |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 3     |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 4     |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 5     |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 6     |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 7     |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 8     | 4.2. Non-timber and multiple uses    |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 9     |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 10    |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 11    |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 12    | 4.2. Timber                          |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 13    |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 14    |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 15    | 4.4. Abandonment, rediscovery        |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 16    |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 17    |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |
| 18    |                                      |            |          |          |       |                              |    |    |    |    |    |    |    |    |    |    |

### 3. Methods

Most of the research in this thesis has been conducted in an interdisciplinary setting, combining sources and methods from history, geography, archaeology and ecology (cf. Szabó 2015). From among the traditional sources of history, the analysis of written sources features in many papers. We used a wide variety of written primary sources from the Middle Ages until the 20<sup>th</sup> century, including for example charters, *urbaria*, estate surveys, court records, legislation, cadastres, archival maps and forest management plans. Sometimes these sources were used in more traditional historical narratives (**papers 1, 9**), in other cases they were collected *en masse* and utilized in quantitative analyses (**papers 6, 10**). For the latter, we created what is still the largest forest historical database in Europe (Szabó et al. 2018). A number of papers used these data for geospatial analyses in a historical GIS framework (**papers 5, 10, 11**). We used landscape archaeological methods in two papers, focusing especially on the physical remains of past woodland management and forest drainage in the landscape (**papers 2, 16**). For the deeper past, we compared archival information to data gained with the help of palaeoecological methods, including palynology (**papers 8, 16**) and dendrochronology (**papers 12, 13, 14**). The sources and methods of (neo)ecology were also used, especially when examining the connections between the past physical reality of forest landscapes as modified by humans and current patterns of biodiversity (**papers 11, 15, 16**).

### 4. Results and discussion

#### 4.1. *Traditional woodland management: the long-term history of coppicing in social, economic and geographical contexts*

As described above, the most common traditional management type in densely populated lowland regions all over Europe in the Middle Ages and Early Modern Period was coppicing (Buckley 2020). Coppicing is the repeated cutting on short rotation of stems growing from permanent stumps (stools) in broadleaved forests. Because of its usefulness to produce easily workable firewood, researchers often assumed that coppicing started already in the Neolithic. However, detecting coppicing with certainty before the appearance of written records is highly problematic. In **paper 3**, I conducted an overview of methods and current progress in the research on the history of coppicing from prehistory until the present. Coppicing (and pollarding, which entails coppicing at a height to protect the shoots from grazing animals) was inferred early on using palynology (Troel Smith 1960) and dendrochronology (Rackham 1977).



However, the suitability of both methods to distinguish intentional coppicing from the opportunistic harvesting of young branches was questioned already in the 1980s (Crone 1987, Rasmussen 1990). The only study to date to try to empirically test the connection between coppicing and pollen was carried out in three English woods (Waller et al. 2012). The results were inconclusive in the sense that the pollen changes connected to coppicing could be caused by multiple factors, therefore pollen evidence alone seems insufficient to provide unquestionable proof for coppicing in the past. Dendroarchaeological evidence was used especially in the form of annual tree ring width, wood diameter and cambial age. Annual tree rings can show a sudden decline in coppice stools after harvesting or a sudden increase in standard trees when coppice underwood is cut (Rackham 1975). The latter was for example demonstrated in a paper on Děvín Wood, which I co-authored (Altman et al. 2013). A recent paper used the same methodology in France and Germany and concluded that coppicing was practiced at least 800 years prior to its appearance in written sources in the 13<sup>th</sup> century (Muigg et al. 2020). As for wood diameter and cambial age, according to recent research, which to a large extent built on the pioneering work of Billamboz (1992), these can potentially detect formal coppicing, but the strength of the conclusions will depend on sample size (Out et al. 2013, 2018). Perhaps surprisingly, when tested on wood assemblages from six Neolithic sites in Denmark, the Netherlands, Slovenia and Spain, existing models could not provide evidence of intentional coppicing (Out et al. 2020). Rather than focusing on a single source information, the way forward to detect woodland management in prehistory appears to be a combination of sources and methods, by which individual conclusions would reinforce each other (Dufraisse et al. 2022).

Beginning with the Late Middle Ages, there is copious written evidence to study coppicing also in the study area. The best-known coppice wood in the Czech Republic, as far as its historical development is concerned, is Děvín in Pálava. It is located in an ancient cultural landscape, with a highly significant Palaeolithic archaeological site right at its foot (Vandiver et al. 1989). The first written evidence of coppicing in Děvín Wood is from 1386: a woodland survey that was copied into an *urbarium* in 1414. A steady flow of documents followed, including six *urbaria* from the 16<sup>th</sup> and 17<sup>th</sup> centuries, a woodland survey from 1692 and forest accounts books from 1685 to the 20<sup>th</sup> century. These are complemented by ten forest management plans from 1807 to 1971 (for dates and archival shelfmarks, see **paper 1**). In addition to the maps that accompanied forest management plans, the Mikulov estate, which included Děvín Wood, has one of the oldest maps in the country (from 1675), which survives in an 1802 copy. In sum,

Děvín Wood is exceptionally well-documented by any standards. Furthermore, some documents are extraordinarily detailed: the 1807–1808 management plan for example recorded all 6,779 standard trees individually.

Děvín Wood was managed as a coppice since at least the late 14<sup>th</sup> century (**paper 1**). At that point the usual management cycle was seven years, which fits into the late medieval pattern observed elsewhere in Europe (e.g. Rackham 1980, Johann 2008, Vandekerkhove et al. 2016). The beginnings of coppicing at the site are unknown – when the system was first recorded in writing, it was already fully developed. Existing standard trees provided evidence of coppicing in the past (Altman et al. 2013), but they do not reach back as far as the 14<sup>th</sup> century. The largest coppice stools are certainly ancient but they are near impossible to date (Fig. 4). Similarly sized coppice stool in the nearby Podyjí National Park were estimated to be 800 years old (Vrška et al. 2016).



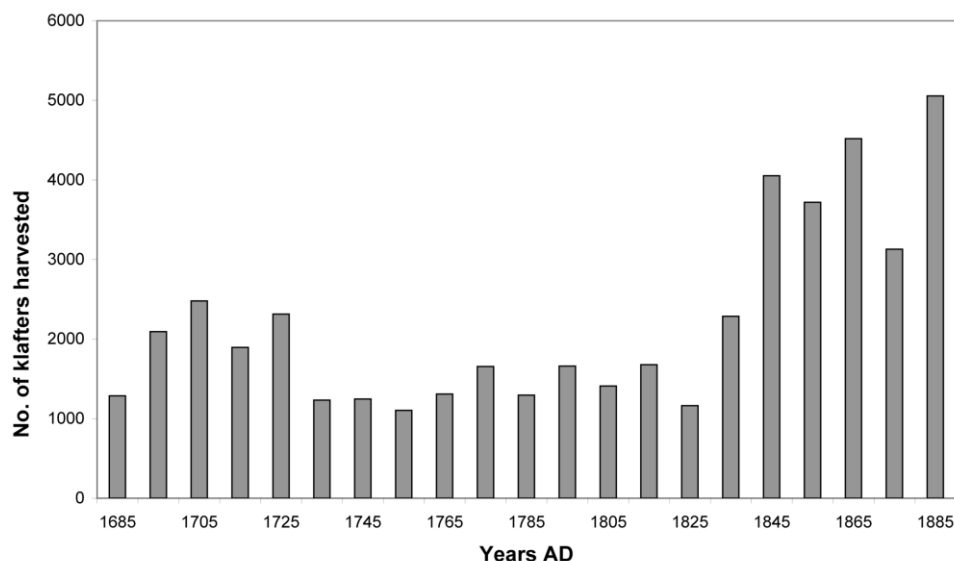
**Figure 4.** Large coppice stool in Děvín Wood. Similar stools elsewhere were estimated to be several centuries old. Photo by author.

The coppice cycle was prolonged to 12 years in the 17<sup>th</sup> century, 30 years by 1807 and 40 years by 1948. Again, this fits into a general European trend, the reasons for which are currently

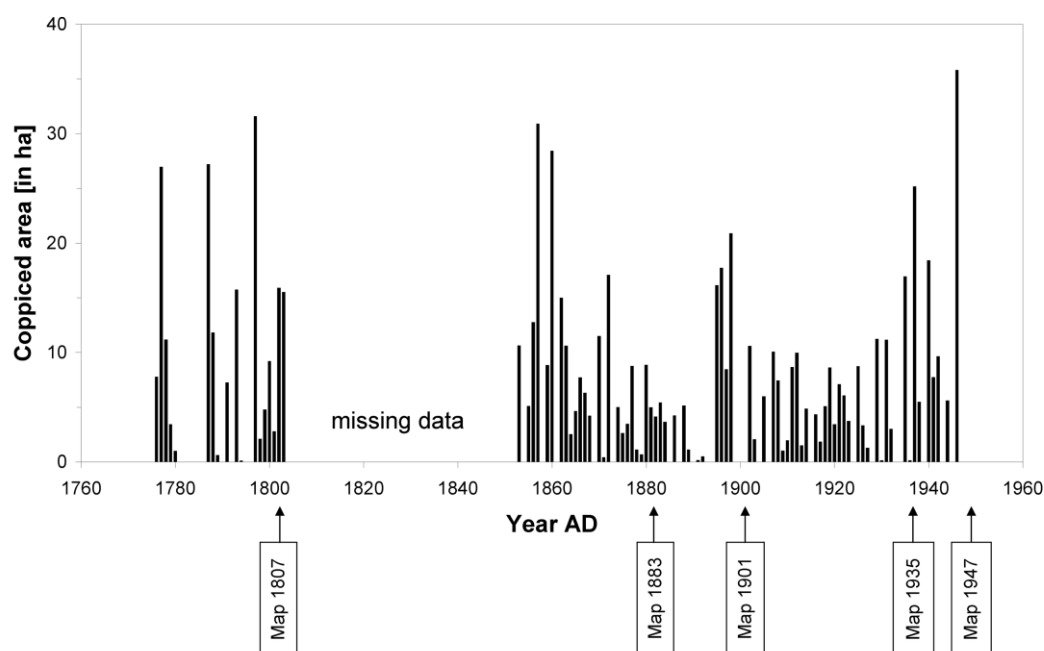
unknown. As expected, the number of standard trees was highly variable, ranging from zero in the Late Middle Ages to 33 and 13 per hectare in 1807 and 1938, respectively. This reflected the growing importance of building timber, and, more importantly, the fact that standards were harvested when needed rather than on a regular pattern (**paper 1**).

The coppice system was maintained by various socioeconomic driving forces. In the Middle Ages, the firewood was sold to the peasants, providing a solid source of income for the Lichtenstein family, the owners of the Mikulov estate. When in the 16<sup>th</sup> century woodland was replaced by other land-uses and economic activities as the main sources of income, the new owners of the estate – the Dietrichstein family – leased out most of their woodlands (including parts of Děvín) to the neighbouring villages for a fixed yearly fee. The remaining areas were used for the estate's own firewood supply. Because of the need for firewood, coppicing continued until 1946, when the Wood was included in a non-intervention nature reserve (**paper 1**).

Available evidence showed two contrasting fuelwood production patterns, which illustrate the substance of traditional woodland management on the Mikulov estate in general and in Děvín Wood in particular. Detailed accounts books recorded firewood production on the entire Mikulov estate, which, according to our reconstruction, was remarkably stable at ca. 1600 fathoms (*Klafter*) per year from 1685 to c. 1850 (Fig. 5) (**paper 7**). This was probably the amount of firewood the woods could produce, which was sufficient to cover the needs of the local population even when it started increasing especially in the 18<sup>th</sup> century (**paper 4**). Yearly harvests suddenly increased to around 4000 fathoms after 1850, which (if it reflected a real change rather than, for example, a change in the volume of the local fathom) could probably be connected to the introduction of scientific forestry on the Mikulov estate. In contrast to the stability of firewood production on the estate, the actual area cut in Děvín Wood – as reconstructed from a series of forestry maps with known ages of individual stands – was highly variable (Fig. 6) (**paper 7**). In the context of woodland management on the Mikulov estate, this probably reflected a deep practical knowledge of individual forests, in which – in the typical fashion of traditional systems – each stand produced a different amount of wood. These pieces of production information were carefully put together by woodland managers to define the area to be cut yearly in each woodlot to produce a steady supply of firewood on the estate as a whole.



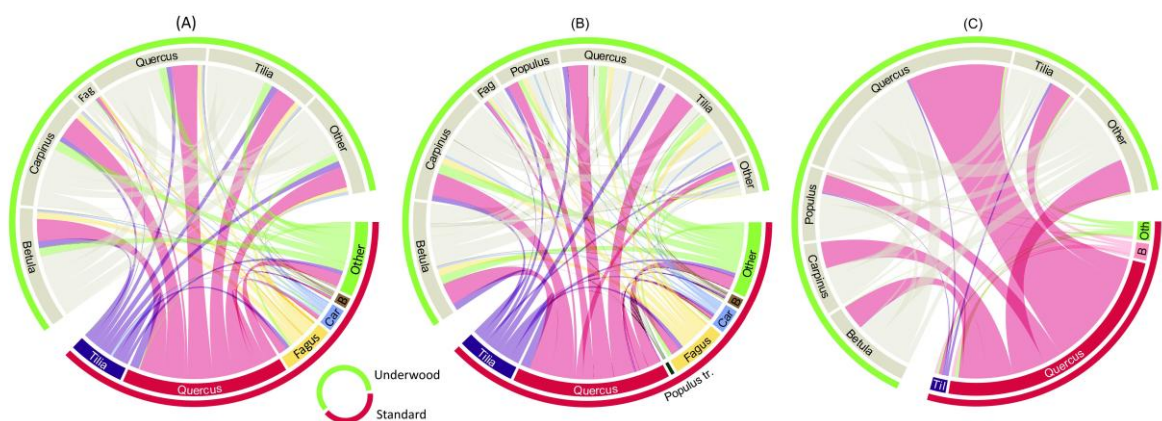
**Figure 5.** Yearly firewood production on the Mikulov estate. Every tenth year was sampled. One *Klafter* (English fathom) is ca. 3.4 m<sup>3</sup>. From paper 7.



**Figure 6.** Yearly harvested areas in Děvín Wood. Sources of information (maps) are marked. From paper 7.

As mentioned above, standard trees in Děvín Wood occurred in highly variable numbers, and they tended to be oaks as opposed to the more common lime underwood. Several studies in Europe hypothesized that oak was the preferred species for standards and was therefore actively promoted by forest managers (Rackham 1975; Lassauce et al. 2012; Szymura et al. 2014). To

test this hypothesis, we used a unique dataset that covers ca. 12,000 hectares of forests in southern and central Moravia around 1900, including 1507 forest compartments in 21 forestry units (**paper 6**). Standards and underwood were recorded in these surveys separately. In 11 forestry units, 90,184 standard trees were individually counted, while in the other 10 units standards were assigned a percentage value. Underwood was always expressed in percentages of dominant tree species. Using co-correspondence analysis and association analysis with the help of a  $\chi^2$  test, we examined whether there were statistically significant differences between standard trees and underwood in the same compartments. Results showed that oak was the most common trees species in both standards and underwood, although less so in the latter. In all analyses, oak standards and underwood showed a positive association, i.e. the occurrence of standards increased the probability of the occurrence of underwood and vice versa. At the same time, the species composition of standards and underwood were significantly correlated (Fig. 7).

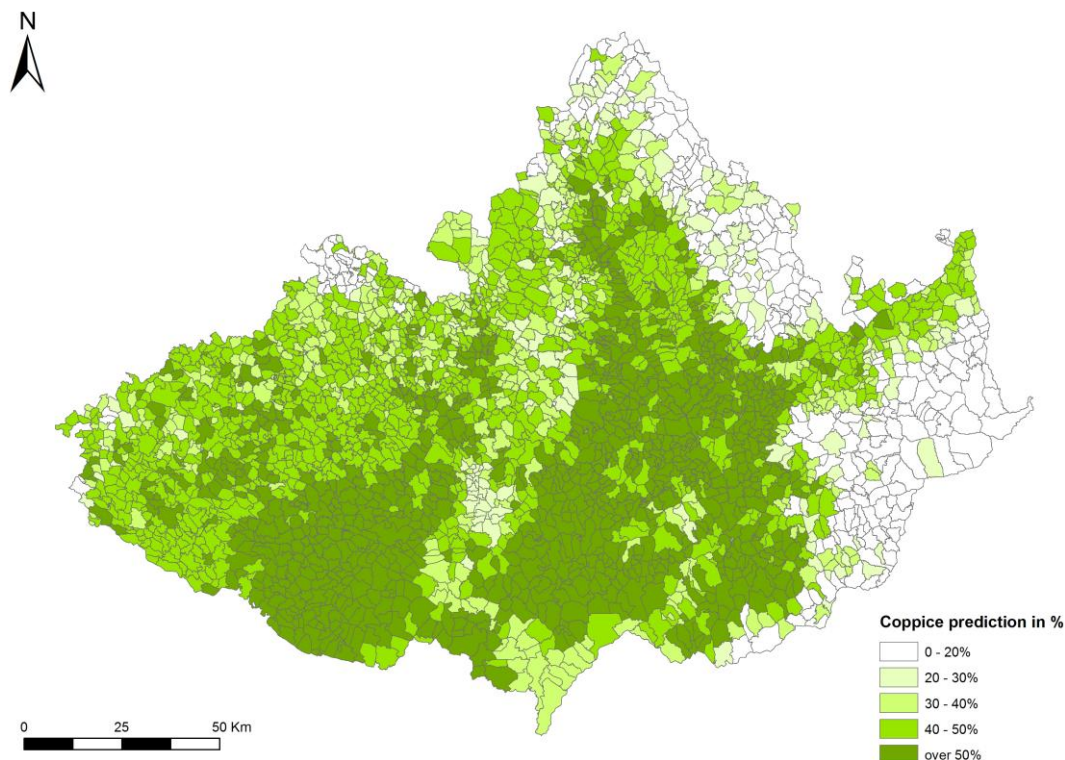


**Figure 7.** Co-occurrences of pairs of taxa in standards (colour), underwood (grey), or both in all data (A), Lichtenstein forests (B) and state forests (C). Only the most common taxa are shown separately, the rest are merged in “other”. Abbreviations: B–*Betula*, Car–*Carpinus*, Fag–*Fagus*, Til–*Tilia*, Oth–other. From paper 6.

In sum, the preference for oak standards, as suggested by earlier research as well as normative archival sources, was not confirmed in our dataset: forest managers did not alter the tree species composition of standards to a degree that would have been recognizable by our analyses. The reason behind this was a combination of natural properties, environmental conditions and management decisions. Probably the most important single factor was the simple fact that oak was very common as underwood as well.

There are many individual, usually small forests in Europe, similar to Děvín Wood, where coppicing is well documented from the Middle Ages onwards. This has led to the assumption that coppicing was the prevalent form of woodland management in thickly populated European lowlands until the 19<sup>th</sup> century. However, actual evidence for this in the form regional or national surveys is rare, especially for earlier periods. Few studies exist that tried to capture the large-scale distribution of coppicing prior to the 19<sup>th</sup> century, and such works always acknowledged the patchiness and unreliability of the data (e.g. Bergendorff & Emanuelsson 1996; Perrin & Daly 2010). To circumvent this lack of evidence, a 2015 study used a modelling approach to estimate the percentage of coppices in Europe based on demand for fuelwood (McGrath et al. 2015). Although fraught with the usual uncertainties connected to such large-scale models, their reconstruction of 36% of all European forests as coppices appears in line with what scattered individual sources suggest. In contrast to research based on demand, we tried to reconstruct the medieval distribution of coppices for our study area using a modelling approach based on evidence of coppice woods themselves (**paper 5**). We identified the Latin term used in late medieval documents to denote coppices (*rubetum*) and subsequently manually examined 7057 charters and 17,996 entries from the so-called *zemské desky* (which recorded land transactions of the nobility) to map the minimum distribution of coppices in the 14<sup>th</sup>-16<sup>th</sup> centuries in Moravia. In order to fill the gaps in our dataset (we lacked information for approximately half of the townships), we used the Maximum Entropy Algorithm (MAXENT), originally created for species distribution modelling. MAXENT was well-suited for our purposes, as it works with presence-only data, which fits the circumstances created by historical sources, where lack of evidence does not equal lack of presence. The predictors in the model included environmental information on climatic conditions (annual temperature and precipitation) and elevation mean averages for each township. Soil type and bedrock did not improve the performance of the model and were therefore not used in the analysis. In the resulting model, the presence of coppices was predicted with a probability exceeding 50% for 1043 townships, or 35% of Moravia (Fig. 8). Most of these townships were within the average elevation range of 259–480 m a.s.l., annual temperature of 7.5–8.6 °C, and annual precipitation of 582–655 mm. Providing the word *rubetum* indeed referred to coppices, which we acknowledge is an inherently speculative argument, coppicing was indeed omnipresent in lowland woodlands.





**Figure 8.** Model of coppice distribution in the Late Middle Ages in Moravia constructed using the MAXENT algorithm. From paper 5.

Subsequently, we compared these results to the potential level of coeval firewood consumption. Existing studies put the population of Moravia at ca. 900,000 in 1400 (Boháč 1987). Estimating firewood consumption is a much more complicated matter. For subsistence firewood, estimates for different European regions and periods vary from less than one cubic metre to almost five cubic metres of solid wood per person per year, but generally move between one and two cubic metres (Warde 2006a, Lindmark & Anderson 2010, Pleinerová 1986). Taking  $1.5 \text{ m}^3$  as the average means that  $1,350,000 \text{ m}^3$  of firewood were used in Moravia each year to provide for heating and cooking alone. The next step was to calculate how much coppice woodland could have produced this amount. Medieval values for wood production are practically absent, and general estimates for the Early Modern Period put productivity at ca.  $3 \text{ m}^3$  per hectare (Warde 2006a). Local evidence in Moravia suggests similar values. On the Mikulov estate, overall yearly increment stood at  $2.55 \text{ m}^3$  per hectare. In sum, with firewood consumption at  $1,350,000 \text{ m}^3$  and yearly increment at an optimistic  $3 \text{ m}^3/\text{ha}$ , the area of woodland that would have needed to be intensively managed in late medieval Moravia was 450,000 ha, that is  $4500 \text{ km}^2$ . This is roughly 20% of the entire land surface, some of which was certainly not all coppice woodland, as many regions had coniferous trees. While such calculations must be interpreted with caution,

as minor changes in values can lead to very different results, the combined evidence of the distribution model and consumption/production estimates both supported the conclusion that coppicing was the dominant form of woodland management in the broadleaved forests of Moravia in the Late Middle Ages. Unpublished data from the LONGWOOD database (Szabó et al. 2018) show a similar picture in the 18<sup>th</sup> century, when practically all broadleaved forests were coppiced.

Forests are often hotspots of archaeological research, as they tend to preserve landscape features connected to activities in periods before the site became a forest. This is a prolific research field; however, forests here simply represent the space where otherwise non-forest related archaeological remains have survived (Chase et al. 2017, Irlinger & Suhr 2017, Medarić 2025). In contrast, there also exist physical traces of past forest management in forested landscapes. In addition to large ancient coppice stools, as discussed above, which are typical biocultural monuments (Westin et al. 2024), the most important such traces are connected to boundaries. In many cases in the past, the boundaries of forests were permanently demarcated in order to avoid usage and property disputes. In my research, I showed that such boundaries could be of four kinds: woodbanks, walls, stone rows and lynchets (**paper 2**). Woodbanks were created by digging a linear ditch and throwing the earth towards the inside of the wood thus creating a bank (Fig. 9).



**Figure 9.** Woodbank in Dúbrava Wood, dug at the end of the 18<sup>th</sup> century. Photo by author.



Such woodbanks were dug in many European countries, for example in the Netherlands, Germany, France, Romania, Belgium, Scotland, Wales, Hungary, Denmark or the Czech Republic (Rackham 1976, Schotsman & During 1977, Tack et al. 1993, Fritzbøger 2004, Smout et al. 2005, Szabó 2005, Maděra et al. 2016). In regular cases, the bank is on the inside of the wood and the ditch on the outside to keep grazing domestic animals out of the wood, although there can be considerable variation, including ditches on both sides of the bank, or ditches without any bank. The bank was often reinforced by a permanent fence, for example a hedge. In hunting reserves, the ditch was usually on the inside to keep the game inside.

Woodbanks did not necessarily surround entire forests. If they only defined a part of the boundary, they usually separated woodland from pasture. For example, in Děvín Wood, woodbanks existed where the Wood adjoined pasture in the eighteenth century, but not where it abutted on the many local vineyards, which had their own fences (**paper 1**).

Some woods were surrounded by walls, sometimes combined with a ditch or a bank. In France, for example, the local woodland of the Abbey of Bec in Normandy is surrounded by an eight-kilometre-long wall (Rackham 2000). Many Scottish, Danish and Welsh woods are also surrounded by walls (Smout et al. 2005, Fritzbøger 2004). The above-mentioned hunting reserves, which required firm fences, often had stone walls built around them. Pheasantries, specialized forms of parks that were very wide-spread in central Europe in the eighteenth century, were often surrounded by walls. Some of these could be quite substantial, as shown by the surviving example near the town of Mikulov in the Pálava region (Svobodová 2014).

Stone rows as woodland boundaries were the by-product of agriculture. Since the beginning of agriculture, people have removed stones from arable land, and in many areas, rows of stones have been created between fields (Jackovičová et al. 2023). Where a field adjoins a wood, the stones were placed right on the woodland edge (cf. Peterken 1996 for North America). As the stones were gathered continuously through long time periods, stone rows could grow into massive structures. The Czech karst, a limestone area ca. 30 km southwest of Prague in the Czech Republic, provides a good example. Here, a number of ancient woods are surrounded mostly by stone rows combined with stone piles and sometimes woodbanks or lynchets (**paper 2**). A typical boundary is a more or less continuous stone row with piles of stones at irregular intervals (Fig. 10). Such piles also typically occur where the boundary turns sharply, and these piles likely served as indicators of the most important boundary points. The size of the stone rows varies from minor lines to huge dry-walls 3 metres in width and 2 metres in height.



**Figure 10.** Stone row on a woodland boundary in the Czech karst. Photo by author.

Lastly, lynchets are terrace-like structures produced in hilly terrain by continuous ploughing (Brown et al. 2020, Pear et al. 2024). The plough constantly moves the soil down the hill, which means that lands above and below the plough-line are separated by a steep slope. Woods on hilltops in arable regions are usually surrounded by lynchets. Within woods, the original slope gradient persists because erosion is less significant than in open farmland. Although lynchets, like stone rows, were not intended as boundaries, they function in the same way as woodbanks: they mark out the legal boundary and protect against grazing.

Dating woodland boundaries is highly complicated, as they were either formed through a long time-period (such as lynchets or stone rows) or provide little datable material without excavation (such as woodbanks or stone walls). Written sources often mentioned woodbanks but the existence of such references depends on the production and survival of workaday economic documents of woodland management, which were more copious in western Europe than in my study region. It is therefore typical that many archival sources referred to woodbanks in England from the 13<sup>th</sup> century onwards, while in east-central Europe woodbanks were usually first mentioned in the Early Modern Period. In addition, the existence of permanent woodland boundaries was also connected to social structures and through these to grazing regimes. The typical example is Denmark, where traditionally strong common rights left many coppice woods unenclosed until the general enclosure movement of ca. 1800 (Fritzbøger 2004, see also Warde 2006b for early modern Württemberg). As regards woods, enclosure meant that woodland

and pasture were separated, and some of the originally more open woodland areas were designated as pasture while the rest were surrounded by permanent boundaries and given over solely to wood production. The result was that trees quickly disappeared from pastures and open areas disappeared from forests. For example, in Hodonínská Dúbrava, the ca. 4430-hectare heavily-grazed woodland was divided into pasture (ca. 1300 ha) and wood (ca. 3130 ha) in 1787. The woodland part was surrounded by a woodbank, which is still visible (**paper 16**) (Fig. 9). A few decades later the pastures had no trees on them, and open areas inside the woods were disappearing.

The woodbanks in Hodonínská Dúbrava lead to the next type of physical remains typical of woodland management: drainage channels. Although these were especially common from the 19<sup>th</sup> century onwards as part of the general “improvement” of forests for scientific forestry management, their creation started much earlier. The basic idea behind these channels was to lead excess water away from forests to provide better conditions for tree growth. In Dúbrava Wood, we mapped the channel network as part of paper that examined the connection between them and hydrological changes in the past 700 years (**paper 16**). Dúbrava Wood had an intricate network of drainage channels, which included the ditches of the woodbank as well. Just like regular woodbanks around coppice woods, these were also abandoned in the second half of the 20<sup>th</sup> century and often survive in a highly eroded state.

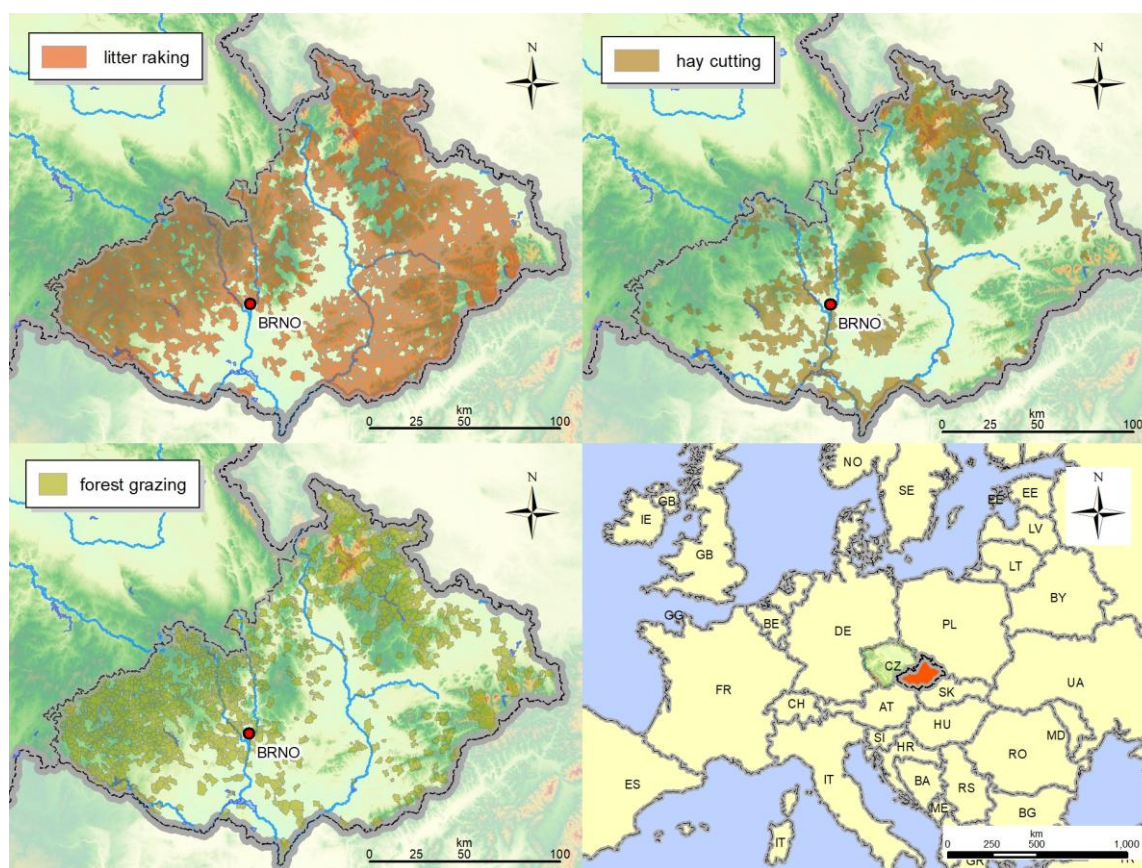
#### *4.2. Non-timber uses and the multiple use of forests*

From time immemorial, forests were used by people for purposes other than wood production. The influential wood-pasture theory of Frans Vera even claimed that the original vegetation of lowland areas in Europe was not closed forest but a dynamic, savanna-like type of vegetation, which was kept open by large herbivores (deer, wild pigs, wild horses, aurochs, bison) and later also by their domesticated counterparts (Vera 2000). In this scenario, grazing in forests figures as the most ancient and basic state of affairs rather than a use that was introduced into closed forests as humans gradually colonized Europe. Coppices, for example, would have been formed out of existing groves within the savanna mosaic. The Vera-hypothesis received much criticism as well as support (e.g. Mitchell 2005, Hodder & Bullock 2005, Szabó 2009, Ejrnæs et al. 2024, Pearce et al. 2025); in any case, it remains a strong reminder of the importance of non-timber uses in forests.

Based on the available written sources, the most important non-timber uses in our study area were grazing, litter raking and hay cutting. Further uses, such as bark stripping or the collection of honey, resin, mushrooms or wild fruits were also recorded, but much less frequently. Forest grazing and hay cutting are reasonably self-explanatory, although it is worth noting that hay cutting in forests meant cutting grass among the trees rather than on semi-formal meadows, which could also be quite common in some forests, including Dúbrava Wood. Leaf litter was a substitute product for straw, to be used as bedding for farm animals (hence the name) and later on as fertilizer on local fields (**paper 9**). While most researchers would agree that non-timber uses were very common in European forests, there is little comprehensive information on their past distribution on anything larger than local scale (for the recent past for forest grazing in Slovakia, see Lepeška et al. 2022). Just like with coppicing, the only available large-scale studies were based on past demand for non-timber products rather than actual records of past use. For example, Gimmi et al. (2013) constructed a model of litter raking for the mid-19<sup>th</sup> century in Switzerland, which showed that 55% of Alpine forests and 30-40% of lowland forests had to be raked annually to meet the probable demand for leaf litter.

To examine how common non-timber uses actually were in our study region, we opted for a method similar to our research on coppicing: we used comprehensive information on the presence of these uses rather than estimations based on coeval demand. We processed relevant data for Moravia and Czech Silesia in the so-called Stable Cadastre (**paper 10**). This cadastral survey was prepared in the first half of the 19<sup>th</sup> and has repeatedly proven to be a useful source for historical geographical and environmental historical investigations (Bičík et al. 2015, Krčmářová & Jeleček 2017, Maděra et al. 2017). The Stable Cadastre is exceptionally suitable for our purposes, because it consistently recorded the presence or absence of forest grazing, litter raking and hay cutting. We homogenized the data for townships for which information was given on the level of individual forests, and supplemented missing information with data from the so-called *Forststatistik von Mähren und Schlesien*, which was a questionnaire-based survey of forests published in 1853-1857 in the journal of Moravian and Silesian foresters. The resulting dataset contained information on 2,857 townships, while 457 townships were completely deforested in the mid-19<sup>th</sup> century. Results showed that non-timber uses were indeed extremely common and that there were only 263 townships (9.2% of townships with forests) where non-timber uses did not occur. Litter raking was the most common (2276 townships, or 79.6% of townships with forests), followed by forest grazing (1212 townships, 42.4%) and hay cutting (596 townships, 20.8%) (Fig. 11). To understand the connection between the

geographical distribution of non-timber uses and environmental (mean annual temperature and precipitation, mean elevation, soil fertility), land use and forest management (high forest or coppice) predictors, we combined two statistical approaches: supervised learning classification and logistic regression models. These demonstrated that hay cutting had the most easily explicable distribution pattern: it typically occurred in townships with large forests and few grasslands, i.e. in places where grasslands could not provide enough hay. Such townships were common along the treeless lowland belt of central Moravia, where much of the population lived. In contrast, grazing was typical at higher elevations in high forests on soils of lower fertility, which confirmed its traditional image as a highland activity. Lastly, litter raking was so ubiquitous in the study region that our models could not clearly connect it to the predictors, except perhaps that it was negatively related to the size of forests, i.e. it was mainly missing in townships next the agricultural areas with sufficient amounts of straw.

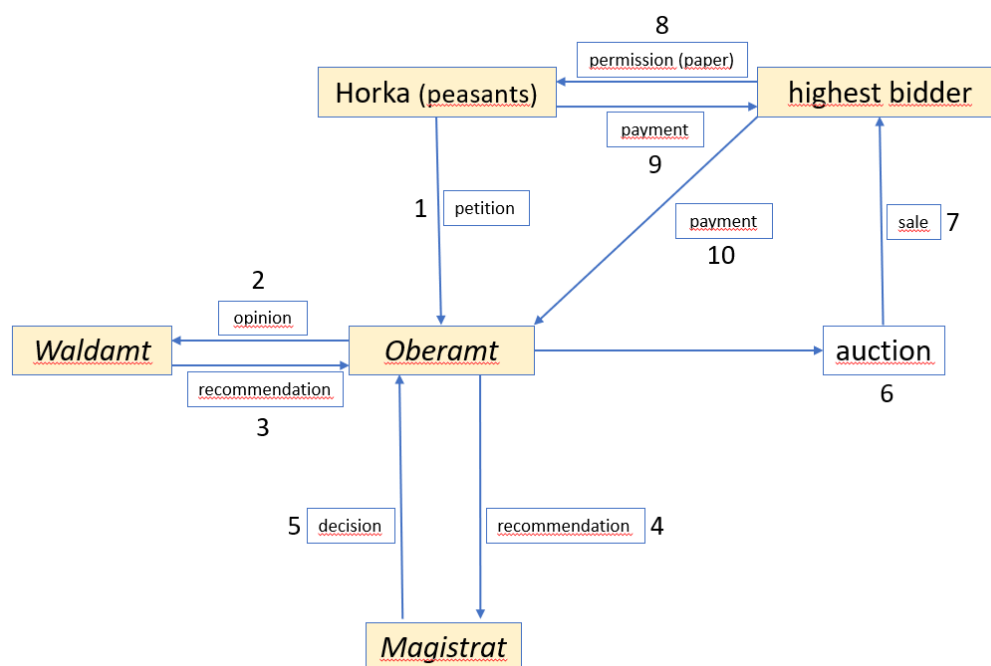


**Figure 11.** The distribution of non-timber uses in Moravia in the first half of the 19<sup>th</sup> century, as recorded in the Stable Cadastre. From paper 10.

While these results provided an overall image of non-timber uses at a large spatial scale, it is worth zooming in to understand how such uses worked in reality and how they fitted into local



socioeconomic and ecological systems. To achieve this, I conducted a detailed study of a court case of illegal litter raking in 1845 in a village called Horka, which belonged to the city of Olomouc in central Moravia. In this court case, 28 people, representing ca. one fourth of Horka households, gave testimony. The essence of the matter was that several Horka villagers had petitioned Olomouc for a permission to rake litter, which was first granted but eventually denied, making any raking that had taken place illegal. The court records provided minute details about the bureaucratic processes involved and the constant back-and-forth between various actors. Data showed that once litter raking (and by implication all other non-timber uses) became subject to permission from the land-owner, they were very closely regulated. In the Horka case, the Olomouc economic office administered matters, the forest office gave recommendations and the city magistracy made decision, while litter raking itself was rented out through a public auction for a fixed sum to a single petitioner, who organized the actual litter raking himself (Fig. 12).



**Figure 12.** The process of authorizing and carrying out litter raking in Horka in 1845.

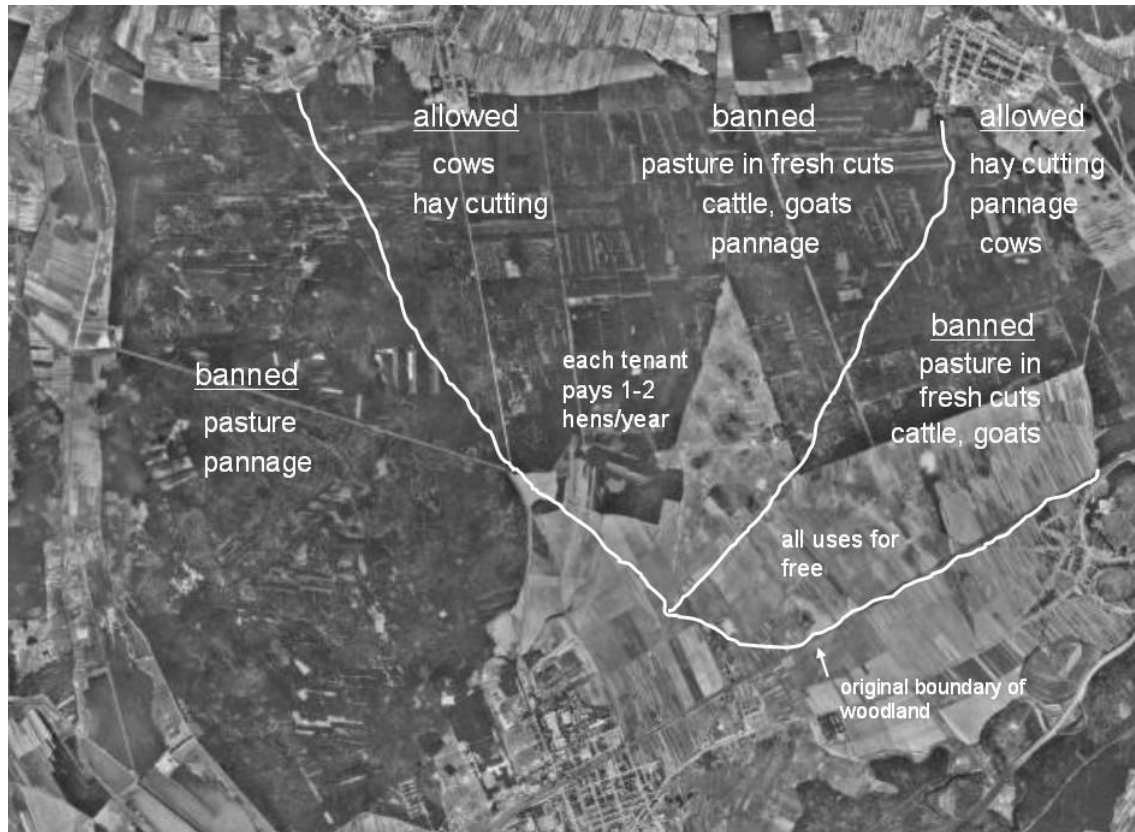
It also became clear that interpreting all foresters involved as proponents of scientific forestry, i.e. opponents of non-timber uses, is an oversimplification. The head forester of Olomouc was well-aware of the theoretical arguments of scientific forestry against litter raking and used them when necessary or ignored them when convenient. The local district forester in Horka, on the other hand, did not receive any formal forestry training and may have been involved in illegal

forest raking himself. The conclusion of the court case, in which the local forester was held responsible and removed from Horka to another forest district, also demonstrated that although peasants eventually lost their traditional forest use rights, for a long time they could relentlessly pursue their interests with potentially little backlash. Overall, the Horka case study showed that the abandonment of traditional non-timber uses (see also Chapter 4.4 below) and the advance of scientific forestry was a complex rather than straightforward process deeply imbedded in local social and ecological conditions.

While the Horka case-study analysed a relatively recent event, the history of Hodonínská Dúbrava offered a long-term perspective on a different non-timber use and also demonstrated the subtle connections between historical management practices and current ecosystems. Dúbrava Wood was a typical multiple use forest, in which especially forest grazing played a major role. In an interdisciplinary study conducted with palaeoecologists and vegetation ecologists, we investigated the effects this multiple management had on the development of forest vegetation (**paper 8**). Dúbrava is protected as an oak forest, which is in fact what its very name means. Long-term palaeoecological research also showed that oak had formed a significant part of the vegetation for thousands of years, however, it had not been quite as dominant as in the recent past (Jamrichová et al. 2017). We sampled two shallow depressions in the forest which were dated to approximately to the past two millennia with slower accumulation rates after the 14<sup>th</sup> century. We compared palynological, anthracological and macrofossil analyses to archival documents, which – similarly to Děvín – are available in large amounts. Palynological results showed that the most significant spread of oak occurred in the 14<sup>th</sup> century, when the forest took on the form it has today. This was reinforced by a simultaneous gradual change in the name of the Wood, which was originally called Klečka (‘a place with shrubs’). While there have been similar changes observed elsewhere in the region, the timing in Dúbrava Wood seemed unique. This asynchronicity made it unlikely that the changes were connected to the onset of the Little Ice Age. A lack of major changes in charcoal concentrations indicated that fire was not the driving force behind vegetation change, either. A more plausible explanation is human impact: several charters showed that oaks were actively protected by the estate owners from the mid-14<sup>th</sup> century onwards to promote grazing. Similar conclusions were arrived at for example for an earlier period at the nearby site of Pohansko, where the spread of oak was connected to grazing by pigs (Kratochvíl 1981, Svobodová 1990), or for the Záhorie region on the Slovakian side of the Morava river for the 15<sup>th</sup> century (Jamrichová et al. 2019). Similarly to litter raking in Horka, the practice of grazing in Dúbrava



Wood was also highly complicated and regulated. For example in 1692, the town of Hodonín had three distinct sets of grazing rights in three parts of the forest, which, however, was just one part in a much more complex system of grazing and hay cutting rights (Fig. 13) (Szabó 2013).



**Figure 13.** Grazing rights of the town of Hodonín in Dúbrava Wood in 1691. From Szabó (2013).

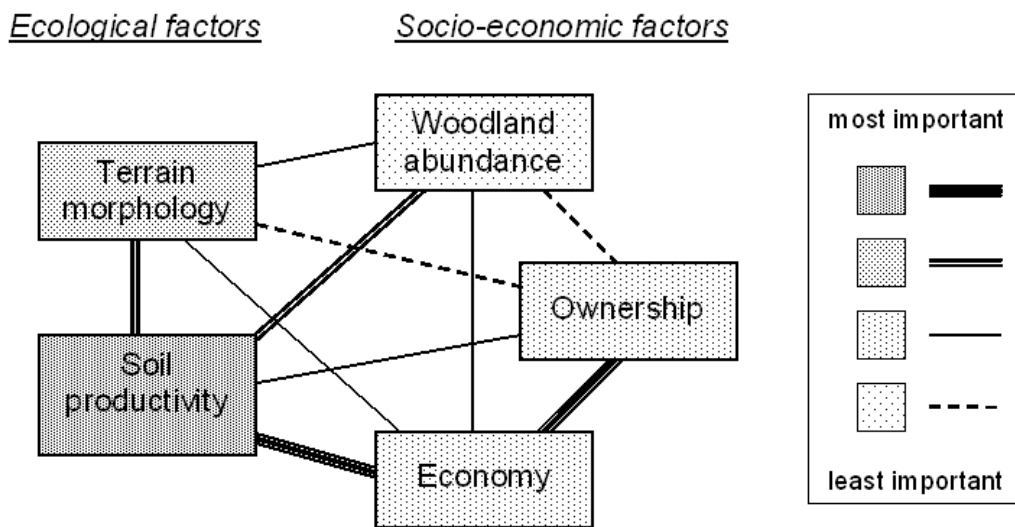
Archival sources indicated that multiple management gradually ended in Dúbrava Wood from the mid-18<sup>th</sup> century onwards, eradicating open areas and giving way to high forest management, which is typical of the site today.

The above three studies (**papers 8, 9, 10**) demonstrated that non-timber uses were practically omnipresent in the study area and that they could be, at least in certain periods and contexts, highly regulated. **Paper 8** also indicated that non-timber uses in the past could have far-reaching consequences as regards present vegetation. Moving along these lines and extending the scale of investigation, in a further study we examined the long-term legacy of litter raking on temperate forest plant communities (**paper 11**). We used data from the Stable Cadastre and combined them with 2,494 vegetation plots surveyed between 1980 and 2015. We explored the effects of past litter raking on species richness and the diversity of the herb layer and also tested whether long-term soil acidification and nutrient depletion – presumably caused by litter raking

– were reflected in so-called Ellenberg indicator values of plants for nutrients and soil reaction or in the higher abundance of specialists of acidophilous forest types. In spite of several sources of uncertainty in our data (unknown length and intensity of litter raking, long time since the abandonment of litter raking, different spatial scale for historical and vegetation data, overwhelming dominance of raked plots), we managed to identify a weak but recognizable legacy of past litter raking in the present forest herbaceous layer. Litter raking had no significant effect on overall species richness but there were significant differences among forest types. In particular, there was lower species richness in raked oak forests and higher richness in raked eutrophic forests. In addition, historically raked plots were taxonomically more homogeneous than unraked plots. Overall, while the observed effects were perhaps weaker than expected, the results opened up various opportunities for interpretation including the possible connection between the distribution of basic forest types and past non-timber management, which was hypothesized for example in Switzerland (Gimmi et al. 2010).

Lastly, to understand the driving forces behind the choices that led to the prevalence of intensive coppicing or multiple non-timber use, we conducted a comparative study of the Mikulov estate (especially Milovice Wood) and Hodonínská Důbrava between the 14<sup>th</sup> and 19<sup>th</sup> centuries (**paper 4**). We examined five possible explanations for the difference in their management: terrain morphology, soil productivity, abundance of woodland, ownership (communal or private) and economy. The analysis revealed complex patterns with multiple interactions, in which the importance of the five factors varied between the two estates and within the study period (Fig. 14). Soil productivity was probably the most important single factor, but it strongly interacted with most other factors. Together with economy and indirectly with ownership, the three formed a crucial conjunction influencing past decision making in woodland management on the two estates. The two ecological factors were closely correlated. Terrain morphology was an important element contributing to soil productivity, which we approached through texture and nutrient content. Morphology had little interaction with factors other than soil productivity, but it may have played an important role in designating more accessible areas as wood-pasture and steeper slopes as coppices. However, counterexamples to this general pattern on the estates indicate that the effect of morphology was more pronounced when combined with soil productivity. Overall, steeper terrain with fertile soils tended to be coppiced, while flat areas of poor, sandy soils were used as wood-pasture. As for socio-economic factors, woodland abundance could not account for the differences in the management on the two estates as there was no difference in this factor. The same holds true for ownership and usufruct (both forests

were private with extensive common rights) although this may have been different in the Middle Ages, which could have influenced the original management choices.



**Figure 14.** Diagram showing the strength of the individual factors (shading) and of the interactions between the factors (line width). The legend indicating level of importance/strength of interaction is on the right side of the picture. From paper 4.

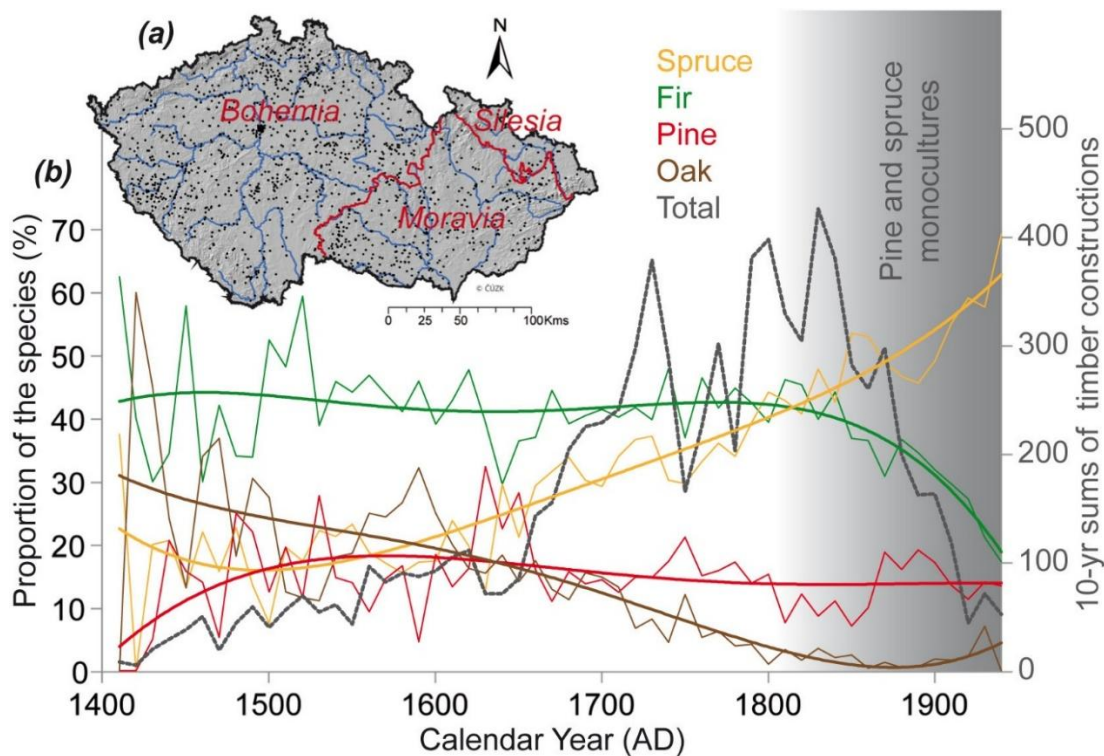
Overall, the explanations could be grouped into three basic categories: ecological conditions, socio-economic demands and tradition (or conservatism in the system). The original choice and later maintenance of woodland management was the combined result of these categories. Ecological conditions played the most obvious role, while the influence of socio-economic demands was subtler. The role of tradition (the maintenance of management after some of the conditions that had created it changed) was most influential in making it difficult to change existing management regimes. This was often facilitated by customs and hereditary rights to certain woodland produce, such as the pasturing rights in Dúbrava, discussed above. Management could change at the end of a long process and it needed the combination of two factors: economic pressure and a change in ideology. When for example coppices lost their economic significance on the Mikulov estate in the 16<sup>th</sup> century, their ownership conditions changed as a result but their management did not. This partly followed from a constant need for firewood in the neighbouring villages. In contrast, in the late 18<sup>th</sup> century in Dúbrava Wood, changes in socio-economic conditions and ideology coincided. By this time woodland-related incomes were insignificant and the growing population on the estate needed more firewood and more pasture. At the same time, as discussed in the Introduction, the general European trend based on the ideology of the Enlightenment condemned common rights and multiple land uses.

The result was radical change. The villages around Dúbrava were offered ca. one third of the Wood as private property in exchange for the abolition of their former common rights, which they willingly accepted. Wood-pastures were quickly transformed into pastures or coppices (see also Chapter 4.1. for the woodbanks on their boundary, Fig. 9).

#### *4.3. Timber: species, origins and the factors influencing building activity*

While Chapters 4.1 and 4.2 focused on firewood and non-timber uses, this chapter examines the third main product of forest management: building timber. As discussed above, building timber was for most of European history the secondary product as regards quantity. Nonetheless, it was irreplaceable for human settlements. Even in regions where buildings were predominantly made of stone or brick, they still contained large amounts of timber in their roof and ceiling structure. We examined three fundamental questions regarding the past use of building timber in the study area: which species of trees were used (**paper 12**), from where timber was sourced (**paper 13**) and how the intensity of building activities changed through time (**paper 14**). All three papers were based on the combination of data from the Czech dendrochronological database ([www.dendrochronologie.cz](http://www.dendrochronologie.cz)) and archival sources.

In **paper 12**, we used 8135 precisely dated timber constructions covering the period from 1400 to 1900 and hypothesized that the utilization of region-specific conifers dominated the constructions with increasing human influence through time. Results showed that silver fir was the most common building timber from the 15<sup>th</sup> to the 18<sup>th</sup> centuries. Spruce became increasingly common after the 16<sup>th</sup> century and eventually dominant in the 19<sup>th</sup> century, especially at the expense of fir. In contrast, the proportion of pine remained relatively stable over time. The only broadleaved tree to have a non-negligible proportion in the dataset was oak, although it was far less common than the other three species and its proportion gradually and considerably decreased through time (Fig. 15).



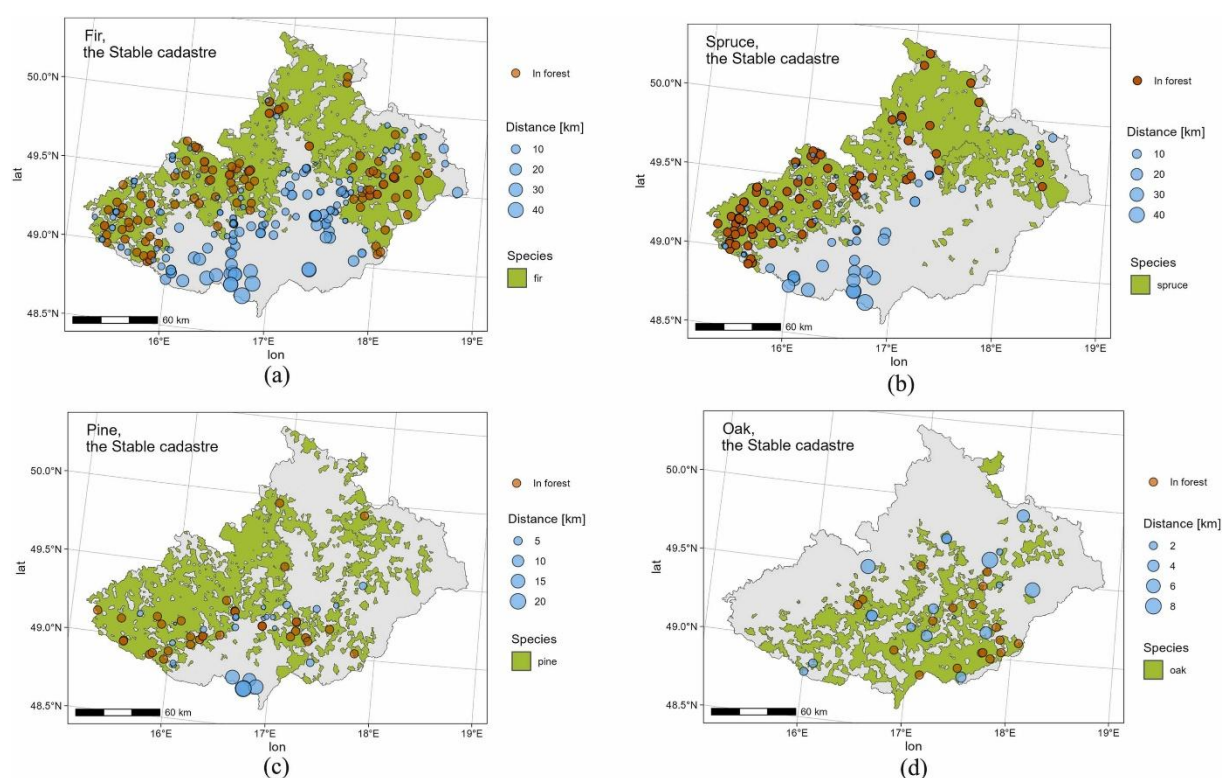
**Figure 15.** All precisely dated historical timber constructions distributed across the Czech lands. The three historical regions of Bohemia, Moravia, and Silesia are also indicated (b) 10-yr moving sums of the total amount of the dated historical timber constructions (dotted line) and percentage proportions of fir, spruce, pine and oak smoothed by polynomial regression over the period 1400–1900. From paper 12.

The spatial distribution of constructions showed a clear dependence on altitude with spruce, fir, pine and oak from highest to lowest, although it is to be noted that the mean altitude even for spruce was as low as 394 m a.s.l. Regionally, spatial analyses showed that fir was particularly prevalent in eastern Moravia and Silesia until the 17<sup>th</sup> century, which is related to the conspicuous absence of spruce in these regions. In contrast, spruce was common in the western and especially central parts of the country. Pine and oak constructions were typical of lower-lying regions. Pine first occurred in western and southern Bohemia, and, from the 17<sup>th</sup> century onwards, also in southern Moravia. Lastly, the distribution of oak was concentrated in the lowland regions of central Bohemia and southern Moravia. These results confirmed the absolute dominance as well as regional specificity of coniferous trees in historic constructions. The emergence of spruce as the most frequent timber tree reflected its probably climate-induced gradual spread towards lowland regions from the 17<sup>th</sup> century onwards as well as its status as the primary forestry plantation species in the 19<sup>th</sup> century. The spatiotemporal distribution of pine confirmed expectations with the exception of southern Moravia, where palaeoecological

studies revealed its continuous presence throughout the Holocene (Jamrichová et al. 2019), but where locally available oak was arguably preferred to it as building timber until the 17<sup>th</sup> century.

The regional specificity of building timber was further examined in **paper 13**. Here, we compared 1231 precisely dated historical timber constructions from the 18<sup>th</sup> and 19<sup>th</sup> centuries to archival data on tree species composition in coeval forests in Moravia and Silesia to find out whether or not the tree species used in constructions were commonly available in forests within a short distance from the location of the constructions. In addition to data from the Stable Cadastre (cf. **paper 10** and **paper 11**), we also utilized data from the so-called Josephian cadastre. This taxation survey was conducted in 1787-1789 and included the first comprehensive description of all forests in the Czech lands. Data on dominant tree species from both surveys were individually processed for 3567 townships. For 425 and 811 townships, species were differentiated only on the level of hardwood (incl. oak) or softwood (incl. pine, spruce and fir), respectively. These were aggregated with townships where data on tree species were available. To reduce potential errors due to changes in the boundary of townships (cf. Frajer 2019), we used the centroids rather than outside boundaries of townships in our calculations. For spatial analyses, we adopted a method based on the analysis of the mutual distance between constructions using a given tree species and the townships where the same species was present in local forests. Results showed that the distribution of the locations of constructions was clustered and significantly differed from random distribution. The proportion of constructions located directly within townships where the given tree species occurred ranged from 35% (oak in Josephian cadastre) to 73% (spruce in Josephian cadastre). For the remaining townships, the overall distribution of the distances of constructions from the nearest township with the given tree species was strongly asymmetric and positively skewed, i.e. short distances were dominant. For example, the most common distance (mode) varied from 606 metres to 1350 metres and even the third quartile distances mostly did not exceed 6000 metres. In other words, the tree species in constructions were usually available either in the very same township or in a township within a few kilometres from the construction (Fig. 16). We also conducted spatial analyses using the crossG function to investigate the spatial interaction of the constructions and the forested townships closest to them. These reinforced the close connection between trees species in constructions and townships: in most cases in both cadastral surveys, coniferous species in constructions and forests showed positive association until ca. 1500-2000 m and negative association above that value. Lastly, we used simulations to quantify the extent to which the observed distances of constructions from the nearest relevant forested township

differed from the distances that would have been observed in the case of a purely random distribution of constructions. These showed that the probability of the occurrence of the modal value of real data was very low (less than 1%) in most cases. In sum, our research confirmed the hypothesis that locally available timber dominated constructions in the 18<sup>th</sup> and 19<sup>th</sup> centuries. While this demonstrated a pattern of probable supply area, our data did not directly reveal that timber was actually sourced locally. Nonetheless, the only profitable way to transport timber to longer distances in the period was by floating on rivers, which was, unlike in Bohemia, the exception rather than the rule in Moravia and Silesia. Otherwise, costs were prohibitively high: contemporary sources estimated that timber could be profitably transported on land for a few dozen kilometres at most. In light of the above, our results clearly showed that timber for ordinary buildings was cut and used locally.

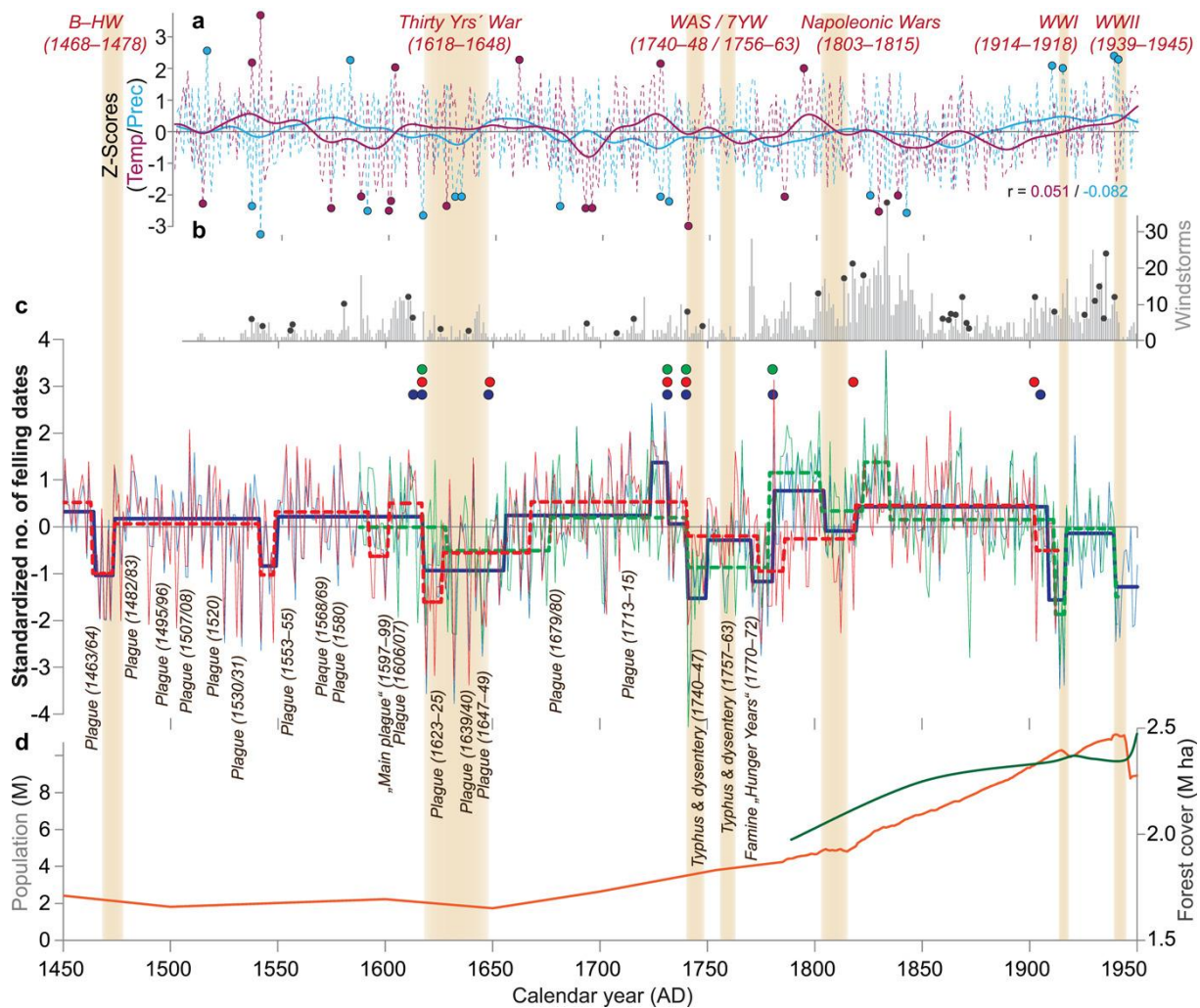


**Figure 16.** Spatial distribution of fir, spruce, pine and oak trees in Moravian and Silesian forests based on data in the Stable Cadastre (shaded areas). Dots indicate the locations of constructions distinguishing whether the given tree species was (red) or was not (blue) available in the forests of the same township. The size of the blue dot shows the distance to the centroid of the nearest township where the given tree species was available. From paper 13.

Having established what kind of timber was used in constructions and where it was taken from, the last paper discussed the broader socioeconomic implications of timber use (**paper 14**). Focusing on all three of the Czech lands, we asked what kind of influence political turmoil,



epidemic outbreaks and adverse weather and climate conditions had on building activities between 1450 and 1950. For this paper, we used 6514 intra-annually resolved tree-ring dates from the Czech dendrochronological database. We also constructed a database of the most significant war events, famines and epidemic outbreaks from existing literature. In addition, we used temperature and precipitation reconstructions compiled from documentary evidence and instrumental measurements (Dobrovolný et al. 2010, 2015) as well as data on significant windstorms (Brázdil 2004). After the standardization of the data, we applied two methods of breakpoint analysis (Sequential T-test analysis of regime shifts and regime shift index) as well as the superposed epoch analysis to establish statistically significant connections between the above factors and changes in the number of felling dates. Results showed the clearest connections between decreases in building activity and wars, in particular the Thirty Years' War (1618-1648), the War of the Austrian Succession (1740-1748), the Seven Years' War (1756-1763) and the Napoleonic wars (1803-1815) (Fig. 17). Most of these events were accompanied by epidemic outbreaks. However, epidemics by themselves did not have a strong effect on building activities. This is in partial contrast to the earlier findings of Ljungqvist et al. (2018), which, however, also included the catastrophic Black Death epidemic of 1346-1353. Climatic factors did not seem to have a significant effect on building activity, either. On the other hand, three of the six most devastating windstorms in the study period were clearly connected to increased building activity. The results confirmed that social turmoil, especially in the form of war, reduces building activity. Such effects for the Thirty Years' War were noted already by McNeill (2004). At the other end of the spectrum, the availability of cheap building material after major windstorms led, in some cases, to increased building activity (cf. Kaucká 2025 for the Šumava region). In other cases, notably for the most destructive windstorm of the 18<sup>th</sup> century in 1740 (Brázdil et al. 2017), the effects could be masked by the contemporaneous wars, in this case the beginning of the War of the Austrian Succession. Overall, our results indicated, contrary to some general conclusions in environmental historical works, that wars significantly reduced building activity thereby alleviating some pressure on forests, although this could be outweighed by excessive cutting for military purposes (Rotherham 2024).



**Figure 17.** (a) Reconstruction of annual temperature and precipitation anomalies smoothed by Gaussian low-pass filter and Pearson's correlation coefficients between these climate parameters and standardised number of felling dates for the common period 1501–1950. (b) Number of recorded local windstorms with highlighted widespread windstorms (black dots). (c) Variability of standardised felling-date indices completed with the model of regime shifts indicating individual breakpoints using Sequential T-test Analysis of Regime Shifts (bold line) and Pettitt's test (coloured dots) for the whole dataset (blue) in the period 1450–1950 and separately for ecclesiastical and noble buildings (red; 1450–1913), and rural buildings (green; 1588–1941). The most severe wars, epidemics and famines are indicated. (d) Evolution of population and forest cover in the Czech lands. B–HW = Bohemian–Hungarian War, WAS = War of the Austrian succession, 7YW = Seven years' war. From paper 14.

#### 4.4. The abandonment and rediscovery of traditional management: causes and consequences

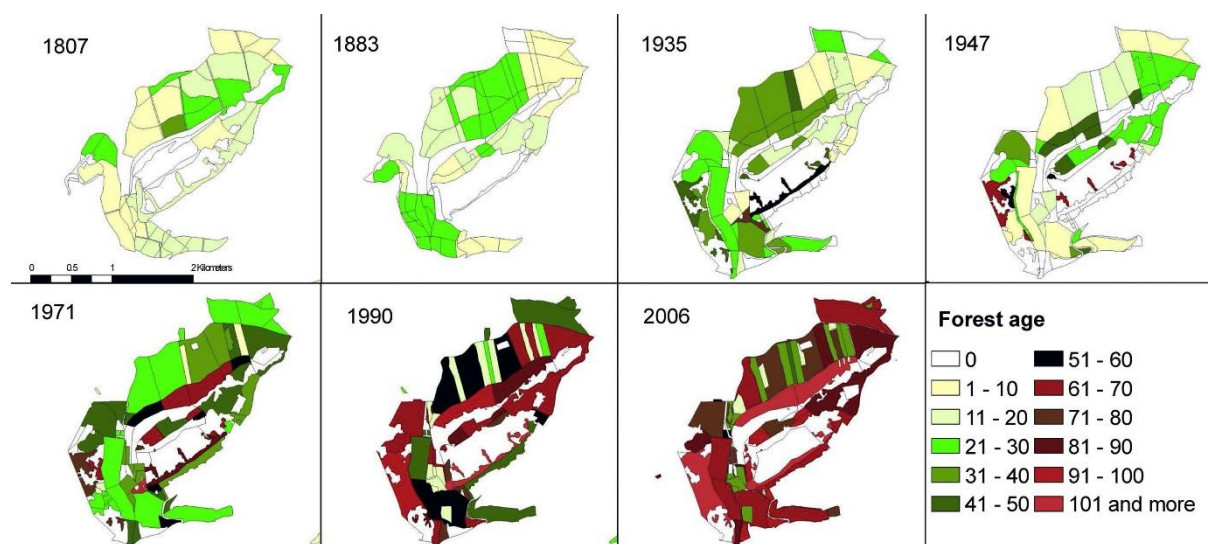
As outlined in the Introduction, traditional woodland management was abandoned in favour of scientific forestry in the 19<sup>th</sup> and 20<sup>th</sup> centuries. However, since the second half of the 20<sup>th</sup> century, it has become increasingly clear that scientific forestry faces significant challenges that partly follow from its own conceptual and organizational principles. These challenges are

threefold: first, the principle of predictable and constant yields is difficult to realize in single-species plantations that are highly susceptible to diseases, extreme weather events and the adverse effects of global climate change (Spiecker 2003; Paquette & Messier 2013). Second, the abandonment of traditional management in many cases led to a decrease in biodiversity, even in protected areas (Kopecký et al. 2013; Buckley 2020). Third, society's expectations of forestry have gone through radical changes in the past few decades: in many countries, including the Czech Republic, people prioritize the biodiversity protection or recreational functions of forests over the earlier dominant timber production. Sociological research has shown that this has pushed the forestry profession into a somewhat defensive position (Stachová 2018; Riedl 2025). Nonetheless, foresters have taken up many of these challenges and the profession is changing towards a more inclusive and diverse platform, represented for example by the popularity of close-to-nature silviculture and the related continuous cover forestry (Kennedy et al. 2001; Bürgi 2015; Pommerening et al. 2025).

Coppicing has been retreating all over Europe for at least a century, although it still has strongholds in the Mediterranean and in south-eastern Europe (Unrau et al. 2018). In the Czech lands, there were ca. 150,000 hectares of coppice woods in the mid-19<sup>th</sup> century, of which ca. 100,000 hectares remained by the early 1940s and only 1000 hectares by the 21<sup>st</sup> century (Maděra et al. 2017). Realizing that little is known about the spatial patterns of this lengthy process, we studied the abandonment of coppicing in Pálava (**paper 7**). With the help of generalized linear models, we compared the year of abandonment for each forest compartment in Děvín and Milovice Woods (established using archival maps) and three groups of explanatory variables: the distance of forest compartment centroids from roads and villages, morphometric environmental factors derived from a digital elevation model, and site productivity. In sharp contrast to the highly organized nature of contemporary scientific forestry operations, there appeared to be little planning in coppice abandonment apart from the most rudimentary effects of terrain morphology, i.e. that steeper and less accessible compartments were likely to be abandoned first. Otherwise not even income mattered: in Milovice Wood, productive sites were just as likely to be abandoned as infertile ones and the remoteness of compartments from roads did not affect their time of abandonment, either. These results suggested that coppice woods that were unsuitable for profitable modern forestry were simply left to their own faith as scientific foresters focused their attention on larger forested areas.

Centuries of continuous management has left its marks on the vegetation of coppice woods. The fine mosaic of differently-aged forest stands as well as the intensive removal of biomass

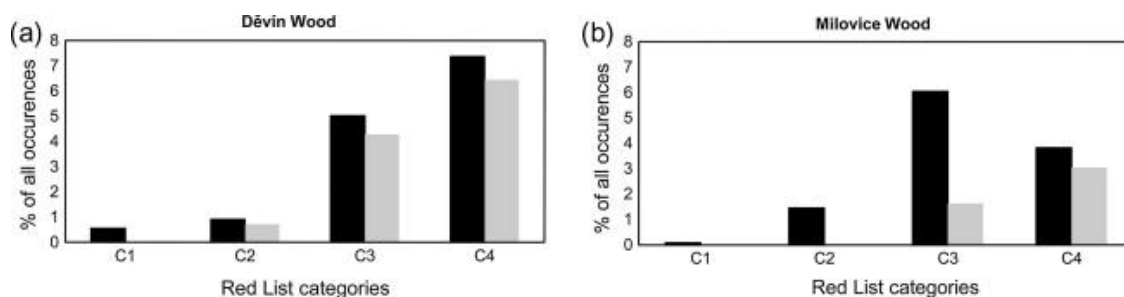
provided favourable conditions for a variety of invertebrates, fungi or herbaceous plants, leading to high species diversity. The same holds true for forest grazing as well (Hartel & Plieninger 2014). After the abandonment of traditional management, many such species have lost their habitats and disappeared through the gradual aging of forest stands and the closing of the tree canopy (Fig. 18) as well as the build-up of nutrients, exacerbated by increased atmospheric nitrogen deposition (Verheyen et al. 2012).



**Figure 18.** The ageing of individual forest stands in Děvín Wood in the past two centuries. From paper 7.

We analysed this process in Pálava by comparing 122 and 46 vegetation survey plots from the 1950s in Děvín Wood and Milovice Wood, respectively, with current resurvey plots. We complemented data on tree species with archival records going back to the 17<sup>th</sup> century (**paper 15**). Whereas tree species composition was relatively stable over four centuries, we observed considerable changes in the herb layer. Out of 325 species recorded in Děvín Wood, 313 occurred in the old survey, while only 194 were present in the new one. 183 species (56%) were present in both surveys. A striking 130 species (40%) were observed only in the old survey, compared with only 12 species (4%) unique for the new survey. We recorded a similar situation for Milovice Wood with 234 species in total, out of which 104 (45%) were common in both datasets, 75 (32%) were exclusive to the old dataset and 54 (23%) were to the new dataset. Furthermore, rare and endangered species decreased at both sites, and critically endangered plant species completely disappeared from the resurveyed plots (Fig. 19). In Dúbrava Wood, the cessation of multiple use (especially grazing) led to increasingly shady conditions through the past seven centuries, as reflected by the indicator values for light of macroremains we took

from three shallow depressions (**paper 16**). At the same time, the level of eutrophication increased. Open water pools in the forest became overgrown by tall grasses, shrubs and trees. These trends were confirmed by another study I participated in, which emphasized that the observed shift to shadier, more nutrient-rich communities and the increase in neophytes, nitrophytes and ruderals, as well as the loss of species of open woodlands in fact threaten the very existence of plant communities typical of such steppic oakwoods (Chudomelová et al. 2017).



**Figure 19.** Changes in endangered herb layer species for Dėvín (a) and Milovice (b) Woods between the old (black) and new (grey) surveys. Relative occurrence (percentage) of Red List species for the Czech Republic from the occurrence of all species in the datasets. From paper 15.

These results highlighted a contradiction inherent in today's forest conservation principles: the non-intervention policy, when applied indiscriminately, does not always lead to the fulfilment of predetermined conservation goals. Zero management is suitable for example in primary and old-growth forests, which have had relatively little human impact (Kulakowski et al. 2017; Sabatini et al. 2021). However, lack of management can bring negative results in forests, such as Dėvín and other coppice woods, whose ecosystems have co-evolved with intensive management for centuries. Perhaps paradoxically, including such forests in strict nature reserves may endanger the very characteristics that had led to the site being protected in the first place. As a practical solution, many scientific studies recommend the reintroduction of traditional management as a valid conservation strategy for certain protected forests (**paper 7**; **paper 15**; Kirby et al. 2017; Vymazalová et al. 2021; Doudová et al. 2022). In **paper 17**, I followed the broader context of this process and mapped out how traditional management was first rejected and later rediscovered in the study area. As discussed above, rejection stemmed from the firm stance of scientific forestry against traditional management. In spite of this, traditional management often continued, albeit in a reduced form, until the mid-20<sup>th</sup> century. In Dėvín Wood, for example, the last regular coppice harvests took place around 1940 (Altman et

al. 2013). Nonetheless, the growing pressure of foresters eventually found its way into national legislation as well. For example, while the 1928 Czechoslovak forest law still allowed twenty-year coppice cycles, the 1960 law already prescribed the transformation of all coppices into high forest. The same law banned forest grazing and litter raking as well. The rediscovery of traditional management originated in the 1960s in England, where a group of woodland ecologists started experimenting with the reintroduction of management into neglected coppice woods. One of the first such sites was Hayley Wood in Essex, where management had a positive effect on protected light-demanding plants (Rackham 1975). Many European sites followed suit, and the beneficial influence of coppicing was demonstrated not only for plants but also for butterflies (Fartmann et al. 2013), spiders (Hamřík et al. 2023) and certain small mammals (Martini et al. 2024). Nonetheless, other examples warned that the sudden opening up of the canopy might favour invasive species (Radtke et al. 2013) or release a “nitrogen time bomb” (Verheyen et al. 2012).

By the 2020s, in spite of detailed knowledge of individual sites, there were no regional or national surveys of coppice reintroduction experiments except for a low-resolution map for Germany (Kamp 2022). In consequence, little was known about the motivation of those who initiate coppice reintroduction. This, in turn, has made it difficult to propose effective policies to foster reintroduction on local, regional and global scales. We therefore conducted a survey of all known current coppice reintroduction sites in the Czech Republic in order to understand who was behind these efforts, what motivated them and what obstacles they faced (**paper 18**). We identified eight localities where coppicing is currently being reintroduced. We conducted ten semi-structured interviews with site managers on themes such as historical and current site management practices, their extent and financing, motivations of site managers, perceived obstacles and problems of reintroduction. The interviews were transcribed, coded and inductively analysed. Results showed that coppice reintroduction in the Czech Republic is currently a bottom-up process: it is advanced by forestry or biology experts, who are often site managers. Their most important motivation was the conservation of biological and landscape diversity, and they also found raising public and professional awareness of this ancient management method important. They were divided as to whether coppices are an optimal solution in the face of climate change and did not consider economic aspects (potential income from firewood) significant. Especially this last finding was in contrast with international literature (Jansen & Kuiper 2004; Suchomel et al. 2012; Schweier et al. 2015). In addition, coppicing was not seen as a potential source for rural employment, which needs to be seen in

the general context of the depopulation of peripheral regions in the country and the low wages in the forestry sector (Vaishar et al. 2020). Among the obstacles, site managers mentioned mainly legal and administrative issues, the legitimacy of coppicing (including complaints by locals) and the lack of workforce. They were also aware of biotic risks (such as invasive tree species, especially black locust [*Robinia pseudoacacia*] and tree-of-heaven [*Ailanthus altissima*]) and abiotic factors, for example drought, whose effects can be significant considering that coppices tend to occur in drier regions. We concluded that coppice reintroduction in the Czech Republic was so far a small-scale activity in protected forests dependent on the initiative of enthusiastic site managers and irrespective of larger socioeconomic considerations. Nonetheless, European experiences show that for coppicing to gain more ground, it needs to be accepted as a viable economic option at least for small woodland owners in traditional coppice regions.

## 5. Conclusions and outlook

The research presented in this thesis systematically investigated long-term historical impact on forests in the study area. To be able to study such a complex topic, an interdisciplinary approach was necessary: collaboration needed to be established between historians, geographers, ecologists and archaeologists. Cooperation through the great divide between the “two cultures” of natural sciences and humanities (Snow 1959) required adaptability on both sides, especially as regards identifying a common research agenda and spatiotemporal framework (cf. Szabó & Hédli 2011, Haldon et al. 2018). To that end, I strove to find a balance between various spatiotemporal resolutions ranging from detailed case-studies of a specific time and place (e.g. **paper 9**), to regional studies on a decadal scale (e.g. **paper 13**) to centennial scale studies of a single locality (e.g. **paper 1**) or the entire study area (e.g. **paper 14**).

I focused on four topics I consider of key importance as regards human influence on forests in the past millennium. The first three aimed at understanding how traditional management functioned and included coppicing, non-timber multiple uses and timber use. The fourth topic examined the abandonment and rediscovery of pre-scientific forestry forest use, thereby connecting the research results to present-day socioeconomic processes and nature conservation. Traditional management emerges from the results as a systematic, coherent and – within the context of its time – rational system. Its defining features included the use of a high variety local resources to satisfy the correspondingly varied demands of human societies.



Nonetheless, at least in lowland regions, forests have been perceived since the Middle Ages as a finite resource whose use had to be regulated to avoid scarcity.

Human influence on forests took on many forms from intensive coppicing and timber harvesting to extensive but regulated pasture. Although by its very nature such influence was local, an important conclusion that emerges from this thesis is that traditional management was widespread enough for its cumulative effect to have been significant on larger scales as well. Nonetheless, spatiotemporal variation needs to be considered. Whereas lowland forests were fully used and modified already in the Middle Ages, mountain forests were arguably less influenced until the Early Modern Period. Overall population pressure and growing industrial activities culminated in the 19<sup>th</sup> century, when our data clearly demonstrated a peak in human impact on forests. This impact was always contingent upon socioeconomic processes, which in turn showed the intricate relationship between current patterns in forest ecosystems and past human activities. It is also important to realize that whether or not researchers can disentangle these connections depends on the availability of natural scientific and archival sources, the methods used, as well as on the theoretical underpinnings of the research. For example, in Hodonínská Důbrava, the connection between medieval management decisions and current ecosystems was surprising rather than intuitive and could only be established through the fortunate coexistence of high-resolution pollen cores and relevant archival sources. In contrast, the amount and detail of 19<sup>th</sup>-century written records allowed for the targeted investigation of certain topics and the usage of methods that are practically out of reach for earlier periods. We could examine the driving forces behind the distribution of secondary forest uses with the help of machine learning or the sourcing of timber using spatial modelling. At the same time, the Horka case-study demonstrated the intricacies of socioeconomic processes that contributed to large-scale patterns of litter raking with statistically significant effects today.

Humans have affected practically all aspects of forests in the past millennium. Various management types created various forest structures from the mosaic of coppices to the semi-open landscapes of forest pasture. This in turn influenced the species composition of the tree and herb layers. Importantly, traditional management provided habitats for light-demanding species adapted to nutrient-poor soils. Furthermore, humans also modified the physical terrain and hydrology of forests by constructing woodbanks and drainage channels.

All of the above means that when modern forestry took full control of forests in the second half of the 19<sup>th</sup> century, they were already heavily modified. Nonetheless, as argued in the Introduction, such influence was of a different kind than that of modern forestry in the sense

that it completely relied on the self-renewing capacity of forests. This is a less direct form of influence than logging and replanting, however, as this thesis argues, traditional management could continue with little change for several centuries, and it is this tenacity that explains the lasting effect it has had on forests.

Despite its centuries-long history, traditional management was clearly unfit for the socioeconomic conditions that developed in the 18<sup>th</sup> and 19<sup>th</sup> centuries, which saw the emergence of modern forestry. This new system dominated forests throughout most of the 20<sup>th</sup> century. However, with the advent of the 21<sup>st</sup> century, modern forestry itself appears in need of renewal. As societies gradually redefine their relationship with forests, there is a growing recognition and appreciation of the long-term history of human influence on forests. It is my hope that this thesis contributed to a better understanding of this influence and of how the knowledge thus gained can be used to foster a balanced coexistence of humans and forests.

## 6. References

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## 7. Supplements

List of attached publications

### Paper 1:

**Szabó, P.** (2010) Driving forces of stability and change in woodland structure: A case-study from the Czech lowlands. *Forest Ecology and Management* 259: 650-656. [Q1 AIS on WoS]

Abstract: This paper presents how long-term socioeconomic processes influenced the management and structure of a lowland ancient wood in the south-eastern Czech Republic from the 14<sup>th</sup> century to the present. The analysis draws on a wide range of historical documents to establish that the size, management and structure of Děvín Wood was remarkably stable throughout the study period except for the last 60 years. It is argued, however, that the long-term stability of woodland management and structure contrasts with the multiple changes that can be observed in the driving forces behind this stability. Four kinds of driving forces are distinguished (business, need for firewood, nature conservation and forestry policy), whose various combinations maintained the coppice structure of the Wood for six centuries. It is concluded that landscape ‘stability’ and ‘change’ are highly context-dependent, and that socioeconomic driving factors are a crucial link between forest ecology and history, representing a means to understand and control current ecosystems and future changes. The paper also demonstrates that in European historical ecology it is necessary to integrate qualitative and quantitative sources in order to study periods before ca. 1800 AD, i.e. the appearance of modern quantitative sources, because societal processes have exerted their influence on landscapes much longer than 200 years.

### Paper 2:

**Szabó, P.** (2010) Ancient woodland boundaries in Europe. *Journal of Historical Geography* 36: 205-214. [Q2 AIS on WoS]

Abstract: In Western and Central Europe, many woods are clearly separated from the surrounding countryside by permanent physical boundaries. While such boundaries are now out of use, in the past they were widespread and important landscape features. This paper argues that many woodland boundaries originate from the Middle Ages and perhaps even more from the Early Modern Period. Their existence was connected to a specific form of woodland management (coppicing) but also to ownership structures and through these to grazing regimes. With their various forms, permanent woodland boundaries served to separate woodland from the surrounding countryside both in a legal and physical sense. There are four basic types of permanent woodland boundaries: woodbanks, walls, stone rows and lynchets, all of which can still be studied in the landscape today. Because of their varied state of preservation and also because of the difficulties in creating relative chronologies, dating woodland boundaries is a very challenging task. However, even a basic typology can provide valuable information for a number of scientific disciplines, including landscape history, historical geography, archaeology and ecology. Permanent woodland boundaries are a part of European cultural heritage. They should be recognised and protected similarly to all other ancient landscape features.

### Paper 3:

**Szabó, P.** (2024) It's a fair coppice: methodological considerations of the history of woodland management. In *Countryside History: The Life and Legacy of Oliver Rackham*, ed. I. D. Rotherham & J. Moody, pp. 258-270. Pelagic Publishing: London.  
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Abstract: This paper reviews the sources and methods used to detect the uses of European woodlands for the production of coppice, especially for firewood. Three main source types are distinguished: written evidence, pollen and wood. Because each type has advantages and limits, the paper argues that the best way to approach the history of coppicing is using multiple sources and lines of investigation.

#### **Paper 4:**

**Szabó, P.** & Hédl R. (2013) Socio-economic demands, ecological conditions and the power of tradition: past woodland management decisions in a Central European landscape. *Landscape Research* 38: 243-261. [Q3 AIS on WoS]

Not included in the public version of the thesis due to copyright.

Abstract: Humans have managed European landscapes, including woodlands, for millennia. Prior to the birth of modern forestry in the eighteenth and nineteenth centuries, there existed two basic management forms for lowland broadleaved woods: coppicing and wood pasture. While the existence and characteristics of these two basic management types are well-known, the reasons why particular woods were coppiced while others pastured are little investigated. As a case-study, we chose two large ancient woods in the southern Moravian region of Central Europe. One was managed as coppice, while the other as wood pasture for most of their histories. The woods are similar in size, location, climate and vegetation. We examined several potential explanations (terrain morphology, soil productivity, abundance of woodland, ownership and economy) for past management decisions in these woods. We found that the links between soil productivity, economic demands and ownership were of key importance. Other factors were less significant, for example woodland abundance played no detectable role in spite of the decreasing availability of woodland resources. We also found that tradition mattered; it took a major shift in ideology to change entire management strategies. In sum, management decisions were driven by a complex network of multiple interactions among the individual factors.

#### **Paper 5:**

**Szabó, P.**, Müllerová J., Suchánková S. & Kotačka M. (2015) Intensive woodland management in the Middle Ages: spatial modelling based on archival data. *Journal of Historical Geography* 48: 1-10. [Q2 AIS on WoS]

Abstract: Firewood played an indispensable role in European socio-economic systems from prehistory until the nineteenth century. Recent research has shown that in European temperate lowlands the most important management form to produce firewood was coppicing. In spite of the growing body of research on traditional woodland management, there remain large gaps in knowledge. Detailed studies of individual sites or smaller areas have provided a wealth of information on the methods of medieval coppicing, and at such sites the long-term effects of coppicing on vegetation structure and composition have also been examined. However, little is known about the distribution and extent of coppicing at the landscape scale, and forming a coherent picture of the spatial extent rather than the management details of coppicing in larger regions remains a challenge. This paper investigates the distribution and extent of coppice management in Moravia (eastern Czech Republic, ca. 22,300 km<sup>2</sup>) in the Late Middle Ages. We created an extensive database of written sources that contained information on the presence of coppice woods at the parish level. Subsequently we used the MAXENT algorithm to create a model of the distribution of coppicing over the entire area. With the help of wood production and consumption estimates, we also calculated the minimum area of managed woodland for the



study period. Results show that coppicing was predominant in the lowlands and often occurred at higher elevations as well, where neither natural conditions nor tree species composition were favourable. The paper also highlights the potential of spatial models based on archival data for historical landscape reconstructions.

#### **Paper 6:**

**Szabó, P.**, Šipoš J. & Hédli H. (2021) Standards versus underwood: historical patterns of tree taxon occurrence in coppice forests. *Journal of Vegetation Science* 32: e12963. [Q1 AIS on WoS]

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**Abstract:** Coppice woods were once widespread in Europe. It is usually assumed that underwood tree taxon composition was not directly influenced by people, whereas especially *Quercus* was promoted among standard trees. However, no work has quantitatively tested these assumptions. Our main question was whether there were any patterns in our data to suggest that certain trees occurred more frequently as standards than as underwood, possibly as a result of management decisions. We constructed a database covering 12,000 hectares of forests around AD 1900. We recorded the occurrence of tree taxa for standards and underwood in 1,507 compartments in 21 forest units. We visualised patterns in these data by bar graphs and chord diagrams. We analysed correlation patterns through association analysis and co-correspondence analysis. There was a statistically significant association between the occurrences of standards and underwood in individual compartments for *Quercus*, *Alnus*, *Carpinus*, *Fagus*, *Larix*, *Populus tremula* and *Tilia*. Only *Quercus* standards and underwood showed a positive association. The taxon composition of standards and underwood in forest compartments was statistically significantly correlated. No simple answer can be given to the question whether or not the taxon composition of standards and underwood in coppice woods differed as a result of management. At the level of individual tree taxa, some trees were more common as standards while others, as underwood. However, the prevalence of *Quercus* among standards was not confirmed because in our study area *Quercus* was a common underwood tree as well. At the same time, no significant differences were apparent in the taxon composition of standards and underwood in individual forest compartments. It seems difficult to differentiate between the effects of human selection and indirect selection through natural properties and environmental factors. Our results also highlight the need to carefully consider the properties of written historical sources.

#### **Paper 7:**

Müllerová, J., **Szabó, P.** & Hédli, R. (2014) The rise and fall of traditional forest management in southern Moravia: A history of the past 700 years. *Forest Ecology and Management* 331: 104-115. [Q1 AIS on WoS]

**Abstract:** European broadleaved forests have been influenced by humans for centuries. Historical management practices are related to environmental conditions but the role of socio-economic factors is also important. For the successful restoration of traditional management for conservation purposes, detailed knowledge on management history and on the driving forces of historical forest changes is necessary. In order to reconstruct long-term spatio-temporal dynamics in forest management, we chose the Pálava Protected Landscape Area, Czech Republic and analyzed archival sources spanning the past seven centuries. Forests in the study

area comprise two relatively large woods (Děvín and Milovice) with different environmental conditions. Historical forest management in both woods was coppicing. The coppice cycle was lengthened from 7 years (14th century) to more than 30 years (19th century) with a fluctuating density of standards. After WWII, coppicing was completely abandoned. This led to pronounced changes in forest age structure accompanied by stand unification indicated by a sharp decrease in the Shannon index of age diversity. To study local attributes responsible for spatial patterns in coppice abandonment, we constructed a regression model with the date of abandonment as a dependent variable and three groups of explanatory variables: (i) remoteness of forest parcels, (ii) morphometric environmental factors and (iii) site productivity. In Děvín Wood, coppicing was abandoned gradually with the pattern of abandonment related significantly to slope steepness and forest productivity. Poorly accessible upper slopes and low productive forest sites were abandoned earlier. By contrast, in Milovice Wood, where no clear topographic gradient is present, the abandonment of coppicing was not related to any of the variables we studied. Our study brings insights into the history and consequences of past management practices, and can be used in current attempts to re-establish coppice management for conservation purposes and as a source of sustainable energy.

#### **Paper 8:**

Jamrichová, E., **Szabó, P.**, Hédli, R., Kuneš, P., Bobek, P. & Pelánková, B. (2013) Continuity and change in the vegetation of a Central European oakwood. *Holocene* 23: 46-56. [Q1 AIS on WoS]

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**Abstract:** The issue of continuity in deciduous oakwood vegetation has been in the forefront of woodland ecological studies for many decades. The two basic questions that emerge from existing research are whether or not oakwoods can be characterized by long-term stability and what may be the driving forces of the observed stability or change. To answer these questions in a well-defined case study, we examined the history of a large subcontinental oakwood (Důbrava) in the southeastern Czech Republic with interdisciplinary methods using palaeoecological and archival sources. Palaeoecology allowed us to reconstruct the vegetation composition and fire disturbances in Důbrava in the past 2000 years, while written sources provided information about tree composition and management from the 14th century onwards. The pollen profiles show that the present oakwood was established in the mid-14th century with an abrupt change from shrubby, hazel-dominated vegetation to oak forest. This change was most probably caused by a ban on oak felling in ad 1350. From the 14th to the late 18th centuries Důbrava had multiple uses, of which wood-pasture and hay-cutting kept the forest considerably open. The second remarkable change was dated to the late 18th century, when multiple-use management was abandoned and Důbrava was divided into pasture-only and coppice-only parts. The last major shift occurred in the mid-19th century, when modern forestry and Scotch pine plantation became dominant. We conclude that Důbrava Wood did not show stability in the long run and that its species composition has dramatically changed during the last two millennia. The most important driving force in the shaping and maintenance of the unique vegetation of Důbrava was human management.

#### **Paper 9:**

**Szabó, P.** (2023) The Horka litter raking incident: On foresters and peasants in nineteenth-century Moravia. *Environment and History* 29: 323-343. [Q2 AIS on WoS]

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**Abstract:** Litter raking was a traditional forest use representing an interface between forestry and agriculture. In forest history, it has usually been presented as the harmful removal by peasants of biomass, which was gradually eliminated by foresters, leading to better forest preservation. Based on the example of an exceptionally well-documented case of illegal litter raking in Moravia in 1845, in this paper I argue that juxtaposing foresters and peasants in connection with litter raking masks a much more complicated reality. Neither foresters nor peasants can be interpreted as homogeneous groups because there were significant differences in the opinions and agendas of various representatives within these groups. In addition, opinions were not static on either side but could change in a discursive pattern. In a wider context, the environmental historical analysis of the Horka litter raking incident facilitates the understanding of larger societal processes that influenced past woodland management in Central Europe, and therefore current ecosystems too.

#### **Paper 10:**

**Szabó, P.,** Diniz, É. S. & Houška, J. (2024) Traditional agroforestry on forested land: a comprehensive analysis of its distribution pattern in the 19th century. *Agroforestry Systems* 98: 115-127. [Q2 AIS on WoS]

**Abstract:** Traditional agroforestry on agricultural land was common in the past in Central Europe. However, much less is known about agroforestry on forested land, especially because it was often banned by forestry authorities during the 20th century. We used data from the so-called stable cadastre to map the occurrence of agroforestry uses (litter raking, hay cutting and forest grazing) on forested land in the mid-19th century in Moravia (eastern part of the Czech Republic, ca. 27,000 km<sup>2</sup>) in high spatial resolution. We combined machine learning algorithms and logistic models to reveal which environmental, land use and forest management factors could be linked to the occurrence of individual agroforestry uses. Results showed that agroforestry on forested land was very common in the 19th century: only 9.2% of townships with forests had no agroforestry uses. The distribution of agroforestry uses was clearly connected to environmental factors and to the availability of agricultural products that agroforestry uses were meant to supplement (e.g. hay cutting in forests was the most common in townships with large forests and few grasslands). However, the ubiquity of some uses (especially litter raking) made it more difficult to arrive at straightforward conclusions. In addition, we discussed the limitations inherent in the stable cadastre and how these might influence the interpretation of the results.

#### **Paper 11:**

Vild, O., Šipoš, J., **Szabó, P.**, Macek, M., Chudomelová, M., Kopecký, M., Suchánková, S., Houška, J., Kotačka, M. & Hédli, R (2018) Legacy of historical litter raking in temperate forest plant communities. *Journal of Vegetation Science* 29: 596-606. [Q1 AIS on WoS]  
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**Abstract:** European temperate forests have been managed for millennia, and this management has left a long-lasting legacy in soil chemistry and plant species composition and diversity. One of the most common practices was the raking of leaf litter, which was used as bedding for farm animals. We asked, what is the legacy of historical litter raking for contemporary forest plant communities? We explored the effect of historical litter raking on species richness and diversity of the forest herbaceous layer. We also tested whether long-term soil acidification and nutrient depletion caused by litter raking were reflected in Ellenberg indicator values for nutrients and soil reaction and in the higher abundance of specialists of acidophilous forest types. We used written historical evidence to identify areas where litter raking was practised in the 19th century.

We analysed the differences between vegetation plots located in areas affected and unaffected by the past litter raking. Our analysis included almost 2,500 vegetation plots recorded between 1980 and 2015. Litter raking was historically practised in a striking 85% of forested townships. Although litter raking had no significant effect on overall species richness, we found significant differences of diversity patterns among forest types. Historically raked plots were taxonomically more similar. We found no difference in the mean Ellenberg indicator values for soil reaction and nutrients between the affected and unaffected plots, and only a weak positive response of selected herb species of acidophilous forests. We provide the first empirical evidence of the historical litter-raking legacy in forest communities on a large scale. Despite its historical frequency, we found only a weak legacy of historical litter raking in present-day plant communities. Future studies could potentially use other, finer-scale methods in smaller territories to complement our results.

#### **Paper 12:**

Kolář, T., Dobrovolný, P., **Szabó, P.**, Mikita, T., Kyncl, T., Kyncl, J., Sochová, I. & Rybníček, M. (2021) Wood species utilization for timber constructions in the Czech lands over the period 1400-1900. *Dendrochronologia* 70: 125900. [Q1 AIS on WoS]

Abstract: Longstanding demographic growth accompanied by rising settlement activities and development of industry led to an increasing demand on utilization of wood. Tree species were selected for their specific properties. As a consequence of regional differences of forest species composition, wood has become an extremely important trade commodity. Therefore, the utilization of individual species could substantially change in space and time. In this study, we use 8135 precisely dated timber constructions from a dendrochronological database to investigate spatiotemporal changes in wood utilization across the Czech lands from the 15<sup>th</sup> to the 19<sup>th</sup> century. Our results suggest that the utilization of individual species in historical timber constructions was primarily limited by their availability. Species selection was also based on wood properties and stem geometry. Most of historical constructions (99.7%), represented mainly by roofs and ceilings, are made of fir, spruce, pine, and oak. While fir constructions prevail in eastern Moravia and Silesia, spruce constructions are largely spread across the western and central part of the Czech Republic. Pine and oak constructions reflect natural occurrence of such forests in lower elevated central Bohemia and southern Moravia. Although fir prevailed in timber construction in the late-Medieval and post-Medieval times, planting of spruce monocultures resulted in its significantly increased utilization by the end of the 19<sup>th</sup> century. This study demonstrates the value of dendrochronological databases as an indicator of historical wood utilization.

#### **Paper 13:**

**Szabó, P.**, Dobrovolný, P., Kolář, T., Rybníček, M., Kyncl, J. & Kyncl, T. (2025) Local timber dominated pre-industrial construction: Insights from archival and dendrochronological data. *Dendrochronologia* 91: 126337. [Q1 AIS on WoS]

Abstract: In pre-modern Europe, timber was notoriously difficult and costly to transport on land, therefore it is usually assumed that ordinary buildings – except for those close to navigable watercourses – were constructed using timber from local sources. We hypothesized that species of timber used in constructions prior to the late 19th century were commonly available in forests within a short distance from the location of the constructions. To test this hypothesis, we compared high-resolution archival information on the tree species composition of forests in Moravia (eastern Czech Republic, ca. 27,000 km<sup>2</sup>) in the 18th and 19th centuries to a database of 1231 dated timber constructions in the same region and period. Our analysis was based on

the mutual distances between the locations of timber constructions and the occurrences of forests with the given tree species. We compared real distances with distances obtained through random simulations. Results showed that in more than half of the cases, the tree species from constructions occurred in the forests of the same township. In the rest of the cases, the modal distance values to the centroid of the nearest township where the same species was present in the forests were usually less than two kilometres and distances larger than five kilometres were generally rare. While our results testify to the availability of timber rather than to the direct source of particular pieces of timber, they strongly suggest that timber was usually sourced locally. We believe our interdisciplinary study demonstrated the usefulness of archival data in the research of timber sourcing. For future studies, we see the combination of our approach with dendroprovenancing and other natural scientific methods as the most promising way to gain deeper knowledge on the sourcing of timber.

#### **Paper 14:**

Kolář, T., Dobrovolný, P., **Szabó, P.**, Mikita, T., Kyncl, T., Kyncl, J., Sochová, I., Flídr, A., Merta, D. & Rybníček, M. (2022) Effects of social and climatic factors on building activity in the Czech lands between 1450 and 1950: a dendrochronological analysis. *Journal of Quaternary Science* 37: 123-132. [Q2 AIS on WoS]

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**Abstract:** The development of settlement and building activity is the result of socioeconomic, political and demographic changes in the past. However, accurate information on temporal variation in building activity is rather limited. Dendrochronological databases containing dated historical wooden constructions provide an important resource. We used 6514 tree-felling dates to reconstruct building activity in the Czech lands for the period 1450–1950. Comparing felling dates with historical events demonstrated that building activity was negatively associated with intense wars, particularly during the Thirty Years' War (1618–1648). After the Peace of Westphalia (1648), socioeconomic renewal and demographic growth were reflected in an upsurge of building activity, especially ecclesiastical buildings. While the construction of ecclesiastical and noble buildings culminated around the 1720s, rural buildings peaked in the 1780s and the 1820s. Although no direct effect of climate was demonstrated, adverse climatic conditions leading to harvest failures and subsequent famines (e.g. the 'Hunger Years' 1770–1772) significantly contributed to declines in building activity. In contrast, a higher number of felling dates were detected when strong and/or frequent windstorms occurred. This study provides a comprehensive understanding of building activity in Central Europe and advocates the use of dendrochronological databases for the investigation of human activities in history.

#### **Paper 15:**

Müllerová, J., Hédl, R. & **Szabó, P.** (2015) Coppice abandonment and its implications for species diversity in forest vegetation. *Forest Ecology and Management* 343: 88-100. [Q1 AIS on WoS]

**Abstract:** Coppicing, once a common type of management in European broadleaved forests, was abandoned in many places after WWII. This form of management provided a variety of structural and microclimatic conditions for tree and understorey vegetation. After the abandonment of this intensive management, succession towards mature close forests ensued, and suitable habitats for species ecologically connected to coppicing were reduced. In our study, we chose a region in central Europe where coppicing was the dominant type of forest management until the first half of the 20th century but was abandoned after WWII. We investigated long-term changes in both woody and herbaceous species composition in the

Lower Morava UNESCO Biosphere Reserve using historical sources and vegetation plot resurveys from the 17th to the 21st century. The impact of coppice abandonment on vegetation composition and on the conservation value of forests was evaluated. Dominant tree species appeared to be very stable throughout the past four centuries, but changes occurred in their proportions. A shift from species rich oak–hornbeam woodland towards species poorer communities with increasing proportions of lime, ash and maple was observed after the abandonment of coppicing. The observed tendencies partly differed according to site and data source. The conservation value of forests was measured as the occurrence of red-list species, which were considerably reduced after coppice abandonment. To stop the process of biodiversity loss and support the goals of nature conservation, the re-establishment of coppice management is proposed.

#### **Paper 16:**

**Szabó, P.**, Gálová, A., Jamrichová, E., Šumberová, K., Šipoš, J. & Hédli, R. (2017) Trends and events through seven centuries: the history of a wetland landscape in the Czech Republic. *Regional Environmental Change* 17: 501-514. [Q1 AIS on WoS]  
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**Abstract:** Environmental change can be viewed as the combined result of long-term processes and singular events. While long-term trends appear to be readily available for observation (in the form of temporal comparisons or space-for-time substitution), it is more difficult to gain information on singular events in the past, although these can be equally significant in shaping ecosystems. We examined the past 700 years in the history of a lowland wetland landscape in the Czech Republic with the help of palaeoecological, ecological, landscape archaeological, and archival data. Macrofossil and pollen data were compared to known drainage works in the area and historical climatological data. Trends and events in habitat conditions were assessed using species indicator values. Results showed that ecological succession was the general process in the study area, detected as a trend towards eutrophication, desiccation, and vegetation closure. Short-term events influenced development at the sites mainly from the second half of the nineteenth century. This is consistent with drainage history, although bias related to sample frequency cannot be excluded. On the whole, long-term trends and discrete events were complementary on different scales. We conclude that humans facilitated and accelerated background processes, which can be most likely associated with the succession of open wetlands towards terrestrial ecosystems.

#### **Paper 17:**

**Szabó, P.** (2020) Traditional woodland management, forest legislation, and modern nature conservation in east-central Europe. In *Conservation's Roots: Managing for Sustainability in Preindustrial Europe, 1100–1800*, ed. Dowling A. & Keyser R., pp. 304-326. Berghahn: New York & Oxford.

**Abstract:** This paper examines the historical development of woodland management in east-central Europe and its relationship to forest legislation and contemporary nature conservation. Focusing on the long-term interaction between human societies and forest ecosystems, the paper explores traditional practices such as coppicing, wood pasture, and multifunctional woodland use prior to the rise of modern scientific forestry in the eighteenth and nineteenth centuries. It argues that preindustrial woodland management systems were often adaptive, sustainable, and closely integrated with local economic and social structures. It further analyses how centralized forest legislation gradually transformed these customary practices, promoting timber-oriented forestry while marginalizing traditional forms of land use. The consequences

of these changes are traced into the modern era, particularly in relation to biodiversity conservation. By combining environmental history with conservation science, the chapter demonstrates that many habitats currently valued for their ecological richness are products of centuries of human management. The study highlights the importance of historical knowledge for contemporary conservation strategies and advocates for a more nuanced understanding of cultural landscapes in east-central Europe.

**Paper 18:**

Kozdasová, A., Galčánová Batista, L., Hédli, R. & **Szabó, P.** (2024) Coppice reintroduction in the Czech Republic: extent, motivation and obstacles. *European Journal of Forest Research* 143: 305-317. [Q1 AIS on WoS]

Abstract: Coppicing is a form of forest management in European broadleaved forests. While it is still practised in south-eastern Europe, in central and western Europe it was almost completely replaced by high forest management. Currently, there are increasing efforts to reintroduce coppice management into former coppice woods. However, little comprehensive knowledge is available about the extent and management of coppice reintroduction and the processes governing it. In this paper, we present an overview of localities in the Czech Republic where coppice reintroduction was taking place in 2020. We identified 8 localities and conducted 10 semi-structured interviews with experts involved in their management in order to understand what motivated them to restart coppicing and what obstacles they have had to face. The main motivation of site managers is nature conservation, while the most important obstacles are operational issues, such as bureaucracy, complicated land ownership and legal responsibilities or lack of workforce. Other motivating factors identified in other European countries (production of a renewable energy source and potential for rural employment) have so far played a minor role in the Czech Republic. We conclude that a major challenge for future forest policies will be to utilise the economic experiences of regions with active coppicing to foster the spread of coppice woods in order to combine renewable energy production with biodiversity conservation.



# Driving forces of stability and change in woodland structure: A case-study from the Czech lowlands

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## ARTICLE INFO

### Article history:

Received 14 October 2009

Received in revised form 13 November 2009

Accepted 17 November 2009

### Keywords:

Woodland management

Forest structure

Historical ecology

Driving forces

Coppicing

## ABSTRACT

This paper presents how long-term socioeconomic processes influenced the management and structure of a lowland ancient wood in the south-eastern Czech Republic from the 14th century to the present. The analysis draws on a wide range of historical documents to establish that the size, management and structure of Děvín Wood was remarkably stable throughout the study period except for the last 60 years. It is argued, however, that the long-term stability of woodland management and structure contrasts with the multiple changes that can be observed in the driving forces behind this stability. Four kinds of driving forces are distinguished (business, need for firewood, nature conservation and forestry policy), whose various combinations maintained the coppice structure of the Wood for six centuries. It is concluded that landscape 'stability' and 'change' are highly context-dependent, and that socioeconomic driving factors are a crucial link between forest ecology and history, representing a means to understand and control current ecosystems and future changes. The paper also demonstrates that in European historical ecology it is necessary to integrate qualitative and quantitative sources in order to study periods before ca. 1800 AD, i.e. the appearance of modern quantitative sources, because societal processes have exerted their influence on landscapes much longer than 200 years.

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## 1. Introduction

European woodlands have been directly influenced by human activities for at least 8000 years (e.g. Rackham, 2003; Billamboz, 2003; Haneca et al., 2005; Summers et al., 2008; Plue et al., 2008; Johann, 2004; Bradshaw, 2004; Gardner, 2002; Pott, 1993). As a consequence, knowledge of the long-term history of human impacts is essential to understanding the ecology of present-day forests. The first ecologically oriented studies of woodland history appeared approximately 40 years ago (e.g. Tubbs, 1968), and in the decades that followed, many studies aimed at analyzing one of the numerous aspects of human-nature interactions in wooded landscapes (e.g. Rackham, 1975, 2003; Kirby and Watkins, 1998; Johann, 2007; Honnay et al., 2004; Agnoletti and Anderson, 2000; Warde, 2006a; Fritzboeger, 2004; Smout et al., 2005; Szabó, 2005). Such research is necessarily interdisciplinary, because it involves data and methods from the humanities as well as the natural sciences (Bürgi and Russel, 2001).

Although considerable amounts of material are available on the history of woodland clearance and management both on a local

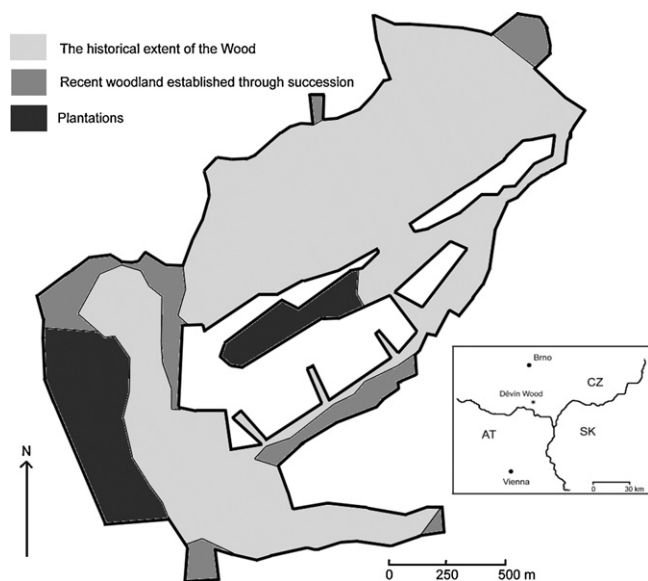
and a wider scale (Warde, 2006b; Williams, 2000), some of the key issues connecting forests and the societies that managed them have so far received less attention. Such a key issue is the question of socioeconomic driving forces of woodland management and structure (Bürgi, 1999; Bürgi and Schuler, 2003). Throughout European history, people used various management forms to produce the kinds of trees they needed for specific purposes. As their needs changed through time, so did the forms and extent of forest management. Although local environmental conditions and vegetation had to be respected, which management form was chosen in a particular wood in a given historical period almost entirely depended on woodland owners and managers. The driving forces behind the choices between the various management forms were deeply rooted in society, and they had and continue to have a huge impact on forest structure and consequently on species composition. Exploring and analyzing these driving factors not only allows for a better understanding of current forest ecosystems but also helps to develop forestry management techniques that can function in a sustainable manner in the current socioeconomic conditions.

This paper is based on a case-study of the changes and stability of management forms in a Czech ancient wood in the past 650 years. My main aims are to establish the size of Děvín Wood in different historical periods, and to ascertain how it has been

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**Fig. 1.** Map of Děvín Wood. The historical boundaries of the Wood are also indicated by woodbanks and lynchets. Areas left blank are steppes and cliffs inside the Wood.

managed since the 14th century. Based on these results, I examine the historical socioeconomic context to determine the possible driving forces behind the management forms in different periods and I also try to find out why various systems of driving forces replaced each other. With few exceptions (e.g. Verheyen et al., 1999; Rackham, 2003), existing historical ecological studies of particular woods cover shorter time periods (100–200 years). In a wider methodological context, this paper is also an attempt to bridge the disciplinary gap between history and forest ecology for a longer time series including the European Middle Ages and Early Modern Period, in which quantitative datasets routinely used by historical ecologists are often not available.

## 2. Study area

Děvín Wood lies on top of a small but conspicuous hill (550 asl) in the otherwise flat south-eastern part of the Czech Republic, 35 km south of Brno and 75 km north of Vienna in Austria (Fig. 1). The Wood covers an area of ca. 260 ha in the north-western tip of the Pannonian biogeographical region. The forest vegetation comprises xerothermic oak communities (*Quercion pubescentis-petraeae*), thermophilous to mesophilous oak-hornbeam forests (*Carpinion*), and ravine forests dominated by large-leaved lime (*Tilio-Acerion*) (Hédl and Rejšek, 2007). Small-scale black pine (*Pinus nigra*) and turkey oak (*Quercus cerris*) plantations are also present.

From the 13th to the 20th centuries, Děvín Wood belonged to the estate (a group of more or less contiguous settlements usually governed from a local central place) of the neighbouring town of Mikulov, which included ca. 15 settlements and was one of the most significant estates in Moravia. Until their partial dissolution in the mid-19th century, such estates were complete little worlds in themselves. The village tenants directly depended on the overlord, who also had legal authority over them. All decisions regarding the estate woodlands, including Děvín Wood, were made by the Mikulov overlords. The Wood, then, can only be interpreted within the larger context of the Mikulov estate. In the 13th to 16th centuries, the overlords of Mikulov were the Lichtenstein. They then sold the estate, which changed hands several times, and finally in 1570s ended up in the possession of the Dietrichstein

family (Řezníček, 1966). They possessed it until after WW II, when – similarly to all other noble estates – it was confiscated and nationalised by the emerging Communist regime. Today, Děvín Wood is state-owned and forms part of the Pálava Landscape Protection Area, a UNESCO Biosphere Reserve and the NATURA 2000 network. It is a strict reserve with – in theory – very few activities allowed, however, forestry operations have never ceased completely. Děvín is also a popular tourist destination with hikers swarming on the slopes every summer weekend.

## 3. Materials and methods

Modern forestry with its extensive bureaucratic procedures and large-scale document production appeared in the study region ca. 200 years ago. As a result, for the last two centuries detailed surveys are available about the management, structure and size of Děvín Wood. From before that time, information on woodland is nearly always secondary in the sense that it was produced for some other purpose than describing forests. Most available documents are parts of surveys that were intended to establish the income available to the landowner from various sources including woods. Source criticism, the most fundamental method of historical sciences, is therefore essential in assessing the information contained in the sources. We have to know who produced the documents, to what purpose and, in consequence, how reliable they are.

In this study, the following types of sources have been used:

- (i) *Urbaria* (singular *urbarium*) that is, conscriptions of all incomes from an estate. The main concern of *urbaria* was the conscription of tenants and the dues they had to pay for using the land they farmed. Woodlands appear in these documents in two forms: either as land managed directly by the overlord or as land leased to the peasantry. In the former case the income was generated by wood sales (Keyser, 2009), in the latter, by the lease money paid by the villages. *Urbaria* were conducted in the Czech Lands from the 13th to the 19th centuries, when the former bondage between overlords and peasants was finally abolished and peasants became the owners of their land. Seven *urbaria* survive that provide relevant information about the Mikulov estate. These date from 1414 (Bretholz, 1930), two from 1560 (MZA F18 inv.č. 6792, 6793; analysed in Řezníček, 1966), 1574 (MZA F18 inv.č. 6794), 1579 (MZA F18 inv.č. 7703), 1590 (MZA F18 karta 1250) and 1629 (MZA F18 karta 1250; analysed in Kryčer, 1954).
- (ii) *Early woodland surveys* are documents produced by woodland managers prior to the birth of modern forestry. They are less detailed than later surveys but have the advantage (or disadvantage) of not being formulaic. This makes them difficult to compare, however, they often contain unusual bits of information. In this study, I have used a source that surveyed all woods in the Mikulov dominium in the year 1692 (MZA F18 inv.č. 7679). Included in this survey are names of woods directly managed by the estate, number of woods leased to the tenants, kinds and numbers of standard trees in each wood and coppice cycles.
- (iii) *Account books* were kept by woodland owners to register incomes generated by the cutting and selling of underwood and timber. In the Czech Lands, account books for individual woods are available from the 15th century onwards (Šimůnek, 2004). For the Mikulov estate, a continuous series of woodland account books survives from 1685 to the 20th century (MZA F18 inv.č. 10362–10598, F72 inv.č. 3353–3429). These record not only sales, but also the amount of underwood and timber harvested as well as the number of

- fathoms (German *Klafter*, a volume measure for underwood) and timber trees distributed without payment within the estate.
- (iv) *Cadastrs* are nationwide surveys of land-use types and tenure for taxation. Different land-uses were given different values, based on which the owner's taxes were established. In the Czech Lands, there are three sets of cadastrs theoretically recording all land: the so-called Theresian Cadastre (mid-18th century), the Josephian Cadastre (1780s), and the Stabile Cadastre (mid-19th century) (Pekař, 1915; Hradecký, 1956; Brůna et al., 2005).
  - (v) *Forestry management plans* are detailed surveys containing information on the name, size and position of each woodlot (Bürgi, 1999), as well as on tree composition and forest structure, supplemented by present and future management. Modern forestry appeared in the study region in 1807–1808, when a survey of all woods on the Mikulov estate was ordered with the aim of reforming existing management (MZA F72 karton 1125). At this time management was planned for a 30-year cycle, which would have meant three further surveys in the 19th century. These, however, were most probably never completed. Management plans started to be compiled again in 1847–1848. The one made in 1863 was still used by the authors of the 1905 survey, however, the earliest surviving management plan dates from 1885 (MZA F72 karton 1128). Unlike the 1808 survey, this was already prepared by filling in pre-printed forms and contains the same information as all management plans until 1996. After 1885, surveys were conducted in 1901, 1905 (both MZA F72 karton 1128), 1925, 1935, 1948 and 1971 (MZA F72 kniha 113, 116, F121 kniha 5, 31, respectively).
  - (vi) *Large-scale maps* (ca. 1:30 000 and larger) started to be produced in the Czech Lands in the 17th century (Roček, 2001), and are more generally available from the 18th century onwards. The best-known examples are the three nationwide surveys prepared by the Austrian Army in 1764–1783, 1836–1852 (both 1:28,800) and 1876–1880 (1:25,000) (available online at <http://oldmaps.geolab.cz>). A much more detailed (1:2880) set of maps were drawn in 1824–1843 as part of the above-mentioned Stabile Cadastre. As the specific purpose of these was recording land-use types, they are especially useful in historical landscape ecological studies (Bičík et al., 2001). In addition to these overall surveys, many large-scale maps depict individual estates or parts thereof. For the study of woodland history, the most useful are maps produced as parts of forestry surveys. These routinely record names and areas of woodlots as well as main tree species and soil conditions. For the study area, the earliest large-scale map is dated to 1675, when the whole Mikulov estate was surveyed (MZA F18 mapa 12). Many forestry maps are available from the late 18th century onwards. Especially useful are those prepared as part of the 1807–1808 survey (MZA F18 mapa 18, 27).
  - (vii) *Aerial photographs* are standard tools in landscape ecological research. Where older as well as recent photos are available, these are often compared to establish changes or stability in various plant communities, or indeed in any other landscape unit (Müllerová et al., 2005; Rango et al., 2008). For the Czech Republic, the earliest aerial photographs are available from the late 1930s. Děvín Wood has a complete set of these historic photographs from the year 1938, which provide valuable information on forest structure.
  - (viii) *Permanent linear woodland boundaries* are physical landscape features that were created in the past to mark the boundary

between woodland and the surrounding countryside. The typical European woodland boundary is a bank and a ditch, but other forms (wall, lynchet, stone row) are also possible (Rackham, 2006). Děvín Wood is surrounded by woodbanks and lynchets (terrace-like structures between woodland and farmland created by ploughing, which moves the soil downhill on the farmland side).

Information in the sources about the size of the Wood presents few difficulties, because the measurements easily translate into modern hectares. Data on woodland management and structure are also relatively straightforward. In Děvín Wood (similarly to many other lowland broadleaved woods), basically two types of structure can be differentiated: coppice and high-forest. In the *coppice* system, trees after cutting regenerate vegetatively by growing shoots either from the stool (the part of the tree that remains in the ground) or from the root-system. The same tree can be cut – normally on a short rotation of 10–30 years – many times without losing its ability to grow new shoots. A coppice wood produces small poles in large quantities. These are used mostly as fuelwood. *High-forests*, on the other hand, consist of standard trees that grow from seed and have one, clearly discernable trunk. Such timber trees are generally used as building material. Coppice woods and high-forests can be combined into a form that is called *coppice-with-standards*. Here coppice stools are topped by a layer of taller standard trees.

The interpretation of the results is carried out through the examination of the basic socioeconomic processes that affected woodland management in the study region. These processes are mapped based on the study of the primary sources. As remarked by Bürgi and Schuler (2003), such research must necessarily involve “the combination of traditional data driven approaches with the construction of a narrative,” that is, with what is acknowledged as one of the most basic tools in history to establish possible causal relationships (Cronon, 1992; Munslow, 2007).

## 4. Results

### 4.1. Extent of woodland

Data show that Děvín Wood has changed remarkably little since the late 17th century and probably earlier (Fig. 2). Although the 1414 *urbarium* gives no information about acreages, the woodlots mentioned therein seem to cover the area of the present Wood. The 1675 map shows the Wood basically as it is today. The first survey that provides exact measurements is from 1750 (MZA F18 inv.č. 7607), and the size of Děvín Wood recorded here (211 ha) is almost

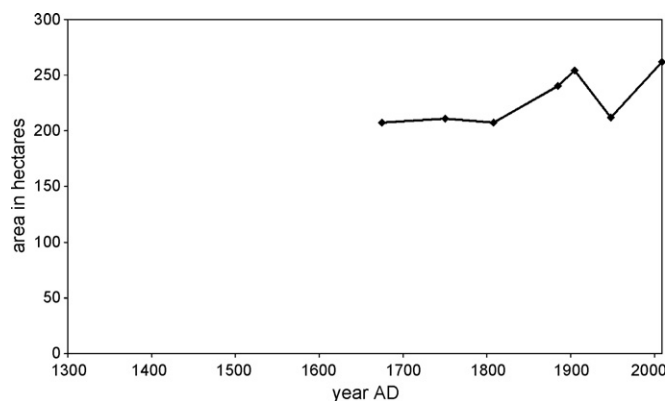


Fig. 2. The size of Děvín Wood through history. The little, non-quantitative material available from before the 17th century suggests that the size of the Wood was the same since the 14th century.

exactly the same as the one given in 1948 (212 ha) (MZA F121 kniha 5). That this was a historically stable size is further supported by the fact that the woodbanks and lynchets that surround the Wood also enclose the same ca. 210 ha (Fig. 1). After 1807–1808, detailed maps and forestry management plans are available (for references, see Section 3). These show some fluctuation with values up to the current 260 ha.

#### 4.2. Woodland management and structure

The management of Děvín Wood was very stable from the 14th to the 20th centuries until after WW II. Except for the last 60 years, the whole Wood was managed as coppice (or coppice-with-standards). In 1946, it became part of a non-intervention nature reserve, and since that date cutting was theoretically not allowed. Reality, however, was more complicated. Some of the Wood (mostly the steeper slopes with rocky soils) has not been cut for 90 or more years. In other parts coppicing continued until a decade ago. Finally, on large areas coppice stools were singled out to achieve a 'more natural' high-forest structure (Table 2). This means that coppice stools have been gradually disappearing either through singling out or through dying out in very old stands. As a result, it is impossible to say exactly how much of the Wood still retains its coppice structure, but I would estimate the amount to be between one third to half of the total area. Planting trees, a method of modern forestry to create high-forests, was introduced to Děvín Wood in the 1880s. However, the trees (black pine and turkey oak) were planted not in the existing Wood, but rather next to it on a few dozen hectares of former pastures.

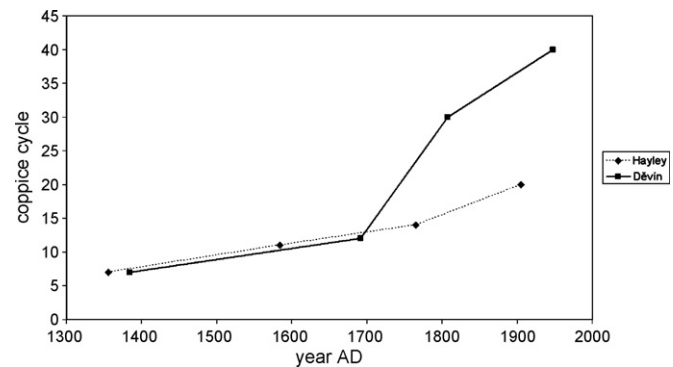
Within the stable coppicing system, there are two factors that affected the structure of Děvín Wood: the length of the coppice cycle and the presence of standard trees. The 1414 *urbarium* (in which the woodland survey dates from 1384) informs us that in the late 14th–early 15th centuries the Wood was managed on a coppice cycle of 7 years. We also know that this very short cycle was rigorously observed, because the *urbarium* gives the actual ages of individual coppice stands as well. Standards were not mentioned in the source.

In 1692, the coppice cycle in Děvín Wood was 12 years, and there were ca. 100 standard trees. By 1808, the coppice cycle grew to 30 years, except for ca. 17 ha on the western side of the wood, where it remained 13 years (this had to do with this part of the Wood being leased to the tenants rather than managed by the estate.) At this moment, there were altogether 6779 standard trees, that is, almost seventy times more than at the end of the 17th century. In 1885, 1905 and 1925 the coppice cycle was still 30 years, but by 1948 it was further extended to 40 years. The difference in the length of the cycle between the originally demesne (i.e. managed directly by the estate) and leased parts disappeared in the 19th century. The management plans available for the late 19th and early 20th centuries unfortunately did not record the number of standard trees in the Wood. In the 1938 aerial photograph, however, standards are clearly visible in the newly cut ca. 20 ha. Their density at this point was approximately 13 trees/ha (Table 1). As for the coppice cycle, we can see a definite tendency from short to longer cycles through the centuries (Fig. 3).

**Table 1**

Number of standard trees per hectare in Děvín Wood. NB: That there were no standard trees in the Middle Ages is implied but not explicitly stated in the available source.

| Year AD                         | 1384 | 1692 | 1808 | 1938 |
|---------------------------------|------|------|------|------|
| number of standards per hectare | 0    | 0.5  | 33   | 13   |



**Fig. 3.** The lengthening of the coppice cycle in Děvín and Hayley Woods. The values are almost identical except for the last two centuries, when in Děvín the cycle got considerably longer. Note that the two Woods are ca. 1300 km from each other. Hayley data are based on Rackham (1975).

## 5. Discussion

### 5.1. Forest size and management

Generally speaking, Děvín Wood was characterised by remarkable stability from the 14th to the 20th centuries both in terms of its size and its management. The apparent growth in the area it covers results from two processes. On the one hand, plantations were established on the south-western side and central plateau from the 1880s on. On the other hand, some of the surrounding pasture, farmland and vineyards were invaded by woodland vegetation, especially in the deep valley that separates the two ridges of the Wood. The plantations, however, were not immediate and straightforward successes. Although now they are indeed wooded, this is the result of a long process with its ups and downs. Whether these more or less successful plantations were included in the total forest area in any given survey depended on the arbitrary choices of foresters. This explains the apparent fluctuation in woodland size in the 20th century (Fig. 2): the 1948 surveyor, as opposed to his colleagues before and after him, decided that the plantations did not deserve to be called woodland.

As far as the management of the Wood is concerned, the 20th century contrasts with earlier periods not only because the prevailing management changed, but also because woodland management and structure became more diverse (Table 2). One question we have to face is to what extent this might be only an illusion resulting from the diversification of sources. If future investigators of the site were to have only the official policy of the nature reserve at their disposal, they may indeed think that no cutting took place in the Wood in the second half of the 20th century. I do not, however, think that in the Middle Ages and Early Modern Period management was more complicated than what the results suggest. The sources at our disposal are workaday documents: they were intended to record everyday realities rather than official policies.

As mentioned above, variation entered coppice management through the changing number of standard trees and the lengthening of the coppice cycle. Data presented in Table 1 on the number of standards are fraught with difficulty for two reasons. First, it was not defined in any of the datasets how big a sapling had to be to be counted. Second, evidence from other countries (Rackham, 2003; Warde, 2006a) shows that standards were not as regularly managed as coppice underwood, therefore the fluctuation in yearly numbers could be substantial. On the other hand, the 1692 and the 1808 surveys in general show low and high values, respectively. Data from early modern England and Germany (Rackham, 2003; Warde, 2006a; Bub, 2003) indicate average values of around 50 standards per hectare, which is

**Table 2**

The management and structure of Děvín Wood in different periods, and the underlying socioeconomic driving forces.

| Period              | Management                                               | Woodland structure                                                    | Driving force     |          |                     |                 |
|---------------------|----------------------------------------------------------|-----------------------------------------------------------------------|-------------------|----------|---------------------|-----------------|
|                     |                                                          |                                                                       | Need for firewood | Business | Nature conservation | Forestry policy |
| Middle Ages         | Coppicing                                                | Coppice                                                               | X                 | X        |                     |                 |
| Early Modern Period | Coppicing and standards                                  | Coppice-with-standards                                                | X                 |          |                     |                 |
| 20th century        | Coppicing and standards, non-intervention, tree-planting | Coppice-with-standards, overgrown coppice-with-standards, high-forest |                   | X        | X                   | X               |

considerably higher than anything recorded for Děvín. The lengthening of the coppice cycle is not a unique feature of Děvín Wood. It is well documented for England (Rackham, 2003), and was probably similar in other European countries as well (Johann, 2008; Warde, 2006a), though continuous series for individual woods have hardly ever been published. For comparison, the values for Hayley Wood (Essex, UK) are shown in Fig. 3. To date, the reasons behind this apparently universal change are practically unknown, but are unlikely to be confined to individual woods.

## 5.2. Socioeconomic driving forces

Even though the size and management of Děvín Wood was stable for six centuries, the driving factors behind this stability need not have been stable themselves. The societal context in which the Wood functions has gone through many obvious changes since the Middle Ages, all of which may have affected why local woodland managers chose to maintain the coppicing system. Based on Brandt et al. (1999), Bürgi et al. (2004) identify five types of driving forces behind landscape change: socioeconomic, political, technological, natural and cultural. While this is certainly a useful theoretical model, real-life phenomena tend to be complex and difficult to categorise. It is especially hard to tell socioeconomic, political and cultural driving forces apart, since these notions often represent various aspects of the same phenomenon. In this paper my main focus is the socioeconomic aspect of the complex cluster of driving forces behind the long-term stability in the woodland management and structure of Děvín.

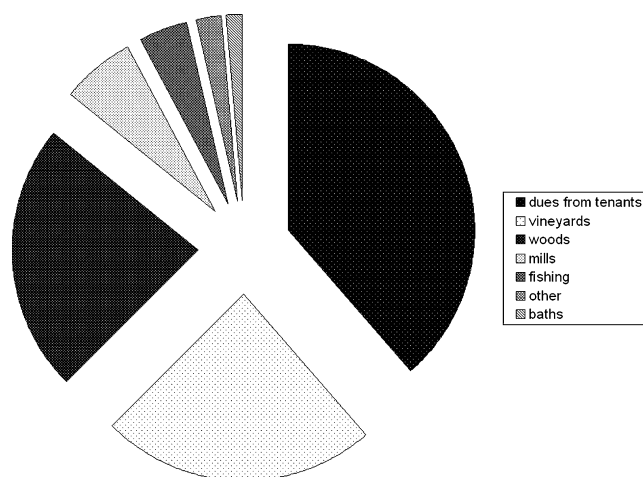
### 5.2.1. The Middle Ages

In the study region, firewood was the only available fuel until the fossil fuel age. Until the 16th century, access to firewood was market-based: all wood from Děvín was sold to the tenants in nearby villages. Selling firewood was lucrative business. In 1414, the Mikulov estate had three major sources of income. The most significant was dues from tenants in money, which provided ca. one third of the total amount. The second and third places, responsible for one fourth each, were occupied by vineyard tithes and coppice sales (Fig. 4). The central position of coppices in contemporary economy can be explained by two factors. First, as convincingly depicted in the 1414 *urbarium* (Bretholz, 1930), the southern Moravian countryside in the 14th–15th centuries was very little wooded. The limited availability of firewood probably kept its price reasonably high. Second, the overlords in Mikulov had complete control over the woods: they could cut and sell as they pleased. Tenants had no rights to firewood or timber, let alone grazing or other alternative uses, at least so it seems from the very detailed *urbarium*, which makes no mention of such things. This resulted in a situation where the Lichtenstein woodland administration could maintain a very intensive 7-year coppice cycle (there was no common grazing to make this complicated) and sell the huge amounts of firewood produced at a good market price. The apparent lack of standard trees in the Wood could also be explained by the woodland managers' efforts to keep firewood production at a maximum.

### 5.2.2. The Early Modern Period

Some time around 1500 the medieval arrangement on the Mikulov estate changed. Our first sources depicting the new situation date from 1560, and in these we witness a very different system of access to woodland products. In the majority of woods, the right to cut underwood was leased out to village communities and the town of Mikulov. Standard trees remained in the possession of the overlord. For the use of the underwood, the village communities paid a set amount of money every year, called *Holzgeld* (wood-money). The remaining, smaller part of the estate woods remained in demesne. Successive *urbaria* (for references, see Section 3) and other surveys (MZA F18 inv.č. 7637) show that the amount of *Holzgeld* as set before 1560 was raised significantly only once (some time between 1579 and 1629) and after this it remained unchanged until it was finally abolished in the 1840s. The amount to be paid in effect became a privilege: that it could not be raised was several times included in village charters (MZA F18 kardon 1235).

At the same time the income from woodlands lost its former economic significance. The proportion of woodland incomes in the overall budget of the Mikulov estate fell from 23.4% in the 15th century to a mere 3% by 1590 (including direct firewood sales and the *Holzgeld*) and stayed at that level in the 17th century. This could have resulted from two processes: either wood became cheaper or other sources of income became more remunerative, in other words, money from woodlands became relatively less significant. The available evidence suggests that the case was the latter. Although we have no information about the price of firewood in the 15th and 16th centuries, there is no reason to suppose that it dropped. The supply of firewood probably remained reasonably constant and demand increased, because population on the estate grew (as evidenced by the *urbaria*) and there were no alternative sources of energy available in this early period. Therefore it is reasonable to suppose that coppicing ceased to be the lucrative business opportunity it was in the Middle Ages, and its place was

**Fig. 4.** The incomes of the Mikulov estate in 1414.



taken by other kinds of income, for example fishing or tolls. This would also explain why the overlords were willing to lease out coppicing.

Děvín Wood was partly affected by this new system of woodland access. Most of its area belonged to the group of woods that were not leased out but remained in demesne. However, the 1807–1808 maps and survey inform us that ca. 17 ha on the western side of the Wood were leased out to the villages of Bavory and Klentnice. But the wood produced in Děvín Wood did not end up on the market, either. Account books (see references in Section 3) report that the vast majority was distributed without payment on the estate, an especially large part ending up in the castle of Mikulov.

In general, we can conclude that business as the main driving factor behind coppice management in the Middle Ages gave way in the Early Modern Period to a less market-oriented system. In lack of alternative sources of energy, firewood was still needed in large quantities, however, the estate gave up on underwood as a market product. The primary driving force that kept up coppicing in this period was the need for firewood. The growing number of standard trees and the lengthening of the coppice cycle are rather difficult to explain. The former is probably a local phenomenon at least partly connected to the fact that standards belonged to the landowners' sphere of interest. On those parts of the Wood that were leased out, the Dietrichstein kept the right to standard trees, and – as evidenced by constant conflicts between them and the tenants – tried to increase the number of timber trees at the expense of coppice stools. In contrast to these local processes, the lengthening of the coppice cycle, as argued above, appears to be a more general phenomenon.

### 5.2.3. The 20th century

For Děvín Wood, the 20th century started in the 1880s, when a game preserve was established that covered most of its territory. Beside the usual deer and wild boar, the Dietrichstein introduced mouflons into the Wood in the 1910s, which have persisted there ever since. Game numbers, however, were apparently kept low enough for coppice management to continue. The one noticeable change for woodland management concerned the coppice cycle. Already in 1905 it was suggested that the 30-year cycle was too short for the Wood given the presence of the game preserve. Successive management plans record that several parts of the Wood were indeed left uncut for unusually long periods. By 1948, the cycle was officially raised to 40 years.

A major turn in the modern history of Děvín Wood came in 1946, when it was included in a non-intervention nature reserve. While this saved some of the Wood from being transformed into a high-forest, which was the fate of most woods in the region, it also meant that for the first time in 600 years coppicing stopped in most of the Wood. As in other European woods with a similar modern history (e.g. Rackham, 1975; Baeten et al., 2009; Van Calster et al., 2008; Corney et al., 2008), the effects on the vegetation have been quite drastic: alpha-diversity sharply decreased through the disappearance of light-demanding species (Hédl, 2005). At the same time, despite the non-intervention policy, large parts of the Wood were transformed into high-forest by singling out the coppice stools. The game preserve continued to exist, and in the 1950s Bezoar goats were added to the list of animals. Further layers of protection were added to the original nature reserve, and finally the game preserve was abolished in 1996, although remains of its barbed wire fence still haunt the edges of the Wood.

The driving forces behind the management and structure of Děvín Wood in the 20th century were nature conservation, the business potential of hunting, and modern forestry policy. The complexity of the situation is demonstrated by the existence of the

strict reserve on a territory managed by foresters who single-out coppice stools because the Forestry Law of the Czech Republic prescribes them to. Nature conservation and forestry policy – which could be considered cultural and political driving forces, respectively, *sensu* Bürgi et al. (2004) – as well as the hunting business all acted towards the abandonment of coppicing. While nature conservationists aimed at non-intervention, foresters tried to replace coppicing with a new management form. This resulted in some of the Wood freezing in the state it was in the late 1940s and other parts acquiring a new structure.

### 5.3. Synthesis

During the six centuries when we are able to follow the driving forces behind the management and structure of Děvín Wood, we see considerably changes (Table 2). In the Middle Ages, people around Děvín needed firewood for their existence, and selling coppice shoots was also a lucrative business. In the Early Modern Period, business as a socioeconomic driving force disappeared, however, people still depended on firewood, which kept up coppice management. The cause of this change was apparently the process in which firewood lost its relative importance in local economy to other sources of income. This system lasted until the end of the 19th century, when alternative sources of energy became widely available, and the villagers around Děvín Wood no longer depended on firewood. In view of this, the Dietrichstein overlords decided to provide Děvín with a new function. They introduced organised hunting, which meant that business once again became a driving force. Already this acted towards the abandonment of management, which became even more pronounced when an entirely new driving force, nature conservation, appeared on the scene. The mid-20th century upsurge of nature conservation – especially in the form of non-intervention reserves – is a general European (and global) phenomenon and eventually stems from the conservation movement and environmentalist ideology. While the above two driving forces acted towards the abandonment of management in Děvín Wood, forestry policy aimed to replace coppicing with another method. The whole 20<sup>th</sup> century can be characterised by the uneasy balance between conservationists and foresters.

## 6. Conclusions

This paper presented how long-term socioeconomic processes influenced the structure of a lowland ancient wood in the south-eastern Czech Republic from the 14th century to the present. Results showed that the management and structure of Děvín Wood was remarkably stable throughout the study period except for the last 60 years. This long-term stability contrasts with the multiple changes that can be observed in the driving forces. This raises the issue of the interpretation of 'stability' and 'change' in woodlands. Both concepts appear to be highly context-dependent. Whereas from a strictly vegetation ecological point of view the long-term history of Děvín Wood is characterised by a high level of stability, the socioeconomic and cultural systems that supported this stability were themselves far from static. Understanding socioeconomic driving forces of stability or change provides a crucial link between forest ecology and history, because it allows us to connect wooded landscapes with the societies that produced and maintained them (Hersperger and Bürgi, 2009). This knowledge is critical for the effective management of present-day forests. This paper also showed that in European historical ecology it is necessary to study periods before ca. 1800, i.e. the appearance of mass-produced quantitative sources, because societal processes have exerted their influence on landscapes much longer than 200 years. Through a source critical approach, the integration of

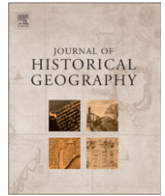
qualitative and quantitative documents can bring new insights into the long-term development of European forests.

## Acknowledgements

This paper was written with the help of grant IAA600050812 and institutional long-term research plan AVOZ60050516, both from the Academy of Sciences of the Czech Republic. I would like to thank Lucie Křížová for her help with my work in the Moravian Archives, Andreas Mölder for expert advice on German material, Radim Hédli for his insights on the first version of this text, and two anonymous reviewers for their useful comments.

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## Ancient woodland boundaries in Europe

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### Abstract

In Western and Central Europe, many woods are clearly separated from the surrounding countryside by permanent physical boundaries. While such boundaries are now out of use, in the past they were widespread and important landscape features. This paper argues that many woodland boundaries originate from the Middle Ages and perhaps even more from the Early Modern Period. Their existence was connected to a specific form of woodland management (coppicing) but also to ownership structures and through these to grazing regimes. With their various forms, permanent woodland boundaries served to separate woodland from the surrounding countryside both in a legal and physical sense. There are four basic types of permanent woodland boundaries: woodbanks, walls, stone rows and lynchets, all of which can still be studied in the landscape today. Because of their varied state of preservation and also because of the difficulties in creating relative chronologies, dating woodland boundaries is a very challenging task. However, even a basic typology can provide valuable information for a number of scientific disciplines, including landscape history, historical geography, archaeology and ecology. Permanent woodland boundaries are a part of European cultural heritage. They should be recognised and protected similarly to all other ancient landscape features.

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**Keywords:** Woodland boundaries; Ancient woodland; Woodbanks; Historical ecology; Landscape archaeology

### Introduction

Modern European cadastres require that the use of every square metre of land is clearly defined. On paper, we can tell whether any given point is inside or outside a forest. In reality – especially with the recent large-scale abandonment of European agricultural land, resulting in secondary woodland formation<sup>1</sup> – the boundary between woodland and non-woodland is often blurred. The lack of a clear boundary is often taken to be the historically typical situation, which appears to be true in the Mediterranean,<sup>2</sup> in mountainous regions and in European boreal woodlands. There are, however, regions in Western and Central Europe where people have lived (with relatively high population densities) since the Neolithic, and where woodland has been valued as a renewable but limited resource for thousands of years. As a result, woods were often clearly demarcated from the surrounding countryside.

Permanent woodland boundaries occur in many European countries and date from at least the Early Middle Ages to the

nineteenth century. Yet researchers have paid very little attention to them. There is abundant literature, especially in Germany, on various landscape features that happen to be inside woods,<sup>3</sup> but these concern archaeological phenomena that have nothing to do with the forests themselves. Environmental and forest historians sometimes mention the creation or more generally the presence of permanent woodland boundaries in their study regions, but rarely discuss what remains of these boundaries today. This lack of scholarly attention probably results from the fact that woodland boundaries are closely connected, functionally, to woodland management, which falls beyond the interest of most landscape archaeologists and historical geographers. Ecologists, on the other hand, usually take no interest in human-made landscape features.

In this paper, I examine the permanent woodland boundaries that exist in lowland Europe: their types, functions, establishment and preservation. Although temporary fences were also present in many European woods and were undoubtedly important elements

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<sup>1</sup> A. Mather, Afforestation: Progress, trends, policies, in: N. Weber (Ed.), *NEWFOR – New Forests for Europe: Afforestation at the Turn of the Century*, Joensuu, 2000, 11–22; Jerzy Szwagrzyk, Sukcesja leśna na gruntach porolnych; stan obecny, prognozy i wrażliwość (Forest succession on abandoned farmland; current estimates, forecasts and uncertainties), *Sylvan* 4 (2004) 53–59; P. Piussi and D. Pettenella, Spontaneous afforestation of fallows in Italy, in: N. Weber (Ed.), *NEWFOR – New Forests for Europe: Afforestation at the Turn of the Century*, Joensuu, 2000, 151–166.

<sup>2</sup> A.T. Grove and O. Rackham, *The nature of Mediterranean Europe: an Ecological History*, New Haven and London, 2001, 185.

<sup>3</sup> E.g. K. Sippel and U. Stiehl, *Archäologie im Wald*, Kassel, 2005; J. Delfs, Grenzen und Grenzmaie im Wald, *Forst und Holz* 56 (2001) 249–255; H. Koschik (Ed.), *Archäologische Denkmäler in den Wäldern des Rheinlandes*, Köln, 1995.

in woodland management, I focus on permanent boundaries. I explain what kinds of information such boundaries carry for landscape history and ecology, and I put woodland boundaries into the larger context of the history of European territorial boundaries. Data used in this article come partly from secondary literature and partly from my own archival research and fieldwork in the Czech Republic and Hungary.

### Physical boundaries: basic types and functions

Permanent physical boundaries in the landscape have two, interconnected basic functions: legal and physical. Detailed maps are a relatively recent development in European history; in earlier periods visible boundaries were an essential element in protecting one's property rights. Whenever debate arose about a certain piece of land, it had to be decided *in situ* whether it belonged to one party or another. This could only be done if boundaries were physically present in some form. Although we can know little for certain, comparisons with other continents as well as the existence of villages, field systems and long-distance roads suggest that European landscape ownership relations were well developed already in prehistory.<sup>4</sup> The earliest written evidence for boundaries refers to so-called perambulations. A perambulation was a legal procedure requiring that residents of a region (accompanied by the pertinent authorities) walk along the boundary of a property unit (usually a settlement) and memorize its most significant boundary features. Some of these features were natural (a large tree, a hill or a brook), while others were made to purpose (a mound, a ditch or a cross on a tree). When writing started to be valued, perambulations took a written form. The practice of perambulation was strikingly similar in several widely separated regions and time periods. The Hindu Laws of Manu (in their present form ca. 2000 years old) describe a procedure similar to almost the smallest details to English medieval or Hungarian nineteenth-century perambulations.<sup>5</sup> The first written perambulations (rather than descriptions of the procedure) probably come from Crete, and are as old as the Laws of Manu.<sup>6</sup> In this context, smaller areas within settlements became valuable enough to be demarcated by permanent physical boundaries – especially when they were sold or leased. In regions with little woodland, individual woodlots probably reached this status at an early stage, although for want of written evidence we cannot tell exactly when this happened. The earliest woodland boundaries known today are the earthworks in Chalkney Wood in England, which appear to be from the Iron Age.<sup>7</sup>

If a permanent boundary was a linear feature rather than a series of points, it could also serve as a physical barrier, something that was difficult to cross. The best known examples of this kind of boundary are the Great Wall of China, Offa's dyke, Hadrian's Wall, or the fourth-century earthwork fortification – more than 1000 km

in length – that was created to protect the low-lying areas of the Carpathian Basin.<sup>8</sup> More humble examples usually meant a bank and a ditch, and such boundaries surround thousands of European settlements. For example, medieval German *Landwehren* run for hundreds of kilometres often in what is now wooded terrain, marking the boundaries of various administrative units from villages to principalities.<sup>9</sup>

### Types of woodland boundary

Permanent woodland boundaries could be defined by a series of points in the landscape, or by a linear feature. We have extensive knowledge about the former, because of the large number of surviving perambulations from the Middle Ages onwards. Perambulations usually feature in woodland history research in connection with the trees mentioned in them. These boundary trees tended to be species or specimens unusual in the given wood, because they had to be recognisable by future perambulators as well. To further increase their recognition, boundary trees were often marked with nails, engravings or even pictures.<sup>10</sup> In this paper, however, I focus on *linear* woodland boundaries, and identify four basic types: woodbanks, walls, stone rows and lynchets.

#### Woodbanks

A woodbank (which comprises a bank and a ditch) was made around a wood by digging a ditch and throwing the earth towards the inside of the wood, thus creating a bank (Fig. 1). Here is a rather late example from the 1823 Czech adaptation of Georg Ludwig Hartig's *Lehrbuch für Förster* about how to make a woodbank:

So that such a protective ditch is befitting and neat, and tells the passer-by that the forester likes order, it should be made the following way: first we draw a line with rods or sticks where the ditch should be, and put a stick into the ground every ten steps along that line. When this is done, we measure three or four feet at right angles from the width of the ditch. When this is done, we stretch a cord from stick to stick, and with a spade we throw both upper sides of the line of the ditch to the middle [i.e. towards the inside of the wood]. When this finishes, we extract turf in square feet, and put it upside down six fingers from the edge of the ditch so that by this the oblique bank is raised a little. Up to this point, the work should be done by specialised workers. After this, however, if need be, any kind of people can work. However, we have to give each their own task, and teach them to throw the earth on and over the bank, and to dig the ditch in a way so that it is three feet deep and one and a half feet wide at the bottom. This is the only way to make sure that the ditches are laid straight and

<sup>4</sup> M. Houseman, Painful places: ritual encounters with one's homelands, *The Journal of the Royal Anthropological Institute* 4 (1998) 447–467; D.A. Spratt, Recent British research on prehistoric territorial boundaries, *Journal of World Prehistory* 5 (1991) 439–480.

<sup>5</sup> P. Olivelle, Manu's code of law: A critical edition and translation of the *Mānava-Dharmaśāstra*, Oxford, 2005, chapter 8.

<sup>6</sup> O. Rackham and J. Moody, *The making of the Cretan landscape*, Manchester, 1996, 8.

<sup>7</sup> O. Rackham, *Woodlands*, London, 2006, 192.

<sup>8</sup> P. Squatriti, Offa's dyke between nature and culture, *Environmental History* 9 (2004) 37–56; É. Garam, P. Patay and S. Soproni, *Sarmatisches Wallsystem im Karpatenbecken*, Budapest, 1983.

<sup>9</sup> From the extensive literature, see e.g. C. Knepp, *Die Stadtlandwehren des östlichen Münsterlandes*, Münster, 2004.

<sup>10</sup> L. Takács, *Határjelek, határjárás a feudális kor végén Magyarországon* (Boundary Signs and Perambulations at the End of the Feudal Period in Hungary), Budapest, 1987; D. Hooke, Trees in the Anglo-Saxon landscape: the charter evidence, in: C.P. Biggam (Ed.), *From Earth to Art: the Many Aspects of the Plant-world in Anglo-Saxon England*, Amsterdam and New York, 2003, 17–40; L. Ostlund, O. Zackrisson and G. Hornberg, Trees on the border between nature and culture: culturally modified trees in boreal Sweden, *Environmental History* 7 (2002) 48–68; P. Szabó, Medieval trees and modern ecology: how to handle written sources, *Medium Aevum Quotidianum* 46 (2002) 7–25.





Fig. 1. Woodbank in Somlyó Wood, Hungary, December 2005.

nice. Such ditches are also sufficient to protect the wood from cattle, if there is a herdsman, although it is not impossible for them to jump over it.

[A foot here is ca. 31.6 cm, a finger is ca. 2.6 cm]<sup>11</sup>

Such woodbanks exist in many European countries. They are best known in England, but are present in the Netherlands, Germany, France, Romania, Belgium, Scotland, Wales, Hungary, Denmark, the Czech Republic, Austria or Ireland.<sup>12</sup> The list is necessarily incomplete, but it shows that woodbanks are a truly pan-European landscape feature.

In regular cases, the bank is on the inside of the wood and the ditch on the outside to keep grazing domestic animals out of the wood, although there can be considerable variation, including ditches on both sides of the bank, or ditches without any bank. In Scotland and also in the Czech Republic, there are unusual woodbanks where a wood on steeply sloping ground abuts on a flatter field. Here, the ditch was constructed at the bottom of the slope and the earth was thrown not on the steep slope on the woodland side (that would have been pointless) but on the level field side.<sup>13</sup> Where the ditch is on the inside of the bank and there is no topographic reason for this, it is likely that the wood was once a *park*.<sup>14</sup> A park – in the historical rather than the

current meaning of the word – was a place for farming semi-wild animals, mostly deer. Banks and ditches around parks served to keep the valuable game within the area – hence the ditch on the inside. A functioning park contained considerable amounts of grassland as well as trees, because the unusually high number of animals inside required more food than what would be available in a closed forest. Later, however, the park function was usually abandoned, and the former pastures were overgrown by trees. Although in this article I focus on woods rather than game preserves, the latter still deserve attention for three reasons. First, because parks often lost their original function and are now hardly distinguishable from ordinary woods. Second, because there is some evidence to suggest that game preserves were the first partly wooded areas to be systematically surrounded by permanent linear boundaries,<sup>15</sup> and this apparently early medieval tradition may have served as a model for woodland boundaries. Third, because woods in late medieval and early modern Germany and Denmark were so full of game that they had to be fenced to keep wild animals away from the neighbouring fields.

Woodbanks were often topped with a dead or living hedge. When properly managed, this made access to the wood close to impossible for all but the strongest animals. To quote again from Hartig's Czech adaptation:

If we want to protect the enclosed area even better, we plant the soil that was dug out from the ditch 6 feet wide with hornbeam – 2 fingers thick and 6–7 feet long – or with some other tree that readily grows there, and we add to that plantation one or two lines of thin poles reinforced with ropes. This way such protection is made, which, if we maintain it properly, prevents even tall animals from entering.

To allow people and vehicles in, gates with locks were used at road entrances (Fig. 2). Consider, by way of illustration, an example from Somos wood near Carei in Romania from 1712:

One of them [the woodmen] has to walk around the enclosure of our wood every day, and has to look hard for any holes, intrusions and trespasses. If they catch someone he shall be fined 24 *forints*, half of which sum belongs... to the woodmen together with the gardeners, the other half to the lord.... They have to keep the gates locked at all times, and similarly the smaller gates. They have to go through the gate

<sup>11</sup> V.V. Havelka, *Umění lesnj podlé Giřjho Ludwika Hartyga, neyvyššjho řjditelē lesnjho v královských Pruských zemjch, a giných neyvýbornějšjch spisowatelů složené s lesnictwjm vlastenským dle vlastnj zkussenosti srownané* (The Art of Forestry, Compiled Based on Georg Ludwig Hartig, Highest Forestry Director in the Royal Prussian Lands, and on Other Excellent Authors, Compared with our Own Forestry Based on our Own Experiences), Prague, 1823, 181–182. Translation mine. For the measurements, see Č. Hladík, *Metrologický přehled* (Metrological overview), *Archivní časopis* 3 (1953) 87–114.

<sup>12</sup> O. Rackham, *Trees and Woodland in the British Landscape*, London, 1976; N. Schotsman and H.J. During, *Houtwallen in Friesland: Oecologie en beheer, Nederlands Bosbouw Tijdschrift* 49 (1977) 320–326; M. de Geus and T. van Slobbe, *De Bevrjding van het Landschap: vlechtheppen en houtwallen in Nederland*, Waarde, 2000; Rackham, *Woodlands* (note 7), 191–200; P.A. Sansum, *Historical resource use and ecological change in semi-natural woodland: Western oakwoods in Argyll, Scotland*, Ph.D. dissertation, University of Stirling, 2004, 198–201; T.C. Smout, A.R. MacDonald and F. Watson, *A History of the Native Woodlands of Scotland, 1500–1920*, Edinburgh, 2005, 165–171; A. Mölder, *Flora, Vegetation und Bestandesstruktur im Naturwald Großer Freeden, Teutoburger Wald*, M.A. thesis, University of Göttingen, 2005, 34; P. Szabó, *Woodland and Forests in Medieval Hungary*, Oxford, 2005; G. Tack, P. van den Brecht and M. Hermy, *Bossen van Vlaanderen – een historische ecologie*, Leuven, 1993; B. Fritzboeger, *A Windfall for the Magnates: the Development of Woodland Ownership in Denmark c. 1150–1830*, Odense, 2004; C. Sonnlechner, *Verwaltung von Natur. Ressourcenmanagement und das geschriebene Wort in spätmittelalterlichen und frühneuzeitlichen Grundherrschaften*, in: W. Pohl and P. Herold (Eds.), *Vom Nutzen des Schreibens. Soziales Gedächtnis, Herrschaft und Besitz im Mittelalter*, Vienna, 2002, 375–394.

<sup>13</sup> Sunart Oakwoods Research Group, *The Sunart Oakwoods: a Report on their History and Archaeology*, n.p., 2001, quoted in: Smout, MacDonald and Watson, *Native Woodlands of Scotland* (note 12). In the Czech Republic, such woodbanks can be seen on the northern side of Mramor Wood in the Czech karst.

<sup>14</sup> O. Rackham, *The History of the Countryside*, London, 1986, 122–129; A. Andrén, *Paradise lost: looking for deer parks in medieval Denmark and Sweden*, in: H. Andersson, P. Carelli and L. Ersgård (Eds.), *Visions of the Past: Trends and Traditions in Swedish Medieval Archaeology*, Stockholm, 1997, 469–490.

<sup>15</sup> D. Hooke, *Pre-conquest woodland: its distribution and usage*, *Agricultural History Review* 37 (1989) 113–129; W. Metz, *Das 'gahagio regis' der Langobarden und die deutschen Hagen-Ortsnamen*, *Beiträge zur Namenforschung* 5 (1954) 39–51; D. Hooke, *Medieval forests and parks in southern and central England*, in: C. Watkins (Ed.), *European Woods and Forests: Studies in Cultural History*, Wallingford, 1998, 19–32.

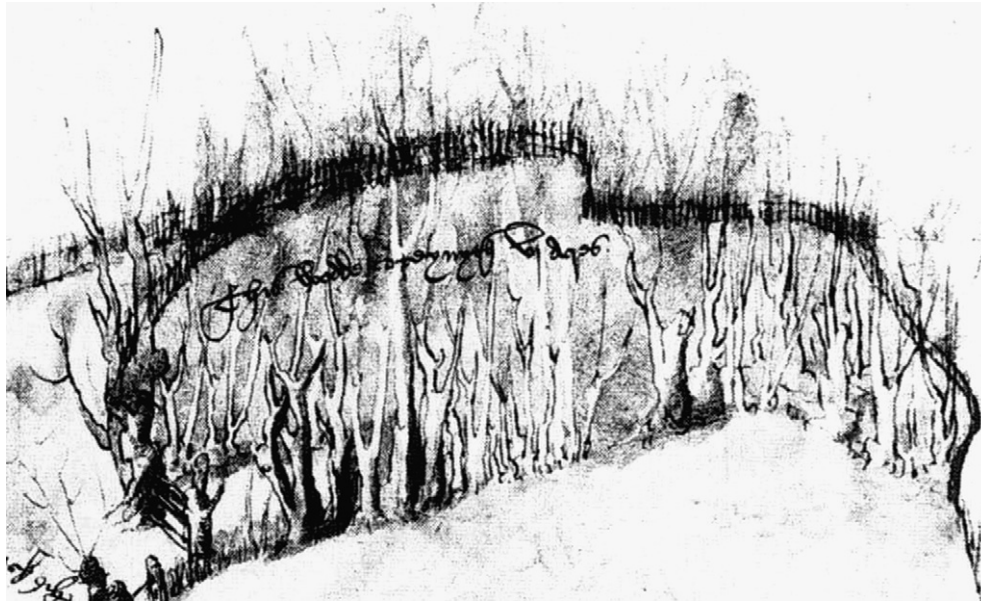


Fig. 2. A wood near Andwell (Hampshire, England) in the early sixteenth century, complete with hedges, fences and a gate. (After P.D.A. Harvey, *Maps in Tudor England*, London, 1993, 17).

which is facing the town, but even that they have to keep locked at all times.<sup>16</sup>

[The *forint* was the currency of the period.]

Woodbanks surrounded woods partly or entirely. In the former case, they most often separated woodland from pasture. For example, in Děvín Wood in the Czech Republic, woodbanks exist where the Wood adjoined pasture in the eighteenth century, but not where it abutted on the many local vineyards, which had their own fences. Woodbanks could also separate the woodlots of different owners.<sup>17</sup>

#### Walls

Some woods are surrounded by walls, sometimes combined with a ditch or a bank. In France, for example, the local woodland of the Abbey of Bec in Normandy is surrounded by an 8-km-long wall.<sup>18</sup> Many Scottish, Danish and Welsh woods are also surrounded by walls.<sup>19</sup> The above-mentioned parks, which required firm fences, often had stone walls built around them. For example the fifteenth-century park of King Matthias of Hungary in what is now Budapest was once surrounded by a stone wall, which is ca. one-metre-wide at the bottom (Fig. 3).<sup>20</sup> Pheasantries, specialised forms of park that were very widespread in Central Europe in the eighteenth century, were often surrounded by walls. In the Czech lands some of these could be quite substantial, as shown by the surviving example near the town of Mikulov in southern Moravia.

#### Stone rows

In parts of Europe the uppermost layers of the soil contain many stones, making ploughing very difficult. Since the beginning of agriculture, people have removed these stones from arable land, and in

many areas, rows of stones have been created between fields. Where a field adjoins a wood, however, the stones were placed right on the woodland edge.<sup>21</sup> Sometimes they were put down in piles – here I suspect that the stones had originally been gathered into a cart. Most often, however, we find the stones in rows, which probably reflects gathering by hand. As time went by, such stone rows could grow into massive structures. The Czech karst, a limestone area ca. 30 km southwest of Prague in the Czech Republic, provides a good example. Here, a number of ancient woods are surrounded mostly by stone rows combined with stone piles and sometimes woodbanks or lynchets. A typical boundary is a more or less continuous stone row with piles of stones at irregular intervals (Fig. 4). Such piles also typically occur where the boundary turns sharply, and these piles likely served as indicators of the most important boundary points – as if creating a polygon. The size of the stone rows varies from minor lines to huge dry-walls 3 m in width and 2 m in height.

Except when high and unbroken, stone rows could only have legal functions and did not protect the woods from browsing animals. They are not artificial woodland boundaries in the same sense as woodbanks or walls, but rather the by-products of agriculture. However, as evidenced by piles of stones accumulated at boundary turning points, people most probably recognised their potential in legal delimitations.

#### Lynchets

Lynchets are terrace-like structures produced in hilly terrain by continuous ploughing. The plough constantly moves the soil down the hill, which means that lands above and below the plough-line are separated by a steep slope. Woods on hilltops in arable country are usually surrounded by lynchets (Fig. 5). Within woods the original slope gradient persists because erosion is less significant

<sup>16</sup> L. Merényi, Nagykárolyi vadászati és erdészeti utasítások (Hunting and woodland management instructions from Nagykároly), *Magyar Gazdaságtörténeti Szemle* 7 (1900) 416. Translation mine.

<sup>17</sup> Fritzboeger, *A Windfall for the Magnates* (note 12), 154.

<sup>18</sup> Rackham, *Woodlands* (note 7), 199–200.

<sup>19</sup> Smout, MacDonald and Watson, *Native Woodlands of Scotland* (note 12), 166–167; Fritzboeger, *A Windfall for the Magnates* (note 12), 310–313.

<sup>20</sup> S. Garády, Mátyás király budai vadaskertje (King Matthias' park in Buda), *Historia* (1931) 40–60.

<sup>21</sup> This can also be observed around American woods: G.F. Peterken, *Natural Woodland: Ecology and Conservation in Northern Temperate Regions*, Cambridge, 1996, 240–241.





Fig. 3. Remains of the fifteenth-century wall of King Matthias' park in Nyék (Budapest, Hungary). August 2005.

than in open farmland. Although lynchets, like stone rows, were not intended as boundaries, they function in the same way as woodbanks: they mark out the legal boundary and protect against grazing. In fact, woodbanks on slopes tend to transform into lynchets through erosion. The original structure can be worked out in three ways: 1) by excavation 2) by looking for a slight (also eroded) bank 3) if the wood is on a slope rather than a hilltop, by looking at the boundaries with the wood downslope. Here, there should be a lynchet on the woodland side – remaining from the woodbank.

### Functions and ages of woodland boundaries

The different boundary forms presented above did not follow the same line of development or serve the same functions across Europe through time. Local conditions were influential determinants of development, form and function.

Although permanent woodland boundaries were primarily physical barriers, they almost always had a legal and symbolic significance as well. The symbolic aspect is difficult to grasp today, because few written sources address it, but the legal and physical sides of the issue are really inseparable.<sup>22</sup> As the historian Bo Fritzboøger remarked in connection with the enclosure of formerly common woods in Denmark in the Early Modern Period:

...the enclosed wood emerged as an island in the ... open landscape surrounding it. Its new status as the inaccessible property of the local manor had simply become visible. Sharp



Fig. 4. Stone row in Bačín Wood (Czech Republic). October 2008.

edges and effective stone walls might have had other purposes, but they contributed positively to the impression of 'private property'.<sup>23</sup>

There was a good deal of variation in the precise purpose of woodland boundaries. First and foremost, they were intended to keep out unwanted people and animals (as emphasised, for example, in Hartig's Czech adaptation quoted above). The typical bank and ditch would stop wheeled access and therefore largely reduce stealing. More importantly, grazing animals needed to be excluded from the woods in certain years. In lowland Europe, many woods have been managed for millennia as *coppices*.<sup>24</sup> This involved cutting broadleaved trees close to the ground and harvesting the new shoots they sprouted on a short rotation (every 7–30 years). This sustainable and relatively cheap method produced much of the fuel required by the inhabitants of most European regions until the coal age. The young shoots of trees, however, are very sensitive to browsing. If animals get into coppice woods when the shoots are still tender, they can cause huge devastation. As a result, coppice woods were generally bounded by ditches and banks.

Yet there is much evidence from Germany, Denmark, Scotland and Hungary<sup>25</sup> suggesting that coppice woods were often used for grazing, by which I do not mean the overall not very significant driving of domestic pigs into woods to feed on the occasional larger crop of acorns or beechmast, but the regular use of woodland areas as pasture. Under these circumstances, woods could become wood-pasture of loosely spaced large trees with spreading crowns and grassland.<sup>26</sup> The trees could also be pollarded, that is, repeatedly

<sup>22</sup> The same holds true for other linear boundaries, too. Was, for example, Hadrian's Wall really impossible to cross or was it there also to impress on possible intruders that there is someone powerful and fearsome on the other side?

<sup>23</sup> Fritzboøger, *A Windfall for the Magnates* (note 12), 313.

<sup>24</sup> E.g. Tack, van den Brecht and Hermy, *Bossen van Vlaanderen* (note 12); G.F. Peterken, *Woodland Conservation and Management*, London, 1981; R. Bärnthol, *Nieder- und Mittelwald in Franken. Waldwirtschaftsformen aus dem Mittelalter*, Bad Windsheim, 2003; P. Warde, *Ecology, Economy and State Formation in Early Modern Germany*, Cambridge, 2006; A. Billamboz, Tree rings and wetland occupation in southwest Germany between 2000 and 500 BC: dendroarchaeology beyond dating (in tribute to F.H. Schweingruber), *Tree-Ring Research* 59 (2003) 37–49; Szabó, *Woodland and Forests* (note 12); O. Ciancio and S. Nocentini, *Il bosco ceduo. Selvicultura, assestamento, gestione*, Florence, 2004; R.L. Keyser, The transformation of traditional woodland management: commercial sylviculture in medieval champagne, *French Historical Studies* 32 (2009) 353–384; Rackham, *Trees and Woodland* (note 12); C. Haneca, J. van Acker and H. Beeckman, Growth trends reveal the forest structure during Roman and medieval times in Western Europe: a comparison between archaeological and actual oak ring series (*Quercus robur* and *Quercus petraea*), *Annals of Forest Science* 62 (2005) 797–805; Fritzboøger, *A Windfall for the Magnates* (note 12); Smout, MacDonald and Watson, *Native Woodlands of Scotland* (note 12).

<sup>25</sup> Warde, *Ecology, Economy and State Formation* (note 25), 79–83; Fritzboøger, *A Windfall for the Magnates* (note 12), 207–210; Smout, MacDonald and Watson, *Native Woodlands of Scotland* (note 12), 102–123, 171.

<sup>26</sup> Frans Vera's famous but controversial theory claims that such was the original state of pre-Neolithic woodland, where large herbivores had a decisive effect on the vegetation. F.W.M. Vera, *Grazing Ecology and Forest History*, Wallingford, 2000. The theory has received much criticism: see K. Hodder and J. Bullock, The 'Vera model' of post-glacial landscapes in Europe: a summary of the debate, in: *Large Herbivores in the Wildwood and Modern Naturalistic Grazing Systems* (English Nature Research Reports no. 648), Peterborough, 2005, 30–61. A critical overview of Vera's historical arguments is P. Szabó, Open woodland in Europe in the Mesolithic and in the Middle Ages: can there be a connection?, *Forest Ecology and Management* 257 (2009) 2327–2330.





Fig. 5. Lynchet on a woodland edge in the Czech karst. October 2008.

cut for firewood at a height where animals could not reach the shoots. In these cases, boundaries were not necessary. If, however, the wood was coppiced, the resulting landscape was a mosaic of grassland patches and coppice stools. To avoid the area quickly turning into treeless pasture, new growth had to be protected. This was achieved by employing herders to control the grazing animals as well as by erecting temporary fences around recently felled areas. These fences were dismantled after a few years, when the coppice shoots were tall and hard enough to survive browsing.<sup>27</sup> The very short medieval rotation (which saw coppice shoots harvested within 7–10 years) left hardly any space for grazing, but as the coppice cycle was extended, there was more time for animal access. At the end of the seventeenth century, the coppice cycle on the Mikulov estate in southern Moravia (Czech Republic) was around 12 years, and grazing was allowed from the fourth year onwards.<sup>28</sup> Later there was even more time: in 1807 in Somlyó Wood (Hungary), grazing was prohibited for 7 years in a coppice cycle of ca. 35 years.<sup>29</sup>

Boundaries on the woodland perimeter could easily fit into the above system. They ran along permanent lines and did not depend on the ever-changing size and shape of the felling areas. In any case, by the Middle Ages many woods, especially in North-Western Europe, were already too small to be divided into compartments: they were normally cut all at once. Still, it seems that in addition to coppicing, the existence of permanent woodland boundaries was also closely connected to ownership relations. Permanent boundaries were associated with private or manorial ownership and the restriction of usage rights in the wood to the owner. The typical medieval English wood with its woodbank belonged to and was directly managed by the local manor. The only Scottish woods we know were surrounded by woodbanks in the Middle Ages were also manorial: they belonged to the Cistercian abbey of Coupar Angus.<sup>30</sup> In Denmark until the eighteenth century, the only type of woodland



Fig. 6. Former woodbank now apparently a hedge cutting through a field in Kerecsend (Hungary).

with permanent boundaries was the *enemærke*, which belonged to the manorial demesne or a single freehold and had no common usage rights attached to it.<sup>31</sup>

This raises the issue of temporal patterns. On a European scale, we know little about the ages of permanent woodland boundaries. Comparison with the medieval woodbanks mentioned above would suggest that Dutch, Belgian and northern French woodbanks are also of medieval origin, but I know of no written evidence to prove this. By contrast, in a number of well-studied regions the first written sources about permanent linear boundaries around woods come from the Early Modern Period, mostly the eighteenth century. There may be two reasons for this. First, in many areas – especially East-Central Europe – there are few of the everyday economic sources that would describe the creation or maintenance of woodland boundaries before the sixteenth century and they do not become numerous until the eighteenth century.<sup>32</sup> A typical example comes from Nagyerdő (lit. Great Wood) near Debrecen in Hungary, where in 1761 a woodbank was made. Were it not for a chance remark in the source describing the event that the line of the boundary follows an earlier woodbank ‘made in some distant past,’ we would have no idea that woodbanks existed in this region prior to the eighteenth century.<sup>33</sup>

Second, the existence of permanent woodland boundaries is also connected to social structures and through these to grazing regimes. The typical example is Denmark, where traditionally strong common rights left many coppice woods unenclosed (and the grazing animals in the custody of herdsman) until the general enclosure movement of ca. 1800 AD.<sup>34</sup> As regards woods, enclosure meant that woodland and pasture were separated, and some of the originally more open woodland areas were designated as pasture

<sup>27</sup> The same is done today in the Bradfield Woods in England, although here the temporary wooden fences are meant to exclude deer and are not dismantled but left to rot away.

<sup>28</sup> Moravský zemský archiv (Moravian Archives) F18 inv.č. 7679.

<sup>29</sup> Magyar Országos Levéltár (Hungarian National Archives) P. 397 D.1.

<sup>30</sup> Smout, MacDonald and Watson, *Native Woodlands of Scotland* (note 12), 157.

<sup>31</sup> Fritzboeger, *A Windfall for the Magnates* (note 12), 154, 173.

<sup>32</sup> P. Szabó, Sources for the historian of medieval woodland, in: J. Laszlovszky and P. Szabó (Eds), *People and Nature in Historical Perspective*, Budapest, 2003, 265–288.

<sup>33</sup> D. Penyigey, *Debrecen erdőgazdálkodása a XVIII. században és a XIX. század első felében* (Woodland Management in Debrecen in the Eighteenth Century and the First Half of the Nineteenth Century), Budapest, 1980, 339.

<sup>34</sup> This also seems to be the case around Württemberg in Early Modern Period. Warde, *Ecology, Economy and State Formation* (note 25), 77.

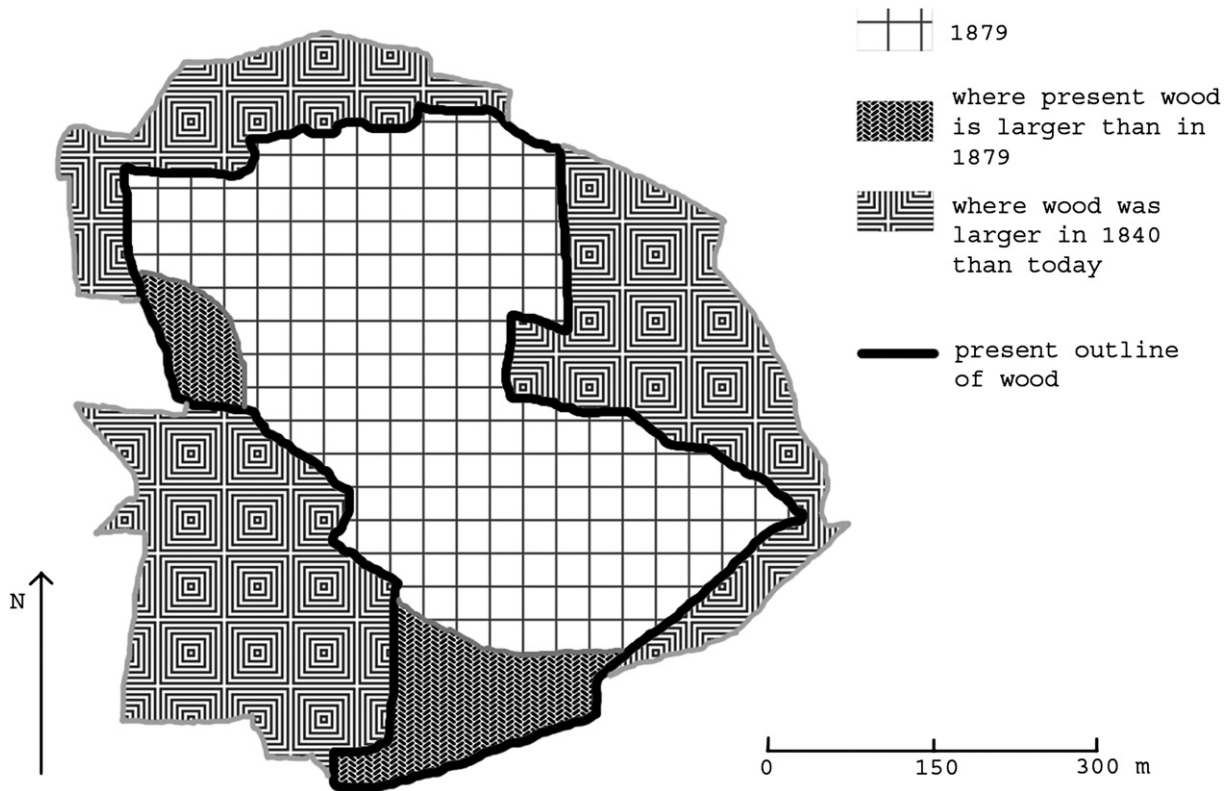


Fig. 7. Changes in woodland cover in Strážiště Wood as represented on maps.

while the rest were surrounded by permanent boundaries (woodbanks and/or walls) and were given over solely to wood production. The result was that trees quickly disappeared from pastures and open areas from woods.<sup>35</sup> The very same thing happened almost at the same time in Dúbrava Wood on the southern Moravian estate of Hodonín, where in 1787 the ca. 4430-hectare heavily-grazed woodland was divided into pasture (ca. 1300 ha) and wood (ca. 3130 ha) and the woodland part was surrounded by a woodbank that is still visible. A few decades later the pastures had no trees on them, and open areas inside the woods were shrinking.<sup>36</sup> In general, it is very probable that permanent woodland boundaries existed in many regions of Europe by the Middle Ages, but they were not universal. There was a great upsurge in their creation in the Early Modern Period, especially in the eighteenth century, when grazing and wood production were deliberately separated.

### Woodland boundaries in the landscape today

#### Preservation

Woodland boundaries could be of very different sizes and robustness. Some woodbanks resemble earthwork fortifications with an overall width of up to 10 m. The idealised woodbank in the German–Czech example quoted above is of moderate size, with the ditch ca. 1.3 m wide and 1 m deep. Lynchets can also be rather high: on steep terrain with a long history of agriculture, the woodland area can be 2 m higher than the surrounding farmland.

The size of stone rows depends on how stoney the soil is and how long ploughing existed, while walls are entirely artificial structures, which were made to the exact requirements of woodland owners.

As time goes by, woodland boundaries change through erosion. Woodbanks take on a characteristic rounded shape, and some of the ditch is filled in. Walls, just like any other built structure, collapse and in the end completely disappear under the earth. Stone rows are probably less altered, because they were originally made into a natural rounded shape. Lynchets, on the other hand, grow higher and higher as long as agriculture is practiced on the non-woodland side. When examining the remains of permanent woodland boundaries, we should remember that microtopographic conditions influence their present state to a very high degree. A woodbank can look as good as new in one section and completely worn-down only a few hundred metres away. Faint boundaries are often difficult to find, because living plants or fallen leaves make them almost invisible. Such boundaries are best looked for in early spring, when ground vegetation has yet to grow and most of the leaf-fall is decomposed. It is also useful to look at sharper corners, where due to the lack of space earthen or stone mounds tend to accumulate on the woodland side.

Although there is little information about this, we know that woodland boundaries – at least the more artificial kinds – were regularly maintained. Walls were renovated and ditches were cleaned, especially in regions where they also served as drainage channels. Presumably such maintenance was continuous as long as

<sup>35</sup> Fritzboøger, *A Windfall for the Magnates* (note 12), 313.

<sup>36</sup> Moravský zemský archiv (Moravian Archives) F5 kn. 232. The process has been partly reversed since and the late eighteenth-century woodbanks are now again inside the woods.

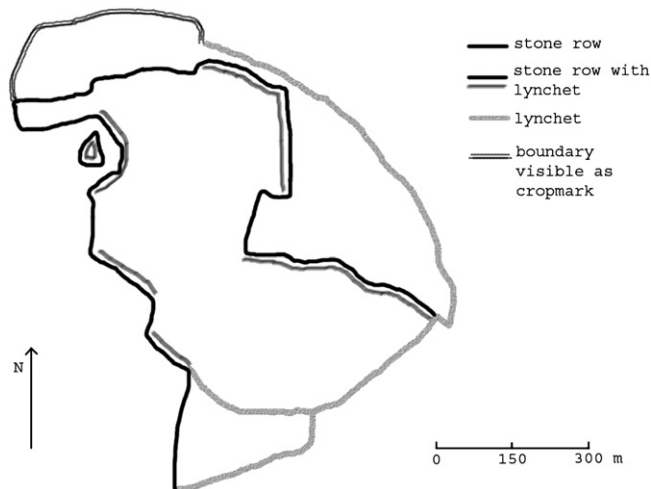


Fig. 8. Permanent woodland boundaries in Strážiště Wood as seen in the landscape today.

coppicing was active. As a result, woods with a more recent coppicing history are expected to have better preserved boundaries.

#### Dating woodland boundaries

Woodland boundaries are difficult features to date, and stone rows and lynchets usually result from very long processes. Woodbanks could theoretically be dated with absolute methods by taking a buried sample from the bottom of the ditch and finding something in it that can be radiocarbon dated.<sup>37</sup> So far, however, no such studies exist. *Faute de mieux*, we have to make do with relative dating based on typology. Walls are theoretically the easiest to date, because they can be compared to other built structures in the neighbourhood that are well-dated. A typology for woodbanks can be worked out with the help of written sources. In the best case, a source describes the making of a particular woodbank that still exists, such as in Hindolveston Wood from the late thirteenth century<sup>38</sup> or Dúbrava Wood near Hodonín from the late eighteenth century, quoted above.

In England, where the only woodbank typology exists, the rule of thumb is that the more massive and sinuous, the more ancient. The earliest woodbanks (apart from the one in Chalkney Wood, already mentioned) seem to be early medieval, while later ones tend to be straighter and less pronounced but more acute. The last feature is easy to explain: newer woodbanks are steeper because erosion has affected them less. Why earlier woodbanks should be more massive and sinuous is more difficult to account for. Straightness tends to be a recent feature in landscape history. Except for some Roman highways, early roads are more winding than modern ones, and in broad terms straight lines on the land are most commonly associated with the eighteenth-century development of engineering and the ideology of the Enlightenment, which preferred centrally organised, regular units in the countryside. A notable exception is that of game preserves, whose boundaries – already in their early medieval forms – appear to be straight.

In other countries, where there is no typology for woodbanks, the English model might be applied, but local evidence is necessary to confirm it. Some elements of this model are easier to test than others. For example, more acute woodbanks are certainly more recent, however, very much depends on local soil conditions. On sandy soils a rather worn-down woodbank can be quite young. Whether more massive, wider woodbanks date from the Middle Ages outside England as well is presently not known. More information is available about the straightness of woodbanks. Written sources suggest that straight woodbanks in Central Europe, such as the nineteenth-century bank and ditch of Ohat Wood (Hungary),<sup>39</sup> are early modern; they therefore conform to the English model.

#### What do ancient woodland boundaries tell us?

Woodland boundaries are independent sources of information about the woods they surround. When put into context, they provide valuable information about landscape history and ecology for woodland historians, ecologists, landscape archaeologists and historical geographers alike.

#### Landscape history

Permanent woodland boundaries are essential tools in deciphering the history of individual woods. The shape and alignment of boundaries provide an opportunity to cross-check information from written documents. Boundaries can also tell the landscape historian about phases in the history of a wood that are otherwise not mentioned in written sources. For example, if part of a wood was sold, it was customary to make a boundary inside the wood to separate the two properties. Finally, when written sources are altogether missing, permanent boundaries – supplemented by vegetation composition and structure – are the only sources of information with which to work out the history of a particular wood.

Sometimes boundaries are the only remnants of former woods.<sup>40</sup> Anomalies in the landscape can often be explained by this. For example, at the southern edge of the present Kerecsend Wood in Hungary,<sup>41</sup> there is a seemingly pointless, ca. 250-m-long hedge cutting across a field (Fig. 6). Closer examination reveals that the hedge covers the remains of a woodbank, presumably dating from the Early Modern Period, when the wood functioned as a pheasantry. Further down the field in a straight line there stands a single tree, whose origins can probably be explained the same way, although the woodbank there does not survive.

An examination of Strážiště Wood, a complex example from the Czech karst area further illustrates these points. Strážiště is a small ancient wood (ca. 20 ha) with a zigzag outline, on top of a hill. It is surrounded on almost all sides by stone rows with stone piles and (less often) by lynchets. At many corners, there are huge stone piles. The topographical history of Strážiště Wood is very complicated. A reliable map of 1840 proves that the wood was then much larger than today, especially on the west and east. A less precise earlier map from the 1760s seems to indicate that – at least on the eastern side – the wood was similar to the 1840 shape. Another map from 1879 shows the wood basically as it is today except in the south and northwest, where it was even smaller. Fig. 7 shows the changes in woodland cover as represented on these maps.

<sup>37</sup> The maintenance of woodbanks (as referred to above), however, would make the results questionable.

<sup>38</sup> Rackham, *Woodlands* (note 7), 192–193.

<sup>39</sup> Penyigey, *Debrecen erdőgazdálkodása* (note 34), 341.

<sup>40</sup> O. Rackham, *Ancient Woodland: Its History, Vegetation and Uses in England*, 2nd Edition, Colvond, 2003, 13.

<sup>41</sup> On the wood, see e.g. B. Zólyomi, Der Tatarenahorn-Eichen-Lösswald der zonalen Waldsteppe (Acereto tatarici-Quercetum), *Acta Botanica Academiae Scientiarum Hungaricae* 3 (1957) 401–424.



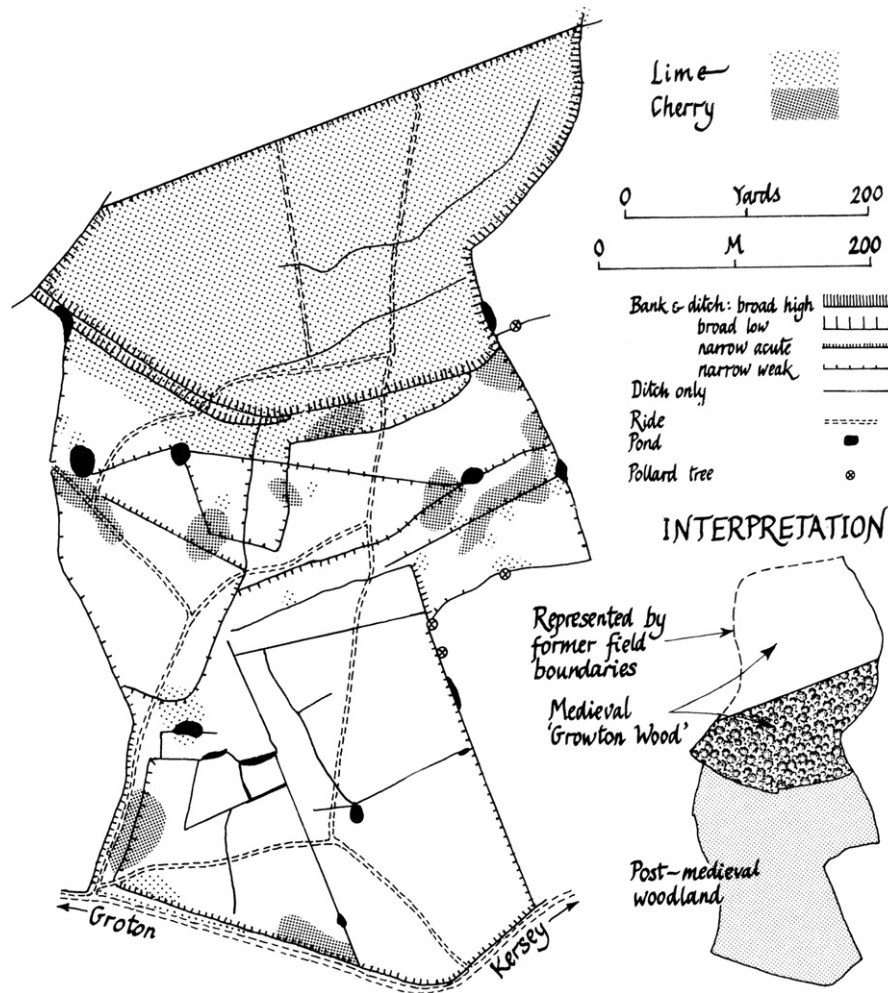


Fig. 9. Groton Wood (Suffolk, England). Small-leaved lime colonized the available land very slowly: it advanced some 20 m in three or four centuries. (After O. Rackham, *Trees and woodland in the British landscape*, London, 1976, 141. Slightly modified).

The study of landscape features (Fig. 8) adds a considerable amount of new information to this overall picture. Almost all the boundaries represented on the maps are detectable in some form. They indicate that the mid-nineteenth-century state was most probably not the 'original' extent of the wood which then shrank, but rather that the originally smaller wood became larger and smaller again. For example on the east, between the present woodland boundary and a huge lynchet that follows the 1840 boundary, there is a meadow. It had to be a field at some point, because the inner (present) boundary has a lynchet as well as a stone row, which implies ploughing. Most probably the inside boundary is the original – hence the fact that there is a stone row only here and not on the 1840 boundary. Some time before the 1760s, the wood was enlarged, and a new lynchet created where ploughing stopped. Between 1840 and 1879, this new area was abandoned and turned into a meadow. A similar story could be told of the western side, however, here the 1840 boundaries are no longer visible.

The physical boundaries also tell us about an event in the history of Strážiště Wood that is not represented on any maps. On the

northwest, a stone row runs inside the present wood and the 1879 boundary. Next to it lies a mysterious, small enclosure. It appears that at this place the original (pre-1760s) boundary was never recovered, probably because the tiny enclosure seemed nonsensical to maintain. It would be much harder to say who made the enclosure and to what purpose. The narrow strip around it could hardly have been anything but pasture, but why leave out a  $20 \times 20$  m circle? Was it perhaps someone's personal property in the Middle Ages or did it serve a purpose that we cannot fathom today?

#### Ecology

In ecology, the most important use of permanent woodland boundaries is that they define areas of ancient woodland even if no other sources (such as early maps or estate surveys) are available. Whether a wood is ancient (that is, whether it has been continuously wooded for several centuries) or recent is a key issue in European woodland ecology, where history is one of the most important factors influencing present vegetation.<sup>42</sup> Present woods

<sup>42</sup> Rackham, *Ancient Woodland* (note 40); M. Hermy, O. Honnay, L. Firbank, C.J. Grashof-Bokdam and J.E. Lawesson, An ecological comparison between ancient and other forest plant species of Europe, and the implication for forest conservation, *Biological Conservation* 91 (1999) 9–22; M. Wulf, Plant species richness of afforestations with different former use and habitat continuity, *Forest Ecology and Management* 195 (2004) 191–204; Z. Dzwonko, Relations between the floristic composition of isolated young woods and their proximity to ancient woodland, *Journal of Vegetation Science* 4 (1993) 693–698.

are often larger than they once were, which means that the historic boundary is now *within* the wood. If, for example, a woodbank inside a present wood appears to be medieval, then we can assume the areas inside that woodbank to have been wooded continuously since at least the Middle Ages. Woodland outside the woodbank can be of any age from immediate post-medieval to very recent, which needs to be worked out from further evidence.

In connection with the above, ecologists also use permanent woodland boundaries in the establishment of plant colonization patterns. If, again, a wood is larger today than its historical size, and the starting date of the abandonment of the old boundary can be established, then we can study the speed with which certain plants are able to invade newly available land (Fig. 9).<sup>43</sup>

Woodland boundaries also create special microhabitats. Because ditches often contain water, wetland plants frequently occur around woodbanks. In wetter areas, woodbanks promote plants that require better drainage.<sup>45</sup> Stone rows and walls are also different from their immediate environment.

## Conclusions

Permanent woodland boundaries were once widespread in Europe. Many of them date from the Middle Ages and perhaps even more from the Early Modern Period. Their existence was connected to a specific form of woodland management (coppicing) but also to ownership structures and through these to grazing regimes. With their various forms, permanent

woodland boundaries served to separate woodland from the surrounding countryside both in a legal and physical sense. Woodbanks, walls, stone rows and lynchets around woods are monuments in themselves. They are a part of European cultural heritage and deserve to be protected the same way as all other ancient landscape features inside and outside woods. In addition, woodland boundaries create special microhabitats, and they also carry valuable information for landscape history and ecology. The present paper summarised current knowledge, but further research is needed – especially in Central Europe – to establish local typologies for dating and also to reveal regional differences in the making, purposes and maintenance of woodland boundaries.

## Acknowledgements

This paper was written with the help of grant IAA600050812 and institutional long-term research plan AV0Z60050516, both from the Academy of Sciences of the Czech Republic, as well as grant VaV SP/2d3/139/07 from the Ministry of Environment of the Czech Republic. I would like to thank Oliver Rackham for introducing me to English woodland historical ecology, Andreas Mölder for his help with the German material, Rick Keyser for his expert advice on France, Cristian Gaşpar for information on ancient perambulations, Radim Hédli for his assistance during fieldwork in the Czech Republic, and three anonymous reviewers for their useful comments.

<sup>43</sup> E.g. K. Verheyen and M. Hermy, The relative importance of dispersal limitation of vascular plants in secondary forest succession in Muizen forest, Belgium, *Journal of Ecology* 89 (2001) 829–840; K. Verheyen, O. Honnay, G. Motzkin, M. Hermy and D.R. Foster, Response of forest plant species to land-use change: a life-history trait-based approach, *Journal of Ecology* 91 (2003) 563–577; J. Brunet, Der Einfluss von Waldnutzung und Waldgeschichte auf die Vegetation südschwedischer Laubwälder, *Norddeutsche Naturschutzakademie-Berichte* 3 (1994) 96–101; J. Brunet, G. von Oheimb and M. Diekmann, Factors influencing vegetation gradients across ancient-recent woodland borderlines in Southern Sweden, *Journal of Vegetation Science* 11 (2000) 515–524.

<sup>45</sup> H.J. During and F. Lloret, The species-pool hypothesis from a bryological perspective, *Folia geobotanica* 36 (2001) 63–70; H.J. During and F. Lloret, Diversity and dynamics in bryophyte communities on earth banks in a Dutch forest, *Symposia biologica Hungarica* 35 (1987) 447–455; B.F. van Tooren and H.J. During, Early succession of bryophyte communities on Dutch forest earth banks, *Lindbergia* 14 (1988) 40–46.



# It's a Fair Coppice: Methodological Considerations of the History of Woodland Management

*Péter Szabó*

## Summary

This chapter presents historical evidence in relation to the uses of European woodlands for the production of coppice, especially for firewood. This account develops ideas initiated by Oliver Rackham to examine the management of woods for fuelwood coppice – a dominant use of many landscapes prior to the emergence of economic ‘scientific’ forestry.

**Keywords:** woodland management, coppice, fuelwood, ‘scientific’ forestry

## Introduction

Coppicing is the repeated cutting on short rotation of stems growing from permanent stumps (called stools) in broadleaved forests. The ability of trees to grow back when cut down (or broken) is in all likelihood older than humanity and could be an evolutionary reaction to an outside force, such as trampling by large animals, breakage by windstorms or tree-felling by beavers (Rackham 2006: 72–73). Most (but not all) conifers lack this property, and it is an open question why certain tree species coppice and others do not. This already puzzled the Greek philosopher Theophrastus in the fourth century BC (Theophrastus, *Enquiry into Plants*, Book II. I–II.4). There are two main reasons why people coppice: first, the freshly growing stems are relatively thin and can be turned into firewood with minimum effort; and second, coppicing ensures that trees regenerate reliably and produce the same quantity and quality of wood in each cycle. Oliver Rackham spent a lifetime studying the history and current ecology of coppice woods. To a large extent through his works, coppicing is now generally acknowledged to have formed the basis for firewood production in practically all parts of broadleaved Europe (and even outside Europe) until the breakthrough of ‘scientific’ forestry in the nineteenth century (Rackham 1976, 1980, 2006).

In spite of its former widespread use, coppicing was all but eradicated in Europe by the 1950s (Fig. 17.1).<sup>1</sup> ‘Scientific’ forestry, with its focus on high forests preferably of conifers,

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1 Except in the Mediterranean, where it was practised for longer. Nonetheless, many existing coppices in the Mediterranean are also out of use (Unrau et al. 2018).



**Figure 17.1** An ancient coppice wood in the south-eastern Czech Republic. Note that coppicing is no longer active and the shoots are much older than they used to be allowed to grow, November 2013. (R. Hédli)

strongly opposed coppicing. This opposition sometimes took the form of direct repression: the Czech forest law of 1995 banned the regular cutting of stands younger than 80 years. For two centuries, coppicing was looked down upon and snubbed by those in positions of power in forestry administration. It was presented as a backward method that produced scrubby growth instead of the orderly stands of tall trees that foresters preferred to see. In an unexpected turn of events, coppicing was rediscovered by nature conservationists as well as foresters in the past half-century (Buckley and Mills 2015a). Plant conservationists are interested in coppicing because many woodland plants seem to be adapted to quick successions of light and dark periods in forests, which result from coppicing. In the absence of light, such plants – many of which are rare and endangered – disappear (Kopecký, Hédli and Szabó 2013). Coppicing is a management tool that can also promote important invertebrates and birds (Beneš et al. 2006; Fartmann, Müller and Poniatowski 2013; Fuller 1992). By contrast, foresters have rediscovered coppicing as a cheap and reliable way to produce firewood. When fossil fuel supplies seemed inexhaustible and nuclear power stations promised to solve energy problems once and for all, firewood appeared to be a thing of the past. By now, however, people are much more aware of the problems connected with fossil fuels and nuclear energy. Firewood has found itself back in the spotlight as one of the desired renewable sources of energy. With growing prices for wood, coppicing can be a viable economic option in certain regions (Kneifl, Kadavý and Knott 2011; Buckley and Mills 2015b).

Coppicing in Europe goes back to prehistory; that is, it has been practised for millennia. Although its basic outlines have remained the same, it has been neither spatially nor technologically static. Untangling the history of coppicing is important if we are to better understand the consequences of its abandonment and the effects of its potential reintroduction for

conservation purposes. The history of coppicing can be approached through several types of sources, ranging from biological to historical. With his extraordinary skills across disciplines, Oliver Rackham was instrumental in discovering, contextualizing and using many of these sources. His research also clearly showed that conclusions about past (and, by implication, about future) woodland management are most solid when based on several types of sources. In this chapter, I try to follow in Rackham's footsteps to systematize and critically examine the ways coppicing can be detected from prehistory until the twenty-first century and give special attention to recent developments in each field. Given the limits of this contribution, I cannot claim to provide an exhaustive review, and my treatment especially of better-researched topics – such as tree-rings or written sources – must inevitably remain cursory.

Evidence to point to the existence of coppicing in the past can be grouped into three basic categories: written historical sources, pollen and wood.<sup>2</sup> In the following, I present these source types describing their properties, advantages and pitfalls.

## Written evidence

Some written sources offer straightforward descriptions of coppicing. Here is the classic example of Hayley Wood (Cambridgeshire, England) from 1356, discovered and quoted by Rackham: 'a certain Wood called Heylewode which contains 80 acres by estimate. Of the underwood of which there can be sold every year, without causing waste or destruction, 11 acres of underwood, which are worth 55s. at 5s. an acre' (Rackham 1975: 26).<sup>3</sup> This text describes a seven-year coppice cycle. Just how widespread this practice was in Europe is demonstrated by the description of a wood called Mulschachen in today's south-eastern Czech Republic 58 years later, in 1414: 'When it becomes seven years old, one estimates it to be worth about 10 lb. den' (Bretholz 1930: 184).

Antique authors were also aware of coppicing. Pliny the Elder, for example, suggested an eight-year coppice cycle for chestnut trees to be used as vineyard stakes (Pliny the Elder, *Naturalis Historiae*, book 17, ch. 34). Descriptions of coppicing became common in the Middle Ages, and countless examples are available from the thirteenth to the twentieth centuries. Until the eighteenth century, the most explicit mentions of coppicing can be found in estate conscriptions of various kinds, such as the examples given here. After that, especially in Central and Western Europe, forest management plans contained very detailed descriptions of coppice management, including maps of coppice compartments (e.g. Bürgi 1999a; Müllerová, Szabó and Hédl 2014) (Fig. 17.2). Coppicing also found its way into prescriptive legislation in the Middle Ages. For example, the 1476 forestry law of Venice ordered a ten-year coppice cycle for all community forests (Appuhn 2009: 112). Legislation usually turned out to be too rigid to reflect realities on the ground: the monks of Montbenoit in 1719 must have felt frustrated explaining that they could not stick to Colbert's famous 1669 *Ordonnance des eaux et forêts*, which prescribed a ten-year coppice cycle, because the pine trees in their forests simply would not grow back from the stump (Matteson 2015: 60). The general trend was for the coppice cycle to get longer throughout the centuries, culminating in about 40 years – although there were many exceptions, and coppice cycles of around 15 years were common even in the nineteenth century. There are only guesses at why the cycle lengthened. Rackham (1975: 31) was among the first to address the issue, which he attributed to the gradual slowing down of growth rates resulting from soil phosphate exhaustion through coppicing. Later, he added the spread of

2 The presence of certain plants, which Rackham called 'coppicing plants', in woodland can also indicate a coppicing history for the given wood (Rackham 2003: 413–38). Being rather indirect evidence, I do not cover these here. Nor do I include archaeobotanical investigations (mostly based on animal dung) of animal fodder.

3 Translation in original. In this chapter, all translations are mine except when indicated otherwise.



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|--------------------------|-------------------------------------|------------------------------------------|--|
| Betriebsklasse: 40 jähr. |                                     | Wirtschaftstheil: <i>Nizovina</i> Nr. 35 |  |
| Standort                 | Gebirgsart: <i>Prinzgar Dvornik</i> |                                          |  |
|                          | Boden: <i>Feuchter Laubboden</i>    |                                          |  |
|                          | Lage: <i>Offener Gelände</i>        |                                          |  |
|                          | Bonität: 5                          |                                          |  |

| Wirtschaftstheil | Parzelle | Fläche<br>Hektar                 | Holzart | Alter |        | Bestandes-Bonität | Bestockung | Holzmasse  |       |       |          |       |       | Anmerkung         |
|------------------|----------|----------------------------------|---------|-------|--------|-------------------|------------|------------|-------|-------|----------|-------|-------|-------------------|
|                  |          |                                  |         | Jahre | Classe |                   |            | pro Hektar |       |       | Zusammen |       |       |                   |
|                  |          |                                  |         |       |        |                   |            | hart       | weich | Summa | hart     | weich | Summa |                   |
|                  |          |                                  |         |       |        |                   |            |            |       |       |          |       |       |                   |
| 35 a             | 15790    | <i>Oberholz</i>                  |         |       |        |                   |            |            |       |       |          |       |       |                   |
|                  |          | <i>Ei. 100</i>                   |         |       |        |                   |            | 16         |       | 16    |          | 261   |       | 261               |
|                  |          | <i>Unterholz</i>                 |         |       |        |                   |            |            |       |       |          |       |       |                   |
|                  |          | <i>Wbu. 5 Ei. 3 Apr. 2. Pen.</i> | 35      | IV    | 5      | 0.9               |            | 86         |       | 86    |          | 1338  |       | 1338              |
| b                | 2250     | <i>Oberholz</i>                  |         |       |        |                   |            |            |       |       |          |       |       |                   |
|                  |          | <i>Ei. 50 Pen. 20</i>            |         |       |        |                   |            | 7          |       | 7     |          | 16    |       | 16                |
|                  |          | <i>Unterholz</i>                 |         |       |        |                   |            |            |       |       |          |       |       |                   |
|                  |          | <i>Wbu. 4 Pen. 4 Ei. 2 Apr.</i>  | 10      | I     | 5      | 0.9               |            | 13         | 8     | 21    |          | 29    | 18    | 47                |
|                  |          |                                  |         |       |        |                   |            |            |       |       |          | 277   |       | 277               |
|                  |          |                                  |         |       |        |                   |            |            |       |       |          | 1387  | 18    | 1405              |
|                  |          |                                  |         |       |        |                   |            |            |       |       |          |       |       | <i>Oberholz.</i>  |
|                  |          |                                  |         |       |        |                   |            |            |       |       |          |       |       | <i>Unterholz.</i> |

**Figure 17.2** Detail from the forest management plan of the Bohuslavice forest district in the south-eastern Czech Republic from 1899. The document specifies the coppice cycle (40 years) as well as the tree species for standards (*Oberholz*) and underwood (*Unterholz*). (Original kept at the Moravian Provincial Archive (Moravský zemský archiv) fond F 31 kniha 388)

chimney building as another possible explanation (Rackham 2003: 140). Others suggested an increased market for larger logs and a shift towards less labour-intensive wood-pasture systems after the Black Death (Galloway, Keene and Murphy 1996).

Most written sources are not quite as explicit as those noted here. When working with these, there is no certainty that our interpretation is correct. When researching single forests, it is best if several types of evidence corroborate each other. One type of such evidence is the names of forests, either geographic names or general woodland typology – although the two are often difficult to tell apart. In many European languages, there are specific words to denote coppices (e.g. French *taillis*, German *Niederwald*, Italian *ceduo*, Hungarian *sarjerdő*) (for more examples, see Unrau et al. 2018). Sometimes these are used to describe forests; sometimes they are (parts of) names of forests. By and large, they denote that the wood in question was coppiced at some point, although they neither establish how permanent coppicing was nor are much help in dating it. In addition to simply faulty interpretation, several factors make the usage of these terms challenging. First, words change through time. The same word can mean different things in different periods, and the same phenomenon can be referred to by different words in different centuries. Some older words that arguably denoted coppices have gradually disappeared from common usage, such as the medieval Hungarian *eresztvény* (Szabó 2005). New words either developed organically or were created to purpose. The two processes could freely overlap. The German *Niederwald*, for instance, appears to be a medieval word, but was not used as a technical term to denote coppices until the nineteenth century.

*Mittelwald* (coppice-with-standards) is claimed to have been created by the renowned forester Heinrich Cotta in the early nineteenth century. In the Swiss case, the promotion of these terms even contributed to shaping the structure of forests that more strictly matched ideal cases than their predecessors (Bürge 1999b). In Spain, today's most common term for coppices (*monte bajo*) was used for the first time in a legal context only in 1574 (Ortego and de Lomana 2017). Second, strict terminology has been in use only for the past two centuries. Before that, coppices did not have to have a specific name at all, especially if coppicing was the commonest form of management. In some countries, woodland structure (i.e. coppicing versus high forests) was not a decisive element in woodland typology. For example, in Denmark, descriptive terms for woodland focused rather on resources and ownership (Fritzbøger 2004). With some words, one can only conjecture that they referred to coppices, such as the Swedish *surskog* in the seventeenth century (Bergendorff and Emanuelsson 1996). It is possible that *Buschwald* (as opposed to *Hochwald*) in western German territories after the fourteenth century also referred to coppices, although there is no way to prove this beyond doubt (Hausrath 1928). Furthermore, even if a word for coppices existed, it was often not applied consistently. In the Domesday Book in late eleventh-century England, *silva minuta* referred to coppices, but this term was used only in a few counties in the eastern Midlands, and in other regions no difference was made between types of woodland (Rackham 2003). Similarly, *silva caedua* meant coppice woods when used by some Roman authors (notably Pliny the Elder), but did not when used by others (Harris 2018). Many words were regional and appear somewhat obscure in the given context today, such as *Maß*, which meant coppice wood in southern Moravia in the early modern period. Third, terms can have several meanings in addition to coppicing. While I identified the Latin term *rubetum* in medieval Czech documents as referring to coppices, it is clear that it could also refer to scrubby vegetation with no specific management (Szabó et al. 2015). Nonetheless, the geographical distribution of hundreds of occurrences of the term seemed to confirm that it was mostly used to describe coppices – even keeping in mind that such argumentation is to a certain extent circular.

The existence of coppicing can be deduced from various other types of sources as well. Richard Keyser brought scholarly attention to the 'Book of sales of the woods of Champagne' and similar documents in thirteenth-century France (Keyser 2009). These documents recorded leases of woodland for cutting for a given period. Although never mentioning coppicing explicitly, lease periods of 6 to 20 years, accompanied by the condition that the merchants can 'cut each tree only once so that it grows back quickly' (Keyser 2009: 372),<sup>4</sup> make it clear that the lease period in fact equalled the coppice cycle. As opposed to the explicit mentioning of coppice cycles, Galloway, Keene and Murphy (1996: 454) termed such information 'implicit coppice cycles'. Furthermore, bans on pasturing were often introduced for a few years after cutting, usually a reliable indicator of coppicing because young coppice shoots are a favourite for browsing animals and need to be protected until they grow tall enough. Keyser's French account books also mentioned the presence of (or, more precisely, the obligation of merchants to leave behind a certain number of) standard trees (*bailivaux*). Coppice woods sometimes (but not always) contained a set of straight and tall trees grown from seed to be used for construction purposes. Just like coppice cycles, the number of standards also made it to medieval legislation, most famously to the 1376 forest code of Charles V of France, which ordered that eight to ten standards be left on every *arpent* (roughly equivalent to an acre) (Isambert, Decrusy and Jourdan 1824: 462). Account books in the strict sense can also reveal the existence of coppicing. In their classic study, Galloway, Keene and Murphy (1996) employed hundreds of manorial accounts in a wide circle around London to assess the fuelwood consumption of the English capital in the fourteenth century. They

4 Translation in original.

convincingly argued that fuelwood came from coppices. Similar research was carried out for early modern Madrid and Paris (Boissière 1990; Bernardos et al. 2011; Ortego and de Lomana 2017). I tried to demonstrate the use of account books to detect coppicing with the example of the Choustník (southern Bohemia) woodland account book of 1447 (Szabó 2018). This book made no mention of cutting cycles, but its closer examination leaves little doubt that it described a fully functioning coppice system. Wood in this region was sold either by the territory or by the piece. Because an average single oak cost one sixth of the average value of all the wood cut on approximately 900 m<sup>2</sup>, the system described was clearly coppice underwood with standards. High forests were so unusual that sometimes they were referred to as such. When – rarely – high forests were sold by the territory (rather than selling individual trees in them), they brought in three to four times more money than the average coppice compartment of the same size. Comparing the area cut in 1447 with what we know about woodland sizes on the estate, I even ventured to estimate the coppice cycle, which appeared to be somewhere between 6 and 18 years: a plausible number for the region and period.

## Pollen

Pollen is the substance plants use to transfer their reproductive material. Pollen grains of individual species or genera are highly characteristic. In favourable conditions (mostly when not exposed to oxygen), grains are extremely resistant. They can survive many thousands of years and still be recognizable under the microscope. In lake and mire sediments, pollen forms temporal layers that can be studied to untangle vegetation history (Faegri, Kaland and Krzywinski 1989). However, the connection between fossil pollen and past vegetation is anything but straightforward. Individual tree species vary tremendously in their production of pollen. The ability of pollen grains to fly also differs, and grains have different taphonomic characteristics. Furthermore, every pollen site is unique: some reflect local vegetation while others gather their pollen from a larger area, depending on size and local geography. Another important issue is the calculation and presentation of pollen counts. Usually 500 grains per sample are counted and the results are presented as percentages in the overall sum. This means that an increase in the pollen percentage of a tree species need not reflect any change in the presence of that tree in the given landscape. Alternative techniques (such as measuring pollen influx) exist to overcome this challenge, but these are not routinely used everywhere (Birks and Berglund 2018). A number of researchers looked at temporal changes in pollen percentages to infer past management practices. For example, Gardner (2002) interpreted a series of fluctuations (over 72–228 years) in oak, hazel and hornbeam pollen as indicators of coppice or pollard management (the latter is similar to coppicing except that trees are cut higher, out of the reach of browsing animals) in Neolithic and Copper Age Hungary. In spite of his conclusions, he admitted that the temporal resolution of the pollen core was too coarse to register actual coppice cycles. He conjectured that ‘there may be a threshold level at which the signal of woodland management is apparent in the pollen record’ (Gardner 2002: 551).

More examples of similar research exist, including the explanation of the mid-Holocene elm decline as the consequence of large-scale pollarding for leaf-fodder, which would have drastically reduced flowering (and therefore pollen production) in elm (Troels Smith 1960; Parker et al. 2002). Oliver Rackham (1980) pointed out that it would have been virtually impossible for early Neolithic populations to achieve this effect by themselves: there were too many elms and too few people. Rasmussen (1990) rightly remarked that pollen cannot provide ‘definite direct evidence’ for coppicing (or pollarding) in prehistory.

Other than subjective interpretations of pollen profiles, the only research known to me that tried to empirically test the connection between coppicing and pollen was published by Waller, Grant and Bunting (2012) for three British woods. They applied a two-stage strategy: first, they followed the number of flowers and the quantity of pollen produced by lime *Tilia* spp.,



Common Hazel *Corylus avellana* and Common Alder *Alnus glutinosa* in active coppice woods throughout the coppice cycle. This was combined with vegetation surveys to establish whether different stages in the coppice cycle produce distinct pollen signals. These data were then used to produce model simulations of the effect of coppicing on the pollen record, and finally these simulations were compared to actual pollen diagrams. Unsurprisingly, the results were not straightforward. In general, coppicing seemed to push woodland composition from canopy species to understorey species and to make more sensitive species altogether invisible in the pollen record. This was consistent with existing pollen cores, especially in East Anglia. However, similar changes in pollen diagrams can be caused by multiple factors; therefore, conclusions were stronger when corroborated by other evidence, such as fossilized wood from prehistoric trackways (of which see more in the next section, below) in the Thames estuary. Waller, Grant and Bunting also pointed out two important limitations of the interpretation of pollen diagrams in search of past coppicing. First, once the wood is not coppiced entirely, the potential signs of coppicing can be completely masked (also mentioned in Rasmussen 1990). Second, size matters: the interaction between the size of coppice compartments and that of the catchment area of pollen sites is an major source of reconstruction error (Bunting, Grant and Waller 2016a). The same authors also examined non-arboreal pollen as a potential tool to identify coppicing and arrived at the same inconclusive results: the pollen of plants other than trees can reflect coppicing, but the interpretation of these signals is ambiguous (Bunting, Grant and Waller 2016b). At present, it seems that pollen diagrams have clear potential to detect coppicing in past woodlands, but more methodological work is needed to realize this potential. As Rackham put it in his usual succinct manner, 'Palynological criteria are wanted to differentiate between the following: forest; savanna [...]; coppice wood; hedges and non-woodland trees; and (in Mediterranean countries) maquis' (Rackham 2006: 80).

A promising direction of future research could be the search for multiple scenarios, of which coppicing can be one, rather than for the elusive 'correct' reconstruction (Bunting, Grant and Waller 2016a).

## Wood

Wood comes in many forms, from fossilized pieces in palaeoecological cores to charcoal fragments in archaeological excavations to living tissues. As far as the history of coppicing is concerned, wood has the advantage over pollen that it can provide more direct evidence of management. Regardless of the form in which the wood gets to the researcher, it has four characteristics that can be used to detect coppicing in the past: anatomy, cambial age (see below), diameter and ring width.

Rackham did pioneering work in wood anatomy, more precisely in the analysis of external morphology. In his 1977 paper on three prehistoric wooden tracks (raised wooden walkways in marshy terrain) in the Somerset Levels, he used his practical knowledge of hazel coppicing to examine archaeological wood remains (Rackham 1977). His conclusions still fascinate today, for he claimed to have worked out the actual method hazel stems were cut from the stools some four millennia ago. He also established that rather than harvesting larger contiguous areas at once, the makers of the tracks preferred to choose individual shoots. The main aim of coppicing, he contended, may have been the production of leaf fodder for animals. Similar work on prehistoric trackways was done in other European countries, for example in Denmark or in the Netherlands as early as 1986 (Malmros 1986; Casperie 1986). In the latter case, the author deduced the existence of willow coppices (including their approximate location!) in the Iron Age. Because at this point metal tools were already available, willow shoots were cut differently from hazel rods in Neolithic Somerset, which were partly torn away.

Living coppice stools of greater antiquity also prove that coppicing existed in the past. Rackham pointed out many times in the 1970s that stools expand with each successive cutting

(because shoots usually appear on the outside), which gives an opportunity to (at least tentatively) date them and establish a *terminus post quem* for coppicing in the given wood (Rackham 1975; 1976). He inferred that many large coppice stools were from the Middle Ages, if not earlier. Pigott's (1989) calculations on lime stools confirmed this view. Systematic efforts at dating stools are rare. A prominent example is Vrška et al. (2016). Through a great amount of manual work, Vrška and colleagues uncovered the root system of several large oak coppice stools in a national park with a known coppicing history in the southern Czech Republic, thereby proving that stems not apparently connected above ground were indeed parts of a single tree. They estimated the largest stools to be more than 800 years old. However, not all multistemmed trees are necessarily coppice stools. Dutch researchers showed that similar structures can emerge through the effects of grazing (Copini et al. 2005).

Wood reacts to the physical impact of cutting as well as to the specific environmental conditions created by coppicing – for instance by changes in the size and distribution of cell types, pore size or by the formation of false rings. These were described in detail based on examples by Schweingruber (2007), and the specific effects of coppice management were studied by Girardclos et al. (2018). Distinguishing between the signals of various types of management (pollarding, coppicing, leaf removal, browsing by animals) is evidently very difficult, if possible at all. Equally challenging is to recognize such signals in archaeological rather than recent wood. This area of research is perhaps the least developed among those discussed in this chapter, and therefore offers the greatest potential. So far, wood anatomical research on archaeological wood appears to focus on pollarding rather than coppicing (Haas and Schweingruber 1993). For example, Bernard, Renaudin and Marguerie (2006) compared living shredded trees with archaeological material. In addition to ring width, similarities in the mean porosity of the rings between recent and archaeological material led the authors to assume the existence of shredding in medieval France (see also Thiebault 2006). In a similar fashion, Bleicher (2014) combined wood anatomical evidence with ring width to draw conclusions about pollarding in the Neolithic in Switzerland.

In contrast to wood anatomy, annual tree-ring width, wood diameter and cambial age have been more often used to make inferences about coppicing. Trees in temperate climates develop a new annual ring each year, because the speed of growth slows down during the vegetation season. The structure of earlywood (spring growth) differs from that of latewood (summer growth), which makes a pattern recognizable to the naked eye. The width of an annual ring is determined by a host of factors, and tremendous amounts of literature exist in dendrochronology and forestry that describe and interpret these factors. The sum of individual tree-rings – plus bast (the inner bark/vascular material) and bark, if present – make up wood diameter. Cambial age is the number of annual rings from the pith (the centre of the tree) in a wood sample. In other words, cambial age tells the researcher how long the tree lived rather when it lived (which is absolute age). The difference between the birth and death dates of a tree equals its cambial age only for the trunks of standard, seed-grown trees. This is especially significant for coppicing: a coppice shoot can have the cambial age of ten years, while the entire tree (the stool) can be hundreds of years old.

That the width of annual tree-rings reflects growing condition around trees has been known for a long time in Europe, and early observations on this are attributed to none other than Leonardo da Vinci (Schweingruber 1988: 256). Later on, it was realized that mechanical damage to the tree can also leave behind recognizable signals in ring width. Measurable reactions in tree-rings can be of two types: a sudden increase ('release') or decline in ring width depending on the type of tree (standard or stool) as well as the part of the tree (trunk or shoot). As ever, Oliver Rackham was among the first to utilize this source type to study the management history of woodland, and his research aptly illustrates the opportunities offered by tree-ring width for the study of historical coppicing. In 1975, he analysed the annual rings of an ash coppice stool in Hayley Wood, which showed sudden declines at about every 14 years followed

each time by prolonged recovery. Rackham connected this to coppicing, when after harvest the stool's ability to grow is drastically reduced (Rackham 1975: 32). Conversely, standard trees can show sudden increases when they get more light either through the cutting of standard trees close to them, as demonstrated by Rackham for Hayley oaks, or by the cutting of underwood (Altman et al. 2013) (Fig. 17.3). Because tree-ring width is influenced by a large number of factors, connecting its changes to management events remains challenging. As also suggested by Rackham, coppice shoots themselves have their particular growth dynamics. Especially in the first few years of their life, they grow very fast. This makes it possible to recognize coppice shoots (and by implication the existence of coppicing) among archaeological wood samples (Rackham 1975: 113; see Bleicher 2014 for a recent overview of tree-ring patterns in the context of prehistoric management). This assumption was tested by Haneca, Van Acker and Beeckman (2005), who compared ring width growth trends in current coppices with archaeological material in Belgium. They observed remarkable similarities, which they tentatively interpreted as signs of coppice management in the Roman and medieval periods. Naturally this method raises its own questions, and Copini and colleagues repeatedly criticized it (e.g. Copini, Sass-Klaassen and den Ouden 2010), arguing that their own oak samples from Dutch coppice forests showed that initial strong growth in itself was not sufficient to distinguish coppice shoots from young seedlings. However, they mentioned that the comparison of earlywood patterns may be a better key to identify the fingerprint of coppicing. Deforce and Haneca (2015) extended such investigations to well-preserved charcoal fragments from fourteenth-century Belgium, reiterating earlier conclusions about the clearly recognizable growth pattern of coppice shoots. Even more recently, Girardclos et al. (2018) countered these



**Figure 17.3** An ancient coppice wood south-east of Brno in the Czech Republic in 1953. This was the period when coppicing was being rapidly abandoned. Note the various stages of coppicing and the standards. (kontaminace.cenia.cz)

arguments based on evidence from a current oak coppice in northern France. Their statistical analysis did not show significant differences in growth rates between coppice underwood and standards. Whether these contradicting conclusions have to do with differences between species (oak appears to produce less clear a signal than other common tree species) or with variations in local conditions and management remains to be seen.

Cambial age and wood diameter have been commonly used in the reconstruction of past woodland management. This is arguably because these properties – as opposed to ring width, the proper measurement of which requires a laboratory – can be recorded and studied by non-specialists. The basic assumption underlying this type of research is that populations of wood samples from managed stands show a pattern in their cambial age and diameter distribution distinct from samples from unmanaged (or differently managed) stands. Strong clustering especially in age distribution can be interpreted as the fingerprint of management. Following up on Rackham's observation in the Somerset Levels, Anne Crone (1987) took samples from existing coppices as comparative material, and came to the conclusion that the age and diameter structure of Somerset wood remains does not support the idea of formal coppicing in the Neolithic. It is clear that because this kind of investigation is based on statistical inferences about population samples, larger amounts of wood are needed to draw meaningful conclusions. Probably the first to bring more rigorous methodology into such research was André Billamboz from the 1980s onwards (Billamboz 1992). He termed his investigations based on thousands of prehistoric wood remains from southern Germany 'dendrotypology'. Welmoed Out and her colleagues recently provided further methodological sophistication in trying to resolve the most important question (already addressed by Crone): whether wood samples from managed and unmanaged stands can be distinguished by cambial age and diameter alone (Out, Vermeeren and Hänninen 2013; 2018). They constructed theoretical models for distribution patterns, which were compared with data from existing coppices and archaeological material. Their conclusions were cautious but promising, detecting management based on cambial age and diameter analysis is possible, but that the 'strength of the conclusions will ... depend on the diameter of the investigated branches, the size and context of samples and the availability of additional indications such as the physical characteristics of the wood' (Out, Vermeeren and Hänninen 2013: 4095).

They recommended using at least 50 wood remains larger than 2 cm in diameter. A related issue, which is especially relevant for archaeological remains, is the reconstruction of original wood diameter sizes from charcoal fragments. Several competing methods were developed, which either compared archaeological finds with contemporary charcoal burning sites, or used mathematical calculations that modelled the way wood breaks into smaller pieces of charcoal (Dufraisse 2008; Ludemann 2008). Once a reconstructed size distribution is available, it can be analysed with the same methods as non-carbonized archaeological finds (Paradis-Grenouillet et al. 2015).

## Rackham's legacy

Many authors quoted in this chapter pointed out that the best way to approach the history of coppicing is using multiple sources and lines of investigation. This brings us full circle to Oliver Rackham's work. He was unique in his ability to analyse written sources with the same confidence as tree-rings or plant distribution. While such universal knowledge appears unattainable for most of us, we may take comfort in noting that the individual disciplines involved in research on coppice history have been moving forward by leaps and bounds in recent decades. With much more research produced and with methods getting increasingly sophisticated and difficult to comprehend but for a handful of specialists, nowadays it is hardly possible to be up to date and active in more than one of the disciplines described here. The way forward is through interdisciplinary teamwork. In addition to building an



atmosphere of mutual trust and scientific respect, the biggest challenge in such teamwork is always to unite the individual researches and results in a common interpretative framework. This is where Oliver Rackham's legacy is most relevant today.

## Acknowledgement

The research leading to this chapter was supported by long-term research development project RVO 67985939 from the Czech Academy of Sciences, and grant GA17-09283S from the Czech Science Foundation.

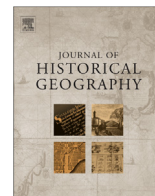
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# Intensive woodland management in the Middle Ages: spatial modelling based on archival data

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## Abstract

Firewood played an indispensable role in European socio-economic systems from prehistory until the nineteenth century. Recent research has shown that in European temperate lowlands the most important management form to produce firewood was coppicing. In spite of the growing body of research on traditional woodland management, there remain large gaps in knowledge. Detailed studies of individual sites or smaller areas have provided a wealth of information on the methods of medieval coppicing, and at such sites the long-term effects of coppicing on vegetation structure and composition have also been examined. However, little is known about the distribution and extent of coppicing at the landscape scale, and forming a coherent picture of the spatial extent rather than the management details of coppicing in larger regions remains a challenge. This paper investigates the distribution and extent of coppice management in Moravia (eastern Czech Republic, ca. 22,300 km<sup>2</sup>) in the Late Middle Ages. We created an extensive database of written sources that contained information on the presence of coppice woods at the parish level. Subsequently we used the MAXENT algorithm to create a model of the distribution of coppicing over the entire area. With the help of wood production and consumption estimates, we also calculated the minimum area of managed woodland for the study period. Results show that coppicing was predominant in the lowlands and often occurred at higher elevations as well, where neither natural conditions nor tree species composition were favourable. The paper also highlights the potential of spatial models based on archival data for historical landscape reconstructions.

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**Keywords:** Coppice; Moravia; Middle Ages; GIS; Historical landscape reconstruction

## Introduction

From prehistory until the nineteenth century, most European societies were dependent on firewood to survive winters. Although there were regions in northwestern Europe where peat provided an alternative or even became the main fuel in certain periods, and coal was of considerable importance in some districts as early as the thirteenth century, the majority of Europeans strove to have access to wood.<sup>1</sup> In addition to heating, fuelwood was essential in cooking

as well. Charcoal (wood burnt slowly in an oxygen-poor environment) was needed to smelt ore. Since the nineteenth century, a range of fossil fuels (coal, oil and natural gas) have been used to provide energy for an exponentially growing population.<sup>2</sup> The diminishing importance of firewood throughout the past two centuries has had a deep impact on European woodlands. Since ca. 1800 AD, markets have preferred construction timber to firewood, which led to the development of new management methods and was partly responsible for the appearance of modern, 'scientific'

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<sup>1</sup> From the vast literature on peat see, for example, C.H. Cornelisse, The economy of peat and its environmental consequences in Holland during the Late Middle Ages, *Jaarboek voor Ecologische Geschiedenis* (2006) 95–121; P.J.E.M. van Dam, Sinking peat bogs: environmental change in Holland, 1350–1550, *Environmental History* 6 (2001) 32–45; I.D. Rotherham, *Peat and Peat Cutting*, Oxford, 2009; C. Smout, Bogs and people in Scotland, in: C. Smout, *Exploring Environmental History: Selected Essays*, Edinburgh, 2009, 99–112. For coal, see P. Brimblecombe, *The Big Smoke: A History of Air Pollution in London since Medieval Times*, London, 1987. In addition, various other sources of energy were used, such as bracken, gorse or even cow dung, but these could be important only locally. On medieval energy sources in general, see R.C. Hoffmann, *An Environmental History of Medieval Europe*, Cambridge, 2014, 196–215.

<sup>2</sup> R.P. Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, Cambridge, 2001.

forestry.<sup>3</sup> During this process, woodland management was taken over by trained professionals and heavy machinery. While the amount of woodland in Europe has grown in the past two centuries, forests have provided a decreasing proportion of the total energy consumption on the continent. In 2010, a mere 4.8% of energy consumption in the EU was covered by wood.<sup>4</sup>

The relative insignificance of firewood as an energy source in the past two centuries as well as efforts by proponents of modern forestry to downplay or altogether dismiss earlier management systems resulted in a deeply-rooted lack of appreciation for the sophistication and extent of woodland management in pre-industrial Europe. This was coupled with lack of knowledge about the extent of woodland in different periods, substituted by unfounded generalizations about 'vast woodlands' that would have provided all that was necessary without systematic management schemes. Such non-systematic and uncontrolled exploitation of woodland resources is argued to have led to 'timber-famine' in the Early Modern Period (ca. 1500–1800 AD), which necessitated state control over forests and the appearance of timber-oriented forestry techniques.<sup>5</sup>

In the past few decades large numbers of studies have overturned most of these assertions. Palynological research has shown that extensive treeless areas were already created in Europe in the Neolithic, and by the Iron Age at the latest woodland was in most places a limited resource.<sup>6</sup> Computerized models of European deforestation since the Neolithic based on population estimates also reinforced these ideas.<sup>7</sup> The analysis of archival sources demonstrated that in some regions of northwestern Europe forests reached their minimum extent as early as the thirteenth or fourteenth centuries.<sup>8</sup> Traditional ways of woodland management were also intensively studied. It is now clear that in European temperate lowlands the most important management form to produce firewood was coppicing.<sup>9</sup> The coppice system is based on the biological fact that after cutting broadleaved trees regenerate vegetatively by growing shoots either from the stool (the part of the tree that remains in the ground) or from the root system. The same tree can be cut many times on a short rotation without losing its ability to grow new shoots. Young coppice shoots (generally referred to as underwood) were ideal for firewood: they could be harvested with minimal energy input and put straight on the fire. Individual shoots were usually tied up in a small bunch

called a faggot, which was often measured by the cartload. For building timber, trees of seed origin were used. Such trees had a (relatively) straight trunk and were left to grow for as long as needed to reach the suitable size. Some timber trees grew up in *high-forests* – woodland consisting exclusively of timber trees. More often, however, timber trees were combined with coppice stools, in which case they were called standards. Such a management system is referred to as *coppice-with-standards*.<sup>10</sup> It is important to note that conifers, as opposed to broadleaved trees, do not coppice (with few exceptions, such as yew or cypress). As a result, coppicing was not a viable management option in regions dominated by coniferous trees, mostly in mountainous areas and in the boreal forests of northern Europe. Coppicing was demonstrated by archaeological methods to have existed already in prehistory.<sup>11</sup> The method itself was highly sustainable in the modern sense: areas to be cut yearly were planned so that the resource was not depleted.<sup>12</sup> Already in the Middle Ages people were aware of this. For example, a survey of Hayley Wood (England) from 1356 AD included that the wood 'contains 80 acres by estimate. Of the underwood of which there can be sold every year, without causing waste or destruction, 11 acres of underwood.'<sup>13</sup> On the other hand, a general lengthening of the coppice cycle (the number of years between successive harvests) can be observed all over Europe from medieval values of under ten years to twenty-five or more years in the eighteenth and nineteenth centuries. Although the reasons for this process are unclear, it may have involved the removal of nutrients from the soil, which in effect questions the long-term viability of coppicing.<sup>14</sup>

In spite of the growing body of research on traditional woodland management, there remain large gaps in knowledge. Detailed studies of individual sites or smaller areas have provided a wealth of information on the methods of medieval coppicing, and at such sites the long-term effects of coppicing on vegetation structure and composition have also been examined.<sup>15</sup> However, little is known about the distribution and extent of coppicing at the landscape scale, and forming a coherent picture of the spatial extent rather than the management details of coppicing in larger regions remains a challenge for key periods. From around the late eighteenth century state-wide tax records and forestry surveys provided such information. However, before that period little is known beyond the existence of individual managed forests.<sup>16</sup> This holds true

<sup>3</sup> R. Hölzl, *Umkämpfte Wälder. Die Geschichte einer ökologischen Reform in Deutschland 1760 bis 1860*, Frankfurt am Main, 2010; K.J. Puettmann, K.D. Coates and C. Messier, *A Critique of Silviculture: Managing for Complexity*, Washington, 2009, 1–40.

<sup>4</sup> Eurostat Commission, Production and consumption of wood in the EU27, Press Release Stat 12/168, Brussels, 2012.

<sup>5</sup> P. Warde, Fear of wood shortage and the reality of the woodland in Europe, c.1450–1850, *History Workshop Journal* 62 (2006) 28–57.

<sup>6</sup> A good starting point for orientation in the vast palynological literature is R.M. Fyfe, J.-L. de Beaulieu, H. Binney, R.H.W. Bradshaw, S. Brewer, A. Le Flao, W. Finsinger, M.-J. Gaillard, T. Giesecke, G. Gil-Romera, E.C. Grimm, B. Huntley, P. Kuneš, N. Kühl, M. Leydet, A.F. Lotter, P.E. Tarasov and S. Tonkov, The European Pollen Database: past efforts and current activities, *Vegetation History and Archaeobotany* 18 (2009) 417–424.

<sup>7</sup> K. Klein Goldewijk, A. Beusen, G. van Dreht and M. de Vos, The HYDE 3.1 spatially explicit database of human-induced global land-use change over the past 12,000 years, *Global Ecology and Biogeography* 20 (2011) 73–86; J.O. Kaplan, K.M. Krumhardt and N. Zimmermann, The prehistoric and preindustrial deforestation of Europe, *Quaternary Science Reviews* 28 (2009) 3016–3034.

<sup>8</sup> G. Tack, P. van den Brecht and M. Hermy, *Bossen van Vlaanderen: Een historische ecologie*, Leuven, 1993; O. Rackham, *Ancient Woodland: Its History, Vegetation and Uses in England*, 2d edition, Dalbeattie, 2003.

<sup>9</sup> For a general overview of coppicing, see G.P. Buckley (Ed), *Ecology and Management of Coppice Woodlands*, London, 1992.

<sup>10</sup> For an overview of the various high-forest management systems as well as of coppice-with-standards, see J.D. Matthews, *Silvicultural Systems*, Oxford, 1989.

<sup>11</sup> A. Billamboz, Tree rings and wetland occupation in southwest Germany between 2000 and 500 BC: dendroarchaeology beyond dating in tribute to F.H. Schweingruber, *Tree-Ring Research* 59 (2003) 37–49; A. Dufraisse, Firewood management and woodland exploitation during the late Neolithic at Lac de Chalain (Jura, France), *Vegetation History and Archaeobotany* 17 (2008) 199–210.

<sup>12</sup> For the semantic changes of the word 'sustainability', see R. Hölzl, Historicizing sustainability: German scientific forestry in the eighteenth and nineteenth centuries, *Science as Culture* 19 (2010) 431–460.

<sup>13</sup> Quoted in O. Rackham, *Hayley Wood: Its History and Ecology*, Cambridge, 1975, 26.

<sup>14</sup> Rackham, *Ancient Woodland* (note 8), 137–141; E. Johann, Wirtschaftsfaktor Wald. Am Beispiel des österreichischen Alpenraums, *Das Mittelalter* 13 (2008) 28–38.

<sup>15</sup> For example Rackham, *Hayley Wood* (note 13); R.L. Keyser, The transformation of traditional woodland management: commercial silviculture in medieval Champagne, *French Historical Studies* 32 (2009) 353–384; K. Verheyen, B. Bossuyt, M. Hermy and G. Tack, The land use history (1278–1990) of a mixed hardwood forest in western Belgium and its relationship with chemical soil properties, *Journal of Biogeography* 26 (1999) 1115–1128; J. Müllerová, P. Szabó and R. Hédli, The rise and fall of traditional forest management in southern Moravia: a history of the past 700 years, *Forest Ecology and Management* 331 (2014) 104–115.

<sup>16</sup> Detailed large-scale information is occasionally available earlier. See for example P. Warde, *Ecology, Economy and State Formation in Early Modern Germany*, Cambridge, 2006, 226–242; Rackham, *Ancient Woodland* (note 8), 118–119; J.A. Galloway, D. Keene and M. Murphy, Fuelling the city: production and distribution of firewood and fuel in London's region, 1290–1400, *Economic History Review* 19 (1996) 447–472.

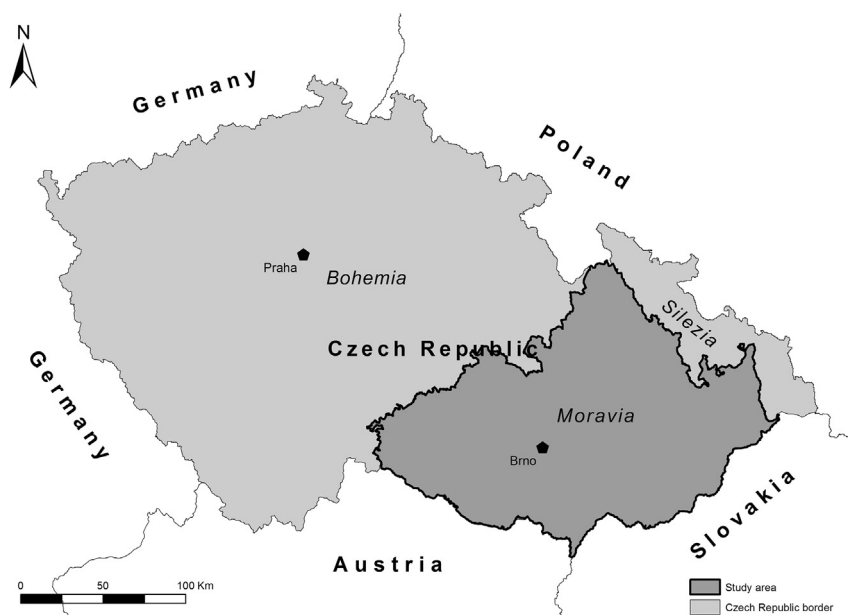


Fig. 1. Study area.

especially for the Middle Ages, for which written evidence on woodland management is scarce. At the same time, the High and Late Middle Ages are considered to be a crucial period in the history of intensive woodland management. It was probably in these centuries that the commercial coppicing of larger areas replaced earlier, more extensive management.<sup>17</sup> This paper aims to investigate the distribution and extent of coppice management in a large study region in the Late Middle Ages (ca. 1300–1500 AD). Based on an extensive database of pertinent written sources analyzed using Geographic Information Systems (GIS) and the distribution modelling approach, we ask the following interconnected questions: how widespread and dominant was intensive coppice management in the study region in the Late Middle Ages? Was coppicing geographically confined to certain areas? What factors determined the distribution of coppice woods?

### The study region: Moravia

Moravia lies the eastern part of the Czech Republic (Fig. 1). It covers ca. 22,300 km<sup>2</sup> with 3074 civil parishes. Moravia is a well-defined geographical and historical unit. Most of the area is the watershed of the river Morava. It is surrounded by mountains on three sides (in the north and west by the Hercynian mountains and in the east by the Carpathians) and the fourth side is bounded by the rivers Morava and Dyje. In the northeast, Moravia abuts the historical region of Silesia, which is now divided between Poland and the Czech Republic. In the west, Moravia's neighbour is Bohemia. Although the boundaries between these three historical regions were stable for almost a millennium, administrative changes in the twentieth century caused them to disappear from the map. In this paper we use the boundaries of Moravia as they stood immediately before the dissolution of historical regions in 1928. Elevation in Moravia ranges between ca. 180 m and 1492 m a.s.l. Average yearly temperatures vary between 0 and 10 °C, precipitation between 500

and 1500 mm. The climate is subatlantic to subcontinental. The main vegetation types include thermophilous oakwoods in the south, oak-hornbeam woods at lower and beechwoods at higher elevations with some spruce forests in the mountains. Agriculture dominates in the lower-lying regions, and there is more woodland in the highlands and mountains. Two main reasons make Moravia a suitable study area. Firstly, land ownership in Moravia was centrally controlled in the Middle Ages, therefore a solid and reasonably complete database of relevant historical sources can be compiled. Information in these sources can be geographically located with high precision. Secondly, Moravia includes a great variety of natural conditions and forests types, thus the results offer relevant comparative material for the whole of Central Europe.

### Sources and methods

#### Archival data

We used two main types of archival sources: charters and the so-called *zemské desky*. Charters document legal transactions. They usually discuss the granting of land, authority or rights. The earliest charters concerning the territory of Moravia were compiled in the tenth century AD. Nonetheless, larger numbers of charters are available only from the thirteenth century onwards. The editing and publication of these charters began in 1836 and continued throughout the nineteenth and twentieth centuries. We processed all 7057 edited charters in the fifteen volumes of the *Codex diplomaticus et epistolaris Moraviae*, which cover the period until 1411.<sup>18</sup> We disregarded all charters that are known to be forgeries (even if medieval). Medieval Moravian *zemské desky* (German *Landtafel*, English literal translation 'land tables' or 'land boards' – where 'land' refers to Moravia) record the transactions of the two 'land courts' in Brno and Olomouc.<sup>19</sup> In this period, two basic kinds of books were kept: those dealing with court cases and those

<sup>17</sup> Rackham, *Ancient Woodland* (note 8), 133–142; Keyser, *The transformation of traditional woodland management* (note 15).

<sup>18</sup> A. Boček, J. Chytil, V. Brandl and B. Bretholz (Eds.), *Codex diplomaticus et epistolaris Moraviae*, 15 volumes, Olomouc and Brno, 1836–1903.

<sup>19</sup> K.J. Demuth, *Geschichte der Landtafel im Markgrathume Mähren*, Brünn, 1857; D. Janiš, *Úvahy nad počátky zemských desk na Moravě*, in: B. Chocholáč, L. Jan, T. Knoz (Eds.), *Nový Mars Moravicus aneb sborník příspěvků, jež věnovali Prof. Dr. Josefu Váškovi jeho žáci a přátelé k sedmdesátinám*, Brno, 1999, 243–250.



recording changes in land ownership. For our purposes the latter type is relevant. As opposed to charters, entries in *zemské desky* are short, because the fact that they were recorded in this source made it unnecessary to include many of the legal details that comprise the bulk of charters. There are altogether 17,996 entries in the two Brno and two Olomouc volumes of *zemské desky*, which cover the period 1348–1566.<sup>20</sup> In total, we processed 25,053 individual charters and *zemské desky* entries searching for references on forests from the thirteenth to the sixteenth centuries AD. Because the vast majority of the data came from the fourteenth and fifteenth centuries, we refer to the study period as the Late Middle Ages but note that data from before and after the late medieval period *sensu strictu* were also included.

As far as geographical coverage is concerned, charters covered all types of landownership (noble, church and communal). Because many donations were made by the king or the Moravian margrave, they included much information on royal property as well. By contrast, *zemské desky* dealt exclusively with noble possessions. This obviously resulted in more data for regions where noble possessions were more frequent. However, it should be noted that most land in late medieval Moravia was owned by the nobility and such ownership was present in virtually every region. The combined evidence of charters and *zemské desky* therefore provide a reasonably unbiased geographical coverage of late medieval Moravia. A note of caution is due, however, concerning our usage of published editions rather than original sources. Some (but not all) editions we used are from the nineteenth century, and the quality of source editions from this period does not always stand the test of time. While the editions of the *zemské desky* are generally reliable and the source itself relatively straightforward, charters provided more reasons for concern. Nevertheless, because of access regulations in many archives, the processing of thousands of single charters would be excessively time-consuming, even if possible. To at least partly address potential problems, we verified where possible the authenticity and contents of charters with the help of the more modern editions of the *Codex diplomaticus et epistolaris regni Bohemiae*.<sup>21</sup> In the end the decision was made to use published editions because we felt that the ability to work with large amounts of data compensated for the imperfections inherent in these published sources.

#### Rubetum: a local word for coppice woods

Some of the documents contain detailed descriptions of woods, including tree species and management. However, in the vast majority of cases we only found brief references to woodland as part of the *pertinentiae* (appurtenances) of a given settlement. When a settlement or a part thereof changed hands, it was customary to include a list of the land use types that the settlement contained. A typical example from 1398 reads ‘Sigismundus of Swrczowicz... sold... Philippus of Swoyenaw... the entire village of

Radostycze with a manor house, arable fields, meadows, pastures, woods, mills and their other appurtenances including the patronage of the church.’<sup>22</sup> In later periods such lists became formulaic, but in the Late Middle Ages they faithfully recorded the various land uses present in a given settlement. References to woodland in such lists formed the core part of our database.

Most documents contained only a simple reference to the existence of woodland in a certain parish, which would not allow for more than the general reconstruction of woodland distribution in late medieval Moravia. However, more in-depth analysis revealed further opportunities. The key to uncovering new information lies in terminology. Many languages possess a separate word to describe coppices. For example, in French they are called *taillis*, in German *Niederwald*, in Italian *ceduo*. Such terminology is dynamic. *Niederwald*, for example, is a relatively modern term.<sup>23</sup> Other expressions were once common and later disappeared. In Hungary the word *eresztvény* and its Latin equivalent *permissorium* referred to coppice woods in the Middle Ages but fell into disuse by the Early Modern Period.<sup>24</sup> In the Czech Lands, medieval terminology for woodlands was simple. The word most often used to describe an area covered with trees was the Latin *silva*. The only other term that was used often and consistently to refer to a wooded environment, and which therefore possibly carried a specific meaning, was the Latin *rubetum* (plural *rubeta*). It was included in documents many hundreds of times, but researchers so far have not investigated what *rubetum* may have meant in terms of vegetation and/or its management.

Many lists of appurtenances included separate references to *silva* and *rubetum*. They often occurred together as part of the same list, but in many cases only *rubetum* (and not *silva*) was mentioned in the list. This strongly suggests that *rubetum* had a meaning different from *silva*. This is further demonstrated by the fact that a *silva* and a *rubetum* could lie right next to each other and contemporaries apparently had no problem telling them apart. For example in Martínkov (southwestern Moravia) in 1447 a certain *silva* called Haspan and a *rubetum* had a common boundary and were both sold as part of the same deal.<sup>25</sup> In the 1379 survey of the Rožmberk estates in southern Bohemia, which is by far the most important medieval land survey in the Czech Lands covering 390 villages and 28 towns, *rubeta* were listed as part of the general survey of woodland (*silva*).<sup>26</sup> It appears that *rubetum* was a special kind of woodland, which was sometimes contrasted with other types of woodland (*silva*) and at other times understood as a sub-category within woodland (*silva*).

The question remains what kind of woodland *rubetum* referred to. The word *rubetum* itself originates from *rubus*, which today means bramble. In the Middle Ages, its meaning may have been more general. For example, in the so-called Klementinský Latin-Czech dictionary from 1455 *rubus* was defined as *keř*, i.e. shrub, and *rubetum* as *křová porostlina*, i.e. shrubby growth.<sup>27</sup> Another word worthy of attention is *virgultum*, which was often used as a

<sup>20</sup> P. Chlumecký, J. Chytil, K. Demuth and A. Wolfskron (Eds), *Moravské zemské desky. I. sv. řady brněnské 1348–1466*, Brno, 1856 (hereafter ZDB I); T. Kalina (Ed), *Moravské zemské desky. II. sv. řady brněnské 1480–1566*, Brno, 1950 (hereafter ZDB II); Chlumecký, J. Chytil, K. Demuth and A. Wolfskron (Eds), *Moravské zemské desky. I. sv. řady olomoucké 1348–1466*, Brno, 1856 (hereafter ZDO I); F. Matějka (Ed), *Moravské zemské desky. II. sv. řady olomoucké 1480–1566*, Brno, 1948 (hereafter ZDO II).

<sup>21</sup> G. Friedrich, Z. Kristen, J. Bistrický, J. Šebánek, S. Dušková, V. Vašků, Z. Sviták, H. Krmíčková, J. Krejčíková, J. Nechutová, D. Havel, K. Maráz, L. Führer, M. Smolová and J. Kalivoda (Eds), *Codex diplomaticus et epistolaris Bohemiae*, 7 volumes, Praha, 1904–2013 (hereafter CDB).

<sup>22</sup> ZDB I, 221, no. 118 (entries in ZDB and ZDO are referred to by quoting the page and entry numbers) (note 20).

<sup>23</sup> M. Bürgi, How terms shape forests: ‘Niederwald’, ‘Mittelwald’, and ‘Hochwald’, and their interaction with forest development in the Canton of Zurich, Switzerland, *Environment and History* 5 (1999) 325–344.

<sup>24</sup> P. Szabó, *Woodland and Forests in Medieval Hungary*, Oxford, 2005, 57–62.

<sup>25</sup> ZDB I (note 20), 369, no. 605.

<sup>26</sup> The survey has been edited: J. Truhlár (Ed), *Registrum bonorum Rosenbergorum anno MCCCXXIX compilatum*, Praha, 1880; A modern, full-scale analysis of it is U. Henningsen, *Besitz und Einkünfte der Herren von Rosenberg in Böhmen nach dem Urbar von 1379/84*, Marburg, 1989.

<sup>27</sup> Czech National Library, sign. XVII F 31, fol. 79r. Edition: K. Voleková, *Latinsko-český slovník Klementinský*, MA dissertation, Praha, 2009. *Rubus* was translated as *keř* (shrub) also in the fourteenth century: see V. Flajšhans, *Klaret a jeho družina I. Slovníky veršované*, Praha, 1926.

synonym for *rubetum*.<sup>28</sup> This comes from *virga*, meaning twigs or young and thin shoots of trees. This was clearly described in the 1249 collection of rights of the town of Jihlava (western Moravia). In connection with wood-theft, this document made a clear legal distinction between trunks of large trees (*truncus*) and smaller pieces of wood (*rubus* or *virga*) which could be taken away in carts.<sup>29</sup> The same is suggested by the contemporary Czech equivalents of *rubetum* and *virgultum*: *chrastina* and *křovina*.<sup>30</sup> Both of these words refer to shrubby vegetation.<sup>31</sup>

What may have created this shrubby vegetation? Although, as argued above, contemporaries thought *rubetum* was some sort of a forest, one option could be abandoned arable or underused pasture invaded by shrubs. This is unlikely because of the apparent stability of *rubeta* and also because such lands are much more likely to have been recorded under their dominant or previous land uses: as arable or pasture. Furthermore, wood-pasture, which was otherwise a relatively frequent phenomenon in medieval Moravia, was never mentioned in connection with *rubeta*. That *rubeta* were not former arable fields was explicitly mentioned for example in the fourteenth-century Czech translation of a donation charter from 1276, which talked about *lesy* and *křoviny* ‘which have not yet been turned into fields.’<sup>32</sup> The 1379 Rožmberk survey, mentioned above, distinguished between two types of woodland: *silva pro edificiis* and *rubeta*. Apparently the first type was dominated by construction timber – the other type then must have been for firewood. In some cases this was explicitly included, such as the *chrast* near Frymburk (southern Bohemia), which was described as ‘for burning’ (*ad cremandum*).<sup>33</sup> A few more documents reinforce this assumption. In 1373, a *rubetum* near Laškov (central Moravia) was described as providing firewood and material for fencing (*ad cremandum et sepiendum*). Another document from 1652 about Králův dvůr (central Bohemia) referred to the lack of timber in the ‘*chrastiny*, which were only for small wood for the fire.’<sup>34</sup>

In sum, *rubetum* was a spatio-temporally stable type of woodland with a shrubby appearance that provided firewood. In the Middle Ages, such woods were coppices. A coppice wood was geographically well-defined (often surrounded by a woodbank), and its appearance, especially in the first few years after harvest, was decidedly shrubby.<sup>35</sup> Coppicing can potentially provide some explanation even for the term *rubetum* itself. Although, as argued above, in the Middle Ages the meaning of *rubus* may not have been

restricted to bramble, connections between coppicing and bramble certainly exist. The *Rubus* genus is taxonomically very complicated with some one hundred species in the Czech Republic.<sup>36</sup> Generally speaking, *Rubus* occurs in larger quantities in moister conditions or, in drier forests (typically in oak-hornbeam regions), in recently cut areas. Because such areas abound in coppices, bramble is an important element in many (but not all) coppice woods. It is even more widespread in mountainous regions.<sup>37</sup> However, *Rubus* presently spreads under the influence of eutrophication and nitrogen deposition.<sup>38</sup> At least as far as nitrogen is concerned, conditions in the Late Middle Ages were certainly different, which means that the behaviour of *Rubus* in the two periods may not necessarily be analogous. In addition, it is noteworthy that *rubeta* were never identified with ‘black woods’ (*silva nigra*), a special term used for coniferous woods.<sup>39</sup> Conifers, as noted above, do not grow young shoots after cutting and are therefore unsuitable for coppicing.

Local studies have documented the existence of coppices in various regions of the Czech Lands in the Late Middle Ages. For example, in the late fourteenth century on the Mikulov estate in southern Moravia, practically every wood was coppiced on a short, seven-year rotation.<sup>40</sup> A similarly short coppice cycle was recorded around Pardubice in the late fifteenth century. Such short cycles were in fact common all over Europe in this period and, significantly for the present study, kept coppices in a permanently shrubby state.<sup>41</sup> Based on the above, we argue that *rubeta* in late medieval Moravian charters and *zemské desky* entries referred to coppices. We acknowledge the inherently speculative nature of this argument. In the absence of direct evidence, one can never know for certain the meaning of this term. However, the sources suggest that *rubetum* did have a specific meaning and the best way to explain it appears to be coppicing. Interpreting *rubetum* as coppice also means that a new opportunity is created to map the spatial distribution of coppices on a large scale in high resolution and to analyze this distribution in relationship to various environmental factors.

#### Method of analysis: GIS and MAXENT

Individual pieces of information from late medieval sources were localized at the level of parishes. Currently Moravia is made up of

<sup>28</sup> See for example CDB V/1 (note 21), 435: ‘*rubeta sive virgulta*.’ In neighbouring Hungary, *rubetum* and *virgultum* were also synonyms in the Late Middle Ages: Szabó, *Woodland and Forests* (note 24), 63–64.

<sup>29</sup> CDB IV/1 (note 21), 320. The document is a contemporary forgery. Because it was written in the thirteenth century, lack of authenticity does not affect its information value for the present purpose.

<sup>30</sup> On these two terms and their identification as equivalents of the Latin terms, see J. Gebauer, *Slovník staročeský*, 2 volumes, Praha, 1970. The two Latin and two Czech terms appear to have been used interchangeably. For example *rubetum* in a thirteenth-century Latin charter was translated into Czech as *křovina* in the fourteenth century: CDB V/2 (note 21), 314–316. *Chrastina* became the standard term from approximately the late sixteenth century as Czech gradually replaced Latin.

<sup>31</sup> In some early Czech dictionaries they were translated into Latin as *dumetum* or *fruticetum* (from *dumus* and *frutex* = shrub). See the Klementinský dictionary cited above (fol. 43r) and V.J. Rosa, *Thesaurus Linguae Bohemicae*. This dictionary is from the second half of the seventeenth century and has recently been edited in an electronic form: <http://vokabular.ujc.cas.cz/nezapojene.aspx?idz=eRosaThesN>, accessed 11/12/2014. See also *Vocabularium Latino-Bohemicum pro usu scholarum nunc denuo diligenter & accurate editum*. Praha, 1704, electronic edition: <http://vokabular.ujc.cas.cz/nezapojene.aspx?idz=Vocabularium>, accessed 11/12/2014.

<sup>32</sup> CDB V/2 (note 21), 501: ‘o lesích a o křovinách, jesto ještě v roli nejsú obráceny’.

<sup>33</sup> Truhlár, *Registrum bonorum Rosenbergorum* (note 26), 28.

<sup>34</sup> ZDO I (note 20), 72, no. 270; Králův dvůr document quoted in J. Nožička, *Přehled vývoje našich lesů*, Praha, 1957, 156.

<sup>35</sup> P. Szabó, Ancient woodland boundaries in Europe, *Journal of Historical Geography* 36 (2010) 205–214.

<sup>36</sup> J. Holub, A preliminary checklist of *Rubus* species occurring in the Czech Republic, *Preslia* 64 (1992) 97–132; J. Danihelka, J. Chrtěk and Z. Kaplan, Checklist of vascular plants of the Czech Republic, *Preslia* 64 (2012) 647–811, esp. 763–766.

<sup>37</sup> R. Hédli, Vegetation of beech forests in the Rychlebské Mountains, Czech Republic, re-inspected after 60 years with assessment of environmental changes, *Plant Ecology* 170 (2004) 243–265.

<sup>38</sup> For example: R. Jobidon, Nitrate fertilization stimulates emergence of red raspberry (*Rubus idaeus* L.) under forest canopy, *Fertilizer Research* 36 (1993) 91–94; B.A. Olsson and O. Kellner, Long-term effects of nitrogen fertilization on ground vegetation in coniferous forests, *Forest Ecology and Management* 237 (2006) 458–470. In the Czech Republic: R. Janík, Dynamics of the above-ground and under-ground biomass production of the *Rubus idaeus* and *Rubus hirtus* species in the conditions of anthropically influenced submountain beech forests, *Lesnictví* 43 (1997) 79–84.

<sup>39</sup> K. Rybníček and E. Rybníčková, Palynological and historical evidence of virgin coniferous forests at middle altitudes in Czechoslovakia, *Vegetatio* 36 (1978) 95–103.

<sup>40</sup> P. Szabó, Driving forces of stability and change in woodland structure: a case-study from the Czech lowlands, *Forest Ecology and Management* 259 (2010) 650–656.

<sup>41</sup> P. Szabó and R. Keyser, Woodland, in: R. Oram, P. Slavin, T. Newfield (Eds), *Handbook of Medieval Environmental History*, 2 volumes: 1000–1350, Leiden, in press.



**Table 1**

Range of values of predictors and comparative sources for the entire study region, rubetum records and predicted coppice distribution.

| Predictors and comparative sources       | Source                                               | Study region                                                                                                                                                                                                                 | Rubetum records                                                                                                                                                   | Predicted coppice distribution (all-variable MAXENT model, over 50% probability)                                                                                                              |
|------------------------------------------|------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mean annual temperature                  | WORLDCLIM                                            | 2.7–9.5 °C                                                                                                                                                                                                                   | 5.8–9.5 °C (1st–3rd Quartile – 7.5–8.6 °C)                                                                                                                        | 6.7–9.5 °C (1st to 3rd Quartile – 8.2–8.8 °C)                                                                                                                                                 |
| Mean annual precipitation                | WORLDCLIM                                            | 515–962 mm                                                                                                                                                                                                                   | 519–774 mm (1st–3rd Quartile – 582–655 mm)                                                                                                                        | 534–724 mm (1st–3rd Quartile – 575–634 mm)                                                                                                                                                    |
| Mean elevation                           | SRTM elevation data                                  | 180–1020 m asl                                                                                                                                                                                                               | 157–752 m asl (1st–3rd Quartile – 259–480 m)                                                                                                                      | 190–643 m asl (1st–3rd Quartile – 238–342 m)                                                                                                                                                  |
| Prevailing bedrock                       | Geological maps 1:500 000<br>Czech Geological Survey | Quaternary (soils, loess, sand and gravel; 26%)<br>Palaeozoic rocks–folded, unmetamorphosed (schists, greywackes, quartzites, limestones; 15%)<br>Tertiary rocks folded during the Alpine Orogeny (sandstones, schists; 12%) | Quaternary (soils, loess, sand and gravel; 31%)<br>Tertiary rocks folded during the Alpine Orogeny (sandstones, schists; 13%)<br>Tertiary rocks (sand, clays; 9%) | Quaternary (soils, loess, sand and gravel, 42%)<br>Tertiary rocks folded during the Alpine Orogeny (sandstones, schists; 16%)<br>Tertiary rocks (sand, clays; 12%)<br>Tertiary deposits (27%) |
| Prevailing soil type                     | Pedological maps 1:50 000<br>Czech Geological Survey | Cambisol (48%)<br>Luvisol (12%)<br>Chernozem (11%)                                                                                                                                                                           | Cambisol (35%)<br>Luvisol (20%)<br>Chernozem (18%)                                                                                                                | Chernozem (28%)<br>Luvisol (25%)<br>Cambisol (20%)                                                                                                                                            |
| Prevailing reconstructed vegetation type | Mykiška (1968)                                       | Oak-hornbeam woodland (Carpinion, 40%)<br>Herb-rich beech woodland (Eu-Fagenion, 17%)<br>Acidophilous beech and silver fir woodland (Luzulo-Fagion, 16%)<br>Alluvial woodland (Alnion incanae, 14%)                          | Oak-hornbeam woodland (Carpinion, 59%)<br>Acidophilous beech and silver fir woodland (Luzulo-Fagion, 16%)<br>Herb-rich beech woodland (Eu-Fagenion, 10%)          | Oak-hornbeam woodland (Carpinion, 62%)<br>Alluvial woodland (Alnion incanae, 18%)                                                                                                             |
| Prevailing potential vegetation type     | Neuhäusleová et al. (1998)                           | Oak-hornbeam woodland (Carpinion, 45%)<br>Acidophilous beech and silver fir woodland (Luzulo-Fagion, 21%)<br>Herb-rich beech woodland (Eu-Fagenion, 19%)                                                                     | Oak-hornbeam woodland (Carpinion, 55%)<br>Acidophilous beech and silver fir woodland (Luzulo-Fagion, 17%)<br>Alluvial woodland (Alnion incanae, 10%)              | Oak-hornbeam woodland (Carpinion, 70%)<br>Alluvial woodland (Alnion incanae, 12%)                                                                                                             |
| Current forest distribution              | CORINE 2010 land cover mapping                       | 8583 km <sup>2</sup>                                                                                                                                                                                                         |                                                                                                                                                                   |                                                                                                                                                                                               |

3074 (civil) parishes, most of which are of medieval origin. As in other parts of Europe, Moravian parish boundaries seem to have been reasonably stable since the Middle Ages.<sup>42</sup> We acquired a GIS layer of current parishes from the Czech Office for Land and Cadastral Surveys, which served as the basis for the database. We connected records of woods to current parishes, which provided spatially exact information that could be further analyzed in the GIS. We excluded from the analysis those 290 parishes that were first mentioned after 1566 (the end date of our historical dataset) and used only the remaining 2784 parishes in the analysis. As a first step we wanted to ensure data quality. We aimed to find out whether the distribution of coppice records forms a pattern statistically significantly different from the distribution of all records with respect to environmental parameters. We performed a Kolmogorov–Smirnov (K–S) test to assess the equality of probability distribution of the whole dataset versus *rubetum* records along elevation, mean annual temperature and precipitation gradients. The K–S test is a non-parametric test for the equality of continuous, one-dimensional probability distributions that can be used to compare two samples.<sup>43</sup> In order to fill the gaps in our dataset (we had no information on management for approximately every

second parish), we decided to create a distribution model for coppicing. We used the Maximum Entropy algorithm (MAXENT), originally created for species distribution modelling.<sup>44</sup> We chose the MAXENT model because, unlike most other models, it works with presence only data. This fits perfectly the conditions created by historical data: in our dataset only records on coppice presence are available and absence data are missing, in other words lack of presence does not equal absence. The predictors in the model (see Table 1) included environmental information on climatic conditions (annual temperature and precipitation) and elevation (means for each parish).<sup>45</sup> Soil type and bedrock did not improve the performance of the model and were therefore not used in the analysis. Univariate models for each explanatory variable and a multivariate model for all the environmental variables were tested using clamping, random seed and cross validation with 50 replicates and 20% random test percentage. The resulting continuous prediction of coppice presence probability was converted into percentage categories, and we chose the threshold of 50% to represent coppice presence.<sup>46</sup> To compare the success of various models, we used the receiver operating characteristic (ROC) analysis, which characterizes the performance of a model at all possible thresholds by a

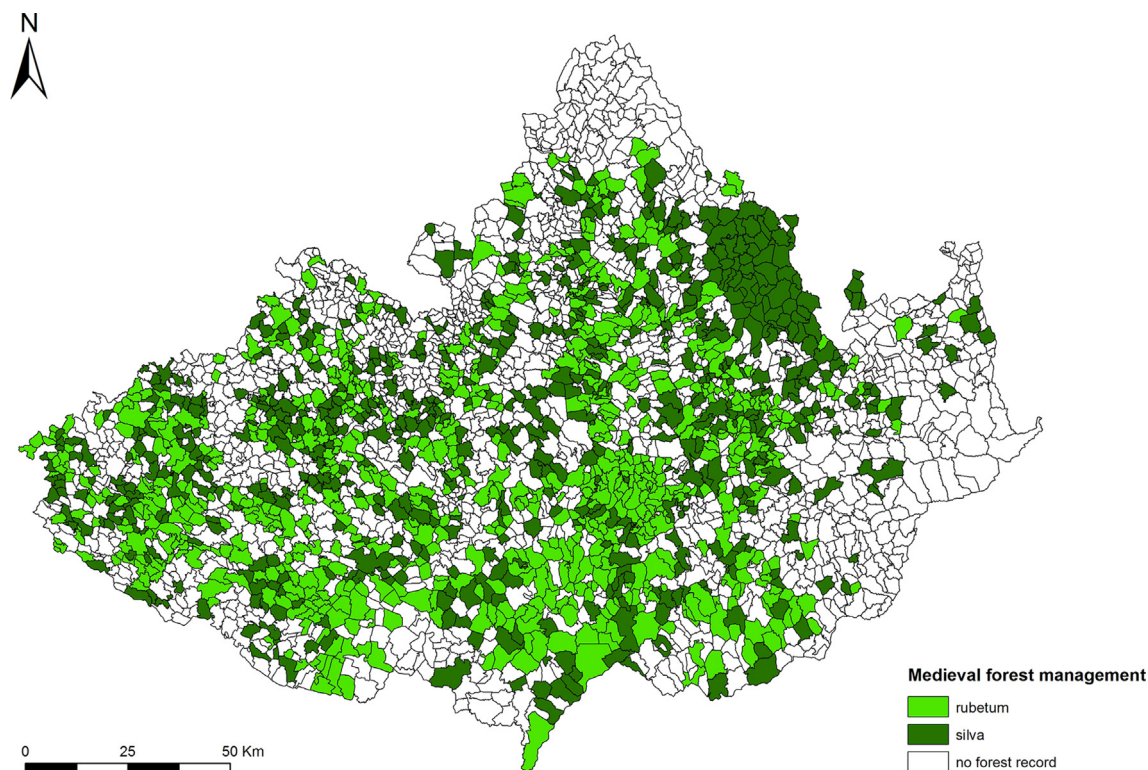
<sup>42</sup> Z. Boháč, Katastry – málo využitý pramen k dějinám osídlení, *Historická geografie* 20 (1982) 15–87; F. Hautefeuille, La délimitation des territoires paroissiaux dans les pays de moyenne Garonne (Xe–XVe siècles), *Médiévales* 49 (2005) 73–88; A. Winchester, *Discovering Parish Boundaries*, Aylesbury, 1990.

<sup>43</sup> G. Marsaglia, W.W. Tsang and J. Wang, Evaluating Kolmogorov's distribution, *Journal of Statistical Software* 8/18 (2003) 1–4.

<sup>44</sup> S.J. Phillips, R.P. Anderson and R.E. Schapire, Maximum entropy modeling of species geographic distributions, *Ecological Modelling* 190 (2006) 231–259; J. Elith, S.J. Phillips, T. Hastie, M. Dudik, Y.E. Chee and C.J. Yates, A statistical explanation of MaxEnt for ecologists, *Diversity and Distributions* 17 (2011) 43–57.

<sup>45</sup> Mean annual temperature and precipitation were derived from WorldClim – Global Climate Data. Downloaded from <http://www.worldclim.org/> (accessed on 20 April 2014). Elevation was derived from Shuttle Radar Topography Mission (SRTM). Downloaded from <http://srtm.usgs.gov/index.php> (accessed on 3 April 2014).

<sup>46</sup> C. Liu, P.M. Berry, T.P. Dawson and R.G. Pearson, Selecting thresholds of occurrence in the prediction of species distributions, *Ecography* 28 (2005) 385–393.



**Fig. 2.** Late medieval archival records in Moravia on coppicing (*rubetum*) and woodland in general (*silva*). Where both *rubetum* and *silva* were recorded for the same parish, the map shows *rubetum*.

single number, the area under the curve (AUC). Statistical analyses were performed in R (version 2.15.3).<sup>47</sup>

## Results

Out of the 2784 parishes we analyzed, details on forest type (*silva* or *rubetum*) were available for 1391 parishes (covering 48% of the study area). *Rubetum* was recorded in 756 parishes (26% of the study area) (Fig. 2). According to the Kolmogorov–Smirnov test, the distribution of parishes in terms of elevation, mean annual temperature and precipitation was significantly different between all forest and *rubetum* records (*p*-values were 0.00104, 5.44e-15, and 2.876e-09, respectively; Fig. 3). Most of the *rubetum* records (1st to 3rd quartile) were found in parishes with average elevation of 259–480 m a.s.l., annual temperature of 7.5–8.6 °C, and annual precipitation of 582–655 mm (see Fig. 3 and Table 1). The most common substrates in these parishes were Quaternary deposits (over 30%), and Cambisol, Luvisol and Chernozem soils.

The late medieval distribution of coppicing was best modelled by using all three environmental variables (mean annual temperature, precipitation and elevation; all-variable model; AUC 0.681; Table 2). Temperature proved to be the most important predictor (Table 3). The potential distribution of coppices in the Late Middle Ages (all-variable model) which was predicted with a probability exceeding 50% included 1043 parishes or 35% of Moravia (see Fig. 4 and Table 1).

## Discussion

### *The distribution of intensive woodland management in the Late Middle Ages*

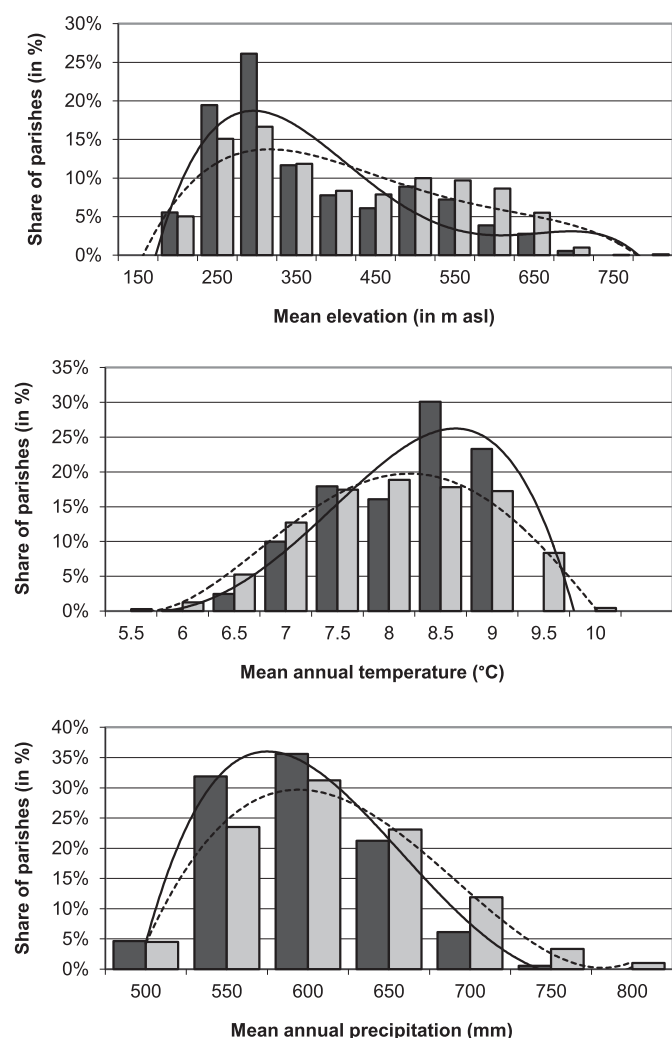
The image of late medieval coppice distribution both in the raw data and in the model generally agrees with representations of the 'natural' landscape created by Mykiška (for reconstructed vegetation) and Neuhäuslová *et al.* (for potential natural vegetation).<sup>48</sup> Coppices appear to have been most common in the oak-hornbeam region (Table 1). Such vegetation is generally considered to be favourable for coppicing due to the dominance of easily resprouting species, such as hornbeam, oak and lime. Researchers often connect the emergence of this forest type to human impact, some even argue that such forests are dependent on management for their long-term survival.<sup>49</sup> Predicting late medieval coppices predominantly in this forest type reinforces the validity of our interpretation of the word *rubetum* as coppice.

According to the model, coppicing was omnipresent in the lowlands but approximately two thirds of Moravian parishes at higher elevations had no coppice woods. Nonetheless, the same model shows that coppices were completely absent only in more extreme conditions (above ca. 750 m a.s.l., Table 1 and Fig. 3). It is also noteworthy that one third (1077) of Moravian parishes were modelled to have contained coppices in the Late Middle Ages with a probability of 40–50%. These we interpreted as lacking coppice management, but this is an arbitrary decision and lowering the

<sup>47</sup> R Core Team, *R: A Language and Environment for Statistical Computing*, Auckland, 2013.

<sup>48</sup> R. Mykiška, *Geobotanische Karte der Tschechoslowakei – Böhmen und Mähren*, 1: 200 000, Praha, 1968; Z. Neuhäuslová a kol., *Mapa potenciální přirozené vegetace České republiky*, Praha, 1998.

<sup>49</sup> For example, K. Tybirk and B. Strandberg, Oak forest development as a result of historic land-use patterns and present nitrogen deposition, *Forest Ecology and Management* 114 (1999) 97–106; F.W.M. Vera, *Grazing Ecology and Forest History*, Wallingford, 2000; E. Jamrichová, P. Szabó, R. Hédli, P. Kuneš, P. Bobek and B. Pelánková, Continuity and change in the vegetation of a Central European oakwood, *Holocene* 23 (2013) 46–56.



**Fig. 3.** Frequency distribution of *rubetum* (in black, polynomial trend shown by full line) and all forest records (in grey, polynomial trend shown by dashed line) along elevation, temperature and precipitation gradients.

threshold for coppice presence for example to 45% would have resulted in 1639 parishes with coppice woods (53% of all parishes). Providing the word *rubetum* indeed referred to coppices, it appears that coppicing was practiced everywhere where it was a biologically viable management option. This included higher elevations as well, where neither natural conditions nor tree species composition were favourable for coppicing. However, in such circumstances coppice woods were relatively rare. Although species data for the Late Middle Ages are not available, the typical coppiced tree at higher elevations was probably common alder.

**Table 2**

Overview of the various MAXENT model performances – 50 replicates, 20% random test percentage.

| Type of model               | AUC   |
|-----------------------------|-------|
| Precipitation               | 0.600 |
| Temperature                 | 0.609 |
| Elevation                   | 0.611 |
| Temperature + precipitation | 0.643 |
| Elevation + precipitation   | 0.648 |
| All-variable model          | 0.681 |

**Table 3**

Contribution of predictors to the multivariate MAXENT model.

| Predictors                | Percentage contribution | Permutation importance |
|---------------------------|-------------------------|------------------------|
| Mean annual temperature   | 43.3                    | 59.1                   |
| Mean annual precipitation | 42.1                    | 16.3                   |
| Mean elevation            | 14.6                    | 24.6                   |

### Firewood consumption, woodland productivity and management

Because of the nature of the input data, our model indicates only the presence of coppicing in a given parish, which does not necessarily imply that coppicing was the only or dominant management form there. In order to get a better idea of the importance rather than the distribution of coppicing at the landscape scale, further types of information are needed. With the help of general estimates of population, firewood consumption and woodland productivity, it is possible to approximate the amount of woodland that needed to be managed in a certain period and region.<sup>50</sup> Such estimates naturally must be interpreted with caution and are hard to translate into actual landscapes, but they do give a sense of the dynamics of human-woodland relationships. Several estimates have been put forward for the population of Moravia in the Late Middle Ages.<sup>51</sup> Such estimates range from 570,000 to 2,000,000 people. Recent literature has estimated the population of Moravia to have been ca. 900,000 in 1400 AD.<sup>52</sup> Estimating firewood consumption is a much more complicated matter. For subsistence firewood, estimates – based on ethnographic analogies, nineteenth- and twentieth-century forestry data, experimental archaeology and early modern archival data – for different European regions and periods vary from less than one cubic metre to almost five cubic metres of solid wood per person per year (as opposed to stacked wood, that is, making the air disappear from between the trees in a pile), but generally move between one and two cubic metres.<sup>53</sup> Taking 1.5 m<sup>3</sup> as the average means that 1,350,000 m<sup>3</sup> of firewood were used in Moravia each year to provide for heating and cooking alone. How much woodland was needed to produce this? European wood yields show large regional differences. Currently, in some regions (for example in Germany) woodland produces more than 10 m<sup>3</sup> of wood per hectare, while in other regions (southwestern Europe) it is 3.3 m<sup>3</sup> per hectare.<sup>54</sup> However, these values are obtained in timber-oriented and dense high-forests, with considerable amounts of money and energy

<sup>50</sup> For example, Warde, Fear of wood shortage (note 5), 37–39.

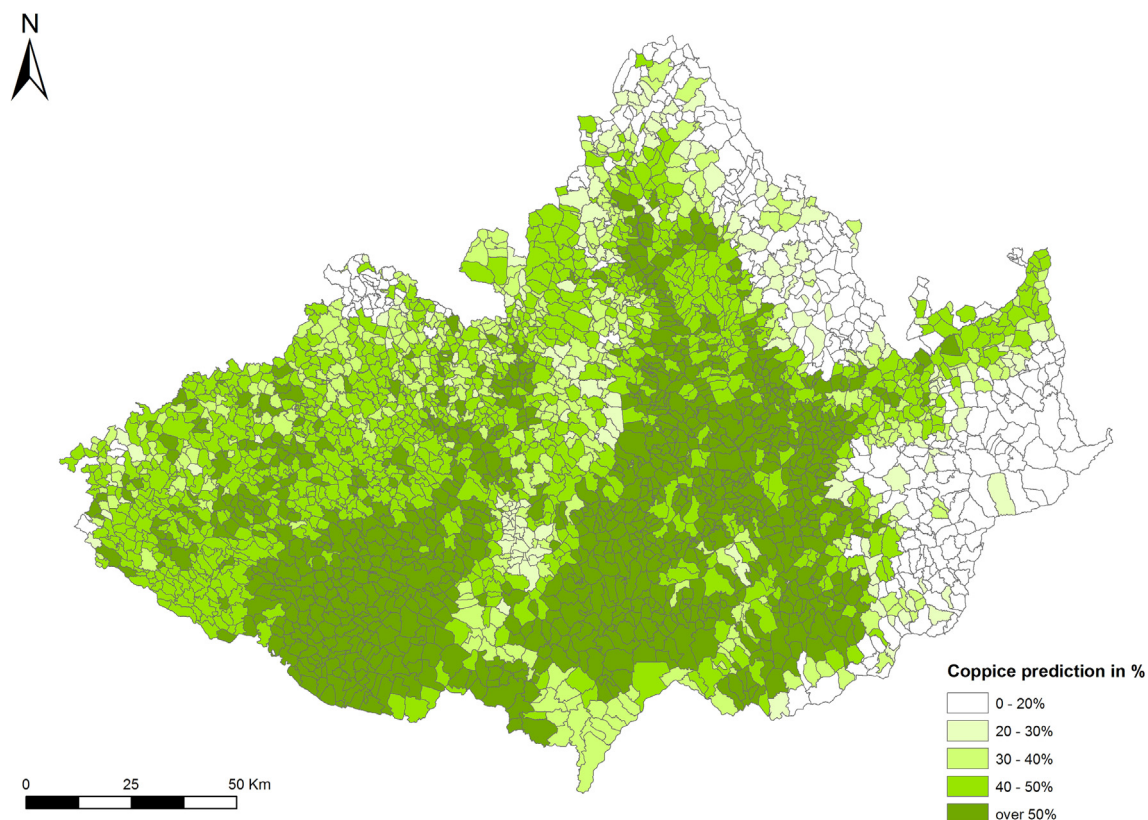
<sup>51</sup> For an overview, see L. Fialová, P. Horská, M. Kučera, E. Maur, J. Musil and M. Stloukal, *Dějiny obyvatelstva českých zemí*, Praha, 1998, 386–388. See also V. Srb, *1000 let obyvateľstva českých zemí*, Praha, 2004.

<sup>52</sup> Z. Boháč, Postup osídlení a demografický vývoj českých zemí do 15. století, *Historická demografie* 12 (1987) 59–88.

<sup>53</sup> Warde, Fear of wood shortage (note 5), 38; M. Lindmark and L. F. Andersson, Household firewood consumption in Sweden during the nineteenth century, *Journal of Northern Studies* 2 (2010) 55–78; I. Pleinerová, Březno: experiments with building old Slavic houses and living in them, *Památky archeologické* 77 (1986) 104–176; G. Billen, S. Barles, J. Garnier, J. Rouillard and P. Benoit, The food-print of Paris: long-term reconstruction of the nitrogen flows imported into the city from its rural hinterland, *Regional Environmental Change* (2009) 13–24.

<sup>54</sup> FOREST EUROPE, UNECE and FAO, *State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe*, Oslo, 2011. Similar values were presented for American forests in connection with charcoal production: T.J. Straka, Historic charcoal production in the US and forest depletion: development of production parameters, *Advances in Historical Studies* 3 (2014) 104–114.





**Fig. 4.** Model of coppice distribution in the Late Middle Ages constructed using the MAXENT algorithm. Mean annual temperature, precipitation and elevation were used as predictors for coppice probability in individual parishes.

invested into tree planting and timber removal. Such values were rarely achieved in the Middle Ages. The only known medieval production estimate was included in the management description of Beaulieu Abbey, England.<sup>55</sup> This envisaged a productivity level of 2 tons per acre of woodland, i.e. 5 tons per hectare. Counting with 1 ton of fresh (as opposed to dry) firewood per cubic metre, overall productivity is at 5 m<sup>3</sup> per hectare. However, Rackham noted that this was unusually high, and that medieval account book data of income per acre hardly reached half this amount, that is ca. 2.5 m<sup>3</sup> per hectare. General estimates for the Early Modern Period put productivity at ca. 3 m<sup>3</sup> per hectare.<sup>56</sup> Local evidence in Moravia suggests similar values. The estate of Mikulov in southern Moravia had approximately 1300 ha of woodland in the Early Modern Period. We sampled every tenth year in the estate woodland account books for the period 1685–1835 to derive a productivity estimate.<sup>57</sup> Average firewood production was 1630 *Klafter*, that is 1.25 *Klafter*/ha. If we convert the local *Klafter* at 3.1 m<sup>3</sup>, the result is 3.87 m<sup>3</sup>/ha.<sup>58</sup> This needs to be multiplied by 0.66 to transform stacked wood into solid wood, which leaves overall yearly increment at 2.55 m<sup>3</sup> per hectare.<sup>59</sup> In sum, with firewood consumption at 1,350,000 m<sup>3</sup> and yearly increment at an optimistic 3 m<sup>3</sup>/ha, the

area of woodland that would have needed to be intensively managed in late medieval Moravia was 450,000 ha, that is 4500 km<sup>2</sup>. This is roughly 20%, or one fifth of the entire land surface.

We emphasize that the sole purpose of the above rough estimate is to give an idea of the minimum extent of woodland management in late medieval Moravia. For example, industrial wood uses, which could be considerable, were not included. Many forests had multi-use management in which wood was only one and often not the most important product.<sup>60</sup> Such forests had much lower yields than 3 m<sup>3</sup>/ha. Of course not all wood was produced in coppices – there were regions of coniferous high-forests at higher altitudes. However, most of the population lived in lowland regions where coppices occurred. These people needed to be supplied with firewood from the close vicinity. Some wood could be rafted down on rivers from the mountains to the lowlands, but this was technologically challenging and more suitable for timber than for firewood.<sup>61</sup> Moving wood on the ground was notoriously expensive in the Middle Ages. Around London in the fourteenth century carrying a cartload of firewood for more than ca. 20 km could be so costly as to eliminate all profits.<sup>62</sup> It is therefore reasonable to assume that a large part of the 4500 km<sup>2</sup> of hypothetical woodland that could

<sup>55</sup> Rackham, *Ancient Woodland* (note 8), 140–142.

<sup>56</sup> For an overview, see Warde, *Fear of wood shortage* (note 5), 37.

<sup>57</sup> Müllerová, Szabó and Hédli, *The rise and fall of traditional forest management* (note 15).

<sup>58</sup> Nožička, *Přehled vývoje* (note 34), 21.

<sup>59</sup> M.A. Fonseca, *The Measurement of Roundwood: Methodologies and Conversion Ratios*, Wallingford, 2005.

<sup>60</sup> P. Szabó and R. Hédli, Socio-economic demands, ecological conditions and the power of tradition: past woodland management decisions in a Central European landscape, *Landscape Research* 38 (2013) 243–261.

<sup>61</sup> I. Honl, Stručný přehled nejstaršího období vltavské plavby, *Historická geografie* 11 (1973) 117–137; F. Holec, Obchod s dřívím v Praze ve 14.–17. století, *Pražský sborník historický* 6 (1971) 5–100.

<sup>62</sup> Galloway, Keene and Murphy, *Fuelling the city* (note 16).

have produced the 1,350,000 m<sup>3</sup> of firewood used yearly in late medieval Moravia indeed existed and most of it was in those regions where the distribution model predicts the occurrence of coppices with high probability. 4500 km<sup>2</sup> of woodland is a very high number. Currently there are 6671 km<sup>2</sup> of woodland in Moravia.<sup>63</sup> In the late 18th century, there were ca. 5140 km<sup>2</sup>, in the mid-19th century ca. 5820 km<sup>2</sup>, and in 1900 ca. 6104 km<sup>2</sup>.<sup>64</sup> Parishes in which our model predicts the occurrence of coppices in the Late Middle Ages are on average only 16% forested nowadays according to the CORINE database, with 1549 km<sup>2</sup> of forests. Over 20% of the parishes in the potentially coppiced region are currently completely deforested. Because woodland cover in medieval Moravia is unknown, one must be cautious in the interpretation of these data. Nonetheless, it is very likely that by the Late Middle Ages lowland regions were largely deforested.<sup>65</sup> If we then compare the available woodland area to the pressure created by the firewood consumption of a sizeable population, we can safely argue that coppicing was not simply widespread in the lowland regions of Moravia in the Late Middle Ages, it was in fact predominant if not exclusive. Practically every lowland wood would have been intensively managed through coppicing and this type of management reached a distribution that would change relatively little until its abandonment in the twentieth century.

### Conclusions: archival data, models and the medieval environment

In this paper we combined archival research with spatial modelling, that is, the traditional toolkit of historians with the modern methods of geographers and landscape ecologists. We used this interdisciplinary approach in order to tackle one of the oldest problems of landscape historical research: how to turn scattered historical evidence into plausible landscape reconstructions? In our view, models have a great potential in this respect because they introduce an element of transparency into the system. Input data and outside variables are chosen in an explicit manner with the aim of reducing subjectivity in the reconstruction process.

The success of such models depends on the quantity and quality of the data and on the choice of outside variables. For the Middle Ages data quantity can be a challenge. Few sources deal with the medieval environment, and, as demonstrated here, it is necessary to have a source type that occurs frequently enough and carries at least some environmental information. Any attempts at reconstructing medieval landscapes at larger scales should begin by identifying such sources. Even if enough data are available, results will always include elements of uncertainty. In our case, the interpretation of the term *rubetum* as coppice is crucial and so is the choice of environmental variables in the model. Another way to test the model would be to compare it to the extent of coppicing in the eighteenth and early nineteenth centuries, when census data are available for the whole study area. This, in fact, will be the subject matter of a further paper.

We emphasize that models should not be confused with reality, and care must be taken in their interpretation. Our model (in combination with wood production and consumption estimates) provides solid evidence for the dominance of coppicing in the lowlands of Moravia in the Late Middle Ages. By contrast, results for regions at higher elevations are less self-evident. Many parishes were modelled to have coppice presence with probabilities in the close vicinity of 50%, and small modifications in the threshold value created rather different reconstructions. In these conditions, any conclusions about these parts of Moravia can only be tentative. In other words, the traditional skill of the historian in creating narratives remains an important tool in the interpretation of models.

### Acknowledgments

We would like to thank the three anonymous reviewers for their useful comments and Radim Hédľ for his help in ecological matters. The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007–2013)/ERC Grant agreement no 278065. This study was supported as a long-term research development project no. RVO 67985939.

<sup>63</sup> According to CORINE land-use data, see Table 1.

<sup>64</sup> J. Radimský and M. Trantírek (Eds), *Tereziánský katastr moravský*, Praha, 1962, 29–30.

<sup>65</sup> For example, in neighbouring Bohemia, the Rožmberk survey recorded approximately one third woodland cover in the late fourteenth century: Henningsen, *Besitz und Einkünfte* (note 26), 92.

# Standard trees versus underwood: Historical patterns of tree taxon occurrence in coppice forests

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**Funding information** Technology Agency of the Czech Republic, Grant no. TL02000314. Long-term research development project RVO 67985939.

**Co-ordinating Editor:** Monika Wulf

## Abstract

**Questions:** Coppice woods were once widespread in Europe. It is usually assumed that underwood tree taxon composition was not directly influenced by people, whereas especially *Quercus* was promoted among standard trees. However, no work has quantitatively tested these assumptions. Our main question was whether there were any patterns in our data to suggest that certain trees occurred more frequently as standards than as underwood, possibly as a result of management decisions.

**Location:** Czech Republic.

**Methods:** We constructed a database covering 12,000 hectares of forests around AD 1900. We recorded the occurrence of tree taxa for standards and underwood in 1,507 compartments in 21 forest units. We visualised patterns in these data by bar graphs and chord diagrams. We analysed correlation patterns through association analysis and co-correspondence analysis.

**Results:** There was a statistically significant association between the occurrences of standards and underwood in individual compartments for *Quercus*, *Alnus*, *Carpinus*, *Fagus*, *Larix*, *Populus tremula* and *Tilia*. Only *Quercus* standards and underwood showed a positive association. The taxon composition of standards and underwood in forest compartments was statistically significantly correlated.

**Conclusions:** No simple answer can be given to the question whether or not the taxon composition of standards and underwood in coppice woods differed as a result of management. At the level of individual tree taxa, some trees were more common as standards while others, as underwood. However, the prevalence of *Quercus* among standards was not confirmed because in our study area *Quercus* was a common underwood tree as well. At the same time, no significant differences were apparent in the taxon composition of standards and underwood in individual forest compartments. It seems difficult to differentiate between the effects of human selection and indirect selection through natural properties and environmental factors. Our results also highlight the need to carefully consider the properties of written historical sources.

## KEYWORDS

coppicing, forest management plans, historical ecology, human impact, standard trees, underwood



## 1 | INTRODUCTION

Reconstructing woodland tree species composition in the past has been a primary goal of historically oriented ecological investigations for at least a century. This included reconstructions based on both material tree remains and written records. Palynology, for example, has been actively engaged in such quests since its proverbial foundation in 1916 (Birks and Berglund, 2018). As for written records, already the earliest forest historical research tried to utilise medieval or Roman sources to establish what often used to be viewed as the 'original' untouched forests (Schwappach, 1886). Detailed surveys from more recent periods were utilised to gain insights into changes in tree species frequency and distribution. Such sources were sometimes interpreted with respect to human impact, especially management (e.g. Warde, 2006).

In Europe, the most basic difference is between broadleaved forests, which are typical of lower-lying temperate regions, and coniferous forests, which mainly occur at higher altitudes and in the boreal zone (Bohn and Neuhäusl, 2004; Mucina *et al.*, 2016). Many forests contain a mix of broadleaved and coniferous trees. Before the birth of modern plantation forestry ca. two centuries ago, many – but of course not all – broadleaved woods were managed as coppices especially in the more densely populated parts of Europe (e.g. Bergendorff and Emanuelsson, 1996; Verheyen *et al.*, 1999; Rackham, 2003; Szabó, 2010; McGrath *et al.*, 2015; Unrau *et al.*, 2018). Coppicing is a technique that uses the ability of broadleaved trees to grow back from the stump (the 'stool') or the root system after cutting (Buckley, 1992). The young shoots are cut on a short rotation to produce easily workable firewood. Coppice firewood provided a large part of the energy used by people in Europe until fossil fuels gradually took over this role in the past two centuries (Sieferle, 1982). The emergence of modern forestry with its focus on high-forest plantations and conifers effectively ended the era of coppicing in Europe (Savill, 2015).

In the coppice system, firewood was the most important product in terms of quantity. However, people also needed building timber, which came from timber trees (known as 'standards') grown from seed among coppice stools. There was an obvious conflict between standards and coppice underwood, because the shade of the former hindered the growth of the latter. The ideal number of standards was often discussed and made it into legislation already in the Middle Ages. For example, the 1376 forest code of Charles V of France ordered that 8–10 standards be left on every acre (Isambert *et al.*, 1824:462). It often happened that the standards and the underwood belonged to different users, in which case both parties tried to maximise the volume of their product at the expense of that of the other. A typical example of this is the pursuit and appropriation of *Quercus* standard trees in coppice woods for shipbuilding by various European maritime polities in the Early Modern Period (Nilsson, 2002; Appuhn, 2009; Wing, 2014).

The difference between standards and underwood is not simply one of generative vs. vegetative origin. Even though not all broadleaved trees have the same calorific value for heating, at present

there is little evidence to suggest that people went to any great length to change the species composition of underwood in any place or period: they simply coppiced whatever was available. In contrast to underwood, standards had more specific uses; therefore, their species composition could be more actively influenced by woodland managers. Based on the overall indication of available sources, it is usually thought that *Quercus* was the preferred taxon for standards, mainly because of its superior qualities as building material (e.g. Rackham, 1975; Lassauce *et al.*, 2012; Szymura *et al.*, 2014). However, no work has ever quantitatively tested the assumption that management resulted in differing taxon composition for underwood and standard trees. This is of some importance for forest historical vegetation reconstruction. On the one hand, the extent to which the taxon composition of standards was influenced by forest managers in pre-industrial times needs to be taken into account when evaluating vegetation history. The interaction between standards and underwood was also a significant and so far little-known component in overall vegetation dynamics. On the other hand, knowledge on the patterns of occurrence of standard and underwood trees in coppice woods helps to better contextualise historical forest surveys. In particular, it can be useful in balancing the potential bias introduced into such sources through their focus on standard rather than underwood trees.

One of the reasons why assumptions about the taxon composition of standards vs. underwood in coppice woods were never tested at a larger spatial scale is the rarity of suitable data. Written surveys of tree taxon composition in European forests are the most relevant source of information to address such issues, because they can contain details on standards and underwood separately in individual forest units. Forest surveys in Europe go back some eight centuries, and they considerably differ in purpose, method and attention to detail. The earliest surveys tended to record woodland size, dominant tree taxa and sometimes management. The first more detailed surveys are mainly from the 16th century. These could be general woodland surveys (e.g. Warde, 2006: 228–242) or could also be commissioned for special purposes, for example to count thousands of individual *Quercus* trees to be used in shipbuilding (Appuhn, 2009). From approximately the late 18th century onwards, forest bureaucracy produced so-called 'forest management plans' (FMPs) in increasing numbers. In many parts of Europe, forests were meticulously surveyed at least once by the beginning of the 20th century (e.g. Bürgi, 1999a; Lebourgeois *et al.*, 2004; Müllerová *et al.*, 2014). Importantly, FMPs are the first documents in which standards and underwood could be (although by no means always were) recorded separately in a consistent manner over larger areas at relatively high spatial resolution. Such sources provide the best opportunity to examine the relationship between standards and underwood.

Using a unique dataset covering ca. 12,000 ha of forests in the Czech Republic around AD 1900, our aim in this paper is to find out whether there are any patterns observable in the data to suggest that certain tree taxa occurred more frequently as standards than as underwood possibly as a result of management decisions. More specifically, we focus on the following questions: (1) did the occurrences



of the same tree taxa as standard and as underwood in individual forest compartments differ from each other; and (2) did the taxon composition of standards and underwood in individual forest compartments differ from each other? We also examine the implications of standard and underwood occurrence for vegetation reconstructions based on historical sources.

## 2 | METHODS

### 2.1 | Data sources and study area

Most of the data analysed in this paper came from the archive of the *Lesní zářizovací kancelář* (=Forest survey office) of the Lichtenstein family, currently held at the *Moravský zemský archiv* (Moravian Provincial Archives, MZA) in Brno, Czech Republic (fonds MZA F 31). The beginnings of this institution go back to the 18th century, and its employees carried out major mapping and surveying campaigns in the 19th and 20th centuries. The significance of this archival fonds is given by the size of Lichtenstein properties in Moravia (the eastern one third of the current Czech Republic) and the related sophistication of the woodland surveys. The entire archival fonds contain ca. 2,000 FMPs and 6,300 maps. FMPs are complex documents, usually consisting of a general site and management description, a detailed stand description and a cutting–replanting plan supported by economic calculations. The basic geographic unit of FMPs is the ‘forest compartment’, which varies in size but is usually not more than 20 hectares. In some FMPs (but not in others), standards and underwood were recorded separately in coppice woods. Unfortunately, nothing indicates in the list of FMPs which ones contain the desired level of detail; therefore suitable FMPs needed to be identified by examining hundreds of individual documents. In suitable documents, underwood was always recorded as percentages for individual tree taxa. Standards were either described as percentages or counted individually. We do not know whether percentages for standards were derived from counts of individual trees or were estimated. In addition to the Lichtenstein FMPs, we also included material from the archival fonds of the *Správa státních lesů Hodonín* (=State forest administration Hodonín) to increase the geographical scope of our dataset. These forests had originally belonged to the Habsburg family and were, at the time of the FMP (1925), recently nationalised by the Czechoslovak state.

In total, we found data suitable for the purposes of this paper in 15 FMPs that contained information on standards and underwood in 1,507 forest compartments in 21 forestry units (German *Revier*, Czech *polesí*). Not all forests compartments in each unit were evidenced as coppices. The archival shelfmarks of the documents are MZA F 31 kniha 388, 389, 392, 394, 396, 397, 400, 401, 404, 405, 408, 1,089, 1,101, 1,392; MZA F 263 kniha 1. The temporal range of the data is 1899–1925 with all FMPs except one coming from the period between 1899 and 1906. The data covered 11,903.59 hectares of forests. The average forest compartment was 7.8 hectares large. In 11 forestry units, 90,184 individual standard trees were recorded

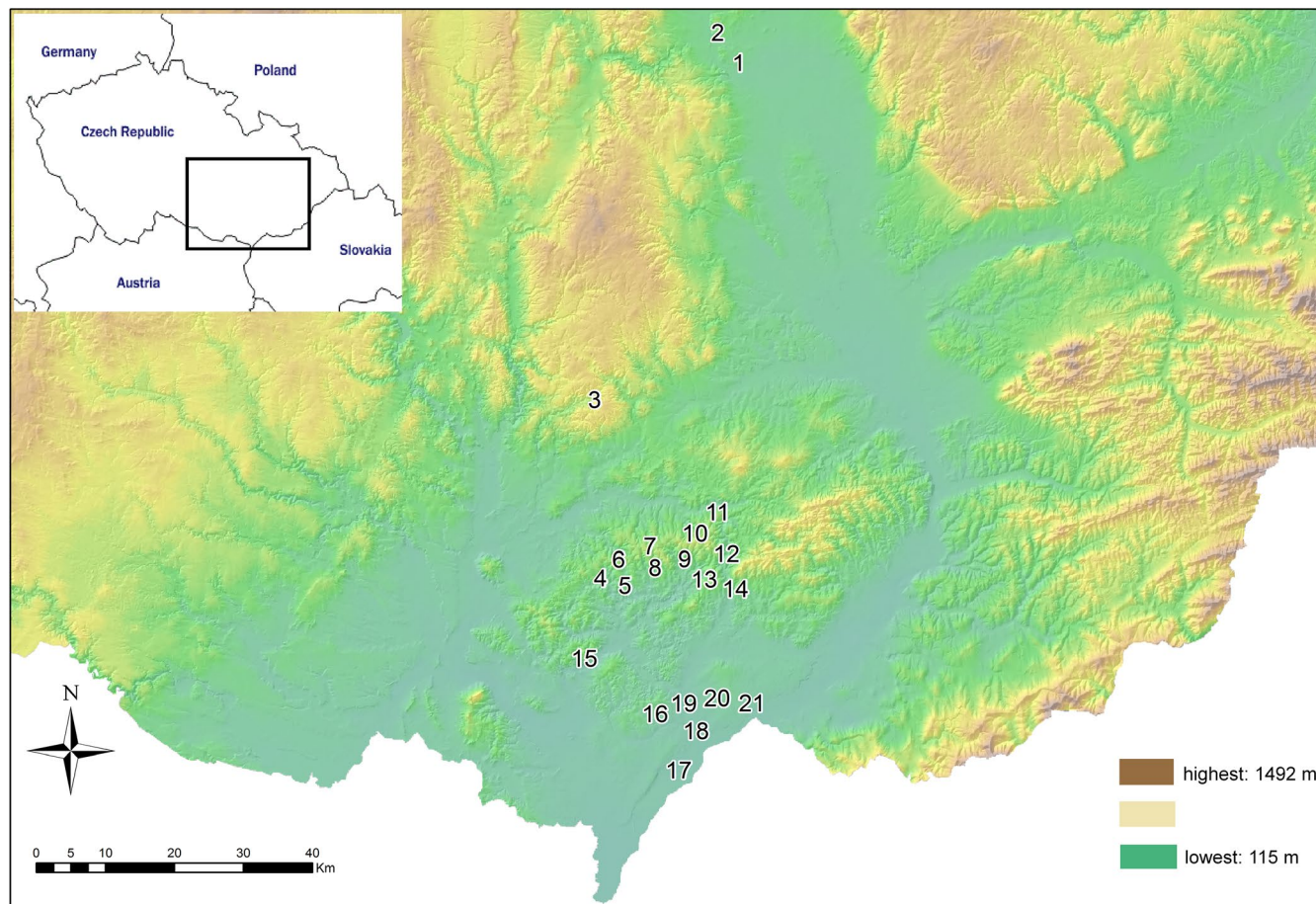
while in the remaining 10 units standard taxa were assigned percentage values. The average density of standards was ca. 19 trees per hectare. Altogether 22 tree taxa were mentioned originally in German or Czech. Some taxa can be identified to the species level in the given context, others only to the genus level. The taxa were the following: oak *Quercus* spp., fir *Abies alba*, maple *Acer* spp., alder *Alnus glutinosa*, birch *Betula* spp., hornbeam *Carpinus betulus*, hazelnut *Corylus avellana*, spindle *Euonymus* spp., beech *Fagus sylvatica*, ash *Fraxinus* spp., larch *Larix decidua*, spruce *Picea abies*, pine *Pinus* spp., poplar *Populus* spp., aspen *Populus tremula*, cherry *Prunus* spp., pear *Pyrus* spp., black locust *Robinia pseudoacacia*, willow *Salix* spp., rowan *Sorbus* spp., lime *Tilia* spp. and elm *Ulmus* spp. This list includes the genus *Populus* and the species *Populus tremula* separately, because the latter was defined as such while the former could apparently refer to any other species in the genus. Most taxa occurred as both standards and underwood with the exception of *Sorbus*, *Prunus* and *Euonymus*, which were only recorded as standards, and *Corylus*, *Salix* and *Pyrus*, which were only recorded as underwood.

Coniferous trees (which do not coppice) often occurred in our data as underwood. This obvious oxymoron indicates the specificity of FMPs as historical sources. When preparing these management plans, it was compulsory for foresters to decide whether a given stand was a coppice or a high forest. For mixed stands of conifers and broad-leaved trees, which were common in this transitional period towards coniferous high forests, this was not always an easy task. The usual procedure to end coppicing was total destruction and replanting with conifers, but underplanting and gradual transition were also known. In addition, *Picea*, *Pinus* and *Abies* regeneration could occur naturally as well. Once a compartment was classified as coppice, all young growth in it had to be recorded as underwood (cf. Bürgi, 1999b). This is why our database contains instances of *Larix*, *Picea*, *Pinus* and *Abies* underwood. These trees would have normally stood mixed with broadleaved coppice stools. Following the logic of our sources, such a compartment would have been moved to the high-forest category at some point.

Geographically, the data covered the typical elevation range of coppice forests in the study area from ca. 150 m to ca. 500 m asl (cf. Maděra *et al.*, 2017). Sites included lowlands, floodplains, smaller hills and upland areas. More data originated from lower elevations than from uplands, a consequence of the past distribution of coppices. The locations of the analysed forests are shown in Figure 1. Forests owned by the Lichtenstein family (henceforth ‘Lichtenstein forests’; 1,196 compartments) mainly occurred on luvisols, whereas state forests formerly owned by the Habsburg family (henceforth ‘state forests’; 311 compartments) occupied lower-lying areas on arenic cambisols (<http://mapy.geology.cz/pudy/>).

### 2.2 | Data analysis

Although abundance data contain more information than presence/absence data, we based our analyses on the latter. We decided to use this type of data because abundance data in standards and



**FIGURE 1** The location within the eastern Czech Republic of the forestry units analysed in this paper. 1, Alej; 2, Úsov; 3, Verlagsplatz; 4, Bošovice; 5, Dambořice; 6, Koberžice; 7, Mouřínov; 8, Archlebov; 9, Ždánice; 10, Nevojice; 11, Nové zámky; 12, Haluzice; 13, Lovčice; 14, Bohuslavice; 15, Kobylí; 16, Mutěnice; 17, Těšice; 18, Červené domky; 19, Zbrod; 20, Pánov; 21, Ratíškovice. Numbers 1–14: Lichtenstein forests; numbers 15–21: state forests

underwood are not directly comparable. Whereas percentages in underwood can be translated into actual cover in hectares by the given tree taxon, 100% *Quercus* in the standard layer could equally refer to a single tree or more than 500 trees in two compartments of similar size. Furthermore, standard values within a compartment are not independent, which would have arguably led to artefacts and false interpretations. For all analyses we used only tree taxa that were present as both standards and underwood and occurred either as standards or underwood in at least 1% ( $n = 15$ ) of all forest compartments. We therefore excluded *Sorbus*, *Euonymus*, *Prunus*, *Corylus*, *Pyrus*, *Salix*, *Abies* and *Populus*.

To understand patterns in tree taxa occurrence, sums of presences of individual tree taxa as underwood, standard, or both in individual forest compartments were displayed in bar graphs for the entire dataset and for Lichtenstein forests and state forests separately. Co-occurrences across the tree taxa as underwood and standards in individual forest compartments were visualised in chord diagrams. To examine whether there is a statistically significant difference between the taxon composition of underwood and that of standards in individual forest compartments, we used co-correspondence analysis. To test whether there is a statistically significant

correlation between the occurrence of standards and underwood of the same tree taxa in individual forest compartments, we used association analysis with the help of a  $\chi^2$  test for  $2 \times 2$  contingency table (Fisher's exact test). The  $\chi^2$  test was performed to test if standards and underwood co-occurred together more often than by chance. Effect size (the strength of the association between the co-occurrence of standards and underwood) was defined by modified log odds ratio; the odds of underwood and standard co-occurrence were calculated as the ratio of the probability that underwood and standards will co-occur to the probability that underwood and standards will occur separately. An odds ratio more than one implies that the chance of the occurrence of standards increases with the occurrence of underwood of the same taxon and *vice versa*. We also calculated the normal approximation confidence interval for each ratio by estimating the standard error of the log-transformed ratio multiplied by 1.96 to obtain the upper and lower limits. For the odds ratio analysis and  $\chi^2$  test, joint absences were excluded from the dataset because these would have artificially inflated positive relationships between standards and underwood of especially rarer taxa. To at least partially control for edaphic, climatic and socioeconomic factors that possibly influenced the results, we repeated all analyses

three times: for the entire dataset, for Lichtenstein forests only and for state forests only.

### 3 | RESULTS

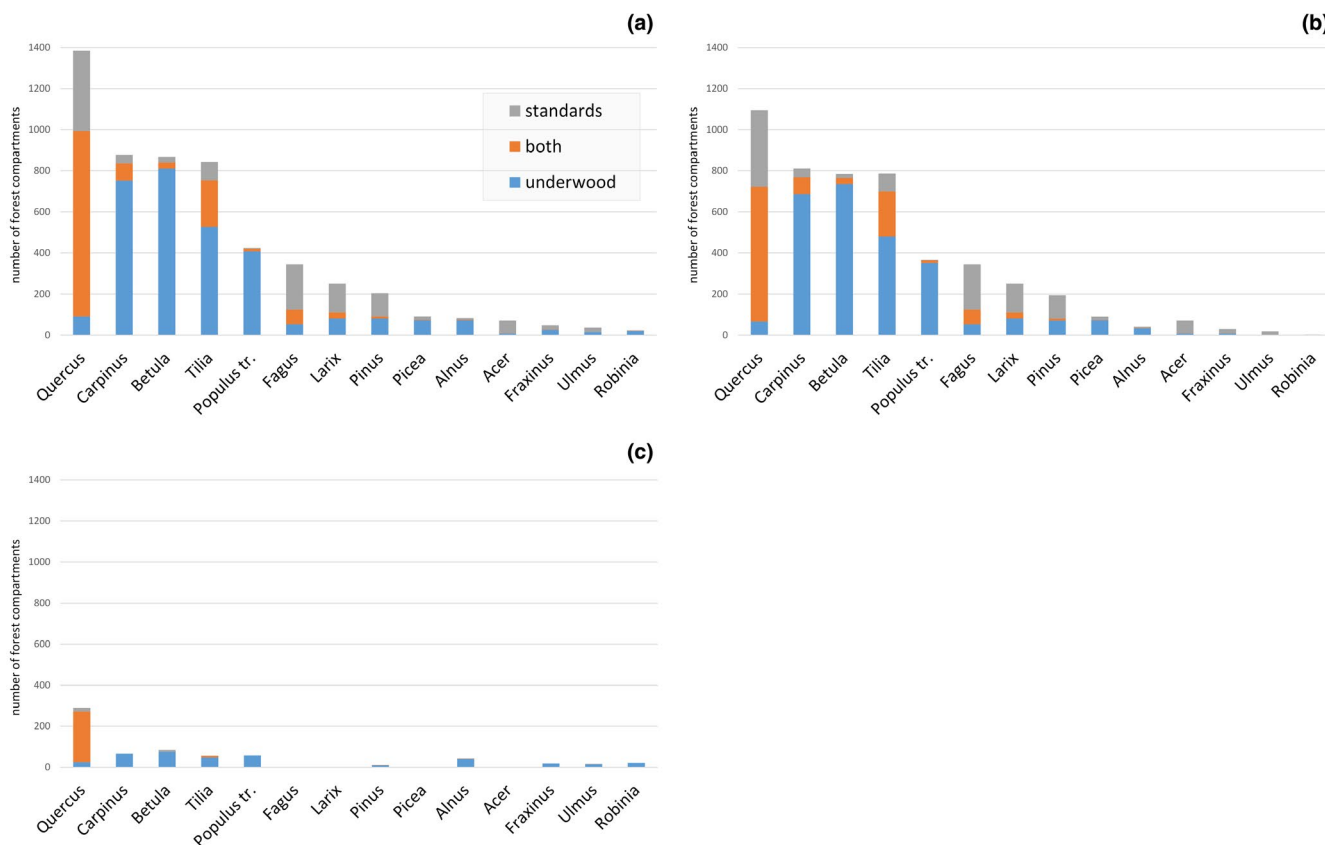
The most frequent tree taxa in the coppices of the study area were *Quercus*, *Carpinus*, *Betula*, *Tilia*, *Populus tremula* and *Fagus* (Figure 2a). Other broadleaved trees occurred only occasionally. Conifers were also recorded, although in relatively low frequencies – most often *Larix*, *Pinus* and *Picea*. *Quercus* was the most common tree taxon in both underwood and in standards, although less so among underwood taxa. *Carpinus*, *Betula*, *Tilia* and *Populus tremula* occurred predominantly as underwood. *Fagus*, *Larix* and *Pinus* were more common as standards. Frequencies of standards and underwood in Lichtenstein forests (Figure 2b) were similar to those in the entire dataset. In contrast, in state forests (Figure 2c) *Quercus* was almost the only standard tree but *Quercus* standards practically always occurred together with *Quercus* underwood. *Fagus* and conifers (except a few occurrences of *Pinus*) were absent here.

Co-occurrence patterns were relatively even across the taxa. *Quercus* standards co-occurred most frequently with other taxa, predominantly with underwood (Figure 3a). The four most common underwood taxa – *Betula*, *Carpinus*, *Quercus* and *Tilia* – were responsible for about 4/5 of all co-occurrences in underwood. As in the case of sums of presences, Lichtenstein forests showed a pattern similar to the overall one. In spite of the dominance of *Quercus*, the

general pattern of relatively even tree taxon co-occurrence could also be observed in state forests (Figure 3b, c). In both cases, *Quercus* standards tended not to occur with standards of other tree taxa.

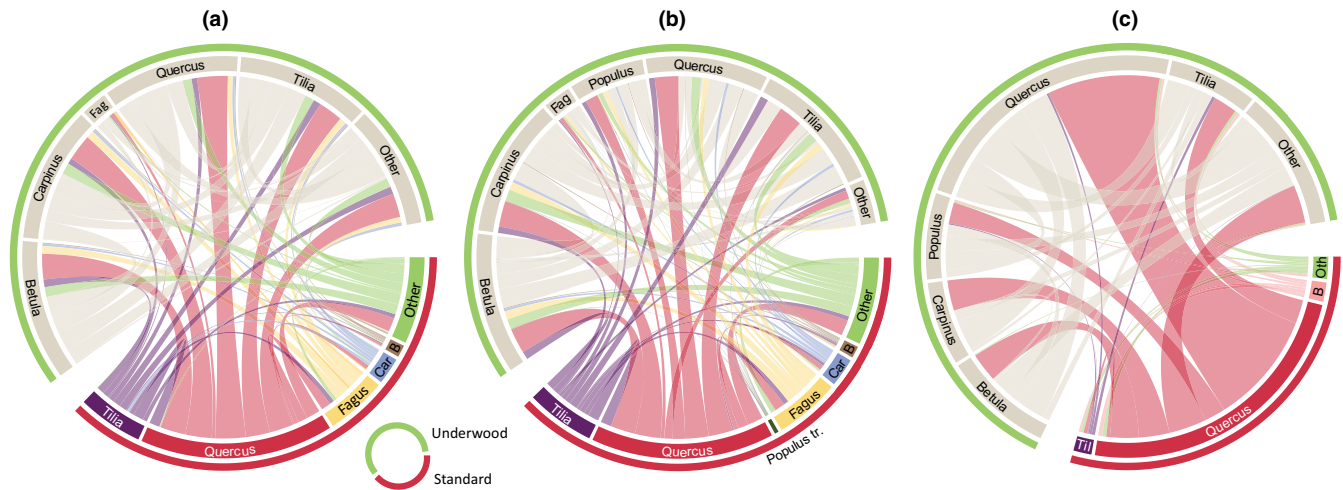
The association analysis (Figure 4) indicated that there was a statistically significant association between the occurrences of standards and underwood in individual compartments for *Quercus*, *Alnus*, *Carpinus*, *Fagus*, *Larix*, *Populus tremula* and *Tilia* when the entire dataset was taken into account. When considering Lichtenstein and state forests separately, the same taxa were significant with the exception of *Carpinus*. In all analyses, only *Quercus* standards and underwood showed a positive association, i.e. the occurrence of standards increased the probability of the occurrence of underwood (and vice versa), all other taxa showed negative associations. This is in accordance with the general message of the bar graphs in Figure 2. The fact that the positive association in *Quercus* was stronger for state forests corresponds to Figure 2c. Negative associations for other taxa means that they occurred significantly more frequently as standards (*Fagus* and *Larix*) or as underwood (*Alnus*, *Populus tremula*, *Tilia*, *Carpinus*). Most of these associations were present only in Lichtenstein forests, which, given that the majority of data originated from these forests, carried over to the overall results.

The co-correspondence analyses (Table 1) showed that in the entire dataset as well as in Lichtenstein and state forests separately, the taxon composition of standards and underwood were statistically significantly correlated. In other words, when the mutual relationships of all tree taxa were examined, forest management (or any other factor) seems not to have suppressed or promoted any

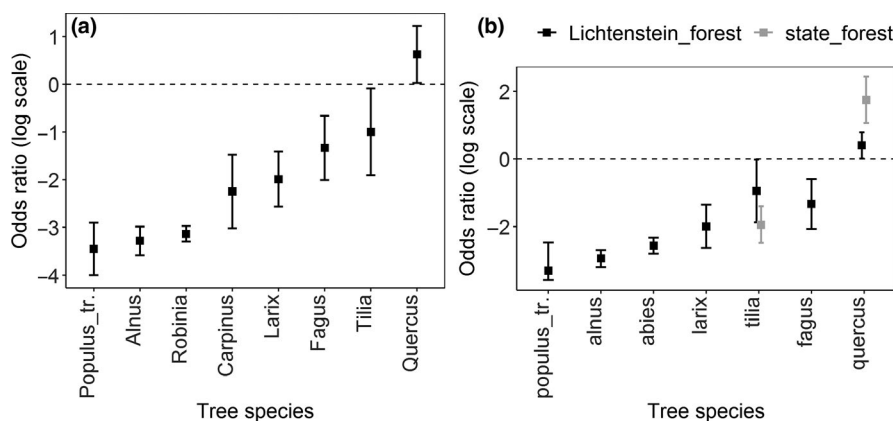


**FIGURE 2** Sum of presences of tree taxa as underwood, standards or both in individual forest compartments. Legend identical for all graphs. (a) entire dataset, (b) Lichtenstein forests, (c) state forests





**FIGURE 3** Co-occurrences of pairs of taxa in forest compartments. Lines comprise individual connections for both forms (standards and underwood) between tree taxa. The thicker the line, the more common the particular type of connection. The width of the ring-section occupied by individual taxa corresponds to the observed co-occurrences with other taxa in both management forms. Emphasis is put on standards; connections between standards and standards as well as between standards and underwood are in colour. Connections between underwood and underwood are in grey. Individual diagrams are for all data (a), Lichtenstein forests (b) and state forests (c). Only the most common taxa are shown separately, the rest are merged in "other". Abbreviations: B, *Betula*; Car, *Carpinus*; Fag, *Fagus*; Til, *Tilia*; Oth, other



**FIGURE 4** Association analysis between the occurrences of standards and underwood of the same taxa in individual forest compartments for the entire dataset (a) and Lichtenstein and state forests separately (b). Only statistically significant results are shown

tree taxa either as a standard or as underwood to a statistically significant degree. This confirms the impression gained from the chord diagrams (Figure 3).

## 4 | DISCUSSION

### 4.1 | Standards and underwood: can preferences be observed?

Our analyses showed that no easy answer can be given to the question whether or not certain tree taxa were preferred and possibly promoted by foresters as standards. The association analysis and the co-correspondence model provided somewhat different results, which accentuates the need to always carefully consider the context of the sources and methods as well as the level of investigation. At the level of individual tree taxa, there existed differences in the occurrence of standards and underwood. However, the preference for *Quercus* as a standard, as suggested by written historical sources,

was not confirmed because in our dataset *Quercus* was very common among underwood trees as well. In contrast to *Quercus*, some other tree taxa were significantly more common as standards or underwood. The reasons behind this are most probably a combination of natural properties, environmental conditions and management decisions. *Fagus*, for example, occurred more frequently as a standard tree, but one should not jump to conclusions and interpret this as simply a sign of management. *Fagus* was not a typical coppicing species in central Europe, in contrast to traditional *Fagus* coppices in southern and southeastern Europe, common especially in the mountains (Mairota *et al.*, 2016; Volařík *et al.*, 2017; but see Máliš *et al.*, 2020). It is to be noted that the management of southern European coppices could be specifically adapted to *Fagus*: in parts of Italy, for example, a special system (selective coppicing) was used to help *Fagus* overcome its known limitations in coppice regeneration (Coppini and Hermanin, 2007). Such – more sophisticated, as it were – systems are currently not known to have occurred in the Czech lands. Furthermore, *Fagus* was unsuitable and therefore very rare as building timber in the study region (Tomáš Kolář, personal



**TABLE 1** Summary of Monte Carlo permutation test of the co-correspondence model

|                                                | Axis 1                                       | Axis 2 | Axis 3 | Axis 4 |
|------------------------------------------------|----------------------------------------------|--------|--------|--------|
| All forests                                    |                                              |        |        |        |
| Eigenvalues (proportion of the total variance) | 0.0268                                       | 0.0158 | 0.0120 | 0.0084 |
| Explained covariation (cumulative)             | 34.83%                                       | 55.41% | 70.98% | 81.88% |
| Test on first axis:                            | First axis eigenvalue = 0.0268, $p = 0.003$  |        |        |        |
| Test on all axes:                              | Eigenvalue sum = 0.0769, $p = 0.0005$        |        |        |        |
| Lichtenstein forests                           |                                              |        |        |        |
| Eigenvalues (proportion of the total variance) | 0.2246                                       | 0.0125 | 0.0098 | 0.0076 |
| Explained covariation (cumulative)             | 82.84%                                       | 87.45% | 91.08% | 93.88% |
| Test on first axis:                            | First axis eigenvalue = 0.2246, $p = 0.001$  |        |        |        |
| Test on all axes:                              | Eigenvalue sum = 0.2711, $p = 0.001$         |        |        |        |
| State forests                                  |                                              |        |        |        |
| Eigenvalues (proportion of the total variance) | 0.0638                                       | 0.0140 | 0.0112 | 0.0037 |
| Explained covariation (cumulative)             | 67.90%                                       | 82.78% | 94.70% | 98.61% |
| Test on first axis:                            | First axis eigenvalue = 0.0638, $p = 0.0329$ |        |        |        |
| Test on all axes:                              | Eigenvalue sum = 0.0939, $p = 0.0254$        |        |        |        |

communication). When, in the first Czech-language forestry handbook, Lenhart (2017, original published in 1793) defined the uses of *Fagus* wood, he emphasised that it was best for charcoal burners and generally as fuel. All the above would predetermine *Fagus* towards coppice management (cf. Paradis-Grenouille *et al.*, 2015). It thus seems that *Fagus* was more common as a standard tree because of its natural properties in the given environmental conditions. In a similar manner, the negative association between standards and underwood in favour of the latter for *Alnus*, *Populus tremula* and *Tilia* can be partly explained by their superior ability to produce coppice shoots (Rackham, 2006; Matula *et al.*, 2012).

While the above patterns were visible at the level of individual tree taxa, interspecific relationships showed no differences between standards and underwood: the taxon composition of standards and underwood in individual compartments was statistically significantly correlated. This means that human management did not alter taxon composition in standards to a degree that would have been discernible with the methods we used in this paper. Overall, our data and analyses do not suggest that selection by foresters radically transformed the taxon composition of standard trees in coppice forests. At the same time, it appears worth considering the opposite end of the issue: i.e. to what extent the taxon composition of underwood may have been artificial. In general, it is not easy to conceptualise underwood as 'natural' because it lacks generative reproduction. However, the ability of broadleaved trees to regrow after cutting is a perfectly natural phenomenon, which was arguably an evolutionary response to an outside force (Rackham, 2006). When applied on a long-term basis, coppicing could maintain the existing tree species composition (Paradis-Grenouille *et al.*, 2015). It would seem logical that at the same time it

reduced genetic diversity, but there is evidence also to the contrary (Valbuena-Carabaña *et al.*, 2008). As mentioned in the *Introduction*, we do not know of any written sources that directly mention the promotion through management of certain underwood tree taxa on the grounds of their higher calorific value. Similarly, investigations based on archaeological material either refute underwood selection as such (Dufraisse, 2008) or offer it as a possible but inconclusive option (Rubiales *et al.*, 2011). However, indirect selection through better coppicing ability is often mentioned: for example, the spread of *Carpinus* in *Quercus-Carpinus* woodlands was connected to coppicing (Rubner, 1960). Máliš *et al.* (2020) argued that coppicing suppressed *Fagus* and favoured *Quercus*. The tendency in our dataset for *Alnus*, *Populus tremula*, *Tilia* and *Carpinus* to occur predominantly as underwood may indicate such a trend. At the same time, the very nature of historical data also needs to be scrutinised. Already the frequent mention of conifers as underwood indicated that complex woodland reality was sometimes hard to translate into simplified forestry tables. This may have been so in some less obvious cases as well. An unexpected result stemming from our data is the high abundance of *Betula* underwood. *Betula* is usually seen as an admixture taxon in established forests in Central Europe (but not necessarily so in Northern Europe, see Hynynen *et al.*, 2009). One of the reasons behind its frequent occurrence in our dataset can be coppicing itself. Although *Betula* grows well from stools, it is also a light-demanding pioneer taxon; therefore, its abundance may be partly explained by its ability to quickly colonise freshly cut areas (Perala and Alm, 1990). In effect, much of the *Betula* underwood recorded in our dataset may have been generative regrowth rather than coppice shoots. Nonetheless, conclusive evidence concerning the indirect effects of coppicing on underwood taxon composition would have



to include detailed information on tree taxon composition before and after the introduction of long-term coppicing into particular woods. There are three major challenges to face in such research and to our knowledge so far no study has successfully overcome all three. First, because coppicing in most places probably started before the appearance of written sources, dendroarchaeological data are needed to establish its existence. However, so far there is no scientific consensus whether archaeological wood remains are suitable at all to safely infer the existence of coppicing (cf. e.g. Copini *et al.*, 2010; Out *et al.*, 2013; Girardclos *et al.*, 2018; Szabó, in press). Second, research has to demonstrate not only the existence of coppicing in the past but also a change in management from high forest (or wood pasture, see Keyser, 2009) to coppice. Lastly, an eternal peril of historical ecological investigations, the *post hoc ergo propter hoc* fallacy needs to be avoided.

#### 4.2 | *Quercus* in coppice woods

*Quercus* was the overwhelmingly dominant tree taxon among standards. In that sense, our results fall in line with other studies that observed the dominance of *Quercus* standards in many lowland regions in Europe. Already in 1975, Rackham noted that *Quercus* was the most common standard tree in Hayley Wood, near Cambridge, UK (Rackham, 1975). Similar observations were reported for example from Belgium (Baeten *et al.*, 2009), Spain (Tedeschi *et al.*, 2006), France (Lassauce *et al.*, 2012) and Poland (Szymura *et al.*, 2014). There is copious written evidence about the active promotion of *Quercus* standards by foresters. For example, the forest instruction of the Mikulov estate (close to our study sites) from 1672 prescribed that when cutting standard trees, young *Quercus* trees had to be spared. In addition, some *Quercus* coppice stools had to be 'singled out': only the strongest stem was supposed to be left on them so that it could develop into a standard-like form (MZA F18 inv.č. 7679, see also Szymura *et al.*, 2014). However, as already mentioned, *Quercus* was not shown to be more common as a standard than as underwood in our study region because it occurred very frequently as an underwood tree as well. Our results are therefore inconclusive rather than negative as regards the deliberate promotion of *Quercus* as a standard tree. In other regions, *Quercus* standards did not always go together with *Quercus* underwood. Returning to the examples above, Baeten *et al.* (2009) recorded *Quercus* standards above an underwood layer of *Corylus*, *Acer* and *Fraxinus*. Lassauce *et al.* (2012) noted that most standards were *Quercus* as opposed to the dominance of *Carpinus* in underwood. In Hayley Wood, Rackham (1975) recorded *Fraxinus*–*Acer*–*Corylus* underwood under mainly *Quercus* standards. In contrast, Tedeschi *et al.* (2006) noted various *Quercus* species in underwood as well as in standards. How often *Quercus* was dominant in underwood as well as among standards in European coppice woods is so far little known. Even in our own study region it is an open question how representative our results may be. Based on historical surveys, Müllerová *et al.* (2015) showed that in two adjacent forests (Děvín and Milovice forests) close to our sites, the position of *Quercus* was very different. In the latter, *Quercus* was dominant

in standards as well as in underwood – a situation similar to our data. In contrast, in Děvín *Quercus* was only a minor constituent of the underwood as opposed to its important role as a standard. This may have been connected to soil conditions: in Děvín forest, richer soils in the long run may have favoured *Tilia* over *Quercus* in the underwood. Such an argumentation can be considered for our data set as well: *Quercus* was more dominant in the underwood of state forests, whose sandy soils are overall less nutrient-rich than those of Lichtenstein forests (cf. Szabó and Hédl, 2013). Furthermore, it is possible that the two families (Lichtenstein vs. the original owners of state forests, the Habsburg family) had contrasting management or marketing strategies that led to different tree taxon composition in their respective forests. In lack of a comprehensive comparative analysis, this would be difficult to decide at present, but previous research highlighted the active promotion of oak in what were to become state forests. Originally to promote grazing, oak has had a more dominant position here since the 14th and 15th centuries than before, which may have had long-term consequences still observable in our data (Jamrichová *et al.*, 2013; Jamrichová *et al.*, 2017). The analysis of Děvín forest also highlighted the need to consider a diachronic aspect as well: whereas *Carpinus* (together with *Quercus*) was the most common standard tree in 1808, it made up merely 3% of all standard trees 140 years later in 1948.

A related issue is the connection between coppice management and *Quercus* regeneration. According to our data, *Quercus* was regenerating in the study area without any problems both vegetatively and generatively. This may have been because it is light-demanding and thrived in the ever-changing mosaic of lighter and darker phases created by coppicing. Currently, however, *Quercus*-dominated forests both in Europe and North America are on the retreat (Nowacki and Abrams, 2008; Amatangelo *et al.*, 2011; Chudomelová *et al.*, 2017; Hanberry *et al.*, 2019). One of the reasons behind this phenomenon – sometimes called the 'oak change' (Watt, 1919; Petersson *et al.*, 2019) – may be the recent decrease in management intensity and the subsequent ecological succession towards more closed forests. In Děvín forest, mentioned above, *Quercus* regeneration stopped after coppice management had been abandoned in the mid-20th century (Altman *et al.*, 2013, see also Müllerová *et al.*, 2016). By contrast, *Quercus* was reported to freely regenerate in the Bradfield Woods, one of the few locations in England where coppice management has been continuous since the Middle Ages (Rackham, 2003). According to a meta-analysis of 234 papers, there is a clear connection between traditional management, the resulting landscape structure and *Quercus* regeneration on a European scale (Bobiec *et al.*, 2018). In lack of management, *Quercus robur* and *Quercus petraea* now mostly regenerate outside woodland.

#### 4.3 | Historical forest surveys and vegetation reconstruction

Keeping in mind the geographical limitations of the dataset, our results can shed some light on the uses of archival sources in general.



The dominance of *Quercus* among standards recorded in many historical sources in Europe could be easily explained away as reflecting the interests of those who commissioned the documents. In practical terms, one may ask whether there were really almost no other standard trees than *Quercus* in certain Venetian forests in the Early Modern Period, or whether other trees were simply not relevant for the purpose of recording (census of trees for shipbuilding) (Appuhn, 2009). After all, most historical sources never claimed to record complete species lists. Our results showed that *Quercus* standards could indeed be overwhelming in coppice woods but that does not necessarily mean that they were not similarly common among underwood trees as well. In fact, it seems that data on standards can serve as an indicator of overall taxon composition. However, the reliability of such indication is strongly limited by geographic and temporal constraints. In other words, only combined information on both standards and underwood can be thought of as reliable for vegetation reconstruction. This poses a challenge, because many of the oldest (medieval and early modern) historical sources dealt exclusively with standards although they often did not explicitly say so. Underwood was usually recorded (if at all) by the volume rather than by tree taxon (e.g. Šimůnek, 2003–2004). As a result, researchers should interpret any observed dominance of *Quercus* (or of any other tree taxon for that matter) in historical sources with caution. This also applies to timber-cutting data in woodland account books, which are the most extensive historical source type for individual European forests. It is also worth noting that standards were cut irregularly to satisfy building requirements; therefore, their composition at any given point in time may have also depended on recent cutting campaigns unknown to the researcher. Different sources may also have recorded different conditions, further complicated by ownership structures. For example on the above-mentioned Mikulov estate, a detailed forest survey in 1692 recorded standard trees not only in woodland but also in individual tenant homes (resulting from recent harvests). Overall, *Quercus* standards made up 82% of standards in forests directly managed by the estate and 78% in forests managed by the villages. But if the number of standards in village woods is combined with the number of standards stored in houses, *Quercus* represented only 50% of all standards (MZA F 18 inv.č. 7679).

## 5 | CONCLUSIONS AND OUTLOOK

Our results do not allow for a simple answer to the question whether or not the taxon composition of standards and underwood in coppice woods differed, let alone regarding the role of management in such potential differences. At the level of individual tree taxa, some trees were more common as standards while others, as underwood. However, the prevalence of *Quercus* among standards, as suggested by existing literature, was not confirmed, most probably because in our study area *Quercus* was a common underwood tree as well. At the same time, the taxon composition of standards and underwood in individual forest compartments was significantly correlated, i.e. at this level of investigation no differences were apparent. In general

terms, it seems rather difficult to differentiate between the possible effects of human selection and indirect selection through natural properties and environmental factors, as demonstrated for example by *Fagus*. In addition, our results also highlight the need to carefully consider the properties of written historical sources themselves: *Betula* or *Pinus* underwood indicated that the complex realities of forest vegetation were sometimes hard to translate into simplified forestry tables.

It is important to keep in mind that our conclusions are geographically constrained and studies in other areas, even within the Czech Republic, may lead to different results especially as concerns the promotion of *Quercus* as a standard tree. More research will be needed to complement and possibly modify our conclusions. Luckily, the potential of FMPs in pan-European research is very high. These documents were produced with similar methods to remarkably similar standards in many parts of Europe. As such, FMPs are one of the few sources in European historical ecology that could be used in continent-wide joint databases and their analyses. In spite of the overall compatibility of these sources in geographically dispersed areas, so far no efforts were made to utilise them in anything like a pan-European manner. We therefore appeal to historical forest ecologists and environmental historians to join forces towards the creation and eventual analysis of such a database.

## ACKNOWLEDGEMENTS

The authors thank Markéta Chudomelová for preparing the chord diagrams.

## AUTHOR CONTRIBUTIONS

PSz conceived of the research idea with input from RH and collected the data. JŠ performed statistical analyses. PSz wrote the paper with contributions from JŠ and RH. All authors discussed the results and commented on the manuscript.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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**How to cite this article:** Szabó P, Hédli R, Šipoš J. Standard trees versus underwood: Historical patterns of tree taxon occurrence in coppice forests. *J Veg Sci.* 2021;32:e12963. <https://doi.org/10.1111/jvs.12963>



# The rise and fall of traditional forest management in southern Moravia: A history of the past 700 years



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## ARTICLE INFO

### Article history:

Received 6 May 2014

Received in revised form 21 July 2014

Accepted 27 July 2014

Available online 29 August 2014

### Keywords:

Archival sources

Conservation

Coppicing

Forest management

Forest history

GIS

## ABSTRACT

European broadleaved forests have been influenced by humans for centuries. Historical management practices are related to environmental conditions but the role of socio-economic factors is also important. For the successful restoration of traditional management for conservation purposes, detailed knowledge on management history and on the driving forces of historical forest changes is necessary. In order to reconstruct long-term spatio-temporal dynamics in forest management, we chose the Pálava Protected Landscape Area, Czech Republic and analyzed archival sources spanning the past seven centuries. Forests in the study area comprise two relatively large woods (Děvín and Milovice) with different environmental conditions. Historical forest management in both woods was coppicing. The coppice cycle was lengthened from 7 years (14th century) to more than 30 years (19th century) with a fluctuating density of standards. After WWII, coppicing was completely abandoned. This led to pronounced changes in forest age structure accompanied by stand unification indicated by a sharp decrease in the Shannon index of age diversity. To study local attributes responsible for spatial patterns in coppice abandonment, we constructed a regression model with the date of abandonment as a dependent variable and three groups of explanatory variables: (i) remoteness of forest parcels, (ii) morphometric environmental factors and (iii) site productivity. In Děvín Wood, coppicing was abandoned gradually with the pattern of abandonment related significantly to slope steepness and forest productivity. Poorly accessible upper slopes and low productive forest sites were abandoned earlier. By contrast, in Milovice Wood, where no clear topographic gradient is present, the abandonment of coppicing was not related to any of the variables we studied. Our study brings insights into the history and consequences of past management practices, and can be used in current attempts to re-establish coppice management for conservation purposes and as a source of sustainable energy.

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## 1. Introduction

Forest management practices depend not only on environmental factors but also on changing socio-economic conditions (Johann, 2007). In pre-industrial times, in densely populated and mostly deforested European lowlands the demand for firewood and construction timber was high, and so was the pressure on the remaining forests. As a result, coppicing – an intensive type of management – was common for centuries in most European lowland forests (Rackham, 2006). In coppice forests, shoots resprout from dormant buds on the stumps (coppice stools) or from the root system and are felled repeatedly at short intervals,

providing a regular supply of firewood. If combined with standard trees (single-stemmed trees left to grow among coppice stools; coppice-with-standards management) such woodlands provide building material as well (Buckley, 1992; Peterken, 1996; Rackham, 2003; Gimmi et al., 2008; Szabó, 2010a). In the past, coppice forests yielded further products, such as leaf fodder, pasture (usually 4–7 years after coppice harvest to protect young shoots), and pannage (domestic pigs fed on acorns and beechmast in autumn and winter) (Rackham, 2003; Szabó, 2013).

Coppicing was commonly practiced on easily re-sprouting oak, lime, hazel, ash, hornbeam, maple, alder, willow, sweet-chestnut, beech, and later on black locust (Peterken, 1996; Rackham, 2003; Matula et al., 2012). Traditionally, the composition of the underwood (i.e. coppice stools and shoots) was not directly influenced by humans, although the actual mixture was sometimes improved by removing unwanted species or encouraging valuable species by

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natural regeneration, layering, plashing or planting (Peterken, 1993; Tack et al., 1993). By contrast, standard tree species were carefully selected, and usually oak was favoured (Buckley, 1992).

Historical coppice management represented a flexible and diverse system as well as a good source of income that could be adjusted in response to almost annual changes in labour availability and demands for timber, wood and pasture (Peterken, 1993). The extent and importance of coppicing was changing over time. By the second half of the 20th century, coppicing virtually disappeared from many parts of Europe, mostly due to the substitution of firewood by fossil fuels (Sieferle, 2001) and changes in silvicultural practices (transition to modern forestry, including plantations and high-forest management) (Rackham, 2008). Nonetheless, in some European countries (notably in the Mediterranean) coppicing (and coppicing with standards) still represents an important form of management; for example in Albania (55%), France (47%), Greece (68%), Hungary (29%), Italy (56%), Portugal (37%) (all data based on UN/ECE-FAO, 2000), Bulgaria (48%, State Forest Agency, 2008), Croatia (22%, Croatian Forests Ltd. 2006), and Macedonia (60%, State Statistical Office of Macedonia, 2004). In other parts of Europe, most coppice woods have been transformed into high-forests or left to overgrow (Peterken, 1996; Logli and Joffre, 2001; Rackham, 2008; Van Calster et al., 2008a). Coppiced trees were often reduced to one or two large trunks ('singled out'), felling cycles were prolonged and canopy structure became more uniform (Buckley, 1992).

Coppicing provided high temporal resource heterogeneity and enabled the co-existence of species with contrasting strategies (light and shade tolerant species). By contrast, in high-forests those plant and animal species that prefer open habitats have disappeared (Rackham, 2003; Beneš et al., 2006; Hermý and Verheyen, 2007; Spitzer et al., 2008; Van Calster et al., 2008b; Hédli et al., 2010; Kopecný et al., 2013; Fartmann et al., 2013). The abandonment of traditional forest management techniques has resulted in the gradual closure of formerly open lowland forests, which has led to taxonomic impoverishment and a homogenization of woodland ecosystems (Strandberg et al., 2005; Spitzer et al., 2008). Ancient coppice stools and woodland-related archaeological features also represent a part of cultural heritage (Hermý and Verheyen, 2007; Rackham, 2008; Szabó, 2010b) and thus enhance the value of traditional management.

Recently there is growing interest in coppice re-establishment in Europe for both ecological and economic purposes (as part of nature conservation and as a source of sustainable energy) (Rydberg, 2000; Jansen and Kuiper, 2004; Coppini and Hermanin, 2007; Roedl, 2010; Merckx et al., 2012; Vild et al., 2013). However, the beneficial effects of restoration coppicing are not guaranteed in all cases. When reintroduced to long-neglected sites, coppicing can pose threats to biodiversity by enhancing the spread of ruderal species of native origin and even the invasion of aliens (Radtke et al., 2013; Vild et al., 2013). Problems partly arise from environmental changes concurrent with but independent from the abandonment of coppicing in the 20th century (Verheyen et al., 2012), and partly from insufficient knowledge on coppicing itself. There are few empirical data available on the details of historical coppice management, such as the density of standards, rotation length, the size and position of coppice compartments, and the spatial pattern of coppice abandonment or transition to other types of management. All these factors are likely to have influenced canopy closure, shrub density, the vigour of coppice re-growth, and the extent and duration of canopy cover (Joys et al., 2004). For conservation to be successful, it is necessary to study and preserve traditional forms of management that shaped forest composition and therefore the distribution and abundance of many rare species for centuries (Hermý and Verheyen, 2007). In order to protect diversity in the long run, deeper knowledge on the spatio-temporal

dynamics of individual species and disturbance regimes is indispensable, and information on land-use legacies must be obtained and processed (Bengtsson et al., 2000; Rotherham, 2011; Navarro-González et al., 2013).

For the present study, we selected the Pálava Protected Landscape Area (southeastern part of the Czech Republic). This area contains the last remnants of lowland forests in an otherwise agricultural landscape inhabited since the Palaeolithic. Being among the few sources of wood in the region, these forests were intensively coppiced since at least the Middle Ages. The abandonment of coppicing in the region around the middle of the 20th century was connected not only to the substitution of wood by fossil fuels but possibly also to the expulsion of local German-speaking inhabitants and the subsequent confiscation of private lands by the Communist regime. Despite more than eight decades of neglect and non-intervention management in parts of the Pálava PLA, the remnants of former coppices are still clearly visible. In our study, we aimed to reconstruct the long-term history of the forests in the area in order to answer the following questions: (i) Were there any significant changes in forest cover?; (ii) How did management and age structure change in the study area over the past seven centuries?; (iii) Are there any detectable spatial patterns in the abandonment of traditional management that could help interpret the forces driving this process?

## 2. Material and methods

### 2.1. Study area

The Pálava Protected Landscape Area (PLA; Fig. 1) (8017 ha) is located in the northwestern corner of the Pannonian Lowland, southern Moravia, Czech Republic. This region represents the warmest and driest part of the Czech Republic with an average annual temperature of 9.6 °C, average annual precipitation of 524 mm, and large seasonal variability. This ancient cultural landscape has been continuously occupied since the Palaeolithic. The dense network of settlements has changed little since the 14th century. From the Middle Ages to the 20th century, the entire area of the PLA belonged to the estate of Mikulov, which was

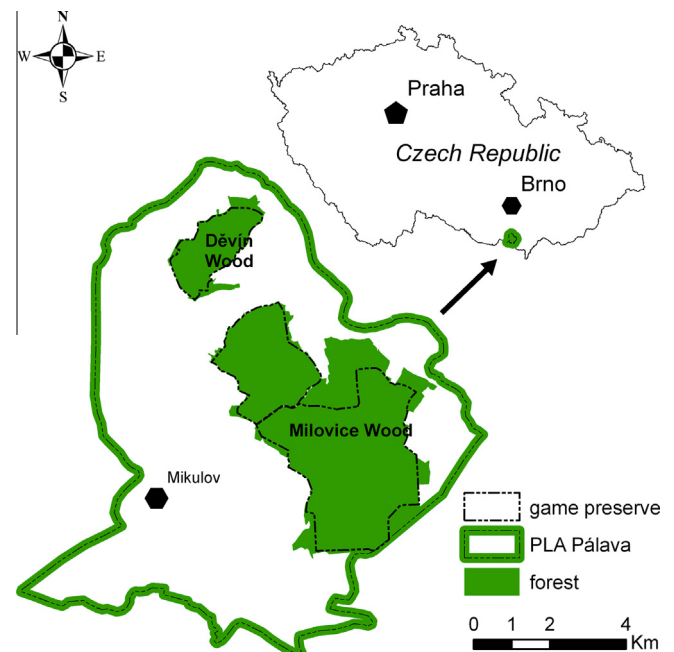


Fig. 1. Map of the study area.



owned by the Lichtenstein family until the 16th century, followed by the Dittrichstein family, who possessed the estate until the formation of Czechoslovakia in the early 20th century.

The intensively cultivated landscape of the region is formed by arable land (40%), vineyards (10%), urban areas (5%), semi-natural to natural grasslands (1.5%), and forests (30%). There are two larger forests in the Pálava PLA: Děvín Wood (400 ha covering most of Děvín Hill, 260 to 549 m a.s.l.) and Milovice Wood (2500 ha, 180 to 324 m a.s.l.). The limestone slopes of Děvín Hill represent a sharp environmental gradient. The northwestern slopes are covered by deep and fertile luvisols and leptosols and are overgrown by thermophilous to mesophilous oak-hornbeam and ravine lime forests. The top and southeastern slopes are exposed to the sun and wind and have poorly developed soils supporting dry grassland and small patches of ravine forests and thermophilous oak forests (Hédl and Rejšek, 2007). The gently undulating loess plateau of Milovice Wood is covered mostly by luvisols that support subcontinental oak forests and small-scale plantations of non-native black pine (Hédl et al., 2010).

Several game preserves were established in the region, some of which are still active. The first game preserve was established in Děvín Wood in 1885 to breed deer and wild boar, and later mouflons (introduced in 1911) and Bezoar goats (introduced in 1953, Fig. 1). After WWII, two additional game preserves covering ca. 80% of Milovice Wood (Fig. 1) were set up in 1965 and 1966 (Bulhary, 1200 ha, red and fallow deer; and Klentnice, 500 ha, fallow deer and mouflons). High numbers of ungulates (0.5, 1.23, and 0.26 animals per hectare in Bulhary, Klentnice and Pálava, respectively, in 1990; Pálava PLA Management Plan 2006) and the resulting problems of overgrazing, trampling and soil erosion facilitated conservation efforts, which led to the abolition of the game preserve in Děvín Wood in 1996, and the reduction of high game densities in Klentnice to 0.72 in 1994 and 0.54 in 2003 (Pálava PLA Management Plan 2006).

The high conservation value of the area, which hosts many endangered species (92 plant, 3 fungi and 159 animal species), resulted in protection measures as early as in 1946, when the Děvín nature reserve (184.6 ha) was established. This area was enlarged and further protected in 1976 as the Pálava PLA (8017 ha, Fig. 1), in 1986 as the Pálava UNESCO Biosphere Reserve, in 2003 as the Lower Morava Biosphere Reserve (354 km<sup>2</sup>, including also the neighbouring Lednice-Valtice area and the floodplain forests at the confluence of Dyje and Morava rivers), and in 2005 as a Natura 2000 locality (eight Sites of Community Importance).

## 2.2. Data sources, processing and analyses

### 2.2.1. Historical changes in forest extent, age structure and management

We compiled a comprehensive dataset of archival information from the 14th to the 20th century (Fig. 2, Table 1, henceforth numbers in brackets in the text refer to individual sources in Table 1). We used the following types of sources: forest maps, topographical and cadastral maps, *urbaria*, estate conscriptions, forest surveys, management instructions for foresters, forest management plans (FMP) and account books (Table 1). In order to assess forest changes, historical maps were scanned, georeferenced, digitized and analyzed in a GIS environment using ArcMap 10.0 (ESRI, 2006). Archival written sources differed markedly in extent, quality, accuracy, scale and information content. The first written archival record comes from 1384 (Bretholz, 1930), the earliest large scale map from 1675 [5]. Some historical maps were difficult to rectify and interpret due to geometrical distortions, discoloration and other deteriorations. On the other hand, large scale forest maps contained precise information on forest extent and age, and the accompanying FMPs and surveys described forest structure and

management. Already the first survey of woodland (1384; Bretholz, 1930 [1]) included names, prices and coppice cycles for most woods in the PLA. The second survey (1692 [9]) listed management (including coppice cycles) for each wood. Highly informative were the forest maps and FMP of 1807/8 [16, 17], which recorded not only the age of underwood for each stand, but also included data on more than 50,000 standards trees that were apparently individually counted. A series of FMPs from the late 19th century (1885 [25], 1901 [27], 1905 [28], 1921–1925 [29], 1933–1936 [30], 1948 [33], 1971 [36] and 2010 [42]) described the age structure of forests in great detail. FMPs from 1885 [25], 1901 [27] and 1933–1936 [30] dealt only with underwood, while the 1948 [33], and 1971 [36], FMPs contained data on both standards and coppice underwood. In the latest source (2010 FMP [41]) standards and underwood were treated together. For the spatial analysis of the information included in FMPs, the accompanying forest maps were used.

In addition to FMPs, three detailed surveys of woodland areas were compiled in 1750 [12], 1789 [15] and 1813 [18]. Further details on management were gleaned from a series of management instructions that were written for local foresters from the late 17th century onwards (1672 [5], 1689 [8], and 1741 [11]). These instructions contained information on for example wood-cutting methods, pasturing in woodlands or haymaking. Unfortunately not all sources covered the entire study area (Table 1). Děvín Wood was covered by all sources, but, as far as more detailed sources are concerned, Milovice Wood was covered partly (ca. 2/3 of the area) by the 1807/8 FMP [17] and entirely only by the most recent sources (1971 [36], and 2010 [42] FMPs).

Archival sources came from the Moravian Archives in Brno, and the Internet – the geoportal INSPIRE of the Czech Environmental Information Agency (CENIA, available from <http://geoportal.gov.cz/>), and the geoportal of Czech Office for Surveying, Mapping and Cadastre (available from <http://archivnimapy.cuzk.cz/>). Source references are summarized in Table 1. Recent forest changes were derived from forest maps and management plans kept at the Forest Management Institute in Brno (1990 and 2006), as well as from aerial imagery (1938 to 1990 provided by the Military Geographic and Hydrometeorologic Office in Dobruška; 2006 by CENIA).

### 2.2.2. Local attributes responsible for spatial patterns in coppice abandonment

We constructed a regression model with the date of abandonment (date of last coppicing) as a dependent variable and three groups of explanatory variables: (i) remoteness of forest parcels expressed by the distance of forest parcel centroids from roads and villages; (ii) morphometric environmental factors derived from a digital elevation model based on the ASTER Global Digital Elevation Model (METI/NASA, 2011) – slope, solar radiation and topographic wetness index (Böhner and Selige, 2006; computed in SAGA GIS version 2.1; SAGA Development Team, 2011) expressed by average values within each parcel, and (iii) site productivity expressed by two parameters (average values within each parcel): (a) price of forest property in 2008 (Supplement No 22 to Regulation 3/2008 Sb) – more valuable property was considered to be more productive for forestry because the evaluation was based on estimated pedological-ecological units; (b) forest productivity (“bonitas”) described in the 1885 FMP [25], ranging between 1 and 4 from least to most productive forests. These variables were chosen to characterize site conditions (e.g. solar radiation was taken into account to include the environmental gradient of shaded vs. sun-exposed slopes). The species composition of the coppice layer was very stable along the coppice abandonment gradient and was therefore not used in the analysis. Prior to the analysis, we tested the multicollinearity of the



Fig. 2. Examples of historical maps depicting Děvín Wood (1675, 1807/8, 1883 and 1947; for source references, see Table 1).

explanatory variables using the inflation factor analysis (VIF) where none of the variables was over 3, therefore they were all used in the models. The above mentioned environmental (predictor) variables were tested with respect to the time of coppice abandonment (dependent variable) using a generalized linear model with a Gaussian error distribution and an identity link function. Univariate models for each explanatory variable, a multivariate model for all the variables, and combinations of variables were tested to determine the best explanatory model for coppice abandonment using Akaike's Information Criterion (Akaike, 1973; Johnson and Omland, 2004). The variables were calculated and morphometric parameters extracted using ArcMap 10.0 (ESRI, 2006) and Geospatial Modelling Environment (Beyer, 2010). Variable testing and modelling were done using the software R version 2.14.2 (R Development Core Team, 2012).

### 3. Results

#### 3.1. Dynamics of forest cover

The first source describing the study area comes from 1384 (Bretholz, 1930) [1]. It lists 26 individual woodlots in the whole study area, usually with their names. Although precise identification in most cases is problematic, the route the surveyors apparently followed indicates that woodland cover was similar to later times. The 1675 map [6] clearly shows that the size of forests in the study area was practically identical to that in the 19th century, although due to problems with georeferencing it was impossible to measure woodland cover precisely. The first detailed forest map,

covering most of Děvín Wood, dates from 1786 [14] and shows the wood basically as it stood in the 19th century. During the 19th century forest cover was stable. At the turn of the 19th and 20th centuries Děvín Wood was enlarged by ca 9% (former pastures forested mostly by black pine), and ca. 10% of Milovice Wood dominated mostly by Scots pine was transformed into arable fields. Since 1946, most of Děvín Hill has been under strict protection with non-intervention management. Pasture, previously commonly practiced mainly on the top and SE slopes, ceased after WWII, and these dry grasslands started to overgrow mainly with shrubs. The process speeded up after 1990, probably due to the abolition of the game preserve and a large reduction of ungulates feeding on these grasslands inside Děvín Wood. These shrubby areas have the potential to be invaded by trees and turn into woodland within a few decades. Apart from these smaller changes, woodland cover in the Pálava PLA has been stable from at least the late 17th century and probably earlier.

#### 3.2. Changes and stability in forest management

Woods in the study area were traditionally managed as coppices. Standard trees were also present albeit in highly variable numbers. The first evidence of coppicing comes from 1384 (Bretholz, 1930) [1]. At this point the coppice cycle was 7 years and apparently there were no standards. Such a short cycle signifies a high demand for firewood. Later on the management became more heterogeneous. The coppice cycle was gradually lengthened and the density of standards grew. At the end of the 17th century, the coppice cycle was 11–13 years and there were ca. 1175

**Table 1**

Main archival sources (AP – aerial photography, FM – forest map; FMP – forest management plan; FS – forest survey; MGHO – Military Geographic and Hydrometeorological Office in Dobruška; MZA – Moravian Archives, letters and numbers refer to archival shelfmarks).

| Year                   | Type of source                            | Reference, archival shelfmark or internet access     | Area covered    |               | Description                                                                                                                                                                                         | Reference in the text |
|------------------------|-------------------------------------------|------------------------------------------------------|-----------------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
|                        |                                           |                                                      | Děvín Wood      | Milovice Wood |                                                                                                                                                                                                     |                       |
| 1414                   | <i>Urbarium</i> of Mikulov estate         | Bretholz (1930)                                      | Entirely        | Entirely      | List of every wood on the estate including age at the time of survey, planned coppice cycle and market price. The woodland survey was completed in 1384 and copied into the later <i>urbarium</i> . | [1]                   |
| 1560                   | <i>Urbaria</i> of Mikulov estate and town | MZA F 18 inv. č. 6792–6793                           | Entirely        | Entirely      | Data on woodland related incomes                                                                                                                                                                    | [2]                   |
| 1590                   | <i>Urbarium</i> of Mikulov estate         | MZA F 18 karton 1250                                 | Entirely        | Entirely      | Data on woodland related incomes                                                                                                                                                                    | [3]                   |
| 1629                   | <i>Urbarium</i> of Mikulov estate         | MZA F 18 karton 1250                                 | Entirely        | Entirely      | Data on woodland related incomes                                                                                                                                                                    | [4]                   |
| 1672                   | Management instructions for foresters     | MZA F 18 inv. č. 7679                                | N/A             | N/A           | Instructions for local foresters issued by the central estate authorities                                                                                                                           | [5]                   |
| 1675                   | Map of Mikulov estate                     | MZA F 18 mapa 12                                     | Entirely        | Entirely      | Copy from 1802                                                                                                                                                                                      | [6]                   |
| 1685–1885              | Forest account books                      | MZA F 18 inv. č. 10362–10598, F 72 inv. č. 3353–3429 | Entirely        | c.2/3         | Yearly accounts of harvest and sale of coppice underwood and timber                                                                                                                                 | [7]                   |
| 1689                   | Management instructions for foresters     | MZA F 18 inv. č. 7679                                | N/A             | N/A           | Instructions for local foresters issued by the central estate authorities                                                                                                                           | [8]                   |
| 1692                   | FS                                        | MZA F 18 inv.č. 7679                                 | Entirely        | Entirely      | Survey of each wood on the estate including age at the time of survey, coppice cycle, number and species of standard trees                                                                          | [9]                   |
| 17th cent <sup>a</sup> | FS                                        | MZA F 18 inv. č. 7679                                | Entirely        | Partly        | Short list of woodlands in demesne including tree species composition                                                                                                                               | [10]                  |
| 1741                   | Management instructions for foresters     | MZA F 18 inv. č. 7679                                | N/A             | N/A           | Instructions for local foresters issued by the central estate authorities                                                                                                                           | [11]                  |
| 1750                   | FS                                        | MZA F 18 inv.č. 7607                                 | Almost entirely | c. 1/3        | Survey of woodland areas                                                                                                                                                                            | [12]                  |
| 1764–1768              | 1st Military Mapping                      | Oldmaps.geolab.cz                                    | Entirely        | Entirely      | Mapping of the Czech, Moravian and Silezian parts of the Habsburg empire by the Army                                                                                                                | [13]                  |
| 1786                   | FM                                        | MZA F 18 mapa 51                                     | Entirely        | None          | Survey of woodland areas                                                                                                                                                                            | [14]                  |
| 1789                   | FS                                        | MZA F 18 inv. č. 7615                                | Entirely        | Entirely      |                                                                                                                                                                                                     | [15]                  |
| 1807–1808              | FM                                        | MZA F 18 mapa 27–31                                  | Entirely        | c.2/3         |                                                                                                                                                                                                     | [16]                  |
| 1807–1808              | FMP                                       | MZA F 72 karton 1124–1125                            | Entirely        | c.2/3         | Species composition, woodland area, number of standards, age of stands                                                                                                                              | [17]                  |
| 1813                   | FS                                        | MZA F 18 inv. č. 7615                                | Entirely        | c.2/3         | Survey of woodland areas                                                                                                                                                                            | [18]                  |
| 1825–1826              | Stable Cadastre Maps                      | Archivnimapy.cuzk.cz                                 | Entirely        | Entirely      | Maps accompanying the taxation survey of the Czech Lands                                                                                                                                            | [19]                  |
| 1837–1838              | 2nd Military Mapping                      | Oldmaps.geolab.cz                                    | Entirely        | Entirely      | Mapping of the Czech, Moravian and Silezian parts of the Habsburg empire by the Army                                                                                                                | [20]                  |
| 1882                   | 3rd Military Mapping                      | Kontaminace.cenia.cz                                 | Entirely        | Entirely      | Mapping of the Czech, Moravian and Silezian parts of the Habsburg empire by the Army                                                                                                                | [21]                  |
| 1847                   | FM                                        | MZA F 72 mapa 27, 45                                 | Entirely        | Partly        | Age, species composition and area by individual stands                                                                                                                                              | [22]                  |
| 1861                   | FM                                        | MZA F 72 mapa 44                                     | Entirely        | None          |                                                                                                                                                                                                     | [23]                  |
| 1883                   | FM                                        | MZA F 72 mapa 22                                     | Entirely        | Partly        |                                                                                                                                                                                                     | [24]                  |
| 1885                   | FMP                                       | MZA F 72 karton 1127–1129                            | Entirely        | c.2/3         | Age, species composition and area by individual stands                                                                                                                                              | [25]                  |
| 1901                   | FM                                        | MZA F 72 mapa 25                                     | Entirely        |               |                                                                                                                                                                                                     | [26]                  |
| 1901                   | FMP                                       | MZA F 72 karton 1128–1129                            | Entirely        | c.2/3         |                                                                                                                                                                                                     | [27]                  |
| 1905                   | FMP                                       | MZA F 72 karton 1128–1129                            | Entirely        | c.2/3         | Age, species composition and area by individual stands                                                                                                                                              | [28]                  |
| 1921–1925              | FMP                                       | MZA F 72 kniha 113                                   | Entirely        | c.2/3         | Age, species composition and area by individual stands                                                                                                                                              | [29]                  |
| 1933–1936              | FMP                                       | MZA F 72 kniha 114–117                               | entirely        | c.2/3         | Age, species composition and area by individual stands                                                                                                                                              | [30]                  |
| 1938                   | AP                                        | MGHO                                                 | Entirely        | entirely      |                                                                                                                                                                                                     | [31]                  |



|      |     |                                                                                                                                          |          |          |      |
|------|-----|------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|------|
| 1947 | FM  | Kouřil M (1955) Reconstruction of forest development based on preserved archival material (in Czech). Diploma Thesis. Original map lost. | Entirely | none     | [32] |
| 1948 | FMP | MZA F 121 kniha 5–9                                                                                                                      | Entirely | Entirely | [33] |
| 1953 | AP  | MGHO                                                                                                                                     | Entirely | Entirely | [34] |
| 1971 | FM  | Forest Management Institute                                                                                                              | Entirely | Entirely | [35] |
| 1971 | FMP | MZA F 121 kniha 30–31                                                                                                                    | Entirely | Entirely | [36] |
| 1976 | AP  | MGHO                                                                                                                                     | Entirely | Entirely | [37] |
| 1990 | FM  | Forest Management Institute                                                                                                              | Entirely | Entirely | [38] |
| 1990 | AP  | MGHO                                                                                                                                     | Entirely | Entirely | [39] |
| 2006 | AP  | GEODIS Prague                                                                                                                            | Entirely | Entirely | [40] |
| 2010 | FM  | Forest Management Institute                                                                                                              | Entirely | Entirely | [41] |
| 2010 | FMP | Forest Management Institute                                                                                                              | Entirely | Entirely | [42] |

<sup>a</sup> Precise dating not available.

standards on ca. 1700 ha of woodland (i.e. 0.7 standards per hectare [8]). Many parcels were managed as simple coppices and had no standards at all. Coeval management instructions recorded pasturing and hay-cutting as well. Pasturing was forbidden in freshly cut coppice compartments for three years and hay cutting for four years (so that coppice shoots are not cut accidentally together with grass). Nonetheless, the main product of these forests was firewood. Firewood production was carefully monitored and documented from the late 17th century onwards. Yearly harvest data (Fig. 3) showed long-term temporal stability with considerable year-to-year variation (see also Fig. 4). Until the mid-19th century, on average ca. 1600 fathoms (Klafter) of coppice underwood (ca. 4 m<sup>3</sup> per hectare) were harvested yearly on the Mikulov estate. This amount increased suddenly to ca. 4000 fathoms (ca. 10.5 m<sup>3</sup> per hectare) in ca. 1850.

Whereas in the Middle Ages coppice firewood represented a significant source of income, later on the economic value of woodland products drastically fell (Fig. 5). As a result, some time in the 16th century the right to underwood in most of the woodland was leased to local peasants for a fixed yearly sum and only a limited number of woods remained in demesne (that is, in the direct management of the estate). The estate owners kept the right to standard trees in all forests, which probably led to a rise in their numbers. Already in the 17th century the practice of singling out coppice stools (cutting each shoot except for the strongest and straightest to grow pseudo high-forests) was recorded in management instructions. In 1807/8 [16] the study area was managed as coppice-with-standards with a maximum cycle of 35 years and a varying density of 1–49 standards per hectare (average 30).

To increase the income from forests, the first game preserve was established in Děvín Wood in 1885 (Fig. 1). Because of the resulting increased grazing pressure, the coppice cycle was extended up to 40 years in 1948 [33]. The length of the coppice cycle differed according to parcel position (longer on the drier southeastern slopes, Fig. 6). Forest management plans included clear instructions on the length of the coppice cycle and the area to be harvested each year, but in reality such plans were not followed too rigidly. In Děvín Wood, the annual sum of harvested area differed significantly year by year (Fig. 4). However, the average sums over longer time periods were close to the planned ideal.

After the study area became protected (1946 for Děvín Hill and 1976 for the whole area including Milovice Wood), a double structure in priorities was formed. While nature conservation bodies preferred non-intervention, foresters aimed to replace coppices with high-forests. Coppices were left to overgrow and were often transformed into high-forest by singling out or destroying the stools. In spite of the formally compulsory non-intervention management, 23% of Děvín and 13% of Milovice Wood was felled after protection had been enacted. In addition, game keeping continued in Děvín Wood until the 1990s, and the two game preserves established in Milovice Wood in the 1960s still exist, covering over 69% of forests in the Pálava PLA (Fig. 1). Management in game preserves is driven by game keeping, therefore in the 1960s and 1970s some woods were turned to pastures, and fructiferous trees, such as horse chestnut, were planted.

### 3.3. Coppice abandonment: patterns and consequences

While in the 19th century all forests were coppiced, in the 20th century this management gradually lost its importance. Most of the coppices were abandoned in the 1920s–1940s, but some compartments, especially in Děvín Wood, were left already at the end of the 19th century (Fig. 7a). Most of the compartments where coppicing was abandoned already in the 19th century were located on sites with low productivity and/or on the steep NW upper slopes of Děvín Hill. After WWII, coppicing was completely



Fig. 3. Firewood production on the Mikulov estate through two centuries. Every tenth year was sampled. Klafter (English fathom) is ca 3.4 m<sup>3</sup>.

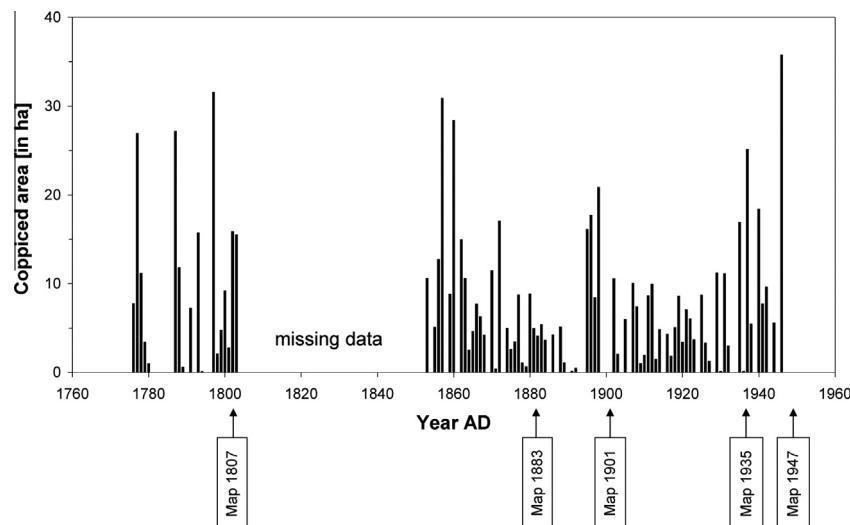


Fig. 4. Changes in coppiced area in time. Annual sum of harvest in DĚVÍN Wood (map sources of information is marked).

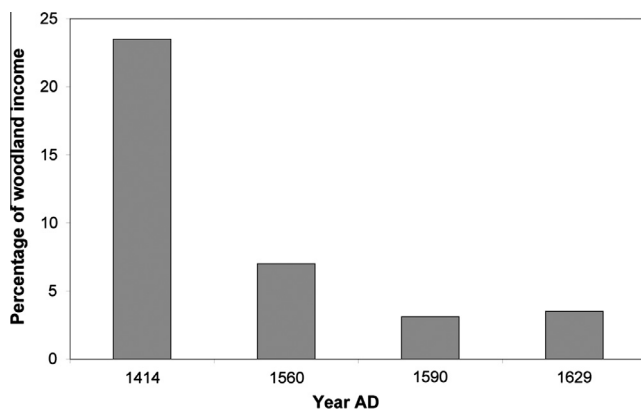


Fig. 5. Percentage of woodland-based income in the overall income of the Mikulov estate.

abandoned (Fig. 4). In 1947/8 [33] as much as 35% of DĚVÍN Wood was already labelled as high-forest. These stands were relatively young (on average 39 years old) and consisted of either broadleaved forests at unproductive sites, such as rocks, steep

slopes and sites under high grazing pressure, or black pine plantations. The rest was divided between coppice-with-standards (47%) and coppice (18%). The average age of standards in 1948 [33] was 64 years ranging from 45 to 90, and the density, calculated from a 1938 aerial photograph, was 10 standards per hectare.

The pattern of coppice abandonment was different in the two woods – whereas in DĚVÍN Wood poorly accessible, steep and rocky slopes were abandoned earlier compared to productive or better accessible sites, in rather uniform Milovice Wood such a relationship could not be demonstrated (Fig. 7b and c). In DĚVÍN Wood, the pattern was significantly related to solar radiation and slope in both uni- and multivariate models, and to the forest productivity expressed by the price of the forest property in multivariate models (Table 2). The other examined variables were insignificant. In Milovice Wood, none of the explanatory variables showed a significant relationship to coppice abandonment.

The extension of the coppice cycle and the final abandonment of intensive management caused substantial changes in forest age and structure. Young forest stages almost disappeared and the proportion of older stages grew (Fig. 8a). While in active coppices young stages on average constituted more than half of all forests (31% for 1–10 years and 22% for 11–20 years in 1807/8 [16]), after the abandonment of coppicing these values fell to 1% and 4%,



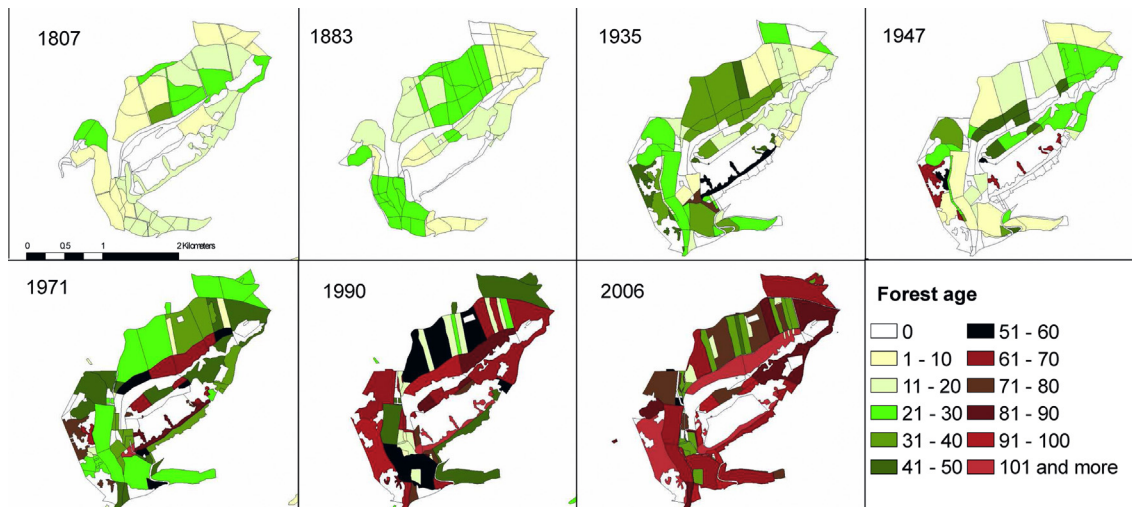


Fig. 6. Aging of Děvín Wood throughout 200 years.

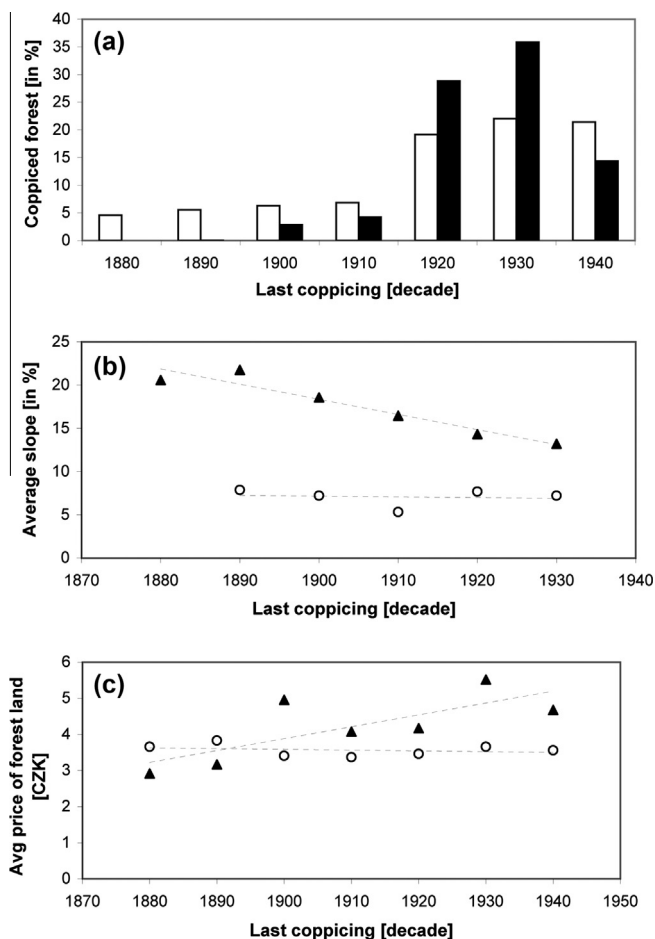


Fig. 7. Pattern of coppice abandonment. Differences between Děvín (empty symbols, circles) and Milovice Wood (filled symbols, triangles): (a) amount of abandoned coppice (percent of the total forest area), (b) relation of coppice abandonment to slope, and (c) to average price of forest land in 2008 based on estimated pedological-ecological units (Supplement No 22 to the Regulation 3/2008 Sb). Dashed lines show linear trend.

respectively. Older stands (over 40 years) were absent until 1883/5 [25] but constituted 15% in 1948 [33], 48% in 1971 [36], and 77% in 2006 [40]. Today, 26% of Děvín Wood is covered by forests older than 100 years, compared to 8% of such forests in Milovice Wood.

The original fast-changing mosaic of open and dense coppice stands has shifted towards the post-abandonment closed-canopy structure of old forests. Open habitats have drastically decreased. This tendency towards uniformity is indicated by a sharp decrease in the Shannon index of age diversity. Based on [Brown and Parker \(1994\)](#), stands over 50 years were interpreted as closed-canopy forest and were therefore merged into one class ([Fig. 8b](#)).

#### 4. Discussion

##### 4.1. Forest cover

Forest cover in the study area was stable throughout the centuries and only small changes occurred. Dynamic processes in usage and access, such as abandoning direct management and leasing out the majority of forests to tenants in the 16th century, did not lead to loss of woodland. Generally speaking, the stability of woodland cover in the study area is similar to other long-settled and little wooded lowland regions in Europe ([Rackham, 2003](#); [Tack et al., 1993](#); [Bürgi, 1999](#)). In such regions, woodland has been valued as a limited resource since the Middle Ages. The Mikulov estate (which included the study area) was ca. 21% wooded. This apparently represented a 'minimum' value in the region, over which the benefits of further woodland clearance in feeding the steadily growing population could not compensate for the loss in firewood supply ([Szabó and Hédli, 2013](#)). A similar minimum percentage of woodland cover was observed to have repeatedly occurred over several centuries in neighbouring Hungary as well ([Szabó, 2008](#)).

##### 4.2. Forest management

Forest management in the region was stable from at least the 14th century until WWII, even though forests experienced shifts in structure and dynamics as the coppice cycle was extended and the density of standards changed ([Szabó, 2010a](#); [Altman et al., 2013](#)). An important difference between changes in the coppice cycle and in the density of standards is that the former was regular (the cycle gradually became longer) while the latter was irregular (the number of standards showed no clear trend over longer periods and could drastically change following major harvests). Nonetheless, in the coppice system underwood was always the major product, and standards were allowed to grow only to the extent so as not to compromise coppice regrowth ([Matthews, 1989](#)). Underwood harvest was planned and regular, while

**Table 2**

The coppice abandonment as a function of environmental variables in both Děvín (37 parcels) and Milovice Wood (69 parcels). Significance was tested in generalized linear models of univariate and multivariate type using software R version 2.14.2 (R Development Core Team, 2012). The best fitted model was determined by the lowest Akaike Information Criterion value. Univariate models are shown only for significant explanatory variables.

| All variable model                   |           | AIC: 556.19 |         |           |
|--------------------------------------|-----------|-------------|---------|-----------|
|                                      | Estimate  | Std. Error  | t value | Pr(> t )  |
| <i>Milovice Wood</i>                 |           |             |         |           |
| (Intercept)                          | 1.92E+03  | 2.49E+01    | 77.164  | <2e–16*** |
| Solar radiation                      | –3.43E+00 | 6.07E+00    | –0.565  | 0.574     |
| Wetness Index                        | 7.55E–01  | 1.32E+00    | 0.573   | 0.569     |
| Slope                                | –9.62E–01 | 7.37E–01    | –1.305  | 0.197     |
| Price                                | –2.51E–01 | 1.76E+00    | –0.143  | 0.887     |
| Forest bonity                        | 2.88E+00  | 3.32E+00    | 0.869   | 0.388     |
| Road distance                        | 2.42E–02  | 3.12E–02    | 0.775   | 0.442     |
| Distance from the village            | 2.14E–03  | 3.47E–03    | 0.617   | 0.54      |
| Univariate model for solar radiation |           | AIC: 322.59 |         |           |
|                                      | Estimate  | Std. Error  | t value | Pr(> t )  |
| <i>Děvín Wood</i>                    |           |             |         |           |
| (Intercept)                          | 1945.87   | 11.1        | 175.333 | <2e–16*** |
| Solar radiation                      | –11.17    | 3.9         | –2.865  | 0.00701** |
| Univariate model for slope           |           | AIC: 324.38 |         |           |
|                                      | Estimate  | Std. Error  | t value | Pr(> t )  |
| (Intercept)                          | 1933.0604 | 7.7957      | 247.964 | <2e–16*** |
| Slope                                | –1.1516   | 0.4638      | –2.483  | 0.018*    |
| All variable model                   |           | AIC: 312.31 |         |           |
|                                      | Estimate  | Std. Error  | t value | Pr(> t )  |
| (Intercept)                          | 2.03E+03  | 3.64E+01    | 55.615  | <2e–16*** |
| Slope                                | –1.27E+00 | 3.82E–01    | –3.32   | 0.00244** |
| Solar radiation                      | –1.04E+01 | 3.75E+00    | –2.786  | 0.00932** |
| Wetness Index                        | –5.39E+00 | 3.20E+00    | –1.685  | 0.10268   |
| Price                                | –4.50E+00 | 1.93E+00    | –2.333  | 0.02681*  |
| Forest productivity                  | 1.28E+00  | 3.69E+00    | 0.346   | 0.73161   |
| Road distance                        | 7.60E–03  | 4.76E–02    | 0.16    | 0.87422   |
| Distance from the village            | –4.05E–03 | 8.05E–03    | –0.503  | 0.61878   |
| Best fitted model                    |           | AIC: 303.87 |         |           |
|                                      | Estimate  | Std. Error  | t value | Pr(> t )  |
| (Intercept)                          | 2070.0942 | 29.448      | 70.297  | <2e–16*** |
| Slope                                | –3.3557   | 1.061       | –3.163  | 0.00349** |
| Solar radiation                      | –27.2469  | 8.2822      | –3.29   | 0.00250** |
| Wetness Index                        | –5.5016   | 2.7455      | –2.004  | 0.05389.  |
| Price                                | –4.8842   | 1.4008      | –3.487  | 0.00149** |
| Slope:Solar radiation                | 0.7961    | 0.3767      | 2.113   | 0.04272*  |

Signif. codes are 0''''', 0.001''', 0.01'', 0.05', 0.1'.

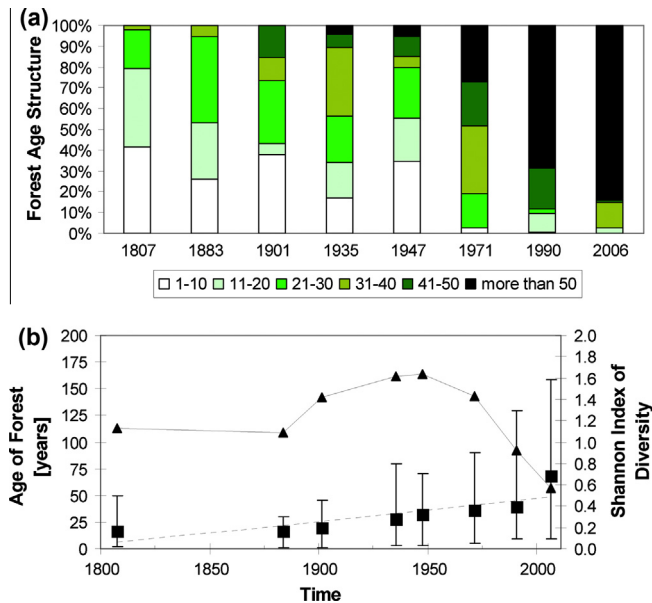
standards were cut occasionally, controlled by local building activities. Therefore the irregularly changing number of standards in the study area was part of the system, and the only real change was the extension of the coppice cycle from the medieval 7 years to several decades in the 19th–20th centuries. This trend was not particular to the study area, in fact it was observed throughout Europe (e.g. Rackham, 2003). Why this happened is presently unknown, reasons might include for example the appearance of chimneys and fireplaces, the declining fertility of forest soils or the growing costs of labour. Another change is visible in Fig. 3. This did not concern the form of management, rather its intensity. Providing that the sudden increase in firewood production reflects a real change (and not for example a change in the volume of the local fathom), it can be arguably connected to the introduction of scientific forestry on the Mikulov estate. It may have resulted from better planning or from increased harvests as part of the effort to transform coppices into high-forests.

The reasons behind stability in woodland management varied over time. Coppice firewood, a major source of income for the estate in the Middle Ages, lost its economic importance in the Early Modern Period, but local society still depended on it (Szabó, 2010a). At the end of the 19th century fossil fuels became

available, and high-forests started to replace coppices. Nonetheless, until WWII coppicing was active in most of the study area except unproductive sites on shallow rocky soils and steep slopes that were difficult to harvest.

#### 4.3. Coppice abandonment

The extension of the coppice cycle and the abandonment of coppicing after WWII had a strong impact on forest characteristics. While the fact that many coppices were abandoned in Europe in this period is well-known (e.g. Bürgi and Russell, 2001; Gondard et al., 2001; Tack et al., 1993; Peterken, 1993; Molnár, 1998), practically no information exists to describe the process of abandonment. A particularly intriguing aspect is the spatial pattern of coppice abandonment and the driving forces behind this pattern. Modern forestry in general can be characterized as a highly planned and organized activity (Matthews, 1989; Puettmann et al., 2009; Lowood, 1990). From the late 19th century onwards, it tried to enforce rigorous wood harvesting regimes, which were unusual in earlier times. By contrast, our results suggest that coppice abandonment in the mid-20th century was an unregulated process. Any discernable spatial pattern was observed only in



**Fig. 8.** Coppicing abandonment caused changes in forest structure. Increase in average forest age (a) and sharp decrease in age diversity of forest patches (b) expressed by Shannon Index of diversity (triangle; the same age categories as for the Figure A, i.e. stands over 50 years are considered as one class). Average age of forest (square) is shown together with age minimum and maximum, and the linear regression line. Results are from the Děvín Wood where data on forest age were more abundant.

Děvín Wood, where we found a significant relationship between the time of coppice abandonment and slope and solar radiation, and a less obvious relationship between time of abandonment and forest productivity. In Milovice Wood, no factors we studied were significantly related to the time of abandonment. This could be explained by differences in environmental conditions. The gradient of elevation and site productivity in Milovice Wood is less pronounced than in Děvín Wood. The latter is steeper, 64% of the area has slopes over 12° compared to only 16% in Milovice Wood. This means that first those coppice compartments were abandoned that were steep, in simple terms those places where it was difficult to harvest. Soil fertility was far less important. If no such places existed (as in Milovice Wood), no pattern could be detected. The length of the abandonment period could also differ. Poorly accessible places in Děvín Wood began to be neglected already in the 19th century, but most of Milovice Wood was abandoned during a relatively short interval (1920s–1940s).

We conclude that there was little planning in coppice abandonment, coppices were in fact left behind in an unregulated manner. Not even income mattered: in Milovice Wood, productive sites were just as likely to be abandoned as infertile ones. It is especially remarkable from this perspective that the remoteness of compartments from roads did not affect their time of abandonment. If the slightest effort had been made to abandon coppices in an organized manner, surely the compartments closest to roads (and therefore harvestable in the most cost-effective manner) would have been abandoned last. The only pattern detected in coppice abandonment indicates that the process was not driven by economic factors (as in the principles of coeval forestry) but rather by down-to-earth considerations to avoid difficult working conditions. The decisions about where not to coppice are likely to have been brought by local foresters rather than the central planning office in Mikulov. In this sense, coppice abandonment was not entirely random but at the same time, when compared to forestry standards, it was not planned, either.

## 5. Conclusions and implications for conservation

Pálava is an ancient landscape that has been co-formed by humans for millennia. The forests in the Pálava PLA demonstrated a high degree of stability for centuries. Both woodland cover and management appear to have changed very little from the Middle Ages to the 20th century. Coppice management was abandoned shortly after WWII, which completely altered the age structure of the forests from young to old, a pattern never experienced in the known history of the Pálava forests. This and the isolation of the remaining few patches of young forest stages have led to drastic changes in vascular plants species composition, which indicate the replacement of thermophilous oakwoods by mesic forests (Hédl et al., 2010; Kopecký et al., 2013). Nonetheless, signs of previous coppice management, such as coppice stools and standards are still recognizable in most of Děvín Wood and in some parts of Milovice Wood. Although the history of the two forests is almost identical, the existence of the game preserves in Milovice Wood creates a situation rather different from strictly protected Děvín Wood. The re-introduction of coppicing would be pointless in the heavily grazed parts of Milovice Wood, but at the same time artificially high numbers of ungulates appear to have held up succession, so that some changes may be more reversible here than in Děvín Wood (Hédl et al., 2010).

Generally speaking, forests in the study area can be viewed as typical for densely settled European lowland regions north of the Alps. In such regions, woodland is often the most conservative landscape element both in extent and management. Similarly to our study region, most European coppice woods were abandoned in the 20th century. A so far unknown element in the abandonment of coppices is the spatial pattern the process followed. In our study region, abandonment appears to have been unregulated. As a result, the current spatial pattern of forest age structure can only be connected to topographic conditions. Based on the general similarities among lowland regions described above, we hypothesize that coppice abandonment was a similarly irregular process in other areas as well.

The haphazard fashion in which coppices were abandoned could have far-reaching consequences for their protection and restoration as well. For example, predicting the distribution patterns for rare and endangered plant species should be approached with caution. Under traditional management, young forest stages dominated in coppices and provided excellent opportunities for the occurrence of light-demanding species (Beneš et al., 2006; Spitzer et al., 2008; Van Calster et al., 2008a; Vodka and Čížek, 2013). However, the precise distribution of species was determined by many other factors, which makes the distribution to a certain extent unpredictable. If, for example, the effect of ungulate grazing produced a spatially heterogeneous pattern (Adler et al., 2001), plant species sensitive to such a disturbance could have been structured following grazing intensity rather than historically relatively homogeneous coppice management. If accidentally heavily grazed parts had been abandoned last, the entire wood would be evaluated as poorer in such species than if an ungrazed part had been managed longest.

Attempts to reintroduce coppice management for conservation purposes should take into account the pattern of abandonment. At present, three models exist for coppice reintroduction. (i) If the entire forest is to be coppiced, it is divided into compartments that are successively cut. This is in fact a complete imitation of the traditional system (e.g. Hauberg Fellinghausen, Germany – Fasel, 2007) (ii) If only part of the forest is planned for coppicing, this may be done in a regular geometric fashion starting from some point (e.g. Hayley Wood, England – Rackham, 1975) or (iii) in a scattered manner in which individual plots are not adjacent to

each other, as it has been done for example on the northern slopes of Děvín Wood for the past few years. Especially in the third case, current age structure can be a strong determining factor. In Děvín Wood, 21.6 ha of overgrown coppices were harvested in 2009–2014, and further thinning is planned to reduce the density of shoots by 60% (V. Riedl, personal communication). Such decisions usually result from a combination of various conservation targets (Fuller and Warren, 1993). A deeper understanding of current age structure through the study of abandonment patterns has the potential to foster more informed decisions with regard to the spatial plan of management reintroduction and can lead to more successful restoration efforts.

The exceptional ecological value of woodlands in the Pálava PLA is partly due to human influence. Traditional management, such as coppicing, has been abandoned due to socio-economic changes as well as to previous concepts of nature protection. In the past, nature protection was defined as the protection of nature with an emphasis on avoiding human influence, now usually termed protection of processes, or non-intervention. The Pálava PLA is a perfect example of the importance of humans in maintaining ecosystem biodiversity.

## Acknowledgements

We thank our colleagues Zdeňka Konopová for technical assistance and Vladan Riedl for useful comments. The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007–2013) – ERC Grant agreement no 278065, long-term research development project no. RVO 67985939, and CZ.1.07/2.3.00/20.0267 of the Ministry of Education of the Czech Republic.

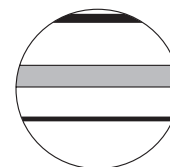
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# Continuity and change in the vegetation of a Central European oakwood

The Holocene  
23(1) 46–56  
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sagepub.co.uk/journalsPermissions.nav  
DOI: 10.1177/0959683612450200  
hol.sagepub.com  


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## Abstract

The issue of continuity in deciduous oakwood vegetation has been in the forefront of woodland ecological studies for many decades. The two basic questions that emerge from existing research are whether or not oakwoods can be characterized by long-term stability and what may be the driving forces of the observed stability or change. To answer these questions in a well-defined case study, we examined the history of a large subcontinental oakwood (Dúbrava) in the southeastern Czech Republic with interdisciplinary methods using palaeoecological and archival sources. Palaeoecology allowed us to reconstruct the vegetation composition and fire disturbances in Dúbrava in the past 2000 years, while written sources provided information about tree composition and management from the 14th century onwards. The pollen profiles show that the present oakwood was established in the mid-14th century with an abrupt change from shrubby, hazel-dominated vegetation to oak forest. This change was most probably caused by a ban on oak felling in AD 1350. From the 14th to the late 18th centuries Dúbrava had multiple uses, of which wood-pasture and hay-cutting kept the forest considerably open. The second remarkable change was dated to the late 18th century, when multiple-use management was abandoned and Dúbrava was divided into pasture-only and coppice-only parts. The last major shift occurred in the mid-19th century, when modern forestry and Scotch pine plantation became dominant. We conclude that Dúbrava Wood did not show stability in the long run and that its species composition has dramatically changed during the last two millennia. The most important driving force in the shaping and maintenance of the unique vegetation of Dúbrava was human management.

## Keywords

ecosystem stability, historical ecology, management history, palynology, *Quercus*, temperate oakwood, written sources

Received 1 December 2011; manuscript accepted revised 30 April 2012

## Introduction

Deciduous oakwoods have been on the decline for a century all over Europe, because oaks fail to regenerate. This phenomenon is often referred to as ‘Oak Change’ or ‘Oak Decline’ (Rackham, 2008; Watt, 1919). Available studies attribute it to various plant diseases (e.g. *Microspphaera alphitoides*, *Phytophthora* species), decline in human management or a combination of various factors (Jung et al., 2000; Luisi et al., 1993). Nonetheless, the term ‘oakwood’ denotes more than the dominance of oak species in the tree layer – deciduous oakwoods are specific biotic assemblages with many species more or less confined to this type of biotope (Ellenberg, 1996; Konvička et al., 2004).

The issue of continuity in deciduous oakwood vegetation has been in the forefront of woodland ecological studies for many decades. The two basic questions that emerge from existing research are whether or not oakwoods can be characterized by long-term stability and what may be the driving forces of the observed stability or change. Some scientists argued that deciduous oakwoods are the natural vegetation of the relatively warm and dry areas of Europe (Bohn and Neuhäusl, 2000; Ellenberg, 1996; Zólyomi, 1957), and are therefore stable communities occupying a restricted range of ecological conditions for several millennia. Others claimed that human management (burning, pasturing, litter raking and coppicing) rather than natural conditions played a decisive role in the maintenance of European deciduous oakwoods. This view is supported by the recent notable decline of oakwood species assemblages and the ‘invasion’ of hornbeam, maples, ash and lime following the abandonment of traditional

management (Hédli et al., 2010; Kwiatkowska et al., 1997; Roleček, 2007). This opinion connects the stability of oakwoods to continuity of management on a millennial case, which implies fluctuations in vegetation with changes in human population densities around particular oak forests.

While the question of stability versus change can be approached using a single disciplinary perspective (such as palynology, Huntley and Webb, 1988; Segerström, 1997; Ritchie, 1995), the study of driving forces requires a multiproxy approach (Bürgi et al., 2004; Ireland et al., 2011; Pechony and Shindell, 2010). The comparison of natural scientific data with historical written sources is particularly useful in this respect, since historical sources can provide a framework of interpretation for palaeoecological data (Lindbladh et al., 2007; Veski et al., 2005). Archival data have been successfully used to detect driving forces of vegetation stability and change (Bürgi, 1999; Szabó, 2010b).

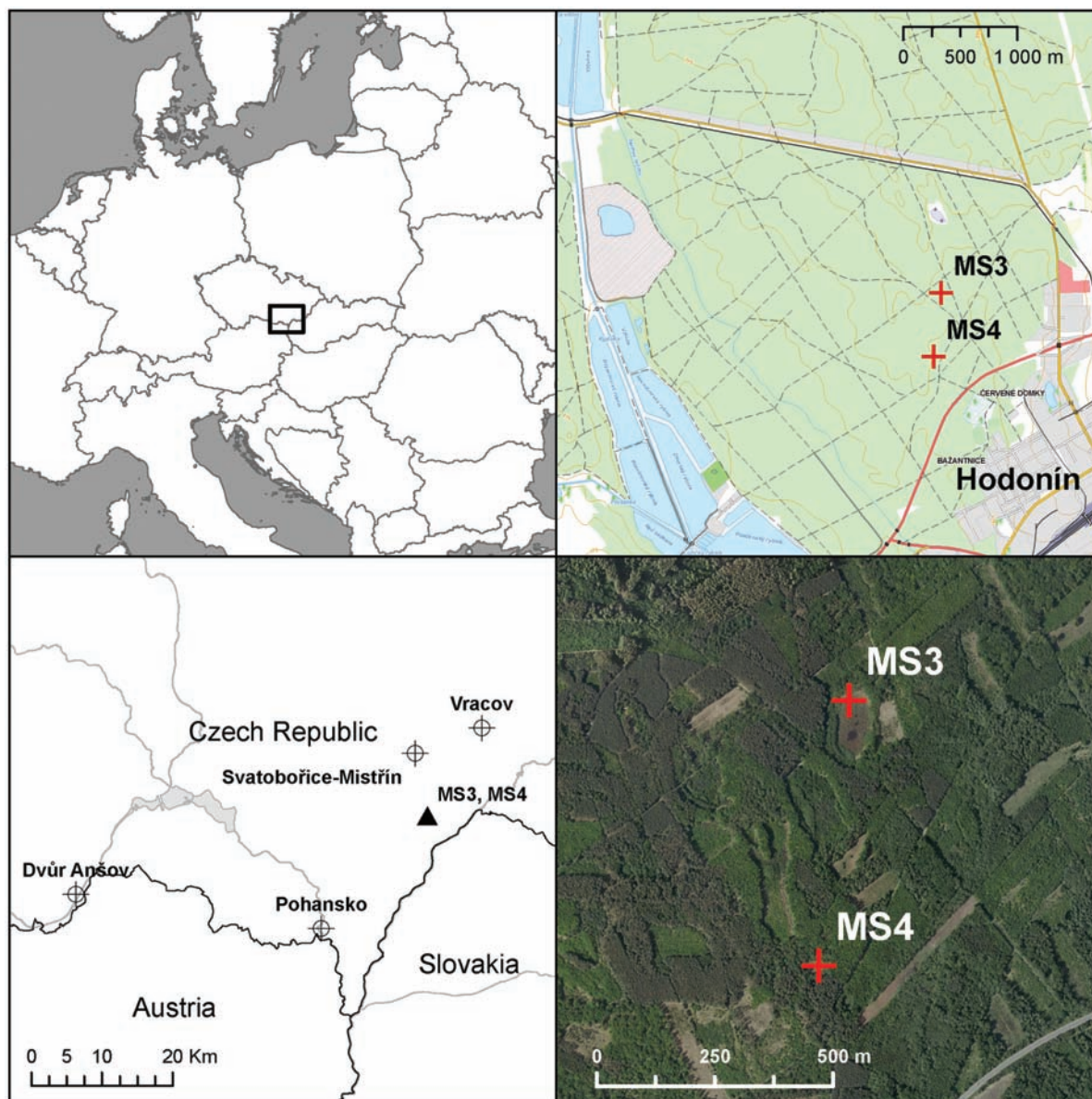
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**Figure 1.** Location of Dúbrava Wood in the Czech Republic with the positions of previously published pollen profiles in the study area.

In this paper we present the results of interdisciplinary research on the long-term dynamics of a large lowland oakwood. This wood is among the best preserved subcontinental deciduous oakwoods in Central Europe (Roleček, 2007). Our study covers the past two millennia, and we integrate (1) pollen and macrocharcoal data from two small forest hollows, and (2) archival written documents on species composition and management at the site. We aim to answer the following two questions:

- (1) Is the oakwood at the study site characterized by long-term stability in species composition or were there significant changes during the past two millennia?
- (2) What were the driving forces of stability or change? Was the role of natural factors or human management apparently more important?

## Materials and methods

### Study site

Hodonínská Dúbrava is a large (c. 3300 ha) and relatively well-preserved ancient woodland (Figure 1). It is the core site of a specific type of subcontinental oakwoods, *Carici fritschii-Quercetum*

*roboris* (Chytrý, 1997; Roleček, 2007) – a community endemic to this and a few adjacent sites. Because of low groundwater levels, other vegetation types, such as alluvial forests (*Alnion incanae*) and alder carrs (*Alnion glutinosae*) also occur. At higher and drier elevations mesic oak-hornbeam woods (*Carpinion*) prevail. Approximately half of the forest was turned into Scotch pine plantations in the 19th and 20th centuries.

Dúbrava is located at the NW edge of the Pannonian Basin (17°05'00''E, 48°52'40''N; Figure 1). Climate is 'humid continental' (cf. Peel et al., 2007). It is relatively warm and dry with c. 9°C of average annual temperature and 500–550 mm of precipitation (Tolasz et al., 2007). The site is gently sloping towards the SW, with elevations from 164 to 242 m. Dúbrava lies on the fringe of the wide alluvium of the Morava river, on 150–200 cm deep Quaternary blown sand deposits (Novák and Pelíšek, 1943). Soils are extremely nutrient-poor arenic dystic cambisols (AOPK CR 2002–2010), slightly acidic and prone to desiccation (Novák and Pelíšek, 1943). The water-table fluctuates during the year. The settlement history of the area is typical of Central European lowlands. People have been living in the region since the Palaeolithic with population peaks in the early Copper (4000–3400 BC), late Bronze (1200–750 BC) and late Iron Ages (400–1 BC)

**Table 1.** Calibration of radiocarbon dates of the MS3 and MS4 profiles.

| Depth (cm) | Lab. code | Sample ID | Dated material  | <sup>14</sup> C age (BP) | Calibrated <sup>14</sup> C age |              |
|------------|-----------|-----------|-----------------|--------------------------|--------------------------------|--------------|
|            |           |           |                 |                          | Mean                           | Range        |
| 40–38      | UG-7745   | MS3,1     | Charcoal        | 2000 ± 25                | AD 6                           | 47 BC–AD 60  |
| 34–32      | UG-7744   | MS3,2     | Carex seeds     | 610 ± 25                 | AD 1349                        | AD 1297–1401 |
| 14–12      | UG-7743   | MS3,3     | Carex seeds     | 170 ± 20                 | AD 1808                        | AD 1665–1950 |
| 44–42      | UG-8518   | MS4       | Charcoal        | 6420 ± 25                | 5413 BC                        | 5472–5341 BC |
| 35–33      | UG-747    | MS4,2     | Seeds, charcoal | 560 ± 25                 | AD 1368                        | AD 1313–1424 |
| 17–15      | UG-7746   | MS4,3     | Carex seeds     | 120 ± 25                 | AD 1809                        | AD 1681–1937 |

AD: Anno Domini; BC: Before Christ; BP: Before Present (1950).

(Měřínský and Šmerda, 2008a). Dúbrava Wood historically belonged to the estate of Hodonín.

### Palaeoecological analyses

The SW part of Dúbrava with numerous spring-submerged depressions was surveyed in 2008. Guidance by R. Řepka helped us locate 15 sites. We chose the six best-preserved sites for coring using a Russian corer in 2008. All profiles were re-sampled for pollen analysis in July 2009, mostly taken from a trench using 10 cm × 10 cm × 50 cm metal boxes. All profiles were analysed for pollen at 5 cm resolution. Following the results of this preliminary analysis and radiocarbon dating (Table 1), we chose two pollen profiles denoted MS3 and MS4. The two sites represent treeless wetlands of c. 50–100 m in diameter. Vegetation is dominated by reed (*Phragmites communis*) at MS3 and by sedges (*Carex* spp.) at MS4. The nearest vicinity of both wetlands is forest of *Quercus petraea*, *Quercus robur* and *Pinus sylvestris*.

Organic sediments from MS3 and MS4 stored in metal boxes were subsampled by 1 cm. The preparation of samples for pollen analysis followed standard techniques (Faegri and Iversen, 1989). Samples containing mineral material were pre-treated with cold concentrated HF for 24 h and then processed by KOH and acetolysis. At least 500 pollen grains were identified using standard key and photo collections (Beug, 2004; Reille, 1992, 1995, 1998); for the determination of non-pollen palynomorphs we used van Geel et al. (1980/1981). The nomenclature of pollen types follows Beug (2004).

Macrocharcoal analysis was carried out on the same sections as the pollen analyses. Sediments were sampled continuously at 1 cm increments using a calibrated sampler of 2 ml volume. The macrocharcoal analysis of MS3 took place after the removal of parts of the sediment for radiocarbon dating, therefore charcoal data from some parts are missing. Extracted material was deflocculated with 10% KOH and subsequently non-charred organic particles were bleached by 3% hydrogen peroxide (Schlachter and Horn, 2010). Particles larger than 125 µm were separated from the samples by wet sieving. Quantification of charred particles was performed using optical analysis of microphotographs processed by ImageJ software (Rasband, 1997). Charcoal fragments were identified according to their black colour and characteristic shape (Enache and Cumming, 2006).

Pollen data are presented as percentages based on terrestrial pollen sum, from which aquatics and local mire plants, pteridophyta, algae, fungi and other non-pollen palynomorphs were excluded. Charcoal concentration is expressed as the number of pieces per 2 ml. Percentage pollen diagrams with macrocharcoal histograms were created in Tilia v. 1.7.16 (Grimm, 2011). The pollen profiles were divided into three (MS3) or four (MS4) pollen zones based on the results of ConsLink and visual analyses. For a comparison of archival and pollen data, it is necessary to understand the relevant source area of pollen (RSAP) (Sugita,

1994). In the case of small basins situated within forests Sugita (1994) estimated the RSAP to be 50–100 m and about 40–50% of pollen coming from trees growing within this radius, while the rest (background pollen) originating from outside the RSAP. Calcote (1995) confirmed this estimation by empirical research of fossil pollen in forest hollows.

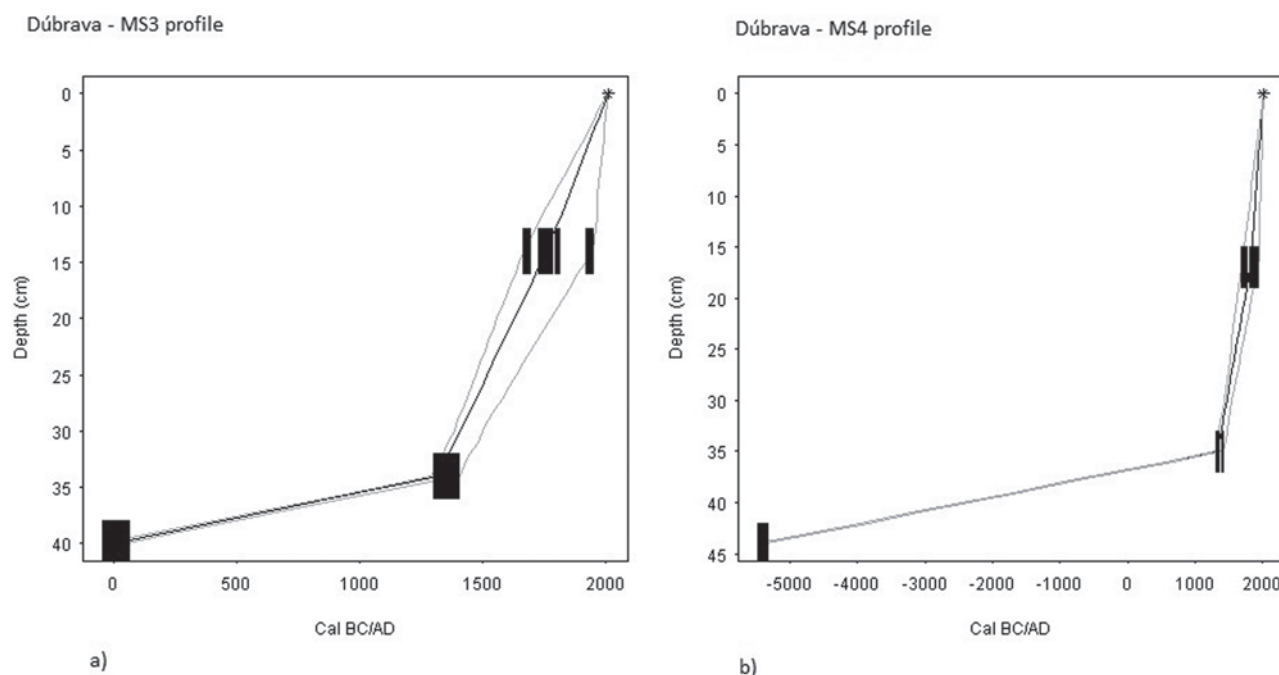
Selected plant macrofossils or charcoal taken from three depths in each profile were used for AMS radiocarbon dating in the Center for Applied Isotopes Studies, University of Georgia, Athens GA, USA. An age–depth relationship model was constructed for both profiles using Clam v.1.0 R code (Blaauw, 2010; R development Core Team, 2008). IntCal04 calibration curve (Reimer et al., 2004) was used to calibrate radiocarbon dates. To estimate the age of every pollen sample, linear interpolation between the midpoints of calibrated dated levels was applied (Table 1). The age–depth model was forced to go through 0 cm = 2009 BC/AD (BC ages are negative) (Figure 2). In this paper we use calibrated years. The radiocarbon date of the organic sediment from the base of the MS4 profile (5413 BC obtained from charcoal) gave a result apparently too old when compared with the MS3 profile, and was not used. This date may have resulted from the sandy base allowing the vertical migration of plant macroremains and charcoal. However, the date could possibly be correct, which would refer to slow accumulation of organic material. Nonetheless, the continuous presence of *Juglans*, which is known to be a Roman import in the region (Hajnalová, 2001), in both profiles appears to indicate that the base of MS4 is unlikely to be older than the Roman Period.

### Archival research

To find out about the history of management and vegetation in Dúbrava, we studied the written records produced by the Hodonín estate administration from the 14th to the 20th centuries. All sources are presently kept at the Moravian Archives (MZA) in Brno. Written sources are precisely dated, which allowed us to establish a firm chronology of management changes. When compared with data on management, for most of the study period information on vegetation was patchy and rather vague. However, for the last two centuries precise data are available on tree species composition. The following kinds of sources were used:

- (1) *Charters* are records of legal transactions. The first charters dealing directly with Dúbrava are from the mid-14th century, while the last ones are from the 18th century.
- (2) *Urbaria* are conscriptions of all incomes from an estate. Four *urbaria* survive that provide relevant information about the Hodonín estate. They date from 1600 (MZA F5 kniha 1a, analyzed in Chocholáč, 1994), c. 1654 (incomplete: MZA F5 kniha 1), 1691 (MZA F5 kniha 3) and 1805 (MZA F5 kniha 4).





**Figure 2.** Age–depth relationship of (a) MS 3 and (b) MS4 profiles based on three radiocarbon dates for each profile. Cal.: calibrated ages; AD: Anno Domini (after Christ); BC: Before Christ.

- (3) *Estate conscriptions* describe the value of landed property in a given historical moment. A detailed conscription survives from 1692 (MZA F5 kniha 5).
- (4) *Account books* were kept by woodland owners to register incomes generated by the cutting and selling of underwood and timber. For Dúbrava only a few remain, covering the years 1765–1772 (MZA F5 karta 538).
- (5) *Forestry management plans* (FMP) are detailed surveys containing information on the name, size and position of each woodlot, as well as on tree composition and forest structure, supplemented by current and planned management. FMPs of Dúbrava are from 1851 (MZA F5 kniha 232), 1864 (MZA F5 kniha 233–236, 238, 240) 1906 (MZA F5 kniha 242, 244, 245), 1925 (MZA F263 kniha 1), 1936 (MZA F263 kniha 4, 5) and 1952 (MZA F302 kniha 4).
- (6) *Forestry documents* were produced by the local forestry administration. Such documents include e.g. various surveys of woodland areas, discussion on types of management and detailed diaries of yearly activities.
- (7) *Large-scale maps* (c. 1: 30,000 and larger) are generally available in the Czech Lands from the 18th century onwards. We used three nationwide surveys prepared by the Austrian Army in 1764–1783, 1836–1852 (both 1: 28,800) and 1876–1880 (1: 25,000), available online at <http://oldmaps.geolab.cz>. A much more detailed (1: 2880) set of maps were drawn in 1824–1843 as part of the so-called Stable Cadastre (Bičík et al., 2001). Finally, maps produced as parts of forestry management plans were used. Three sets of maps survive from Hodonín: 1851 (MZA F5 mapa 54–59), 1884 (MZA F5 mapa 60–64, note that the FMP itself is lost) and 1906 (MZA F5 mapa 65–70).

## Results

### Pollen stratigraphy and vegetation history

Based on changes in dominant taxa (Table 2), the pollen diagrams were divided into three (MS3) or four (MS4) phases. The first three phases are highly similar in both profiles, while the fourth

one, covering the second half of the 20th century, is visible only in MS4 (Figures 3 and 4). Historical documents show corresponding results; major management changes happened approximately in the transition periods between the pollen zones. Because of the high similarity between the pollen spectra and historical sources, the results are presented jointly.

**Roman period to the high Middle Ages (1st century AD–mid-14th century AD) – Phase 1.** At the beginning of the sedimentation process dated to the 1st century AD, Dúbrava consisted mainly of light-demanding woody species, such as *Corylus* (19%) and *Betula* (17%). The relatively low proportion of tree pollen and of *Juniperus* (3%) also suggests open forest vegetation. A high amount of pollen of coniferous trees, such as *Picea* (18%) and *Abies* (6%) was also recorded. *Corylus* produces little pollen as an understorey species (Rackham, 1988). The observed high amount of *Corylus* in the profile suggests that it had a dominant position in the vegetation (Gardner, 2002), and that its pollen spread was hardly hindered by overstorey vegetation. This and the presence of *Juniperus* allow us to interpret the vegetation in the nearest vicinity of the study site as shrubby woodland. Such vegetation is implied in the original, high medieval name of Dúbrava, which was Klečka. This name was first recorded in a charter interpolation from AD 1350 (Boček, 1839: 204–205). In Old Czech, ‘klečka’ refers to a place with shrubs (Gebauer, 1970). The basal layers of both profiles contained low amounts of macroscopic charcoal particles. These provided no evidence for local fire events which could have been connected to the shrubby vegetation dominated by *Corylus* (cf. Tinner et al., 2005).

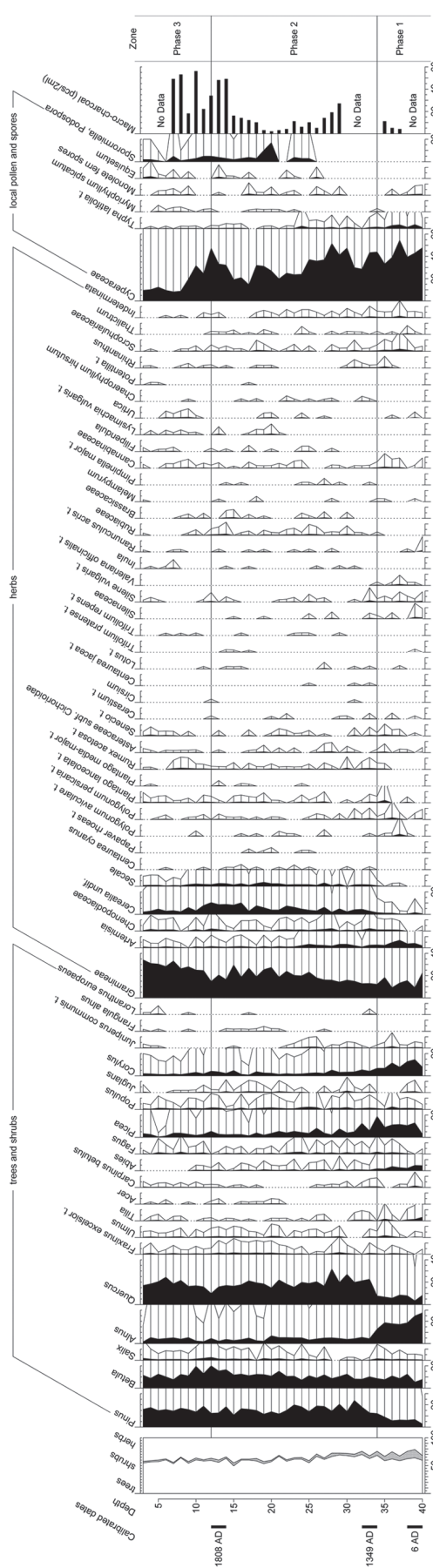
The composition of herbaceous pollen in Phase 1 indicates the presence of an intensively managed landscape. The high amount of *Artemisia*, *Asteraceae*, *Silenaceae*, *Rubiaceae* and *Valeriana officinalis*-type implies meadows. The constant occurrence of *Cerealia* indicates the presence of arable fields in the nearest vicinity of the site. Ruderal plants such as *Polygonum aviculare*-type and *Polygonum persicaria*-type indicate trampled habitats and cultivated land (Behre, 1981; Gaillard, 2007). At the end of Phase 1, the pollen of *Plantago lanceolata*-type, *Rumex acetosa*-type and *Melampyrum* appeared. These could be connected with grazed grasslands.

**Table 2.** Characteristics of main phases based on changes in pollen taxa and historical events.

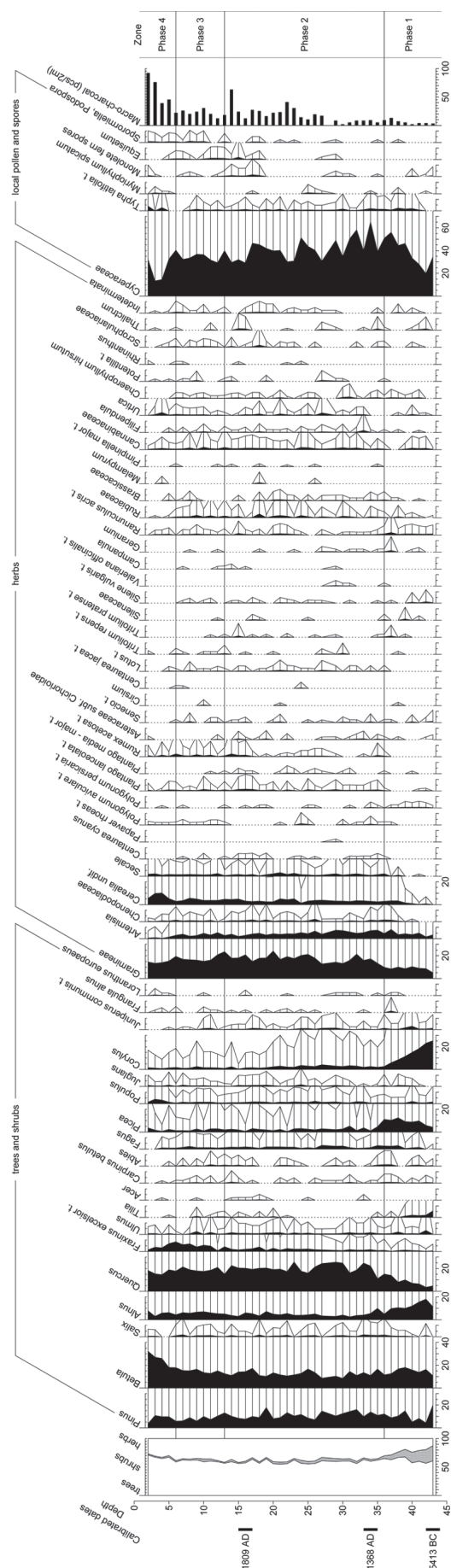
| Cal. AD | MS3         |                                                                                                                                                                                          | MS4                                                                                                                                                                                                                                |                                                             | Written sources                                                                                                                                                                                                                     |
|---------|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|         | Max. %      | Min. %                                                                                                                                                                                   | Max. %                                                                                                                                                                                                                             | Min. %                                                      |                                                                                                                                                                                                                                     |
| Phase 4 | n/a         | n/a                                                                                                                                                                                      | Betula, Populus<br>Cerealia,<br>Zea mays,<br>Typha latifolia t.<br>Fraxinus                                                                                                                                                        | Artemisia<br>Chenopodiaceae<br>Cyperaceae<br><b>Corylus</b> | Dominance of high forests, afforestation of open areas, abandonment of drainage canals                                                                                                                                              |
| Phase 3 | 1941        | Loranthus europaeus<br>Poaceae, Equisetum                                                                                                                                                | <b>Corylus</b> Picea<br>Artemisia, Asteraceae,<br>Scrophulariaceae, Rubiaceae,<br>Cyperaceae, Typha latifolia t.<br>Tilia, Alnus                                                                                                   | Rubiaceae                                                   | Strict coppicing regime in woodland later to be replaced by high-forests, grubbing out of one third of the Wood and turning it into pasture. Digging of of drainage canals. Beginning of Pinus plantations.                         |
|         | 1808/1809   | <b>Quercus</b><br>Betula, Pinus                                                                                                                                                          | <b>Quercus</b><br>Pinus                                                                                                                                                                                                            | Picea, Ulmus, Alnus                                         | Multiple-use management: wood-pasture, hay meadows, coppicing, pannage, wild-fruit and oak gall collection, beehives and arable fields in the Wood. Gradual change in name from Klečka ('place with shrubs') to Dúbrava ('oakwood') |
| Phase 2 |             | Chenopodiaceae, Asteraceae,<br>Rubiaceae, Rumex acetosa t.,<br>Rhinanthus,<br>Polygonum persicaria t.,<br>Cerealia, Secale,<br>Podospora, Sporormiella                                   | Chenopodiaceae, Asteraceae,<br>Brassicaceae, Lotus t., Rubiaceae,<br>Filipendula,<br>Chaerophyllum hirs.<br>Plantago lanceolata t.,<br>Polygonum aviculare t., Secale<br><b>Corylus</b> , Picea, Tilia, Ulmus,<br>Juniperus, Alnus | —                                                           |                                                                                                                                                                                                                                     |
|         | 1349 / 1348 | <b>Corylus</b> , Picea, Abies, Ulmus,<br>Tilia, Juniperus,<br>Alnus                                                                                                                      | <b>Quercus</b> , Pinus                                                                                                                                                                                                             | <b>Quercus</b> , Pinus                                      | Ban on cutting oaks                                                                                                                                                                                                                 |
| Phase 1 |             | Artemisia, Silenaceae, Senecio<br>t., Scrophulariaceae,<br>Valeriana off. t.,<br>Polygonum aviculare t.,<br>Polygonum persicaria t.,<br>Cyperaceae,<br>Typha latifolia t., Sparganium t. | Silenaceae, Ranunculaceae,<br>Senecio t.,<br>Apiaceae<br>Geranium,<br>Polygonum persicaria t.                                                                                                                                      | Cerealia, Secale                                            | Original name Klečka refers to shrubby vegetation                                                                                                                                                                                   |

Cal.: calibrated ages; AD: Anno Domini (after Christ); Max%: maximum (or increasing) of pollen percentage; Min%: minimum (or decreasing) of pollen percentage.





**Figure 3.** Percentage pollen diagram of selected pollen types with macro-charcoal concentrations from MS3 core. Parts of sediment without macrocharcoal analysis are marked as No Data.



**Figure 4.** Percentage pollen diagram of selected pollen types with macrocharcoal concentrations from MS4 core.

**Late Middle Ages to the early Modern Period (mid-14th century AD–end of 18th century AD) – Phase 2.** The first great change in forest composition occurred in the mid-14th century. It was recorded in both profiles and is dated AD 1348 (MS3) and AD 1369 (MS4). This event is characterized by a rapid increase in *Quercus* (30%, i.e. by 20%), and in *Pinus* (to 10%). It was accompanied by a strong decline in *Corylus* (6%), *Abies* (1%) and *Picea* (4%). *Betula* did not change. The dominance of oak, birch and pine has been characteristic for Dúbrava ever since the beginning of Phase 2.

Two charters refer to the active protection of oaks in Dúbrava precisely in this period. The first one is the above-mentioned interpolated charter from 1350, which gave the citizens of Hodonín the right to take dry wood and grass in the Wood but forbade them to fell living oaks (Boček, 1839: 204–205, for a discussion on the dating of the charter, see Měřinský and Šmerda, 2008b). The other one is the foundation charter of the Augustinian monastery in Brno from AD 1370. It was included in this document that the tenants of the monastery had the right to cut timber and firewood in Dúbrava ‘with the exception of oak trees, which they must not cut down at all’ (translation from Latin original, MZA F5 karton 11 inv. č. 744, fol. 25–32). The ban on cutting oaks was included in a number of privileges in later centuries as well (e.g. 1531 – MZA F5 karton 3 inv. č. 29; 1600 *urbarium* – MZA F5 kniha 1a).

In Phase 2 the maxima of *Quercus* in both profiles (34% MS3; 28% MS4) and the highest percentage of AP (78%) were recorded. The subsequent decrease in *Quercus* pollen is synchronous with an increase in the pollen of the other main tree species: *Carpinus*, *Fagus*, *Abies* and *Picea*. From the middle of the 14th century onwards, the general increase in *Cerealia*, the start of a continuous pollen curve of *Secale* and the occurrence of weeds (*Centaurea cyanus* – a typical high-medieval weed, *Papaver rhoeas*-type) may be connected with the expansion of arable land as a consequence of population growth in the surrounding area. The unchanged curves of *Plantago lanceolata*-type, Rubiaceae, *Senecio*-type, *Rumex acetosa*-type, Chenopodiaceae and *Lotus*-type suggest the continuous presence of grasslands and pastures. This argument is also supported by findings of spores of coprophilous fungi (*Podospora*, *Sporormiella*) in the sediment. The pollen of *Juniperus* and the spores of *Sporormiella* are indicators of livestock farming (Davis, 1987).

We observed a gradual increase in macroscopic charcoal particles throughout Phase 2. This could be connected with higher fire susceptibility of the vegetation caused by the expansion of *Pinus* or with the intensification of human activities in the vicinity of the study sites. Higher concentrations of charcoal particles at the end of this phase in both profiles and a slight decrease in *Quercus* and increase in *Betula* and Cyperaceae may indicate a distinct fire event, however, the percentages of *Quercus*, *Betula* and Cyperaceae swiftly returned to their previous values.

In this period the name of the Wood changed. The original Klečka (‘a place with shrubs’) was gradually replaced by Dúbrava (‘oakwood’). ‘Dúbrava’ was first used as a common noun that added information on the Wood (e.g. 1370: ‘the oakwood [dúbrava] that is called Klečka’ – MZA F5 karton 11 inv. č. 744, fol. 25–32), and only later became a geographical name. The last occurrence of the name Klečka is from 1531 (MZA F5 karton 3 inv. č. 29), after that only Dúbrava was used. Two *urbaria* (1600 – MZA F5 kniha 1a; 1691 – MZA F5 kniha 3) provide detailed information on the management of Dúbrava. The most characteristic feature was multiple use, which included wood-pasture, pannage (the fattening of domestic pigs on acorns), hay cutting in woodland meadows, firewood cutting and the collecting of strawberries and oak galls. There were managed ponds, beehives and even arable fields within the Wood. The system was complex but not random: every use was carefully regulated temporally and

spatially. The *urbaria* also include a description of the boundaries of Dúbrava, from which it is clear that the boundaries of the Wood were similar to those of today and that a few hundred metres from the pollen sites we investigated there were arable fields. Relatively little direct information is available on tree species in this period: apart from frequent references to acorns and oak galls, the 1692 estate conscription (MZA F5 kniha 5) mentioned that Dúbrava comprised mostly of oaks and partly of aspen and birch. The lack of *Pinus* in this list is noteworthy.

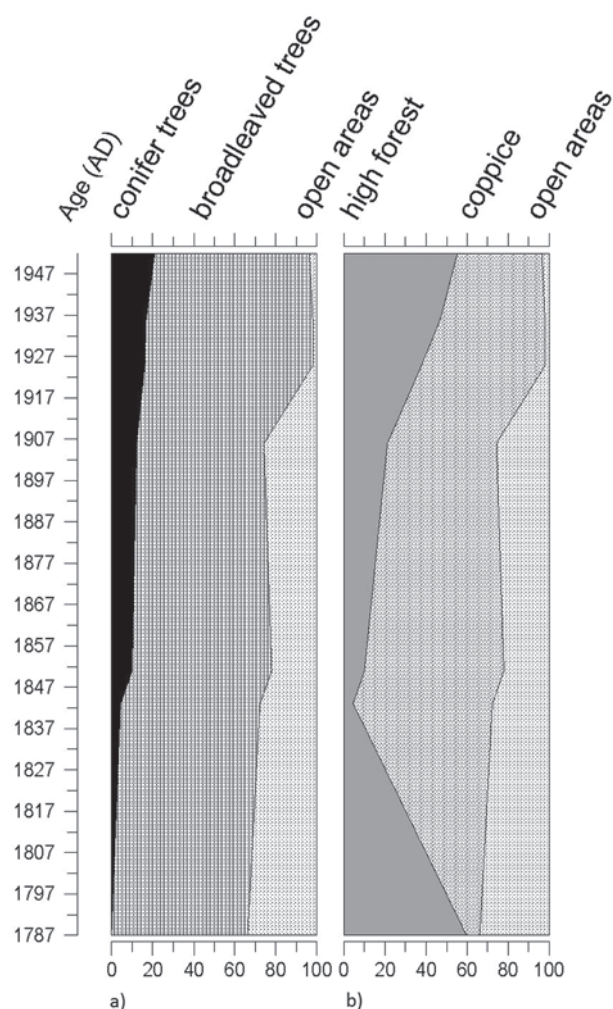
**Modern Period (19th century AD–present) – Phases 3 and 4.** At the beginning of the 19th century the second major change in the composition of Dúbrava can be observed. In the pollen diagrams this was reflected by a change in tree composition. A moderate decline in *Quercus* and increase in *Betula*, *Pinus*, *Salix*, *Populus* and *Fraxinus* can be associated with several, possibly interacting factors. A significant decline in *Cerealia* and *Secale*, dated to the beginning of the 19th century, is visible in MS3 but not in MS4; the latter is characterized by an increase in *Polygonum aviculare*-type, *Trifolium repens*-type and large quantities of coprophilous fungal spores (*Podospora*). The apparent contradiction (increase in human activities in MS4, decrease in MS3) can be explained by the different location of the profiles within the Wood.

The last change was recognized only in MS4 and refers to Phase 4. It is dated to the mid-20th century and is characterized by a rapid increase in *Populus* and *Betula* and the disappearance of pasturing indicators, such as *Plantago lanceolata*-type, *Trifolium repens*-type and Rubiaceae. It refers to the abandonment of pastures and fields inside or immediately outside the Wood and secondary succession with *Populus* and *Betula* as pioneer trees. The curve of *Quercus* rose again but it never reached the medieval maximum of the beginning of Phase 2. At the end of this phase we also recorded a decrease in the curves of other herbs, for example *Filipendula*, *Potentilla*-type, *Chaerophyllum hirsutum*, Silenaceae.

Macroscopic charcoal concentrations steeply increased towards the top of MS4. This indicates the presence of fire events in the fire-prone *Pinus* stands which were established by modern forestry. The increase in charcoal particles could also be associated with the construction of a railway line along Dúbrava Wood. The first steam engine on the Emperor Ferdinand Northern Railway passed through the town Hodonín in AD 1841 (Vykoupil, 2008).

Written sources show a major management change at the beginning of Phase 3. In the late 1780s Dúbrava was divided into two parts. The larger part (c. two-thirds of the whole) was enclosed by a woodbank (Szabó, 2010a) and turned into a coppice, while on the remaining one-third all trees were quickly removed and the area was turned into pasture. The former multiple management was abolished; pasturing, hay-cutting and pannage were banned. By the mid-19th century, however, the forestry administration changed its mind about management and started transforming the coppices into high-forests, partly with the help of *Pinus* plantations. Timber producing high-forests (including plantations) have formed the majority management type since the 1950s (as witnessed by consecutive forestry management plans: 1851 – MZA F5 kniha 232; 1864 – MZA F5 kniha 233–236, 238, 240; 1906 – MZA F5 kniha 242, 244, 245; 1925 – MZA F263 kniha 1; 1936: MZA F263 kniha 4, 5; 1952 – MZA F302 kniha 4). There were continuous efforts to afforest the open areas in the Dúbrava, however, these were unsuccessful until the 1920s. The pastures created in the late 18th century did not last long, and by 1906 (MZA F5 kniha 242, 244, 245) they reverted back to woodland (Figure 5).

The hydrological regime of the Wood was also changed. Some time in the 19th–20th centuries much of the territory of Dúbrava was drained by a network of channels. These channels connected



**Figure 5.** Changes in the amount of (a) broadleaved forest, conifer forest and open areas, (b) high forest, coppice and open areas and in Dúbrava since the end of the 18th century. Data prior to 1851 are approximate.

wetter areas and drained their water into larger canals that had been created in and around the Wood since the 15th century. These drainage channels are still visible in the field but are not maintained any more. Their dating is uncertain. The 1925 FMP (MZA F263 kniha 1) mentioned maintenance work on canals that were created before 1907, therefore we assume that the channels were dug already in the 19th century.

## Discussion

The combination of pollen analysis, macrocharcoal analysis and the study of historical documents provides synergetic results about vegetation stability and historical human impact in Dúbrava Wood. Palaeoecological analyses enabled us to reconstruct vegetation composition and fire disturbances during the past 2000 years while written archival material revealed information on tree composition and management practices for the past seven centuries.

### Stability/change in species composition in a regional context

Our results show that in the study period the species composition of Dúbrava went through significant changes. In the 14th century the vegetation of Dúbrava Wood changed from shrubby growth composed mainly of *Corylus* and *Betula* to subcontinental oakwood. In the past two centuries mesophilous species started to

spread and *Pinus* plantations appeared – this process continues to the present.

To gain a more general picture of forest vegetation development in the study region, we used previously published palaeoecological data from four nearby sites: Vracov (Rybníčková and Rybníček, 1972; Svobodová, 1997), Svatobořice-Mistřín (Svobodová, 1989, 1997), Anšův Dvůr (Svobodová, 1990) and Pohanisko (Doláková et al., 2010; Svobodová, 1990). They showed that *Quercus* started to spread in the study region in c. 6900 BC. After this date, grassy subxerophilous oakwoods or mixed oak-lime-hornbeam forests developed in mesic conditions, and floodplain forests prevailed in wet conditions. All four pollen profiles recorded the dominant presence of *Quercus* from c. 6900 BC to the early Middle Ages, c. 6th–9th centuries AD. Unlike at the other three sites, there were relatively high amounts of *Fagus* and *Abies* at Vracov from c. 3900 BC onwards. This may have resulted from long-distance transport as the site represents a larger lake basin. In contrast to the vegetation recorded in the four profiles, from the 1st to the 14th centuries AD Dúbrava consisted mainly of *Corylus* and *Betula*. *Quercus*, *Tilia*, *Ulmus* and *Carpinus* occurred only as admixture species. However, we cannot tell whether the vegetation observed at the beginning of the study period had been stable in previous centuries or whether it was the result of recent changes.

The most significant spread of oak in Dúbrava was recorded at the beginning of the 14th century. This process was accompanied by a decrease in other trees and shrubs, mainly *Corylus*. A comparison with other pollen diagrams from the region shows a similar decrease in *Corylus* and increase in *Quercus*, however, at a completely different date, in c. 1200 BC (Svobodová, 1997). The massive spread of oak recorded in Dúbrava has no analogues in southern Moravian pollen profiles in this period, all four of which show a decline in *Quercus* starting from the early Middle Ages.

The pollen profiles from Dúbrava ended with a visible decline in oak and an increase in ash, birch and pine in the 19th century. This increase in *Fraxinus* and *Pinus* was recorded in other pollen diagrams from the study region as well. The spreading of *Fraxinus* in predominantly oak forests is probably a natural reaction to the absence of organic matter removal and is part of a gradual change to a shady mesic forest (Hédl et al., 2010; Hofmeister et al., 2004). *Pinus* spread mainly as a result of plantation forestry.

### Driving forces of stability/change in species composition

A possible explanation of the rapid spread of *Quercus* in Dúbrava in the 14th century AD could be provided by the onset of the 'Little Ice Age' (LIA), which began in c. AD 1300 (Matthews and Briffa, 2005). Climate change (cooler and moisture conditions) could have influenced vegetation composition and cause the spreading of *Quercus*, which is less sensitive to late frosts than *Fagus*. In Białowieża forest (Poland), Mitchell and Cole (1998) attribute the dominance of *Quercus* to a competitive edge in edaphic conditions. However, Faliński (1986) described the dominance of *Quercus* in this forest as a result of grazing (herbivores and cattle). After a reduction in grazing, *Quercus* was replaced by *Carpinus*. In our study region, no other pollen profile records an increase in *Quercus* in the LIA; climate change is therefore unlikely to have caused the dramatic change in the vegetation of Dúbrava. Another possible explanation of the massive spread of oak is fire. Recent studies from North America show that the widespread occurrence and dominance of oak is the result of frequent fires (Abrams, 1992). Today, oak is in decline because of fire suppression by humans, which leads to a gradual replacement of oak by shade-tolerant species (Dey, 2002; Little, 1974; Lorimer, 1993; Van Lear, 1991). However, the results of macrocharcoal analyses from Dúbrava showed no major fire event parallel with



the sudden change in species composition at the beginning of Phase 2. There is some indication of a possible fire at the end of Phase 2, nevertheless even in this case higher concentrations of charcoal particles were not connected to any lasting influence on species composition. Fire is therefore unlikely to have been a driving force of species composition changes.

In a regional context, the changes in the species composition of Dúbrava Wood appear to be rather exceptional. In such cases, site history is often the best explanatory factor (Ejarque et al., 2009; Lindbladh et al., 2007; Veski et al., 2005). Two written documents mentioned the protection of oaks in the mid-14th century, which precisely coincides with the pollen data. However, the interpretation of these charters needs careful attention. Such bans were a commonplace in medieval charters and did not necessarily have to have any concrete consequences. In Sweden in the 18th and 19th centuries a similar ban is known to have caused a decline in oak numbers, although the socioeconomic conditions here were very different from late medieval Moravia (Eliasson and Nilsson, 2002). Nonetheless, in our case the existence of two charters and a simultaneous increase in oak pollen can hardly be a coincidence. These charters indicate that from the middle of the 14th century oaks were in fact actively protected in Dúbrava, which led to changes in the vegetation. According to the Vera Hypothesis (Vera, 2000), an increase in wood-pasture (also recorded in the two charters) could also have promoted oaks. Similar conclusions were arrived at for an earlier period at Pohansko, where the spread of *Quercus* accompanied by a slight decrease in *Tilia*, *Fraxinus* and *Ulmus* in c. AD 600–700 was attributed mainly to grazing by pigs (Kratochvíl, 1981; Svobodová, 1990;).

From the 14th to the late 18th centuries, Dúbrava had multiple uses, some of which (pasturing and hay cutting) kept the Wood relatively open. In this phase the maxima of *Quercus* in both profiles (34% MS3; 28% MS4) and the highest percentage of AP (78%) were recorded. This is confirmed by the 1692 estate conscription, which claimed that the Wood comprised mostly of oaks. The change in species composition (slight decline in *Quercus* and spreading of *Fraxinus*, *Betula*, *Populus* and *Pinus*) at the end of this period could have multiple reasons. One is a change in hydrological conditions (the construction of drainage channels), another could be windbreak as suggested by an increase in pioneer trees (*Populus* and *Betula*). Written documents show that multiple-use management ended exactly at this time, and the part where the forest hollows are situated was turned into pure coppice and some 50 years later into high-forest. Therefore the change in species composition can also be associated with a reduction of grazed areas (disappearance of pasturing indicators) and the gradual conversion to high-forest. A similar situation was observed in Białowieża forest (Faliński, 1986; Mitchell and Cole, 1998), where species of open habitats gradually declined and mesophytic tree species (*Carpinus*) replaced oak. This has led to the loss of species assemblages typical for subcontinental oakwoods (Kwiatkowska et al., 1997).

### Protecting the unique vegetation of subcontinental oakwoods

Open canopy oakwoods currently host many endangered species (Spitzer et al., 2008). To sustain their populations, these species had to find suitable habitats throughout the Holocene. It is often argued that open oakwoods with wood-pasture continuity must have been present since prehistoric times (e.g. Vera, 2000; Vodka et al., 2009). While this is certainly possible, other management types and tree species compositions could have provided equally suitable conditions. For example Milovice Wood, a large subcontinental oakwood not far from Dúbrava, was managed as a coppice-with-standards for at least 600 years (Szabó, 2010b). Only when coppicing ceased did the subcontinental character of the

vegetation begin to rapidly fade (Hédl et al., 2010). Our results indicate that open woodland could have consisted of various community types. In Dúbrava, open forest communities were apparently present from the first millennium AD, while the oakwood fully developed only in the 14th century. This suggests that even from the point of view of species sensitive to canopy openness, open oakwoods might not have been the only option for survival in the Holocene.

## Conclusions

We conclude that Dúbrava Wood did not show stability in the long run and that its species composition has dramatically changed during the last two millennia. From AD 0 to 1350 Dúbrava was almost certainly not an oakwood. The origins of its present species composition date back to the 14th century, when intentional management caused a shift from shrubby, hazel-dominated vegetation towards an oakwood. The most important driving force in the shaping and maintenance of the unique vegetation of Dúbrava was human management. medieval management promoted oaks, and the open oakwoods were further maintained by multiple-use management in the early Modern Period. They were subsequently drastically reduced in extent by modern forestry plantations continuing to date. The species in the herb layer could have been present in the millennia preceding the past 2000 years; however, until the 14th century they had to survive in other types of vegetation than subcontinental oakwoods.

## Acknowledgements

We would like to thank Radek Řepka for introducing us to the sites which were sampled for pollen. We are grateful to Dušan Lekeš for his help during fieldwork and to Zuzana Formánková for laboratory work.

## Funding

This study was supported by grant no. IAA600050812 'Lowland woodland in the perspective of historical development' from the Grant Agency of the Academy of Sciences of the Czech Republic and as a long-term research development project no. RVO 67985939.

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## **The Horka Litter Raking Incident: on Foresters and Peasants in Nineteenth Century Moravia**

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### **ABSTRACT**

Litter raking was a traditional forest use representing an interface between forestry and agriculture. In forest history, it has usually been presented as the harmful removal by peasants of biomass, which was gradually eliminated by foresters, leading to better forest preservation. Based on the example of an exceptionally well-documented case of illegal litter raking in Moravia in 1845, in this paper I argue that juxtaposing foresters and peasants in connection with litter raking masks a much more complicated reality. Neither foresters nor peasants can be interpreted as homogenous groups because there were significant differences in the opinions and agendas of various representatives within these groups. In addition, opinions were not static on either side but could change in a discursive pattern. In a wider context, the environmental historical analysis of the Horka litter raking incident facilitates the understanding of larger societal processes that influenced past woodland management in Central Europe, and therefore current ecosystems too.

**Keywords:** traditional forest management, Moravia, forest conflict, leaf litter raking

### **INTRODUCTION**

On 6 November 1845, several dozen people gathered at the office of the *Oberamt* (≈Head Office) in the city of Olomouc in central Moravia, part of the present-day Czech Republic. They were there to testify in a case of illegal forest litter raking that had allegedly taken place a week earlier in the forest district of Horka, not far from Olomouc, to which the forests belonged. The three main suspects were the local forester Joseph Rabenseifer, his wife Eleonora and Horka resident Joseph Powolny.<sup>1</sup> Powolny had earlier acquired – through a public auction organised by the city – the right to rake leaf litter in parts of the forests. Although he was warned that the actual raking was not to commence until final permission from the city arrived, he went on to sell his own private licences to local residents, who promptly started raking the leaves. In the meantime, however, the city authorities changed their mind and banned litter raking for the 1845 season, rendering any litter raking that had already taken place illegal. During the hearing, which took two days to complete, 28 people, mainly representing individual Horka households, gave testimony. Considering that in 1846 there were 116 households in Horka,<sup>2</sup> it is safe to say that the hearing was a significant event in the life of the village. At the end, the local forester was found guilty and was relocated to another forest district 20 kilometres from Horka.

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<sup>1</sup> The Olomouc region was bilingual in this period. Most official documents were written in German but many inhabitants spoke Czech. In this paper, I spell people's names as they were used in the documents. In contrast, I use current place names for ease of identification on the map.

<sup>2</sup> Josef Bartoš, Karel Müller and Stanislava Kovářová, *Horka nad Moravou: od minulosti k současnosti* (Olomouc: Danal, 2001), p. 30.

This paper is an attempt to interpret the Horka litter raking incident in the wider context of traditional forest uses and the conflicts between foresters and local peasant communities. Before the birth of modern forestry, European forests were managed through various traditional methods. Some of these are well known, such as forest pasture, or coppicing.<sup>3</sup> Other methods, mainly those that did not involve tree harvesting, remain less researched. Such neglect does not necessarily stem from their being less significant from an environmental point of view but rather from the fact that forest history, which until recently focused on wood production and extraction, had little interest in non-timber uses.

Litter raking, which was intricately linked to agriculture and nutrient cycles, played an important role in peasant livelihoods in Central Europe until approximately the mid-twentieth century.<sup>4</sup> The basic process was simple: fallen leaves from broadleaved or needle-leaved trees were raked from the forest floor, stuffed into large sacks or baskets and carried away over the shoulder or in carts.<sup>5</sup> Litter was mainly used as bedding for farm animals; deriving from the Latin *lectus* (bed) via Old French and Middle English, the word 'litter' in fact originally means bedding.<sup>6</sup> After use in the stables, the mixture was taken out to fertilise the fields. In some cases, the leaves could also be used for other purposes, for example as filling for mattresses.<sup>7</sup> It is important to note that leaves were usually considered an inferior alternative to straw, which was the preferred product for animal bedding and eventual fertiliser.

In higher-lying areas with more pastures and smaller arable fields, litter raking could be relatively more important than in regions – such as my study area – with significant grain production. In any case, the need for fallen leaves in any particular year strongly depended on grain yields and the resulting abundance of straw, which in turn was heavily influenced by climatic trends and weather events. Weather influenced litter raking in another way as well: because water-soaked leaves are cumbersome to rake, transport and store, the timing of raking was crucial. Another factor that determined the demand for litter was the number of domestic animals – any growth in their numbers (either through general human population increase or a change in subsistence strategies) led to increased demand for litter. A related issue is the amount of time animals spent in stalls. The intensification of animal keeping and agricultural production reduced the time animals spent outside and increased the amount of litter they needed. For example, in the Czech lands, the gradual switch from three-field agriculture (in which one field always lay fallow and served as pasture) to crop rotation (with no fallow) from the late eighteenth century onwards could be responsible for a rise in the significance of litter raking.<sup>8</sup> Lastly,

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<sup>3</sup> Tibor Hartel and Tobias Plieninger (eds), *European Wood-Pastures in Transition: A Social-Ecological Approach* (London and New York: Routledge, 2014); Peter Buckley and Jenny Mills, 'Coppice silviculture: from the Mesolithic to the 21st century', in Keith J. Kirby and Charles Watkins (eds), *Europe's Changing Woods and Forests: From Wildwood to Managed Landscapes* (Wallingford: CABI, 2015), pp. 77–92.

<sup>4</sup> On the environmental historical aspects of litter raking, see Martin Stuber and Matthias Bürgi, 'Agrarische Waldnutzungen in der Schweiz 1800–1950. Nadel- und Laubstreue', *Schweizerische Zeitschrift für Forstwesen* **153** (2002): 397–410. See also Elisabeth Johann, 'Historical interactions between agricultural and forest utilization in the Austrian Alps and their impact on the present forest condition', in Mauro Agnoletti and Steven Anderson (eds), *Forest History: International Studies on Socio-Economic and Forest Ecosystem Change* (Wallingford: CABI, 2000), pp. 161–170. For a more popular expression, see Michael Machatschek, *Laubgeschichten: Gebrauchswissen einer alten Baumwirtschaft, Speise- und Futterlaubkultur* (Wien, Köln and Weimar: Böhlau Verlag, 2017).

<sup>5</sup> See for example the photographs in Matthias Bürgi and Urs Gimmi, 'Three objectives of historical ecology: The case of litter collecting in Central European forests', *Landscape Ecology* **22** (2007): 77–87.

<sup>6</sup> *Definition of litter* [online]. Oxford University Press. Available at: <https://www.lexico.com/definition/litter> (Accessed: 18 December 2020).

<sup>7</sup> Liliane Roth and Matthias Bürgi, 'Bettlaubsammeln als Streunutzung im St. Galler Rheintal', *Schweizerische Zeitschrift für Forstwesen* **157** (2006): 348–356.

<sup>8</sup> Magdalena Beranová and Antonín Kubačák, *Dějiny zemědělství v Čechách a na Moravě* (Praha: Libri, 2010), p. 244.

changes in agricultural crop production could also affect the demand for leaf litter. In my study region, the nineteenth century saw the replacement of traditional wheat crops with potato and sugar beet in many places, which meant less straw and higher need for leaf litter.<sup>9</sup> As Stuber and Bürgi have pointed out, litter raking may be one of the few types of traditional forest management that, rather than contracting, became more widespread in the nineteenth century.<sup>10</sup>

As a result, litter raking was very common in Central European forests. In Moravia, for example, cadastral data demonstrate that litter raking was present in nearly every township that contained forests.<sup>11</sup> Gimmi et al. estimated that 93,000 hectares of forest needed to be raked for litter in Switzerland around 1850.<sup>12</sup> Litter raking seems to have moved around significant amounts of biomass. According to a report published in the official journal of the Society of Bohemian Foresters, in Bohemia in 1875 some 168,000 tons of leaf litter were removed from an overall forest area of 1,474,517 hectares, i.e. an average of 0.11 tons per hectare (an inexact number because not all forests were raked).<sup>13</sup> The quantity of leaves available could be much larger. From the Fichtelgebirge area in Bavaria, Schöllmann estimated that as many as 15 tons of spruce needles could be collected on one hectare, although, as expected, actual litter removal was highly variable.<sup>14</sup>

After its nineteenth-century heyday, litter raking started to retreat from Central European forests. By 1920, only ca. 29,400 tons of leaves were collected in Bohemian forests.<sup>15</sup> In the mid-twentieth century in the whole of Czechoslovakia,<sup>16</sup> Pfeffer estimated that 27,830 tons of leaves were removed from 23,000 hectares of larger forests, to which one needs to add litter removal from at least 200,000 hectares of smaller forests.<sup>17</sup> With the arrival of artificial fertilisers, forestry and agriculture finally

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<sup>9</sup> In the Czech lands, potatoes were first seriously considered as an alternative to grain after the famine of 1770–1772; their production became significant in the nineteenth century. František Kutnar, *Malé dějiny brambor* (Pelhřimov: Nová tiskárna, 2005), pp. 44–45. For sugar beet, see Vladimír Švachula, Josef Pulkrábek, Josef Šroller and Josef Zahradníček, 'Kapitoly z historie řepářství. I. část – Zrození českého řepářství a cukrovarnictví', *Listy cukrovarnické a řepářské* **120** (2004): 292–295.

<sup>10</sup> Stuber and Bürgi, 'Agrarische Waldnutzungen', p. 399.

<sup>11</sup> Ondřej Vild, Jan Šipoš, Péter Szabó, Martin Macek, Markéta Chudomelová, Martin Kopecký, Silvie Suchánková, Jakub Houška, Martin Kotačka and Radim Hédli, 'Legacy of historical litter raking in temperate forest plant communities', *Journal of Vegetation Science* **29** (2018): 596–606.

<sup>12</sup> Urs Gimmi, Benjamin Poulter, Annett Wolf, Hanspeter Portner, Pascale Weber and Matthias Bürgi, 'Soil carbon pools in Swiss forests show legacy effects from historic forest litter raking', *Landscape Ecology* **28** (2013): 835–846.

<sup>13</sup> Josef Zenker, 'Der Stand der Forstwirtschaft in den letzten Jahren im Königreiche Böhmen', *Vereinsschrift für Forst-, Jagd- und Naturkunde* **170** (1890/1891), pp. 9–54, esp. 29–30.

<sup>14</sup> Hubertus Schöllmann, *Ausgewählte Waldnutzungsformen im Fichtelgebirge und ihr Beitrag zur heutigen Ausstattung der Waldökosysteme* (PhD thesis, Georg-August-Universität Göttingen, 1999), pp. 107–109. Urs Gimmi, Matthias Bürgi and Martin Stuber, 'Reconstructing anthropogenic disturbance regimes in forest ecosystems: a case study from the Swiss Rhone valley', *Ecosystems* **11** (2008): 113–124; this paper estimates leaf litter removal of around 1.5–2.5 tons per hectare in a study area of 9,468 hectares in Switzerland.

<sup>15</sup> Jan Auerhan, *Příspěvky ke statistice lesů v republice Československé* (Praha: Státní úřad statistický, 1924), p. 43.

<sup>16</sup> A note of terminology: what is today the Czech Republic is made up of three historical regions: Bohemia, Moravia and Silesia. Most of Silesia now belongs to Poland. These regions (in their various historical extents) are together loosely referred to as 'the Czech lands' and were ruled by the Czech king. The Czech lands were for most of their history part of the Holy Roman Empire or the Austrian (later Austro-Hungarian) Empire. In 1918 the Czech lands gained independence from Austria and were joined with Slovakia to form Czechoslovakia, only to separate in 1993 into the Czech Republic and Slovakia.

<sup>17</sup> Antonín Pfeffer, *Hrabání steliva v lesích a lesní pastva v normálních dobách* (Praha: Knihtiskárna Prometheus, 1948), pp. 2–3.

parted ways and leaf litter raking was gradually abandoned. In the Czech Republic, it has been banned since the 1960 forest law.

The ecological consequences of litter raking could be significant. Kilian argued that in the space of a century litter raking could remove as much biomass from forests as tree cutting itself.<sup>18</sup> According to Pfeffer, losses in tree-growth caused by litter raking in Czechoslovakia were at least as significant (although much less spectacularly visible) as those caused by bark beetle outbreaks.<sup>19</sup> In addition, the effects of litter raking on vegetation can be long-lasting. Vild et al. found differences in the vegetation of raked versus non-raked forests in Moravia that have persisted from the nineteenth century until the present.<sup>20</sup> However, it is worth remembering that what was biomass removal from the point of view of forests was in fact biomass input as far as agricultural land was concerned. Many of the theoretical discussions and practical tugs of war in the nineteenth century concerning litter raking centred around what Schenk called the 'dilemma of leaf and litter removal.'<sup>21</sup>

In the conventional narrative on litter raking, foresters stood against peasants and both parties were presented as relatively homogenous blocks.<sup>22</sup> Foresters supposedly considered litter raking to be harmful for forests and sought to eliminate it. Peasants, on the other hand, would have cared little about forest damage and wanted to extend litter raking to support their agriculture. In the long run, foresters won the battle, thus improving the condition of the forests. This 'triumphant' version of the story is of course that of scientific forestry, closely allied with developing nation-states in Europe.<sup>23</sup> It was promoted by foresters themselves and further articulated in the writings of twentieth-century forest historians, who, in general, subscribed to an apologetic justification of scientific forestry, or, in Tamara Whited's words, a 'history-of-progress outlook.'<sup>24</sup> However, recent work in environmental history emphasised that the history of forest use can (and should) be studied from multiple points of view, including that of the peasants.<sup>25</sup> With this paper my aim is to go one step further and show how the narrative of opposing camps is an oversimplification of the history of litter raking and how opinions and attitudes differed even within the allegedly homogenous camps. Furthermore, I will demonstrate that these opinions and attitudes often interacted and influenced each other and were therefore not static but could develop in a discursive manner.

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<sup>18</sup> Walter Kilian, 'Forest site degradation – temporary deviation from the natural site potential', *Ecological Engineering* 10 (1998): 5–18.

<sup>19</sup> Pfeffer, *Hrabání steliva*, p. 9.

<sup>20</sup> Vild et al., 'Legacy of historical litter raking in temperate forest plant communities'.

<sup>21</sup> Winfried Schenk, *Waldnutzung, Waldzustand und regionale Entwicklung in vorindustrieller Zeit im mittleren Deutschland: historisch-geographische Beiträge zur Erforschung von Kulturlandschaften in Mainfranken und Nordhessen* (Stuttgart: Steiner, 1996), p. 166.

<sup>22</sup> E.g. Jan Frič, 'Několik poznatků k dějin hrabání lesního steliva', *Lesnická práce* 34 (1955): 397–400.

<sup>23</sup> Richard Hölzl and K. Jan Oosthoek, 'Introduction', in K. Jan Oosthoek and Richard Hölzl (eds), *Managing Northern Europe's Forests: Histories from the Age of Improvement to the Age of Ecology* (New York and Oxford: Berghahn, 2018), pp. 1–13.

<sup>24</sup> Tamara Whited, *Forests and Peasant Politics in Modern France* (New Haven: Yale University Press, 2000), p. 4.

<sup>25</sup> Whited, *Forests and Peasant Politics*; Kieko Matteson, *Forests in Revolutionary France: Conservation, Community, and Conflict* (New York: Cambridge University Press, 2015); Richard Hölzl, 'Forests in conflict: rural populations and the advent of modern forestry in pre-industrial Germany, 1760–1860', in Geneviève Massard-Guilbaud and Stephen Mosley (eds), *Common Ground: Integrating the Social and Environmental in History* (Newcastle upon Tyne: Cambridge Scholars Publishing, 2011), pp. 198–223; Bernd-Stefan Grewe, 'Streit um den Wald – ein Ressourcenkonflikt? Das Konfliktfeld Wald in der vorindustriellen Zeit (ca. 1500–1850)', *Geschichte in Wissenschaft und Unterricht* 63 (2012): 551–566.



## CHALLENGES OF SOURCES

Stuber and Bürgi highlighted what they called the 'source problem' of litter raking.<sup>26</sup> They argued that there was a discrepancy between legislative sources and what was actually going on in the forests. They also pointed out that research on litter raking needed to consider the local variation inherent to this type of forest use. To these, one may add that litter raking generally left few sources, especially for earlier periods.<sup>27</sup> The reason for this is that – allowing for a generalisation that does not do justice to all situations – archival sources were produced for those forest uses that had economic value for forest owners. For a long period, litter raking was not one of these uses.

In the Horka case, one can see when and why litter raking moved out of the archival shadows and became available in greater detail to environmental historians. On 24 September 1835, retired *Oberleutenant* (first lieutenant) Karl Winkler, who rented the hunting rights in the Skrbeň and Hynkov forest districts, wrote a letter to the Olomouc magistracy, in which he proposed to rent the litter raking rights in these districts for a yearly sum of 50 florins. The Oberamt, in charge of economic issues,<sup>28</sup> supported the petition and added that granting Winkler what he wanted would be all the more desirable because it would represent a new source of income, 'as until now nothing was paid for this [i.e. litter raking].'<sup>29</sup> The forest management instruction of Olomouc forests from 1797 confirms this information, when it explicitly mentions the fact that local tenants receive litter free of charge.<sup>30</sup> From approximately the second third of the nineteenth century onwards, however, archival sources on litter raking around Olomouc are in fact many as well as manifold. In this paper I will use forest management instructions, letters and petitions by local peasant and foresters, records of the forestry administration, court proceedings, statements by higher authorities, as well as coeval forestry literature.<sup>31</sup>

## THE HORKA LITTER RAKING INCIDENT

After the short description of the Horka litter raking incident at the beginning of this paper, it is time to examine the events in more detail. Although the pertinent documents are missing, references to them in other documents make it clear that it was the villages that initiated the process whereby litter raking (or, to be more precise, the right to organise and supervise litter raking) was put up for auction in 1845. On 19 September, the *Waldamt* (forestry office) wrote to the Olomouc city magistracy asking it to consider auctioning out litter raking in well-defined areas of three forest districts, including Horka.<sup>32</sup> The magistracy agreed and next day (20 September) it ordered that the public auction take place on 18 October, and litter raking itself from 1 to 30 November.<sup>33</sup> There were extensive notes in all official documents describing the precise conditions under which litter raking was to take place, including details on the responsibilities of various parties. A key point – and the reason for the eventual

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<sup>26</sup> Stuber and Bürgi, 'Agrarische Waldnutzungen', pp. 398–399.

<sup>27</sup> This was pointed out for the study region already in Frič, 'Několik poznatků'.

<sup>28</sup> For Olomouc city administration in the period, see Hans Kux, *Verwaltungsgeschichte der Stadt Olmütz* (Olmütz: Verlag der Hauptstadt Olmütz, 1942).

<sup>29</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 692, signatura: W3X, karton 1333 (henceforth: SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333), fol. 2, 5. Translation mine. Henceforth all translations are mine.

<sup>30</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 577, signatura: J1, karton 1094, fol. 483.

<sup>31</sup> References to individual sources will be given later on when appropriate.

<sup>32</sup> All forests in the area were managed as coppices in this period. Ivo Machar, 'Coppice-with-standards in floodplain forests – a new subject for nature protection', *Journal of Forest Science* 55 (2009): 306–311.

<sup>33</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 102–106.

downfall of Joseph Rabenseifer – was that the local forester rather than the renter was responsible for monitoring the process and the deadlines.

The public auction duly took place on 18 October.<sup>34</sup> Litter raking was granted to the highest bidder: Joseph Powolny, resident of Horka, for 41 florins. Significantly, the asking price was 60 florins. Powolny had to pay half of this sum straight away and the other half within two weeks (before 1 November). However, as the Oberamt forwarded its report to the city magistracy for final authorisation, problems emerged. On 24 October, the magistracy refused to accept the result of the public auction, because the highest bid was below the asking price. Therefore they decided that litter raking would not be allowed in the 1845 season at all. The local peasants, they added somewhat enigmatically, did not really need the leaf litter any more.<sup>35</sup> This was proven untrue as soon as Powolny got wind of the new situation. Already two days later, on 26 October, he petitioned the Oberamt to grant him the right to rake litter in spite of the city's recent decision, because, he wrote, he and other residents really needed the leaves.<sup>36</sup> To prove his point, he offered 61 florins, that is, 21 florins more than his original offer and 1 florin more than the asking price. This also showed that the magistracy was not entirely wrong when claiming that the original highest bid had been unrealistically low. Regardless of these negotiations, at this point things were already in motion on the ground. Powolny started selling his own litter raking licenses to interested parties on 24 October and did not stop selling them after 26 October, either. On 27 October, the Oberamt forwarded Powolny's petition to the magistracy arguing that there was no reason to decline his request now that the projected income was going to materialise. The same day, Powolny met local forester Joseph Rabenseifer's wife, Eleonora, in Skrbeň and convinced her to sell litter raking licenses in his name to whoever might be interested. Eleonora sold licenses to four women. Powolny was in a hurry for two good reasons. First, as far as he was concerned, he still had to pay the remaining half of the litter raking rent by 1 November. Second, he was afraid that rainy weather would arrive, in which case, he claimed, he could not sell any licenses.<sup>37</sup>

From his own perspective, Powolny did the right thing. The moment he sold the licenses, he was basically free of care: responsibility for what was going on in the forests rested with Rabenseifer. That is why when, after a hard day's work out in the woods, Rabenseifer met his wife in the evening and found out about the licenses, he became very cross (Fig. 1). The next day (28 October) he went out to the woods to stop all litter raking and he also ordered Eleonora and Powolny to buy all their licenses back. On 31 October, the magistracy brought its final decision: in spite of the Oberamt's recommendation, it declined to allow litter raking.<sup>38</sup> Acknowledging defeat, on 2–3 November Powolny visited everyone he had sold licenses to and bought the licenses back. Finally, the public hearing took place on 6–7 November.<sup>39</sup> The Olomouc magistracy brought its verdict on 15 November: Rabenseifer was responsible for the illegal litter raking. Furthermore, the magistracy claimed that he must have known what was going on and he therefore actively tried to cause financial harm to the city. Eleonora's conduct, the magistracy continued, would especially deserve further investigation. Under the circumstances, the magistracy no longer wanted Rabenseifer in Horka. He was not fired but was

<sup>34</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 108–109.

<sup>35</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 113

<sup>36</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 115.

<sup>37</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 126. Although no direct measurements are available from around Olomouc, weather data from Brno show that this argument – in retrospect – was somewhat opportunistic. Both October and November in 1845 were unusually warm and dry, ideal weather for litter raking. Data were kindly provided by Rudolf Brázdil and Petr Dobrovolný. See also Rudolf Brázdil, Hubert Valášek and Jarmila Macková, *Meteorologická pozorování v Brně v první polovině 19. století* (Brno: Archiv města Brna, 2005), p. 184.

<sup>38</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 120.

<sup>39</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 122–135.



## THE FORESTERS

‘Forestry’ in today’s sense of the word in Europe, sometimes called ‘scientific forestry’ or ‘modern forestry’, is usually presented through the theoretical writings and practical handbooks of leading figures in the discipline.<sup>40</sup> Their ideas, which followed from the perceived ruinous state of forests and in that sense can be conceptualised as the collective opinion of large numbers of forest owners and managers, were modified through scientific advances and implemented in practice mainly in the nineteenth century. This period also witnessed major legislative efforts to force woodland owners and users to conform to these new principles. Litter raking, as I argued above, fits into this narrative as a contributing factor to the forest decline that scientific forestry and its representatives, the foresters, tried to eliminate. Whether the foundations of this story (the catastrophic state of forests and the impending lack of wood) were true or not – and if so from whose perspective – is a complex story in itself,<sup>41</sup> and, as more recent research has demonstrated, so is the role of foresters themselves in constructing and selling their own profession as the saviour of forests.<sup>42</sup> The main message of the Horka litter raking incident, however, lies elsewhere: namely, in showing that forestry in the nineteenth century was a multi-layered profession, whose concrete representatives at various levels could differ from each other in their opinions and even goals.

Starting with influential thinkers – the highest level of forestry, as it were – the theory that litter raking was harmful for forests appeared in Hans Carl von Carlowitz’s 1713 *Sylvicultura Oeconomica*, one of the most prominent works of early forestry.<sup>43</sup> Von Carlowitz presented most of the arguments known from later discussions. Litter raking, he wrote, led to soil desiccation and increased seedling mortality. It also reduced tree growth through removing the natural fertiliser of forests. Lastly, using carts to move the litter caused further damage by trampling down the seedlings. At present it is hard to assess how many of these were von Carlowitz’s own ideas. Earlier references to litter raking are known from forest instructions, for example, but these appear to lack the detail and coherence of von Carlowitz’s expression.<sup>44</sup> In any case, von Carlowitz’s opinion was well known in the Czech lands. When in 1754 the first state level forest law was issued for the Czech Kingdom, it was accompanied by a lengthy

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<sup>40</sup> An excellent overview is Henry E. Lowood, ‘The calculating forester: Quantification, cameral science, and the emergence of scientific forestry management in Germany’, in Tore Frängsmyr, J.L. Heilbron, and Robin E. Rider (eds), *The Quantifying Spirit in the Eighteenth Century* (Berkeley: University of California Press, 1990), pp. 315–342. See also John Dargavell and Elisabeth Johann, *Science and Hope: A Forest History* (Knapwell: White Horse Press, 2013).

<sup>41</sup> Literature on ‘wood shortage’ is extensive. See for example Joachim Radkau, ‘Zur angeblichen Energiekrise des 18. Jahrhunderts: Revisionistische Betrachtungen über die „Holznot“’, *Vierteljahrschrift für Sozial- und Wirtschaftsgeschichte* **73** (1986): 1–37; Bernd-Stefan Grewe, *Der versperrte Wald: Ressourcenmangel in der bayerischen Pfalz (1814–1870)* (Köln: Böhlau, 2004); Paul Warde, ‘Fear of wood shortage and the reality of the woodland in Europe, c. 1450–1850’, *History Workshop Journal* **62** (2006): 28–57; Andrée Corvol-Dessert, ‘Une illusion française: la pénurie des ressources ligneuses, 1814–1914’, in Mauro Agnoletti and Steven Anderson (eds) *Forest History: International Studies on Socio-Economic and Forest Ecosystem Change* (Wallingford: CABI, 2000), pp. 127–142.

<sup>42</sup> Richard Hölzl, *Umkämpfte Wälder: die Geschichte einer ökologischen Reform in Deutschland 1760–1860* (Frankfurt am Main: Campus Verlag, 2010).

<sup>43</sup> Hans Carl von Carlowitz, *Sylvicultura Oeconomica oder haußwirthliche Nachricht und naturmäßige Anweisung zur Wilden Baum-Zucht* (Leipzig: Braun, 1713), p. 71–72, cap V. par. 38.

<sup>44</sup> The Bavarian forest instruction of 1568 banned litter raking but used different arguments, for example the protection provided by the litter layer to young seedlings (*Bayrische Vorstordnung* 1568, Bayerische Staatsbibliothek, 2 Bavar. 296 m). Earlier well-known forestry works, such as John Evelyn’s *Sylva* or the 1669 French forest ordinance contain virtually no references to litter raking in the context discussed here.

practical forestry guide.<sup>45</sup> The part pertaining to litter raking in this tractate was copied almost verbatim from von Carlowitz's book. Heinrich Cotta's classic forestry textbook from 1832 also condemned litter raking and proposed to eliminate it from forests.<sup>46</sup> This was received with much enthusiasm by one of the most influential Bohemian foresters of the time, Christoph Liebich, in his review of Cotta's book.<sup>47</sup> Especially in the second half of the nineteenth century, many books were written by professional foresters on litter raking, basically all arguing against it.<sup>48</sup> At the same time, one could already in 1830 find published works that provided a more nuanced view considering not only the harmful effects of litter raking on tree growth, but also its overall role in the national economy.<sup>49</sup> In a similar manner, books were published that advised peasants on how to manage their arable fields without forest litter.<sup>50</sup> As a result, a range of opinions from dogmatic to pragmatic were available to foresters to build on.

The middle, regional level of forestry in Olomouc was represented by the Waldamt, responsible for all the forests of the city of Olomouc, several thousand hectares in total. The Waldamt in the 1840s was led by *Oberförster* (head forester) Anton Prokop Schwarz, a widowed man in his sixties. He was born in Austria, which made him one of the few non-natives in the Waldamt.<sup>51</sup> He studied at the prestigious Mariabrunn forestry school in Austria, one of the first such institutions in Europe.<sup>52</sup> The Waldamt employed around fifteen people: in addition to Schwarz, a scribe, a carer for the tree garden, six district foresters (*Revierförster*), and one or two forest youths (*Waidjung*) to aid each district forester. Because Schwarz had to represent the Waldamt many times in cases concerning litter raking, we can follow changes in his opinion in detail. In 1835, when the issue first came up officially, he had nothing against litter raking as requested by Oberleutenant Winkler.<sup>53</sup> Four years later, however, he did a complete U-turn. In a letter addressed to the Oberamt, he requested that litter raking be banned in the forests of Olomouc. He argued that there were no sound financial reasons to support litter raking and went on to express the hope that the magistracy would behave responsibly towards the preservation of the forests rather than treating them as a source of additional income.<sup>54</sup> While all this sounded reasonable enough to members of the magistracy Schwarz offered no explanation as to why he had changed his

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<sup>45</sup> Národní archiv Praha, PT, inventární číslo 1498–5.4.1754. I would like to thank Jiří Woitsch for providing me with this document. For an introduction to the 1754 law, see Jiří Woitsch, 'Tereziánský lesní řád. Počátek moderního lesnictví v českých zemích?', *Lesnická práce* 96 (2017): 36–39.

<sup>46</sup> Heinrich Cotta, *Grundriß der Forstwissenschaft* (Dresden and Leipzig: Arnoldische Buchhandlung, 1832), p. 112–115.

<sup>47</sup> Christoph Liebich, 'Recension. Grundriß der Forstwissenschaft von Heinrich Cotta', *Allgemeines Forst- und Jagd-Journal* 2 (1832): 37.

<sup>48</sup> E.g. G.V. Schultes, *Streuwald, oder kurze Erörterung der großen Nachtheile des übermäßigen Streusammelns für die Waldungen* (Coburg and Leipzig: Sinner'schen Hofbuchhandlung, 1849). Especially important and oft quoted is the extensive study of the pedochemical effects of litter raking: Ernst Ebermayer, *Lehre der Waldstreu mit Rücksicht auf die chemische Statik des Waldbaues* (Berlin: Julius Springer, 1876).

<sup>49</sup> Johann Christian Hundeshagen, *Die Waldweide und Waldstreu in ihrer ganzen Bedeutung für Forst-Landwirtschaft und National- Wohlfahrt* (Tübingen: Heinrich Laupy, 1830). Georg Ludwig Hartig's renowned *Forstliches und forstnaturwissenschaftliches Conversations-Lexikon* (Berlin: Nauckschen Buchhandlung, 1834) also discussed litter raking in a wider context.

<sup>50</sup> Georg von Möllendorff and Thunig, *Die Bewirthschaftung des Ackers ohne Waldstreu und Waldweide* (Görlitz: G. Heinze & Comp., 1850); Josef Dumek, *Stelivo, se zvláštním ohledem na hrabanku lesní, vliv jeho na jakost a dobrotu hnoje* (Praha: Kněhupectví B. Stýbla, no date).

<sup>51</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 689, signatura: W3VI, karton 1329, fol. 83–84.

<sup>52</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 689, signatura: W3VI, karton 1328, fol. 180–181.

<sup>53</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 3.

<sup>54</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 45.



mind. A closer reading of his letter, however, indicates signs of frustration. He complained that no one had informed him about the public auctions of litter raking in the previous few years. It is then clear that after initially consulting him in 1845, the Oberamt simply ignored Schwarz and the Waldamt in matters of litter raking. Schwarz arguably felt that his authority as head forester was threatened and reacted accordingly. The arguments against litter raking were well-known to him and he simply decided to utilise them at this point. His reference to the 'preservation' (*Erhaltung*) of forests, which was not normally part of his litter-related vocabulary, is also a sign of his employing a tone more akin to hard-line forestry ideology. His initiative to ban litter raking met with success that may have surprised Schwarz himself. Both the Oberamt and the magistracy supported his proposition and asked the highest authority in the matter, the *Gubernium* of Moravia to ban litter raking in the Olomouc forests. The *Gubernium* did this a few months later in February 1840.<sup>55</sup> However, Schwarz once again changed his mind. When in 1842 several villages asked the Oberamt to allow them to rake leaf litter because of the poor grain harvest, Schwarz argued that although the *Gubernium* had banned litter raking in 1840 (which, one should not forget, was his idea in the first place), the villages should still get what they had asked for. Although, he wrote, litter raking should not be considered a stable forest use, 'in times of need, the forest should and can support agriculture and animal husbandry in a fair manner.'<sup>56</sup> Once again, he offered no explanation. The twenty-first-century reader gets the impression that once Schwarz felt that his authority in the matter was restored, he reverted to the everyday realities of forest management, which included getting along with the local peasants. Just before the Horka litter raking incident in 1845, Schwarz added a new set of arguments to the existing ones: 'According to the principles of forestry, in good forest soils, such as the one that exists in the local forests, and in broadleaved stands with the exception of fresh cuts and young stands up to 20 years, litter raking can take place without disadvantages for tree growth.'<sup>57</sup> In other words, he sought to support his own change of mind through scientific forestry arguments, and such arguments existed. Let us not forget that Schwarz was an educated forester and he also had an active interest in theoretical issues. For example, in 1836 he published a paper on beech regeneration, and in the 1820s he even proposed to write what would have been the first Moravian forestry handbook.<sup>58</sup> Years after the Horka incident, in 1849, Schwarz summarised his views on litter raking in a lengthy letter to the city's economic council.<sup>59</sup> The topic, he wrote, has been discussed many times with numerous arguments for and against, but often these arguments were one-sided. He then listed the arguments he had used himself, usually ending with the rhetorical exclamation 'True and not true!' (*Wahr und nicht wahr!*). What followed was a balanced discussion on various aspects of litter raking: for example, Schwarz wrote, some claim that litter raking reduces tree growth but that is true only on poorer soils. In contrast, in areas flooded each year (such as the Horka forests), mud brings in enough fertility and the water would wash away all the leaves anyway. He also discussed financial matters and access by carts in a similar manner. In sum, we can see how Schwarz's opinion on litter raking changed in the fourteen years between 1835 and 1849 from little interest to active rejection to balanced view through deeper involvement and perhaps understanding. This reflects, if not the evolution, then certainly the diversity of opinions on litter raking in forestry circles in and beyond the Czech lands in the same period.

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<sup>55</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 50.

<sup>56</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 86–87.

<sup>57</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 102.

<sup>58</sup> Anton Prokop Schwarz, 'Ueber die Verjüngung des Buchenhochwaldes durch Besamungs- und Lichtschläge', *Mittheilungen der k.k. Mährisch-Schlesischen Gesellschaft zur Beförderung des Ackerbaues, der Natur- und Landeskunde in Brünn* 31 (1836): 233–236, 241–243. For his handbook proposal, see Josef Nožička, *Přehled vývoje našich lesů* (Praha: Státní zemědělské nakladatelství, 1957), p. 218.

<sup>59</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, 198–200.

Local forester Joseph Rabenseifer represented the lowest, most practical level of forestry in Horka. He was born in 1790 not far from Olomouc, which means that at the time of the Horka incident in 1845 he was 55 years old. He started his forestry service (probably as a Waidjung) at the age of nineteen. He had no formal forestry education. For a long period he was in charge of the tree garden and was promoted to district forester of Horka in 1840, when he was 50 years old. This represented the average age among district foresters in the Olomouc Waldamt. In other words, Rabenseifer's career was ordinary by all accounts.<sup>60</sup> We even know a little about his personality, because in 1852 the Waldamt conducted a survey of its personnel including their 'moral and professional characteristics'.<sup>61</sup> Rabenseifer (at this time already 62 years old) was described as skilful, practical, zealous and reliable. However, on a personal level he was said to be choleric and unbearable (which probably put his wife Eleonora in an unpleasant situation on the evening of 27 October 1845). He died four years later in 1856.<sup>62</sup> District foresters, like Rabenseifer, in the nineteenth century were treated with respect by their superiors but had limited options to influence their own professional fate.<sup>63</sup> There is copious documentation in the Olomouc material about various plans (realised or otherwise) to improve efficiency by moving district foresters and forest youths around among the individual forest districts.<sup>64</sup> We even have a good picture of how the district forester's work was conceptualised by the authorities: there survives from 1852 the oath one Raimund Richter had to take to become a district forester.<sup>65</sup> He swore to maintain the forests in good condition and to follow the rules set by the forest ordinances and his superiors.

However, the top-down attitude emphasised by the Waldamt and the Oberamt masked a reality much more complicated on the ground – and not only because Rabenseifer and his fellow district foresters had to find a *modus vivendi* with the local peasants. Multiple sources indirectly indicate that prior to 1835, district foresters may have been involved in litter raking for their own interest. This is demonstrated, for example, by the pivotal reaction by Rabenseifer's predecessor in the Horka forest district, Johann Stossack, to Oberleutenant Winkler's 1835 proposition to rent litter raking rights.<sup>66</sup> Apparently shocked, Stossack wrote a rather indignant letter to the Oberamt. In this he complained that he had served Olomouc for 29 years and found it very negligent from the city's side that now he would have to get the leaves he needed for his two cows from some other estate. He then attacked Winkler in person, who, he wrote, had a known history of doing injustice to the local peasants. The decision to grant him the litter raking rights therefore 'completely ruined the authority of the overlord [the city]' in front of the peasants. The situation, however, could be remedied, should litter raking be

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<sup>60</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 689, signatura: W3VI, karton 1329, fol. 83–84 and various similar surveys in the same fonds.

<sup>61</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 685, signatura: W3II, karton 1322, fol. 56.

<sup>62</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 685, signatura: W3II, karton 1320, fol. 323.

<sup>63</sup> Zdeněk Orlita, 'Sociální poměry lesnického personálu na hranickém panství v první polovině 19. století', *Střední Morava: vlastivědná revue* 29 (2009): 24–33. For Central Europe, see e.g. Franz Thorsten, *Geschichte der deutschen Forstverwaltung* (Wiesbaden: Springer, 2020); Thomas Götz, 'Der Staat im Wald: Forstpersonal und Forstausbildung im ersten Drittel des 19. Jahrhunderts aus umweltgeschichtlicher Perspektive: Das Beispiel des Rheinkreises', in Christoph Ernst, Bernd-Stefan Grewe and Joachim Kuntz (eds), *Beiträge zur Umweltgeschichte*, vol. 1 (Trier: Universität Trier, 1996), pp. 36–77.

<sup>64</sup> For similar transfers of forestry personnel in Bohemia, see Hana Sedláčková, *Auersperská doména Nasavrky: příspěvek k formování lesní správy velkostatku v 19. století* (PhD thesis, Masaryk University Brno, 2020), pp. 120–122.

<sup>65</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 685, signatura: W3II, karton 1320, fol. 518–519.

<sup>66</sup> SOkA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 20–22.

granted to him, for which he offered 10 florins more than Winkler. Stossack's words show that he himself was using the litter and it is likely that district foresters were involved in illegal selling as well. In his 1839 letter to the Oberamt asking for litter raking to be banned, discussed above, Oberförster Schwarz mentioned the hearsay that local foresters were selling leaf litter for their own profit. Anticipating the accusation that he was pushing for banning litter raking so that his district foresters can continue doing it illegally, he proposed harsh penalties should any forester be caught moving litter out of the forests. Furthermore, we have seen that, even though no direct evidence indicating this was presented, the magistracy was convinced that one way or another Rabenseifer was trying to take financial advantage of litter raking at the expense of the city. It is thus likely that litter raking was originally run as a small private business between district foresters and local peasants. It is also likely that Oberförster Schwarz knew about this but decided to let the matter run its course at the local level until he was pushed from above to engage more.

### THE LOCAL PEASANTS

There is plenty of literature on woodland theft and, more generally, on conflicts between peasants and landlords in forests in the nineteenth century in various parts of Europe.<sup>67</sup> Such conflicts were present in the Olomouc forests as well. According to a letter by Oberförster Schwarz to the Oberamt, in 1845 alone no less than 146 offenders were caught in the Horka forest district committing 'forest crimes,' (almost always wood-theft), of whom 63 paid a compensation fee, 2 received corporal punishment and the rest, who were too poor, faced penal servitude (a few days of forestry work).<sup>68</sup> This represented a very large part of the population of the neighbouring villages, especially considering that many offenders were surely not caught. It appears that, for whatever reason, the locals were ready to break the official rules of forest use. Importantly for the Horka incident, this explains why Rabenseifer was too late to intervene. Rabenseifer, according to his testimony, was already out in the forests at 2a.m. on 27 October 1845 – to watch out for wood thieves, who for obvious reasons preferred to carry out their activities at night. After this night watch, he had to perform his daytime duties and got home too late to stop his wife from handing out litter raking licenses to local women (Fig. 1). Rabenseifer was aware of the impossibility of his task: after the Horka incident, he petitioned the Waldamt to provide him with extra help, which Oberförster Schwarz granted, admitting that forest districts were large and indeed, foresters 'couldn't be everywhere.'<sup>69</sup>

When talking about their motivation regarding litter raking, the locals, as expected, always referred to a lack of the straw that they needed for their cattle. This was so in official petitions as well as in their

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<sup>67</sup> E.g. Uwe Eduard Schmidt, 'Waldfrevel contra staatliche Interessen. Die sozialgeschichtliche Bedeutung des Waldes im 18. und 19. Jahrhundert', *Der Bürger im Staat* 51 (2001): 17-23; Tim Shakesheff, 'Wood and crop theft in rural Herefordshire, 1800–60', *Rural History* 13 (2002): 1–17; Anastasia Fedotova and Elena Korchmina, 'Cattle pasturing as a traditional form of forest use and conflicts between peasants and forestry administration in the long nineteenth century (the case of Białowieża Primeval Forest)', *Global Environment* 13 (2020): 525–554; Stefan von Below and Stefan Breit, *Wald – von der Gottesgabe zum Privateigentum. Gerichtliche Konflikte zwischen Landesherren und Untertanen um den Wald in der frühen Neuzeit* (Stuttgart: Lucius & Lucius, 1998). Such conflicts were not even specific to Europe and analogues can be found in the same period worldwide; see for example Nancy Lee Peluso and Peter Vandergeest, 'Genealogies of the political forest and customary rights in Indonesia, Malaysia, and Thailand', *Journal of Asian Studies* 60 (2001): 761–812.

<sup>68</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 685, signatura: W3II, karton 1321, fol. 78–86.

<sup>69</sup> Státní okresní archiv Olomouc, fond: Archiv města Olomouc, číslo pomůcky: 897, inventární číslo: 685, signatura: W3II, karton 1321, fol. 78–86.

testimonies in the Horka incident. In Horka, we even get glimpses of where exactly most of the litter-fertiliser was intended to end up. Powolny in fact represented a group of Horka inhabitants who rented the so-called Teichtacker, i.e. arable land reclaimed by draining the fishponds at the beginning of the nineteenth century.<sup>70</sup> In addition to the usual claim that crop harvests failed, in his original petition he also argued that the soil of the former fishponds was too infertile and simply had to be manured – employing a mild form of blackmail: if litter raking were not granted, the peasants would not be able to pay their rent to the city.<sup>71</sup> When in need, the peasants were ready to rake litter elsewhere as well. For example, Rabenseifer himself saw people carrying litter in wheelbarrows and carts from the communal forest of Skrbeň and the much larger Jungfernwald right next to it, which belonged to another estate and therefore was not his concern. According to her testimony in the Horka incident, local resident Marianna Beza also raked litter from trees that stood on her land but belonged to the village. Another villager, Marianna Albrecht, reported that she had taken leaves from her garden and also from the Horka ‘common ground’ – presumably wooded pasture.<sup>72</sup> But peasants may also have been interested in litter raking permits for reasons that were not committed to paper. One of these was access to forests. Once in possession of a permit, peasants could legally enter the forest at lower risk of being fined for whatever they were doing there. This is why in 1835, when other renters of hunting rights joined Oberleutenant Winkler in his effort to rent litter raking, they mentioned that the peasants used litter raking as a pretext for poaching.<sup>73</sup>

Generally speaking, peasants were clearly in need but they seem not to have been oppressed in any significant way as regards litter raking: the battle cries of forestry were paid little heed on the ground. The Olomouc sources in fact suggest that peasants relentlessly pushed their own agenda and usually got what they wanted – the Horka incident being one of the few exceptions. But even here, Powolny was not held responsible for anything that transpired. As I mentioned earlier, the system was set up in a way that the only responsibility of the peasants was damage to trees. Until 1840 litter raking was not even on the list of punishable ‘forest crimes’ in Olomouc. In other words, peasants risked little, at least financially, by raking litter illegally. Powolny himself appears to have been unmoved by the 1845 case. When, seven years later in 1852, dozens of peasants again petitioned the city of Olomouc for permission to rake litter in the Horka forest district, the first in the list of signators was Powolny.<sup>74</sup> By this time the peasants had also learned to employ the language of forestry to their advantage. The justification for the petition went beyond the usual complaint about poor grain harvest this time, and included several points raised by Oberförster Schwarz in 1849, for example that the floods would wash the litter away in any case.

As attested by the Horka case, litter raking was carried out almost invariably by local residents who owned very little arable, or none at all. Sixteen of them were in the social category *Häusler* or *Gärtler*, meaning they only had a house and a garden, unlike better established villagers with their own inheritable plots. Five people who testified were even lower in social ranking and did not have their own house. Two witnesses were elderly people who lived in their children’s households. With growing population but a limited number of peasant plots (even if these had been subdivided), this layer of village society became increasingly numerous – especially from the late eighteenth century onward –

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<sup>70</sup> Bartos, Müller and Kovářová, *Horka nad Moravou*, p. 33. On fishpond drainage, see Jindřich Frajer, ‘Zrušení druhanického rybníka u Chotusic aneb environmentálně historická mikrosonda’, *Východočeský sborník historický* 27 (2015): 103–125.

<sup>71</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 115.

<sup>72</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 122–135.

<sup>73</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 11.

<sup>74</sup> SOKA Olomouc, Archiv města Olomouc, inv. č. 692, karton 1333, fol. 239–240.

adding much to the pressure that led to the abolishment of the old system of land tenure in 1848.<sup>75</sup> To make ends meet, they often rented arable from the landlord, a typical example being the group of Teichtacker renters that Powolny represented. Remarkably, women played a significant role in litter raking, at least as reflected in the Horka incident. Of the 28 people who testified, 15 were women. In some cases, it was specified that they represented their husbands, but more often they appear to have acted on their own.<sup>76</sup> Little is known about the role of women in non-timber forest management. For ecologically oriented historical investigations this topic is moot, while environmental historians – who otherwise have a keen interest in gender aspects – have not, to my knowledge, tackled the issue with the exception of Gimmi and Bürgi, whose oral history interviews and accompanying historical photographs in Switzerland showed that litter raking was often the responsibility of women and children.<sup>77</sup> Something similar is indicated not only by the high number of women involved in the Horka incident but also by the role Eleonora Rabenseifer played in these events.

## CONCLUSIONS AND OUTLOOK

The Horka litter raking incident shows that for two major reasons, regardless of the effects of litter raking on forest ecosystems, the traditional narrative of litter raking in which foresters are defenders and peasants destroyers of the forest is hardly tenable.

Firstly, neither foresters nor peasants can be understood as a homogenous group. The forestry profession was multi-layered and should be interpreted as such: we have seen that official forestry ideology concerning litter raking was not unified, offering multiple points of view that Oberförster Schwarz was ready to turn to his advantage. Further down the ladder, Cotta's ideas looked very different at the forestry school in Tharandt than in the muddy forests around Olomouc. So much so, that in some sense it is easier to see Rabenseifer (and certainly Eleonora) as part of the peasantry than part of scientific forestry. As I have argued above, Rabenseifer acquired his forestry skills from practice rather than formal education, so one can assume that the attitude vis-à-vis forests of the community in which he grew up was also a heavy influence on his perspective. Although he represented the Waldamt and had conflicts with the peasants, he was too close to the local community – which necessarily carried consequences. This is why, once his position was compromised, the city authorities had no choice but to remove Rabenseifer from Horka. Overall, Paul Warde's words appear to describe the situation rather precisely: 'Forestry was not a panacea but itself a discursive construct that shaped practice, related to education, style, bearing, class and culture rather more than tried and tested techniques for delivering more wood.'<sup>78</sup> Furthermore, as far as litter raking is concerned, 'local peasants' really only meant less wealthy peasants (especially women), although this layer at this point

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<sup>75</sup> Ivana Německová, 'Sociální stratifikace panství Horšovský Týn v letech 1654–1848', *Historická demografie* **36** (2012): 145–175; Jaroslava Honcová, 'Sociální postavení domkářů a bezzemků v poslední fázi feudalismu (1781–1848)', *Genealogické a heraldické listy* **17**, no. 3–4 (1997): 29–37.

<sup>76</sup> Perhaps some were widows. For the position of widows in this time and place, as well as the choices they faced, see Alice Velková, 'Sebevědomé, nebo zoufalé? Vdovy hospodařící na venkovských usedlostech v první polovině 19. století', in Milan Vojáček (ed.) *Reflexe a sebereflexe ženy v české národní elitě 2. poloviny 19. století* (Praha: Scriptorium, 2007), pp. 321–340.

<sup>77</sup> Urs Gimmi and Matthias Bürgi, 'Using oral history and Forest Management Plans to reconstruct traditional non-timber forest uses in the Swiss Rhone valley (Valais) since the late nineteenth century', *Environment and History* **13** (2007): 211–246. For a contemporary analysis, see Eric A. Coleman and Esther Mwangi, 'Women's participation in forest management: A cross-country analysis', *Global Environmental Change* **23** (2013): 193–205.

<sup>78</sup> Paul Warde, 'Review of *Umkämpfte Wälder: Die Geschichte einer ökologischen Reform in Deutschland 1760–1860*, by Richard Hölzl', *German History* **31** (2013): 421–422.



already represented the majority in many Czech villages. Social stratification was a significant factor in this period<sup>79</sup> and little is known about the attitudes of members of the village elite concerning litter raking. Hidden conflicts came to the surface especially after 1848, when serfdom was abolished and peasants became owners of their land. Those who had no land were even more sharply divided from the 'landed' peasants, and the latter often tried to claim lands previously used in common.<sup>80</sup> Although it is beyond the scope of this paper, it is worth noting that the revolutionary years at the end of the 1840s changed the dynamics of discussions on non-timber forest uses. Notably, the rhetoric of higher forestry circles became especially harsh. In its very first issue in 1849, the journal of Bohemian foresters described the doings of peasants in forests in the darkest terms: 'untameable or misguided hordes attacked the sanctuary of Silvanus and Diana. Here stems succumbed to the saw and axe, there in the hopeful young stands the protective cover of the soil was robbed to the last trace of moss and litter.'<sup>81</sup> With this ideological ammunition, the aim was to eliminate litter raking (and other non-timber uses) wherever possible through compensating the peasants either in money or in land. Much of the literature on litter raking in the 1850s focused on the complicated issue of implementing this compensation.

Secondly, opinions and attitudes were not static on either side but were modified through discursive patterns between the actors. We have seen how Oberförster Schwarz changed his opinion on litter raking several times, reacting flexibly to pressure from below as well as above. As for Rabenseifer, he had to navigate the complicated waters between the locals – with whom, as we are led to believe by the magistracy, he had teamed up to abuse litter raking – and his superiors, a challenge he eventually failed with dire but not fatal consequences. In contrast, the opinions of the peasants appear to have been less changeable. This may stem from the fact that we hear their voices usually in connection with petitions for litter raking, but even in this limited space there are signs of flexibility: the peasants gradually learned to employ forestry terminology when it seemed useful. Furthermore, as Richard Hölzl noted in connection with Spessart municipalities in the same period, legal struggles over forest rights helped the locals to formulate their own opinions and even a common identity – as attested, for example, by the joint petition of Teichtacker renters in Horka.<sup>82</sup> Along the same lines, Joachim Radkau has argued that early modern forest litigation in Europe was exceptional enough to earn special significance even in world environmental history:

It was not the authorities alone who benefited from the juridification of forest usages; other forest users were able to ward off encroachments from higher up. And that, precisely, is the crucial point: various users were able to struggle over forest rights by legal means. The back and forth of charges and countercharges gave rise to a keener perception of what was happening in the woodlands, and the forest awareness to which this gave rise had practical consequences.<sup>83</sup>

In this sense, the exceptionally detailed sources connected to the Horka litter raking incident allow for a rare glance at processes that were, *mutatis mutandis*, happening in many other places too, and thus

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<sup>79</sup> Německová, 'Sociální stratifikace'.

<sup>80</sup> For serfdom and conflicts between well-off and poorer layers within the peasantry, see e.g. Josef Kočí, 'Petice vesnické chudiny k říšskému sněmu 1848–1849', *Sborník prací Filozofické fakulty brněnské univerzity: řada historická* 33 (1984): 155–161; Pavel Kladiwa, 'The issue of "robot" and of hereditary subjection at the Vienna Reichstag during the revolution of 1848', *Hospodářské dějiny* 27 (2012): 3–29.

<sup>81</sup> Anonymous, 'Ueber die Gründung des Vereins böhmischer Forstwirthe', *Vereinsschrift für Forst-, Jagd- und Naturkunde* 1 (1849): 9–10.

<sup>82</sup> Hölzl, 'Forests in conflict', 216–217.

<sup>83</sup> Joachim Radkau, *Nature and Power* (Washington, DC: German Historical Institute and Cambridge University Press, 2008), p. 187.

have more general relevance. As a steadily growing rural population became more vocal and assertive as regards its needs, it was confronted by scientific forestry, which, backed by state authority, represented a more restrictive attitude to forest use. The complex and multi-layered conflicts resulting from this encounter contributed to formulating a new concept of forests, which is still with us today.

#### ACKNOWLEDGEMENTS

This paper was supported as a long-term research development project no. RVO 67985939 and by grant TO01000132 from the Technological Agency of the Czech Republic. I would like to thank Zbyněk Sviták for his help with understanding the administrative structure of the Olomouc estate, Rudolf Brázdil and Petr Dobrovolný for providing me with weather data and Jiří Woitsch for his useful comments on an earlier version of this paper.

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# Traditional agroforestry on forested land: a comprehensive analysis of its distribution pattern in the 19th century

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Received: 3 February 2023 / Accepted: 21 August 2023 / Published online: 8 September 2023  
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**Abstract** Traditional agroforestry on agricultural land was common in the past in Central Europe. However, much less is known about agroforestry on forested land, especially because it was often banned by forestry authorities during the 20th century. We used data from the so-called stable cadastre to map the occurrence of agroforestry uses (litter raking, hay cutting and forest grazing) on forested land in the mid-19th century in Moravia (eastern part of the Czech Republic, ca. 27,000 km<sup>2</sup>) in high spatial resolution. We combined machine learning algorithms and logistic models to reveal which environmental, land use and forest management factors could be linked to the occurrence of individual agroforestry uses. Results showed that agroforestry on forested land was very common in the 19th century: only 9.2% of townships with forests had no agroforestry

uses. The distribution of agroforestry uses was clearly connected to environmental factors and to the availability of agricultural products that agroforestry uses were meant to supplement (e.g. hay cutting in forests was the most common in townships with large forests and few grasslands). However, the ubiquity of some uses (especially litter raking) made it more difficult to arrive at straightforward conclusions. In addition, we discussed the limitations inherent in the stable cadastre and how these might influence the interpretation of the results.

**Keywords** Agroforestry · Hay cutting · Litter raking · Forest grazing · Forest management

## Introduction

Agroforestry (AF) is defined in Article 23 of the Rural Development Regulation 1305/2013 of the European Commission as “land use systems in which trees are grown in combination with agriculture on the same land.” Dupraz et al. (2018) classified agroforestry systems based on whether trees occur within parcels (silvopastoral, silvoarable and agrosilvopastoral AF) or between parcels (linear AF). Using a somewhat different approach, McAdam et al. (2010) created several typologies based for example on components, predominant land use or spatial and temporal arrangement. What all existing typologies have in common is a reliance on AF systems that are currently being

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practiced. While this approach is understandable, such classifications may not cover all AF types that existed in the past. This is important because agroforestry is an ancient land use system that has gone through many changes (Dupraz et al. 2018). A defining feature of AF is diversity, which has a diachronic aspect as well: the dynamic relationship between trees and agriculture could manifest itself in various forms determined by contemporary environmental and socioeconomic conditions. Such conditions are never stable, therefore understanding AF practices in the past can significantly contribute to their sustained use in the future (Lojka et al. 2022).

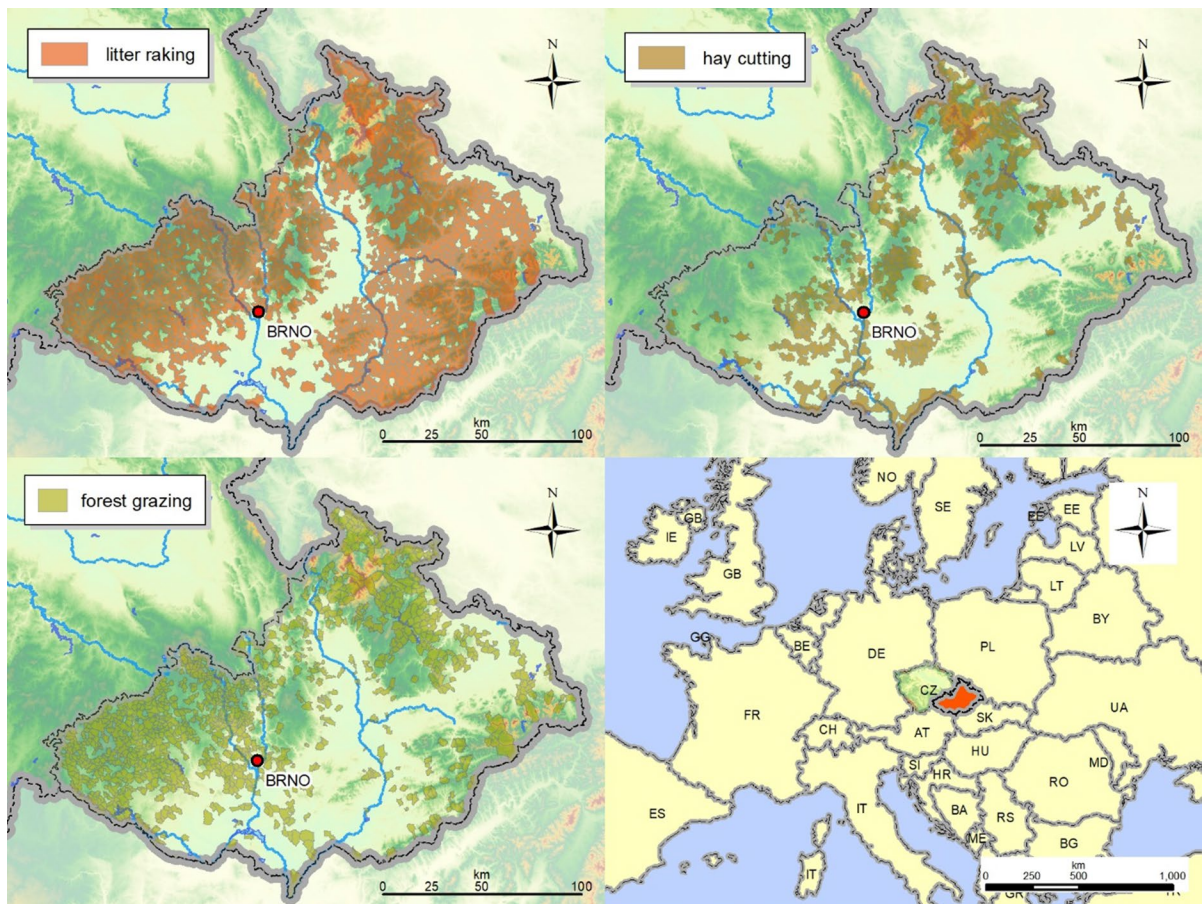
AF systems have had various trajectories through time. Some forms have been continuously practiced for millennia. Forest grazing, for example, is still important in many parts of Europe (Vera 2000; Szabó 2009; Hartel and Plieninger 2014). Other forms, such as the gathering of tree leaves for animal fodder, were once widespread but are currently rarely practiced in Europe (Dupraz et al. 2018). In contrast, they are still predominant in many parts of Asia, especially in mountain regions (Khadka et al. 2021; Dhyani et al. 2013). Still other types could disappear and resurface under various denominations: such as *Waldfeldbau* in the 19th century and the analogous alley cropping in modern times (Bürgi and Stuber 2003; Dagar and Tewari 2017). Lastly, there are AF uses that virtually disappeared in Europe alongside the ecological knowledge that maintained them as parts of traditional agroecosystems. Such uses typically included AF on forested land. Pre-industrial forests in Europe had multiple AF uses, such as forest grazing, litter raking or hay cutting. However, since the 19th century, scientific forestry has gradually eliminated most of these uses in its effort to focus solely on timber production. Apart from grazing, only the gathering of non-wood products (e.g. mushrooms, berries, nuts or saps) has retained some of its former importance (Lovrić et al. 2020). While it is usually assumed that AF uses in forests were very common, data to support this assumption are missing and conclusions are inferred from the hypothetical demand for AF products (Gimmi et al. 2008).

AF uses in forests served specific roles in local livelihoods in Europe. In a sense, they aimed to supplement or substitute agricultural products. Hay cutting in forests (not to be confused with formal meadows), for example, existed to provide additional hay

for the winter feeding of domestic animals. At the same time, it created more open forest stands and influenced tree regeneration (Jamrichová et al. 2013). Forest grazing, which had a similar ecological effect, served the needs of the same animals outside wintertime. Litter raking provided a substitute for straw in the form of tree leaves to be used as bedding in stalls and eventually as fertilizer (Szabó 2021a). It also promoted a reduction in soil carbon pools and exported large quantities of nitrogen from forests to agricultural land, thus modifying soil conditions (Gimmi et al. 2013; McGrath et al. 2015). Given the above, it can be expected that the presence of particular AF uses was related to the availability of the given primary product at appropriate spatial scales and also to environmental, land use and forest management factors (Gimmi et al. 2008). However, the relationship between such factors and the former distribution of AF uses on forested land is virtually unknown.

With the advancement of computer programming, the development of robust predictive algorithms has offered tools that can be used to predict the occurrence of a wide range of phenomena, events or conditions, including forest management (Kusters et al. 2020; Rana and Varshney 2021). These algorithms include traditional regression and supervised machine learning models, such as logistic regression and Random Forest (RF), respectively (Lin et al. 2011; Bavaghar 2016; Shabani et al. 2020). Although predictive algorithms, especially machine learning, have been increasingly applied to classify and map the occurrence of agriculture and forestry activities (Meshram et al. 2021; Cheng et al. 2022), studies directly related to AF systems are rare (e.g. Ahmad et al. 2019; Singh et al. 2022) and have so far hardly tackled the history of AF (but see Krčmářová and Jeleček 2017).

The main aims of this paper are therefore to comprehensively map the distribution of AF uses on forested land in the 19th century in a well-defined region in Central Europe and, with the help of predictive algorithms, to understand what factors were related to their distribution. More specifically, we ask the following interconnected questions: (1) What was the spatial distribution of the most common AF uses on forested land in the 19th century? (2) Which environmental, land use and forest management factors can be linked to the occurrence of individual AF uses?



**Fig. 1** The distribution of litter raking, hay cutting and forest grazing in the 19th century in Moravia, as recorded in the stable cadastre

## Methods

### Study site

We conducted our study in Moravia and Czech Silesia (together c. 27,000 km<sup>2</sup>) in the eastern half of the Czech Republic in Central Europe (Fig. 1). A historic region within the Czech Lands, Moravia enjoyed relative independence from the Middle Ages until the 20th century. The territory of Czech Silesia was formed following the division of Silesia between Prussia and the Habsburg monarchy in the mid-18th century. As Moravia and Czech Silesia were often administratively united, for the purposes of this paper we refer to them together as Moravia. The area has a temperate climate with mean annual temperatures of 1–10 °C and precipitation of 500–1500 mm.

Landforms include lowlands as well as mountains of max. 1491 m a.s.l. Approximately one third of the area is covered by forests. A low-lying, wide and mostly treeless belt of agricultural settlements separates highlands in the west from more mountainous areas in the north and east. Moravia is made up of 3567 townships. A township is essentially a village and its surrounding lands including arable, forests, meadows and pastures. Townships have deep historical roots and were formalized as the lowest tier of local administration in the 18th century (Szabó et al. 2017).

### Data collection

To map the presence and absence of AF uses in forests in the 19th century, we used the so-called stable



cadastre. This cadastral survey was prepared in the first half of the 19th century and has been proven to be a useful source of information in historical geographical and ecological investigations (e.g. Bičík et al. 2015; Vild et al. 2018). Surveys for Moravia and Czech Silesia were prepared separately (with identical methodology) and are kept at the Moravian Provincial Archive in Brno and the Silesian Provincial Archive in Opava, respectively. Part of the cadastral survey was a protocol of the forest commission, which included information on the size and management of forests as well as on the presence of AF uses (*Nebennutzungen* in the German original) for each township. The forest protocol recorded three types of AF uses: litter raking, hay cutting and forest grazing. It sometimes contained information on the level of individual forests within townships. To homogenize the data, we aggregated the forest areas and recorded the prevalent management type (high forest or coppice) for each township. In addition, we deducted from the dataset pastures with trees, which were recorded in the forest protocol but did not in fact concern forested land (cf. Forejt et al. 2017). In spite of the comprehensive nature and excellent preservation of the stable cadastre, for some townships we could not identify suitable information. For these, we used data from the so-called *Forststatistik von Mähren und Schlesien*. Published in 1853–1857 in the journal of Moravian and Silesian foresters (*Verhandlungen der Forst-Section für Mähren und Schlesien*), this survey was based on questionnaires sent out to foresters and recorded information on agroforestry uses for individual townships. The resulting combined dataset contains information on 2857 townships. 475 townships had no forests in this period. For 235 townships, no data were available. The majority of these townships either fell outside Moravia in the 19th century or have been created since the mid-19th century. Preliminary and spatially incomplete versions of agroforestry use on forested land were published by Szabó et al. (2018) and Vild et al. (2018).

We extracted information for each township on mean annual temperature and mean annual precipitation from the WORLDCLIM database and on mean elevation from SRTM elevation data (cf. Szabó et al. 2015). We also used average agricultural soil prices established by the Czech Ministry of Agriculture in

1996 as a proxy for soil fertility.<sup>1</sup> Furthermore, we established the proportion of permanent grasslands (meadows and pastures) and arable in each township based on the so-called Second Military Survey, a detailed mapping of the study area in the mid-19th century. For these purposes and for data visualisation, we used current township boundaries, which are not always identical with 19th-century boundaries but have strong continuity (see also Krčmářová and Jeleček 2017). The final dataset consists of the presence and absence of litter raking, hay cutting and forest grazing as target variables, as well as seven numeric variables for each township (mean elevation, mean annual precipitation, mean annual temperature, soil price in 1996, size of forests, proportion of arable land, proportion of permanent grassland) and one factor variable (forest management type: high forest or coppice) as predictors.

### Statistical modelling

To investigate the influence of environmental, land use and forest management predictors on the occurrence of the three AF uses (forest grazing, hay cutting and litter raking), we combined two distinct but related approaches: supervised learning classification and logistic models. These two approaches are complementary: machine learning algorithms are recognized as efficient and robust for making overall predictions, regardless of the nature of the relationship (i.e. positive or negative) and rank the importance of the predictor variables for the occurrence of the target variable. Logistic models, on the other hand, complement this information by showing the specificity of the relationship. Prior to modelling, we calculated Spearman's rank correlation coefficients among the numeric variables to evaluate their levels of multicollinearity considering  $<0.70$  as threshold for cutting-off coefficients (Dormann et al. 2013). All predictors satisfied this criterion and were kept in the models.

### Supervised classification of agroforestry types

We used Random Forest (RF) as the supervised learning classifier to predict the occurrence

<sup>1</sup> As contained in laws no. 215/1995 Sb. and 282/1996 Sb. of the Ministry of Agriculture.

(0-absence; 1-presence) of the AF types, given its recognized predictive power (Breiman et al. 2017; Diniz et al. 2021; Svoboda et al. 2022). Such predictive efficiency can be mainly attributed to the framework of RF based on decision trees employing ‘bootstrap’ aggregation, which reduces error rates of the predictions and increases the stability of the results (Breiman et al. 2017). For that, the RF algorithm randomly selects a set of observations to construct multiple decision trees and train its model (Khaledian and Miller 2020); the constructed trees underlie the computing of the estimated residual squared error. To train the model, we split the database into two subsets using the function “createDataPartition” of the package “caret” (Kuhn 2008): training (70%) and test (30%) samples. From the training model (70%), the algorithm ranked the importance of the predictors for the RF classifications (Breiman 2001; Grömping 2009). We evaluated the importance of each predictor based on the ranked mean values from the Gini index, calculated using the function “importance” of the “randomForest” package (Liaw and Wiener 2002). The higher the value of the Gini index, the higher the importance of the predictor (Strobl et al. 2008; Grömping 2009). The test model (30% of the data) was used to compute the errors from the average of the variance of all trees built and to estimate the overall predictive performance of the RF models (Breiman 2001; Khaledian and Miller 2020). The overall classification performance of the RF models was evaluated based on the metrics accuracy rate (%) and Kappa index calculated by using the function “confusionMatrix” of the package “caret”—the closer to 1 their values are, the better the performance. In order to enhance the predictive power of the RF algorithm, we additionally tuned two important hyperparameters in the models using the function “tuneRF” of the package “randomForest”: mtry (number of predictors randomly sampled at each split of the decision trees) set using all predictors, and ntree (number of trees to grow during the iterations) set as 500 trees. All procedures were performed in the R programming environment.

#### *Logistic modelling of agroforestry types*

Complementarily to RF supervised classification, we created logistic regression models from

generalized linear models (GLMs) with binomial distribution for evaluating direct relationships by estimating coefficients between the target variables and the predictors. Logistic regressions model the probability of a set of predictors to explain the presence or absence of a target variable (Hosmer and Lemeshow 2000; Agresti 2002). For that, the coefficients in the models are typically estimated from the maximum likelihood (Menard 2002). Each coefficient indicates the odds of occurrence of the target variable (litter raking, forest grazing, hay cutting) given the influence of a predictor provided all else being equal: positive numbers indicate increased likelihood of influence in the occurrence of the target variable, while negative numbers indicate decreased likelihood (Hosmer and Lemeshow 2000; Menard 2002). We evaluated the explanatory significance of the predictors for the occurrences of AF types by computing likelihood-ratio tests (LR Chisq) for each model using the function “Anova” of the package “car”. This test is based on a chi-square distribution with a single degree of freedom and is therefore appropriate to derive explanatory significances in logistic models (Menard 2002). Further, we calculated the variance inflation factor (VIF) using the function “vif” of the package “car” for all models in order to assure that they are not biased by severe multicollinearity effects in the estimated coefficients (Gareth et al. 2017). We considered values of  $VIF < 5$  as the cut-off for keeping a predictor in the model (Zuur et al. 2010), and all predictors fulfilled this criterion. Finally, we evaluated the overall performance of the models to predict the probability of occurrence of the AF types by adjusting their curve fit: the ROC (Receiver Operating Characteristics) curve in relation to its AUC (Area Under Curve), i.e. AUROC. AUROC demonstrates the true positive rate against the false positive rate. The true positive rate (sensitivity) represents the rate of correct prediction of the occurrence of the target variable, whereas the false positive rate (specificity) indicates the correct prediction rate of its absence. The closer the AUROC value to 1 (100%), the higher the performance of the model (Manel et al. 2001).

**Table 1** Performance of the Random Forest supervised learning algorithm to predict the occurrence of agroforestry types

| Agroforestry use | Accuracy | Kappa |
|------------------|----------|-------|
| Hay cutting      | 0.83     | 0.73  |
| Forest grazing   | 0.78     | 0.72  |
| Litter raking    | 0.84     | 0.79  |

## Results

### Occurrence and spatial distribution of agroforestry uses

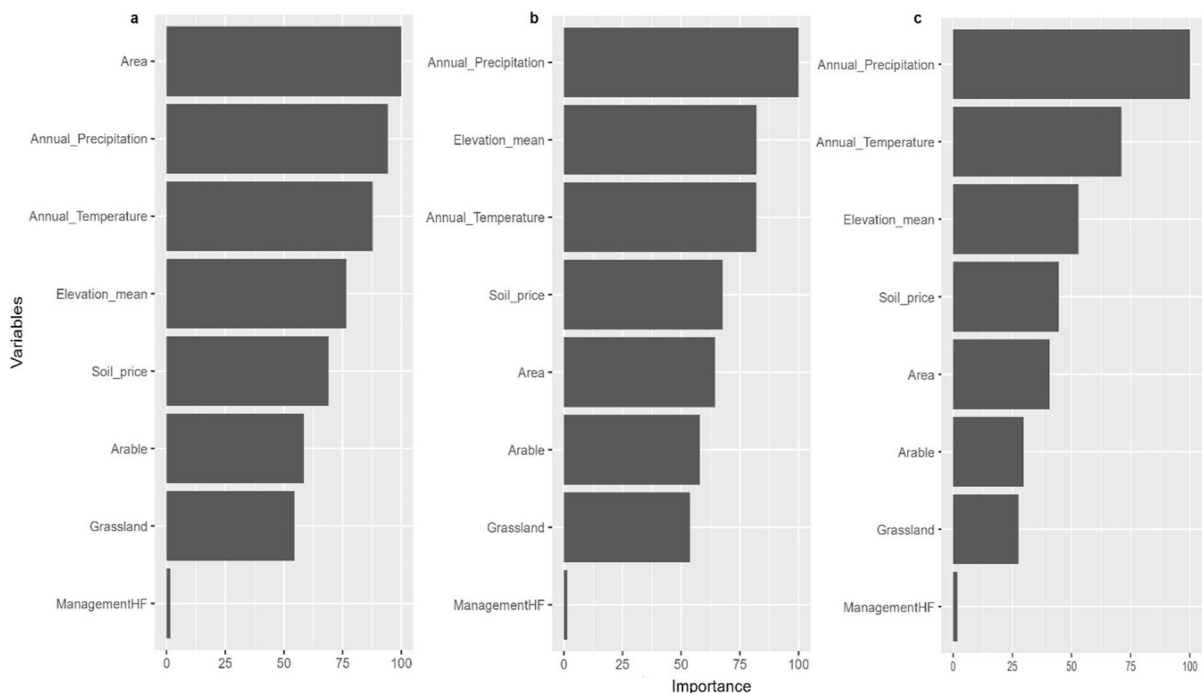
Our data demonstrated that agroforestry was very common in Moravian forests in the 19th century. There were only 263 townships (9.2% of townships with forests) where no AF uses were recorded. The most common AF use was litter raking (2276 townships, or 79.6% of townships with forests), followed by forest grazing (1212 townships, 42.4%) and hay cutting (596 townships, 20.8%). The geographic distribution of AF uses was uneven (Fig. 1). Litter

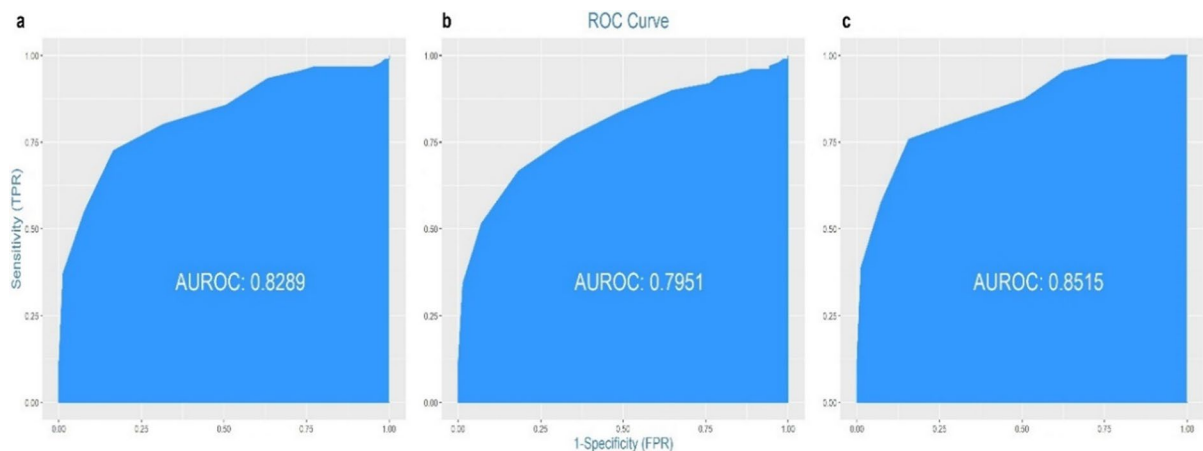
raking, while almost omnipresent, was missing in a wide area along the lowland belt that cuts Moravia in half. Forest grazing was very common in the western highlands and northern mountains but was rare in the east. Hay-cutting presented a more-or-less inverted version of the distribution of litter raking: it was especially common along the lowland belt, but also in the mountains in the north.

### Predicting the distribution of agroforestry uses

The supervised learning classification of the occurrence of AF uses with RF displayed good predictive performance, as demonstrated by Kappa ranging from 0.73 to 0.79, and accuracy ranging from 0.78 to 0.83 (Table 1).

Regarding the importance of predictors in the RF models for classifying AF uses, annual mean temperature, annual mean precipitation and mean elevation were the most important ones for predicting litter raking and forest grazing (Fig. 2). For hay cutting, forest area was the most important predictor. For all models, soil price (i.e. fertility) exhibited

**Fig. 2** Importance of predictors for the Random Forest algorithm to classify the occurrence of agroforestry uses (**a** hay cutting; **b** forest grazing; **c** litter raking)



**Fig. 3** Performance of the logistic regression in explaining the occurrence of agroforestry types (**a** hay cutting; **b** forest grazing; **c** litter raking) demonstrated by the percentage of AUROC

(ROC—receiver operating characteristics curve in relation to the AUC—area under curve)

**Table 2** Significance of the predictor variables in the logistic models explaining the likelihood of the occurrence of agroforestry uses

| Predictor            | Hay cutting |          | Forest grazing |          | Litter raking |          |
|----------------------|-------------|----------|----------------|----------|---------------|----------|
|                      | LR Chisq    | <i>p</i> | LR Chisq       | <i>p</i> | LR Chisq      | <i>p</i> |
| Management           | 0.32        | 0.574    | 8.90           | 0.003    | 55.41         | <0.001   |
| Area                 | 33.70       | <0.001   | 1.59           | 0.207    | 25.54         | <0.001   |
| Mean elevation       | 6.34        | 0.012    | 120.33         | <0.001   | 20.83         | <0.001   |
| Annual temperature   | 6.97        | 0.008    | 65.49          | <0.001   | 2.48          | 0.115    |
| Annual precipitation | 38.31       | <0.001   | 106.49         | <0.001   | 24.40         | <0.001   |
| Soil price           | 0.05        | 0.823    | 36.77          | <0.001   | 20.19         | <0.001   |
| Arable               | 30.58       | <0.001   | 52.73          | <0.001   | 8.42          | 0.004    |
| Grassland            | 27.60       | <0.001   | 19.66          | <0.001   | 9.13          | 0.003    |

LR Chisq: likelihood-ratio chisquare test; *p*: value of significance

intermediate predictive importance, whereas forest management was the least important.

Similar to the RF results, logistic models also showed good overall predictive performance, reaching >0.75 when evaluating the rate of certainty in the AUROC of the models regarding the relationship between the sensitivity of the occurrence and the specificity of the absence of AF uses (Fig. 3). In other words, all three models reached good predictive power without serious misclassifications.

Among the predictor variables, only annual mean temperature did not significantly influence the performance of the logistic model in predicting the likelihood of the occurrence of litter raking. For hay cutting, forest management and soil price did not exert a significant effect. The forest grazing model

was not significantly explained only by the area of the forest (Table 2).

More specifically, litter raking was significantly more likely to occur at sites with higher presence of coppice management and under higher annual mean precipitation, but less likely to occur at higher ranges of elevation, forest area, soil price, proportion of arable land and proportion of grasslands. Hay cutting was significantly more likely to occur with larger forest area and at higher elevation and mean temperature, but less likely with high mean precipitation and larger proportion of arable land and grasslands. Forest grazing was more likely to occur with high forest management, at higher elevations and temperature and larger proportions of arable land and grasslands, but less likely under high

**Table 3** Coefficients of the relationships between the predictors and agroforestry uses, and their significance

| Variable             | Hay cutting |          | Forest grazing |          | Litter raking |          |
|----------------------|-------------|----------|----------------|----------|---------------|----------|
|                      | Coef.       | <i>p</i> | Coef.          | <i>p</i> | Coef.         | <i>p</i> |
| Management C         | 0.47        | 0.622    | − 5.90         | <0.001   | 2.26          | 0.018    |
| Management HF        | − 0.08      | 0.574    | 0.36           | 0.003    | 1.00          | <0.001   |
| Area                 | 0.04        | <0.001   | 0.09           | 0.205    | − 0.04        | <0.001   |
| Mean elevation       | 0.02        | 0.012    | 0.01           | <0.001   | − 0.03        | <0.001   |
| Annual temperature   | 0.29        | 0.008    | 0.85           | <0.001   | − 0.17        | 0.117    |
| Annual precipitation | − 0.01      | <0.001   | − 0.01         | <0.001   | 0.04          | <0.001   |
| Soil price           | 0.01        | 0.823    | − 0.16         | <0.001   | − 0.13        | <0.001   |
| Arable               | − 0.02      | <0.001   | 0.02           | <0.001   | − 0.09        | 0.004    |
| Grassland            | − 0.03      | <0.001   | 0.02           | <0.001   | − 0.02        | 0.002    |

Coef.: coefficient;  
*p*: significance value

precipitation, high soil price and high occurrence of coppicing (Table 3).

## Discussion

### Ubiquity of agroforestry uses on forested land

Krčmářová and Jeleček (2017) argued that even though AF on agricultural land is practically unknown in the Czech Republic at present, it was very common in the 19th century and occurred in almost every township. Our results complement this conclusion by demonstrating that AF was widespread in forests as well. Based on these two studies, it is clear that a combination of agriculture and forestry was prevalent in 19th-century land management. This also implies that the sharp division between land uses that was depicted on the maps of the stable cadastre was probably less well-recognizable on the ground. Based on the analysis of parcel boundaries on the maps of the stable cadastre, Forejt et al. (2018) argued that the division line between pastures, wooded pastures and forests was especially blurry. In accordance with these findings, our results suggest that agricultural and forestry uses formed a dynamic mixture that gave way to the current system of sharply differentiated monocultures (of trees or agricultural crops) only after the mid-19th century. In spite of the fact that AF was very common, we emphasize that the amount of forested land under AF use cannot be easily calculated. The stable cadastre simply noted that a given AF use was present in a township without specifying the proportion of forests where this use in fact occurred. Details were sometimes provided

(for example that litter was raked in some forests but not in others), but recording was inconsistent. Local studies confirmed that AF uses were always closely regulated and were never present in all forests stands (Szabó 2021a).

### Predicting the occurrence hay cutting, forest grazing and litter raking

Our predictions of the occurrence of AF uses from RF classification were accurate, which signified a robust statistical framework (Hegulich 2016; Khaledian and Miller 2020). The logistic models also showed good predictive performance, and, therefore, appear to be a useful tool to refine the RF outcomes by reliably specifying the kind of relationships (positive or negative) between the AF types and the predictors of their occurrence (Hosmer and Lemeshow 2000). Of the three agroforestry uses discussed in this paper, hay cutting showed a pattern of relations closest to expectations. RF classification suggested that the size of forests was the most important predictor for the occurrence of hay cutting. Logistic models provided further details: hay cutting typically occurred in townships with large forests where the proportion of grasslands was low. In other words, hay was cut in places where permanent grasslands could not provide enough hay. This also illustrates that hay from forests was indeed meant as a supplementary product: where local grasslands sufficed, hay was typically not mown in forests. This was understandably so, because hay cutting in forests is a cumbersome activity that had to be closely regulated and monitored. Already in the 17th century, forest management instructions from the region pointed out the dangers of destroying



tree saplings and coppice shoots through the careless use of scythes or sickles (Müllerová et al. 2014). The occurrence of hay cutting was positively and negatively related to temperature and precipitation, respectively, which reflected the fact that this AF use was mostly concentrated towards relatively warmer and drier areas. In addition to the forested mountain region in the north, townships with larger forests were especially common along the treeless lowland belt in central Moravia. This was partly because lowland regions featured high population densities and therefore a high need for firewood, which—given transport conditions—could not be brought from large distances (Szabó et al. 2015). At the same time, lowland regions were highly agricultural with few grasslands. In such socioecological circumstances, there was an increased need for hay cutting in neighbouring forests. However, it should also be noted that forests in lower-lying regions were probably more open than mountain forests (Miklín and Čížek 2014), and such open stands provided favourable conditions for hay cutting (Jamrichová et al. 2013), even under coppice management. According to the practical forestry guide attached to the 1754 Czech forest law—the first of its kind in the country—the best quality grass grew in coppice woods, arguably not because of coppicing per se but rather because such woods occurred in regions that favoured grasslands.<sup>2</sup>

Forest grazing was typical at higher elevations under high forest management and on soils of lower fertility, which confirmed the traditional image of this AF use as a highland activity in the Czech Republic (Nožička 1957). Wooded pastures—which, as argued above, may have had a similar physiognomy to grazed forests—were also most widespread in such regions (Krčmářová and Jeleček 2017). Forest grazing was positively related with the amount of arable and grasslands. While the former is clearly connected to less land available for pasturing, the latter is less intuitive and can probably be explained by the spatial distribution of forest grazing. This AF use was most common in the western highlands, which were rich in grasslands. Lastly, the negative relationship of forest grazing with precipitation could be connected with the fact that it was largely absent in the wet eastern

mountains of Moravia. This is a very conspicuous feature of its distribution, and precipitation was highlighted as the most important factor in RF results. However, it is quite possible that it was an artefact of our archival sources, to be discussed below.

Litter raking appears to have been a case of overwhelming need translated into widespread distribution. Such intense use in the 19th century was observed in Switzerland and Germany (Gimmi et al. 2013; Schöllmann 1999) and also outside Europe for example in the Himalayas (Khadka et al. 2021). Its primary drivers were the growing demand for leaves for increasing numbers of livestock (which, because of changes in agricultural production, spent more time in stalls requiring more litter) and a coeval decrease in straw production (Szabó 2021a; Bürgi and Stuber 2003). Because litter raking was so common, our models produced somewhat ambiguous results. As expected, litter—being a substitute product for straw—was typically raked in townships with less arable. Reflecting its inverse distribution vis-à-vis hay cutting, litter raking was negatively related with the size of forests: it was absent in townships that were close to the main agricultural zone of Moravia with sufficient straw. According to the RF model, the most important factor to predict litter raking distribution was increased precipitation, and the logistic models showed a positive relation. This appears to be another expression of the fact that litter raking was conspicuously missing in the drier lowlands. However, why litter raking should be negatively related to elevation would be difficult to explain at this point. The occurrence of litter raking was more common in high forests, which is accordance with existing results (Szabó 2021a), even though management had only a minor influence according to RF classification.

#### Limitations of sources and further possible factors to explain AF distribution

AF uses were very common and their distribution was connected to environmental as well as land management factors. At the same time, some characteristics of distribution patterns—notably the absence of forest grazing in eastern Moravia—appear to be beyond the grasp of the explanatory framework we set up. Lojka et al. (2022) showed that wooded pastures (i.e. pastures with wild trees on them) were very frequently recorded in eastern Moravia in the stable cadastre.

<sup>2</sup> The shelfmark for this archival source is Národní archiv Praha, PT, inv.č. 1498–5.4.1754.

Moreover, these pastures were of a type with extensive tree cover. It is therefore possible (although by no means certain) that for taxation purposes (which were the *raison d'être* of the stable cadastre), vegetation that was otherwise similar was recorded as pasture with trees in eastern Moravia but as forest with grazing elsewhere.

We also note that there might have been further factors that influenced the spatial distribution of AF uses on forested land in the 19th century. Most importantly, the number of domestic animals would have been an obvious candidate (cf. Gimmi et al. 2013). Even though such data are available in the stable cadastre, they have so far not been systematically processed and therefore could not be included in our analyses (cf. also Krčmářová and Jeleček 2017). At the same time, all three AF uses we studied were connected to the provisioning of domestic animals, therefore this factor may not have been overly useful in explaining differences in their distribution. A further possible factor is ownership, because communal forests were probably more intensively used for AF than allodial forests (Szabó 2021a; Nožička 1957). However, in this period communal forests constituted a small minority among all forests in Moravia (Szabó 2021b). Furthermore, as noted above, information on AF uses was aggregated for each township in our database, which could accentuate the role of communal forests in the results.

## Conclusions and outlook

For the first time ever on a regional scale and in high spatial resolution, our results provided a comprehensive picture of the distribution of traditional AF uses in forests in the past. AF on forested land was very common in the 19th century in Moravia. Together with earlier research on AF on agricultural land, these results showed that the combination of trees and agricultural crops was an integral part of the life of practically every settlement. The distribution of AF on forested land reflected environmental, land use and forest management factors. For hay cutting and forest grazing (especially for the former) the pattern is remarkably clear, while the ubiquitous presence of litter raking made it more difficult to decipher the relationship between predictors and this AF use.

Our results also highlighted possible areas for future research. Importantly, the proportion of forests within townships actually affected by AF remains unknown, because our data lacked such details. Gathering information about this for thousands of individual townships would be nearly impossible, but targeted case studies could at least provide an overall impression (cf. Szabó 2021a). Another open question is how typical the mid-19th century abundance of AF uses (inside and outside forests) was for pre-industrial times. Given the general increase in rural populations in the 19th century in Central Europe as well as the growing tensions between peasants and landlords that eventually led to the abandonment of the old system of land tenure in the late 1840s, it appears logical that pressure on forests, in the form of AF uses, was historically the highest in the 19th century. This could imply that AF on forested land was less common in the 18th century and before, which would then have far-reaching consequences for research on the long-term ecological impacts of agroforestry on Central European forests as well as for the potential reintroduction of these uses into forests for conservation purposes (Vild et al. 2015; Douda et al. 2017).

Lastly, as mentioned above, further factors influencing the distribution of AF uses could be considered. Moreover, more types of AF use should be included in future investigations. Our sources mentioned three types; these, therefore, must have been the most common. However, other types are known to have existed. For example, the harvesting of tree leaves for fodder was often mentioned in archival sources and it may have had a more significant role than that suggested by the stable cadastre. In addition, significant differences between subtypes could be hidden under the three categories: for example, pannage—the feeding of domestic pigs on oak acorns and beechmast, which has a distinct effect on vegetation (Molnár et al. 2021)—had been a separate category in medieval and early modern sources. It continued into the 19th century but was recorded simply as forest grazing. Overall, our study demonstrated that traditional agroforestry was very common in forests in the 19th century and that its presence was influenced by environmental and socioeconomic conditions.

**Acknowledgements** This study was supported by long-term research development Project No. RVO 67985939 and by

Project No. SS02030018 financed by the Technology Agency of the Czech Republic.

**Author contributions** PS and ÉSD wrote the main manuscript text with contributions from JH. PS prepared the archival data. ÉSD designed and carried out the statistical analyses. JH provided land-use data and prepared Fig. 1. All authors reviewed the manuscript.

## Declarations

**Conflict of interest** The authors declare no competing interests.

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## RESEARCH ARTICLE



# Legacy of historical litter raking in temperate forest plant communities

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## Funding information

Grantová Agentura České Republiky, Grant/Award Number: 17-09283S; European Research Council under the European Union's Seventh Framework Programme, Grant/Award Number: FP7/2007-2013 and 278065; Long-term Research Development Project, Grant/Award Number: RVO 67985939

Co-ordinating Editor: Sara Cousins

## Abstract

**Question:** European temperate forests have been managed for millennia, and this management has left a long-lasting legacy in soil chemistry and plant species composition and diversity. One of the most common practices was the raking of leaf litter, which was used as bedding for farm animals. We asked, what is the legacy of historical litter raking for contemporary forest plant communities?

**Location:** Czech Republic.

**Methods:** We explored the effect of historical litter raking on species richness and diversity of the forest herbaceous layer. We also tested whether long-term soil acidification and nutrient depletion caused by litter raking were reflected in Ellenberg indicator values for nutrients and soil reaction and in the higher abundance of specialists of acidophilous forest types. We used written historical evidence to identify areas where litter raking was practised in the 19th century. We analysed the differences between vegetation plots located in areas affected and unaffected by the past litter raking. Our analysis included almost 2,500 vegetation plots recorded between 1980 and 2015.

**Results:** Litter raking was historically practised in a striking 85% of forested townships. Although litter raking had no significant effect on overall species richness, we found significant differences of diversity patterns among forest types. Historically raked plots were taxonomically more similar. We found no difference in the mean Ellenberg indicator values for soil reaction and nutrients between the affected and unaffected plots, and only a weak positive response of selected herb species of acidophilous forests.

**Conclusions:** We provide the first empirical evidence of the historical litter-raking legacy in forest communities on a large scale. Despite its historical frequency, we found only a weak legacy of historical litter raking in present-day plant communities. Future studies could potentially use other, finer-scale methods in smaller territories to complement our results.

## KEYWORDS

biotic homogenization, forest management, herbaceous layer, historical ecology, human impact, management legacy, plant species diversity, temperate forest

## 1 | INTRODUCTION

Past human management has left a legacy in present ecosystems (Foster et al., 2003). This knowledge is particularly obvious in Europe where evidence that ecosystems have co-evolved with humans since prehistory is plentiful (Birks, Birks, Kaland, & Moe, 1988). Soils can bear traces of past agricultural use for millennia (Dambrine et al., 2007; Plue et al., 2008). Altered soil chemistry is subsequently reflected in vegetation composition and diversity. Examples include sites of Roman villas abandoned 2,000 years ago (Dupouey, Dambrine, Laffite, & Moares, 2002), late medieval villages (Hejcman, Karlík, Ondráček, & Klír, 2013) and high medieval mottes (Closset-Kopp & Decocq, 2015).

Knowledge of land-use legacies is important for the assessments of driving factors behind recent vegetation patterns and processes. In their review, Perring et al. (2016) argue that it is necessary to understand the interactions of past management with recent environmental changes, such as increased atmospheric N deposition or climate change. However, studies addressing management usually considered the most obvious factors, such as tree cutting intensity and game density, while other historically important management forms remain little researched (e.g., Bernhardt-Römermann et al., 2015; Verheyen et al., 2012; but see Den Ouden, 2000). One such management form was litter raking, which was widely practised in European forests for centuries (Glatzel, 1991; Leuschner & Ellenberg, 2017). However, its legacy for current forest biodiversity and composition is largely unknown, leaving a gap in both basic research and its applications in nature management.

Forest litter was historically collected as bedding for domestic animals. Afterwards, bound with animal excrement, it was used as manure for fertilizing crops (Glatzel, 1991). The practice was probably very common in the past few centuries (Bürgi, Gimmi, & Stuber, 2013). By integrating historical data into a geochemical model, Gimmi et al. (2013) demonstrated that litter raking in the past caused a reduction in soil C pools, from which recovery is still on-going. McGrath et al. (2015) showed that litter raking resulted in the export of large quantities of N from forests to agricultural land. Regarding tree species preference, pine, spruce and birch litter were the most popular (Gimmi & Bürgi, 2007; Pfeffer, 1948), but litter from other trees was also used (Ebermayer, 1876). Forest accessibility was an important factor regarding the presence and regularity of litter raking (Gimmi & Bürgi, 2007).

Tree litter plays a significant role in forest ecosystems. It protects soil against erosion and compaction, and buffers microclimatic fluctuations in the soil. It is also an important part of an ecosystem's nutrient cycle and buffering capacity (Facelli & Pickett, 1991; Glatzel, 1991). The export of large amounts of base cations from forest ecosystems probably caused soil acidification (Bürgi et al., 2013; Glatzel, 1991) and changed C cycling, soil physical properties and soil microclimate (Sayer, 2005). Field experiments simulating litter raking in forest ecosystems corroborated these findings. Hofmeister, Oulehle, Krám, and Hruška (2008) showed that cation pools in the soil and spruce needles significantly decreased already

in the first years of experimental litter raking in a mountain forest. In a 7-year litter raking experiment in a Scots pine forest in southern Germany, Prietzel and Kaiser (2005) demonstrated that N concentration decreased more in sites subject to higher N deposition levels. As a result, litter raking affected the performance of woody species, including seedling germination and growth (Prietzel & Kaiser, 2005; Sayer, 2005). Due to its adverse effects on soil fertility and timber production, litter raking was banned in many European countries in the second half of the 19th century (Ebermayer, 1876). Despite the ban, litter raking was occasionally practised, particularly in remote areas, well into the 20th century (Bürgi et al., 2013).

Only a handful of experimental studies documented the impact of litter raking on plant community diversity and composition (cf. Sayer, 2005). In temperate forests, the herbaceous layer is especially important, because most plant diversity is concentrated there (Gilliam, 2007). Changes induced by litter raking can be driven by four mechanisms: (a) removing litter causes higher humidity and temperature fluctuations between the outer environment and the soil, affecting decomposition and mineralization of dead organic matter (Xu, Liu, & Sayer, 2013); (b) soil nutrient pool impoverishment (Kreutzer, 1972; Prietzel & Kaiser, 2005; Tyrol Soil Survey 1988); (c) changes in tree layer composition mediating light conditions in the understorey and soil chemistry (Gimmi, Wohlgemuth, Rigling, Hoffmann, & Bürgi, 2010); and (d) regular mechanical disturbances in the herbaceous layer (no specific focus in published literature). The few existing field experiments with litter raking demonstrated that the forest herbaceous layer responded in the expected manner. For example, a 16-year long field experiment by Dzwonko and Gawroński (2002) showed that litter raking prevented change from acidophilous to neutrophilous vegetation. Similar results were observed in a 5-year experiment in a thermophilous oak forest (Douda, Boublík, Doudová, & Kyncl, 2017). In a 7-year experiment in *Pinus sylvestris* stands on dune sand, Beer and Ewald (2005) observed a decrease in Ellenberg indicator values for nutrients. Soil disturbances can lead to the exclusion of sensitive plant species in favour of stress-tolerant and ruderal species (cf. Lindholm & Nummelin, 1983; Wiegmann & Waller, 2006). Regarding the effect on plot species richness, most field studies documented a positive effect (Douda et al., 2017; Dzwonko & Gawroński, 2002; Lindholm & Nummelin, 1983; Vild, Kalwij, & Hédl, 2015). The impact on taxonomic heterogeneity is still unknown. Beer and Ewald (2005) reported increased within-plot compositional heterogeneity, but it is unclear whether the same applies to heterogeneity among plots. At the landscape scale, litter raking, as a relatively uniform type of regular disturbance, will likely have a homogenizing effect on plant communities in the forest herbaceous layer.

Some herbaceous layer changes, such as the above-mentioned increased richness of ruderal species, are likely to be transitional because most ruderal species are not able to survive without regular disturbances (Baskin & Baskin, 2014). On the other hand, changes induced by soil impoverishment and acidification may last much longer, because the recovery of soil chemistry after management abandonment can be rather slow (Hüttel & Schaaf, 1995;

Kreutzer, 1972; Tyrol Soil Survey 1988). Jandl, Starlinger, Englisch, Herzberger, and Johann (2002) mentioned that the transformation of oak forests into pine forests in southern Austria was claimed to have been the result of site “degradation” (meaning probably soil nutrient impoverishment) induced by litter raking as early as the 16th century.

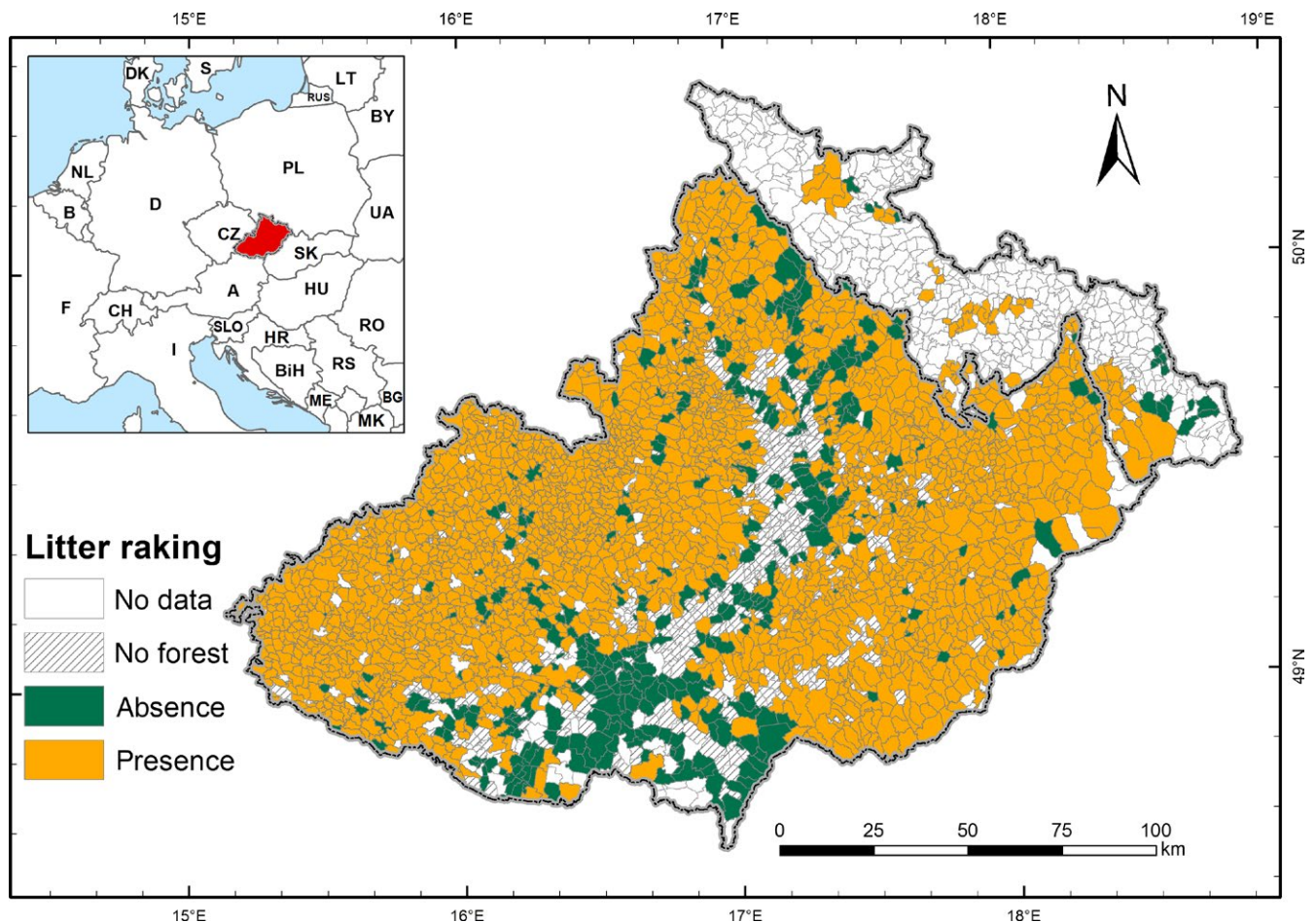
But is there any scientific evidence of the persisting long-term effects of past litter raking on the herbaceous layer? To the best of our knowledge, this topic has not been evaluated so far (cf. Sayer, 2005). Furthermore, most studies focusing on legacies of other management forms were conducted on small scales (Den Ouden, 2000). In the present study, we used 19th-century litter raking data from the eastern part of the Czech Republic (ca. 27,000 km<sup>2</sup>) and evaluated its net effect on forest herbaceous layer communities recorded in thousands of recent plots. By comparing understorey vascular plant communities between sites where litter raking was historically practised and sites where it was not, we focused on the following hypotheses. Plots with historical litter raking have (a) higher species richness, (b) lower compositional heterogeneity, (c) higher richness of selected specialists of acidophilous forest types, (d) lower average Ellenberg indicator values for nutrients and soil reaction, and (e)

different responses according to the five main forest vegetation types occurring in the study region.

## 2 | METHODS

### 2.1 | Study area

The study area covers the historical regions of Moravia and Czech Silesia (Figure 1) in the eastern part of the Czech Republic. The area comprises 26,808 km<sup>2</sup>. Land forms range from flat lowlands in the southern and central parts to mountains up to 1,491 m a.s.l. in the north and northeast. Climate is temperate with mean annual temperatures ranging from about 1–10°C and precipitation from about 500–1,500 mm (Tolasz, Míková, Valeriánová, & Voženílek, 2007). Geologically, the region lies between the Bohemian Massif on the west and the Western Carpathians on the east. These two units are built mostly of crystalline and sedimentary bedrock, respectively. Land cover has been co-determined by human management at least since the Neolithic, ca. 7,500 years ago. Forests constitute about 34% of the land cover and increasingly dominate with altitude. The currently prevailing Norway spruce is a native species but its proportion has increased through planting in the past two centuries.



**FIGURE 1** Map of the study area with indication of the 19th century litter raking. Spatial units (townships) are delimited by thin grey lines, and historical regions by thick lines: the northeast part is Silesia and the southwest part is Moravia

## 2.2 | Vegetation data

Vegetation-plot data were retrieved from two resources: the Czech National Phytosociological Database (Chytrý & Michalcová, 2012) and a database of forest vegetation plots maintained at the Institute of Botany of the Czech Academy of Sciences (<http://ekol-brno.ibot.cas.cz/en/database>). Vegetation was recorded by means of the Braun-Blanquet approach (Dengler, Chytrý, & Ewald, 2008), i.e., all species were recorded within vertical layers and their cover was estimated. The sampling period was limited to dates after 1980 so that the data reflect forest vegetation in the past three decades (1980–2015) and plot sizes were restricted to the range between 100 and 500 m<sup>2</sup>. We further used only plots located in townships with a known litter raking history (see Historical data below) and plots with reasonably accurate geographic coordinates (we excluded plots with duplicated coordinates and plots with coordinates outside forested areas). The resulting data set consisted of 2,494 plots.

## 2.3 | Environmental data

We used plot header data for altitude, aspect and slope when available. If missing, we used values extracted from the fourth generation Digital Terrain Model of the Czech Republic (Czech Office for Surveying, Mapping and Cadastre, <http://geoportal.cuzk.cz/>). We calculated the *Heat Load Index* based on aspect, slope and spatial coordinates using Equation 3 in McCune and Keon (2002). The SRTM digital elevation model with 90-m resolution (v 4.1; <http://srtm.csi.cgiar.org>) was used to calculate three topographic variables capturing different aspects of land-surface topography. As a proxy for local soil moisture, we calculated the *Topographic Wetness Index* using FD8Q flow-routing recommended by Kopecký and Čížková (2010). To characterize plot position at the watershed scale, we calculated the *Convergence Index* expressing terrain convexity up to 900 m from the plot. To give higher importance to local topography, we used inverse distance-weighted cell values in the calculation. Finally, to express the topographic position of plots at the landscape scale, we calculated plot *Vertical Distance to Channel Network* defined as cells having catchment area above 10e<sup>6</sup> (FD8Q flow-routing). We used SAGA GIS (Conrad et al., 2015) for all calculations.

*Soil group* according to the soil classification system for the Czech Republic (Němeček, Macků, Vokoun, Vavříček, & Novák, 2001) was extracted from a digital soil map (Czech Geological Survey, Soil map 1:50,000; <http://mapy.geology.cz>). Additionally, the categories of the Czech Forest Ecosystem Classification based on the Typological System of Forest Management Planning Institute (Viewegh, Kusbach, & Mikeska, 2003) were used. Forest types were defined by two environmental factors: climate and soil conditions. These categories formed the *Forest Site Complex* as a synthetic variable of abiotic site conditions.

The *Phytogeographic Division* of the Czech Republic (Skalický, 1988) was used to categorize areas along a floristic altitudinal and geographic gradient, which is also related to the intensity of historical

human impact. Each plot was associated with a corresponding phytogeographic district.

We used monthly maximum and minimum temperatures and monthly precipitation to calculate 19 bioclimatic variables often used in species distribution modelling (so-called core bioclim variables (Kriticos et al., 2012). The mean (1986–2010) monthly climatic values were extracted from interpolated grids with 0.5-km resolution provided by the Czech Hydrometeorological Institute. To calculate 19 bioclimatic variables from monthly climatic values for each vegetation plot, we used the *biovars* function from the *dismo* R package (R Foundation for Statistical Computing, Vienna, AT).

To assess the impact of historical litter raking following *Forest type*, the data set was classified into five groups of plots according to the dominant tree species: (a) oak forests, dominated by oak (*Quercus petraea*, *Q. robur* and *Q. pubescens*), (b) oak-hornbeam forests, with lime (*Tilia cordata*, *T. platyphyllos*) or hornbeam (*Carpinus betulus*) mixed with oak (as above), (c) beech forests, dominated by beech (*Fagus sylvatica*), (d) eutrophic forests, dominated by lime (as above), maple (*Acer platanoides*, *A. pseudoplatanus*), ash (*Fraxinus excelsior*) or alder (*Alnus glutinosa*), (e) coniferous forests, dominated by pine (*Pinus sylvestris*), fir (*Abies alba*) or spruce (*Picea abies*).

We also calculated the proportion of forested area in a 500-m buffer around each vegetation plot (*Distance to Forest Edge*) using Corine Land Cover 2006, v 18\_4 (European Environment Agency under the framework of the Copernicus programme).

## 2.4 | Historical data

The most important source used in this paper was the so-called Stable Cadastre. Cadastral surveys were prepared in the Czech Lands since the 17th century. Their main aim was to survey the entire country and describe the use of each piece of land, based on which tax was established (Bumba, 2007). The first reasonably accurate survey to include all land was the Josephian Cadastres at the end of the 18th century. However, this cadastre lacked accurate maps. In contrast, the Stable Cadastre was based on a dense network of triangulation points resulting in high-quality maps (Bičík et al., 2015). Moravia and Silesia were mapped between 1824 and 1836. This was followed by office work to establish the land use, value and tax of each parcel, which included many terrain visits to settle contested issues. For Moravia, the results of this long process were put on paper between the years 1841 and 1850 (the material is kept in the Moravian Provincial Archives under shelfmark MZA D 8). Many types of detailed and summary documents were produced. For our purposes, the most important are the protocols of the forest commission. Among other things, these protocols contained information on the presence of *Nebennutzungen* ('side uses' meaning non-timber uses) in each township (*Katastralgemeinde* in the original, meaning a village and its lands). Litter raking was one of these uses. The protocols were explicitly meant to contain complete information; therefore the lack of information on litter raking meant the actual absence of this practice. For most townships, only presence/absence was recorded.





**TABLE 1** Percentage of townships with data on litter raking (*litter raking present/absent, no forest, no data*) according to the altitudinal zones of the phytogeographic division of the Czech Republic

|                        | Presence | Absence | No forest | No data |
|------------------------|----------|---------|-----------|---------|
| Thermophyticum (%)     | 34.3     | 24.5    | 33.2      | 8       |
| Mesophyticum (%)       | 70.3     | 7.2     | 4.4       | 18.1    |
| Oreophyticum (%)       | 72.5     | 10      | 0.6       | 16.9    |
| Whole study region (%) | 62.6     | 11      | 10.4      | 15.9    |

Processing the Stable Cadastre is very time-consuming and poses considerable challenges in document access. Therefore we could not include in the database data from Silesia, for which documents are kept at the Provincial Archives in Opava. To compensate for this, we processed the so-called *Forststatistik von Mähren und Schlesien*. This survey was initiated by local forest statistician Heinrich C. Weeber. Published in the journal of Moravian and Silesian foresters (*Verhandlungen der Forst-Section für Mähren und Schlesien*) in the years 1853–1857, the survey was based on information gathered from local forest managers in a form compatible to cadastral surveys. Non-timber uses were recorded as qualitative information (present/absent) only. Furthermore, recording was not comprehensive; therefore we interpreted the lack of litter raking as actual absence only if other uses were mentioned. As described in detail in the next paragraph, this restriction meant that data were available for very few townships in Silesia, rendering the possible differences in data quality between the Stable Cadastre and the *Forststatistik* of minor importance as far as the overall results were concerned. To obtain a proxy for human pressure on forests for each township, we used data on human populations (*Number of houses*) from the first comprehensive population survey in 1869 (Růžková & Škrabal, 2006). We obtained a digital version of these data from the Land Use Cover Changes (LUCC) Czechia Database (<http://web.natur.cuni.cz/ksgrrsek/lucc/index.php?scn=2>). Lastly, we used *forest area* (in ha) in the 19th century in each township.

Results of the archival work are displayed in the Figure 1. We found written evidence of litter raking in 63% of all townships in the study region – i.e., 85% of forested townships with known litter raking history. In 11% of all townships litter raking was absent; 10% of townships had no forests and no data were available for 16% of townships (mostly due to the lack of sources in Czech Silesia). Despite our efforts with the *Forststatistik*, we managed to find data for only 77 townships in Silesia, i.e., less than 3% of all townships with data on litter raking in this region. The proportion of forested townships with litter raking was the lowest in the lowlands (Thermophyticum), whereas it was much higher in the uplands (Mesophyticum) and in the mountains (Oreophyticum) (Table 1).

Using historical data for analysing species diversity in vegetation plots suffers from the relatively coarse, although the best available, resolution of archival data. As a result, we cannot be sure whether each single plot in townships with documented historical management was indeed subjected to litter raking because there were usually several forests in a single township, which may have differed in dominant forest type. Also, we cannot assume that litter raking was never practised in regions where our data showed its absence. Even

if litter raking was not practised in 19th century, it may have been practised earlier or later. Therefore, the townships analysed in this study may differ only in the time since litter raking abandonment.

## 2.5 | Data analyses

### 2.5.1 | Permutation tests of multivariate regression

Multiple relationships between species richness and environmental variables were analysed using regression modelling. We tested the hypothesis that the explanatory variable *litter raking* influences species diversity. Our data did not distinguish for raking intensity; therefore we created two data sets with and without raking. Due to the unequal number of plots, we randomly selected the same number of samples without replacement from each data set. Environmental conditions for each vegetation plot were used as covariates represented by topographic factors (*Altitude, Convergence Index, Heat Load Index, Topographic Wetness Index, Vertical Distance to Channel Network*), climatic factors (*PCA axis1, PCA axis2*), edaphic factors (*Czech Forest Ecosystem Classification, Soil group*), anthropogenic factors (*Number of houses in 1869*), biotic factors (*Forest Type, Forest Area, Phytogeographic Division*) and methodological factors (*Year of sampling, Plot area* and spatial coordinates). Comparison of raked and non-raked plots for selected variables is shown in supporting information Appendix S1. The model was adjusted for spatial and temporal correlations. It included sampling year and 2-D smooth of longitude and latitude as covariates. To assess the significance of the partial effect of the explanatory variable (litter raking), the frequency distribution of the *F*-statistic was estimated from multiple regression models calculated on 500 bootstrapped samples with replacement from the data set. The *p*-value was calculated as the proportion of 500 iterations where the *F*-statistic from the randomized data equalled or exceeded the *F*-statistic from the non-randomized data. This approach was applied to the whole data set and also separately for each forest type except coniferous forests (due to the small number of plots).

### 2.5.2 | Beta diversity calculation

To assess whether litter raking caused taxonomic homogenization, we calculated  $\beta$ -diversity among plots through the multiple site dissimilarity approach (Baselga, 2010) implemented in the *betapart* package (Baselga & Orme, 2012) in the R software (v 3.2.3). To gain deeper insights into  $\beta$ -diversity patterns, we decomposed the overall  $\beta$ -diversity into two components – nestedness and spatial



turnover. We calculated spatial turnover to assess the measure of replacement of certain species by other species.

Because of the unbalanced number of plots with litter raking and without litter raking, we adjusted the number of plots by randomly selecting the same number of samples from litter raking and the control data set. This selection was repeated 500 times with replacement. The mean values of  $\beta$ -diversity components and species numbers were calculated for each iteration. To assess the differences in species number and  $\beta$ -diversity between plots with and without raking, the frequency distribution of the mean was calculated and graphically displayed. Finally, the significance of differences between plots with and without raking was determined by bootstrap analysis. At first, we calculated randomized sampling distribution of the difference between means. Following this approach we tested the hypothesis that the difference between mean species diversity in the plots with and without raking equals zero. The proportion of the 500 iterations for which the randomized mean difference equals or exceeds the non-randomized mean difference was used for  $p$ -value estimation. This approach was applied on the whole data set and also separately for each specific forest type except coniferous forests (due to the small number of plots).

### 2.5.3 | Effects through soil acidity and fertility

To evaluate the hypothesis that litter raking supports species of oligotrophic and acidophilous substrates due to the effect on soil chemistry, we evaluated the performance of diagnostic species of acidophilous oak forests (*Genisto germanicae-Quercion*) and beech forests (*Luzulo-Fagion*) based on vegetation classification in the Czech Republic (Chytrý & Tichý, 2003).

To specify the relationship between each diagnostic species and the presence of litter raking, we used species response curves based on detrended canonical correspondence analysis (DCCA). To adjust the model for potential correlations, explanatory variables *Year*, *Forest type*, *Altitude* and *Geographic coordinates* were used as covariates. Species-response curves were fitted by GLM with Poisson error distribution, log link function and control for over-dispersion.

Finally, we evaluated the hypothesis that raked plots have lower Ellenberg indicator values (EIVs) for soil reaction and nutrients by comparing plot averages (Diekmann, 2003; Ellenberg, Weber, Düll, Wirth, & Werner, 1992). We tested the differences among two groups of samples with and without litter raking using a modified permutation test (MoPeT) with mean of species weighted by species abundances (Zelený & Schaffers, 2012). The testing procedure is based on the permutation of the mean randomized EIVs calculated from species EIVs randomized among species.

## 3 | RESULTS

### 3.1 | Effects on diversity and compositional heterogeneity

Results from multivariate regression analysis showed no independent effect of litter raking on species richness for the

whole data set ( $pseudoF_{4,1949} = 0.89$ ,  $p = 0.282$ ). On the other hand, we found a significant partial effect of interaction terms between litter raking and forest type on species richness ( $pseudoF_{4,1945} = 4.71$ ,  $p = 0.042$ ). This means that the assumed legacy of litter raking in present species richness has been structured according to forest type. There was significantly lower species richness in raked oak forests (raked mean = 27.38, non-raked mean = 30.55,  $p = 0.004$ ), while species richness was higher in raked eutrophic forests (raked mean = 30.87, non-raked mean = 26.63,  $p = 0.001$ ; Figure 2). No significant difference was found in other forest types.

Testing for the potential effects of litter raking on compositional heterogeneity among plots showed that in the plots with litter raking the mean value of turnover was lower (raked mean = 0.9915, non-raked mean = 0.9921,  $p = 0.011$ ; Figure 2).

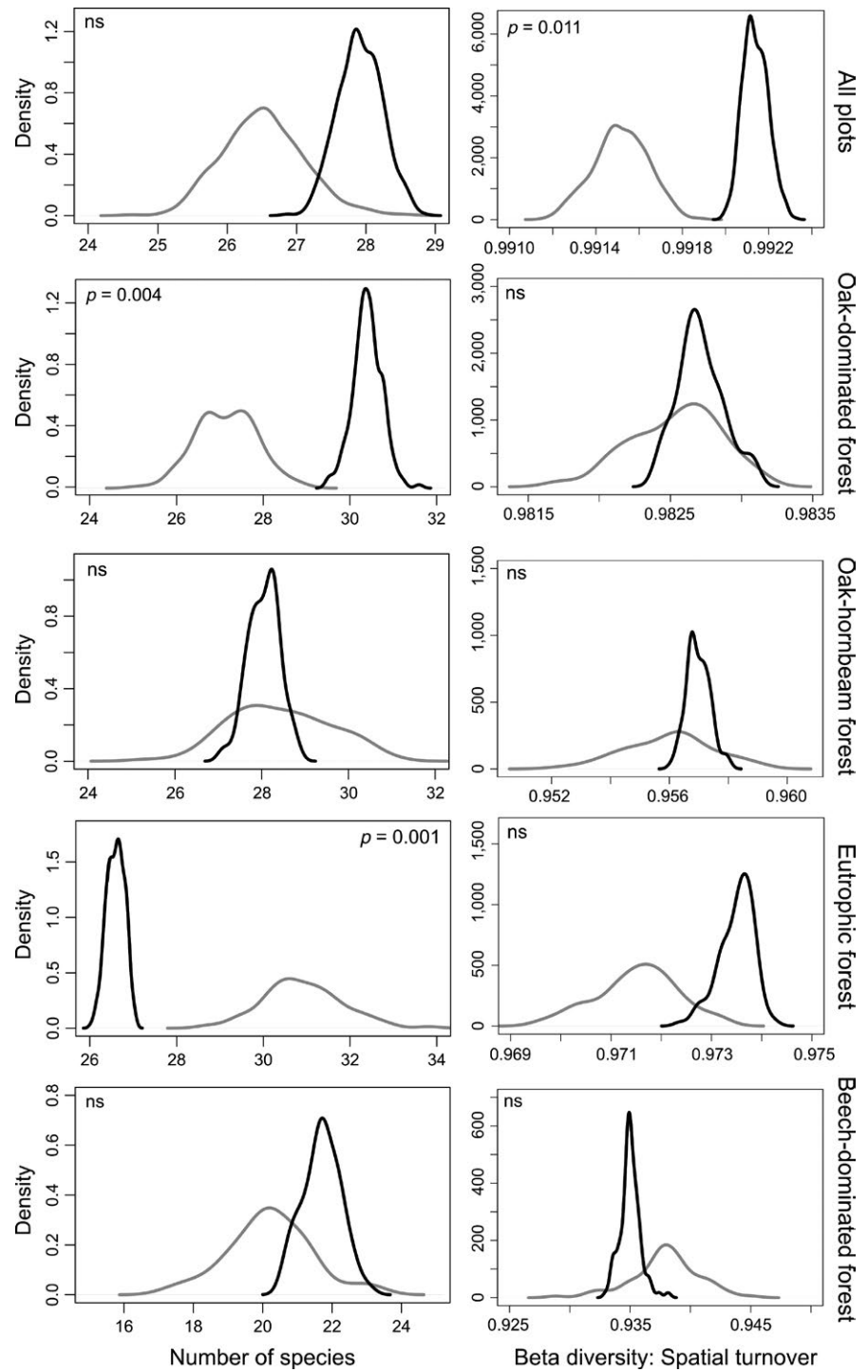
### 3.2 | Effects through soil acidity and fertility

Only four out of 15 selected species diagnostic for acidophilous forest types had significantly higher predicted abundance in plots with litter raking (Table 2). Contrary to the hypothesis, there was no difference in either average EIVs for nutrients ( $F = 13.680$ ,  $p = 0.331$ ) or soil reaction ( $F = 3.328$ ,  $p = 0.645$ ) between the plots in historically raked and non-raked sites.

## 4 | DISCUSSION

### 4.1 | Ecological legacy of historical litter raking

Our results showed that the legacy of past litter raking on the current herb layer is weaker than expected from experimental inference and studies on soil chemistry legacies. Contrary to our expectations, only four out of 15 species selected as the most sensitive to historical litter removal showed a significant positive response (see Appendix S2 for all species). Specifically, we indirectly corroborated the observation of Lindholm and Nummelin (1983) that *Avenella flexuosa* responds well to litter raking. A potential explanation for the lack of change is that the effect of historical litter raking is relatively short term. If litter raking was abandoned shortly after the period recorded in the historical sources we used, its legacy may no longer be detectable. Other considerations include the recovery of chemistry conditions in the upper soil layer after disturbances (Leuschner, Wulf, Bächler, & Hertel, 2014). Soil recovery is probably facilitated by litter accumulation and subsequent decomposition, which in turn replenish basic cations and P pools (Facelli & Pickett, 1991). As the first 10 cm of a soil profile are the most important for herb layer species, the recovery of soil can quickly drive compositional changes. Besides, there are indications that this recovery can be hastened by N addition into the soil, because, as Jandl et al. (2002) showed, planting N-fixing plants improved soil chemistry conditions in forest sites degraded by historical litter raking in Austria. Current atmospheric N deposition probably acts in a similar way. A weak relationship between litter raking and current



**FIGURE 2** Comparison of the number of species per plot and  $\beta$ -diversity between plots with litter raking (grey lines) and without litter raking (black lines) for all plots and specific forest types. Density shows the distribution of 500 bootstrap replicates of the species number and  $\beta$ -diversity

vegetation can also be strongly affected due to high levels of noise stemming from the coarseness of the historical data (see Methods).

We did not detect increased species richness due to the legacy of historical litter raking, although most field experiments supported such a hypothesis. In experiments the increase was to a large extent constituted by annual species that were apparently not able to survive without regular disturbances. A partly connected and probably more plausible explanation lies in scale differences. Litter raking experiments are carried out on areas of a few square metres to a hectare while historical litter raking was a landscape-scale factor that

affected entire local to regional species pools. This may explain why the assumed impact of historical litter raking on herb layer diversity is more complex and differs among forest types. Another difference is the time scale, both regarding the duration of litter raking and the time period that elapsed between raking and vegetation survey.

#### 4.2 | Different responses among forest types

There are several potential mechanisms that may contribute to differences among forest types. First, the intensity of litter raking

**TABLE 2** List of selected species diagnostic for acidophilous forest types (following Chytrý & Tichý, 2003)

| Species name                     | Regression coef. | F-value     | p-value          |
|----------------------------------|------------------|-------------|------------------|
| <i>Vaccinium vitis-idaea</i>     | <b>80.91</b>     | <b>12.3</b> | <b>&lt;0.001</b> |
| <i>Avenella flexuosa</i>         | <b>7.66</b>      | <b>4.4</b>  | <b>0.035</b>     |
| <i>Luzula luzuloides</i>         | <b>3.30</b>      | <b>12.9</b> | <b>&lt;0.001</b> |
| <i>Hieracium murorum</i>         | <b>1.80</b>      | <b>9.5</b>  | <b>&lt;0.010</b> |
| <i>Vaccinium myrtillus</i>       | 1.74             | 1.1         | 0.295            |
| <i>Oxalis acetosella</i>         | 1.20             | 1.4         | 0.243            |
| <i>Dryopteris dilatata</i>       | 0.95             | 0.3         | 0.596            |
| <i>Prenanthes purpurea</i>       | 0.28             | 0.1         | 0.812            |
| <i>Maianthemum bifolium</i>      | −0.30            | 0.1         | 0.747            |
| <i>Hieracium sabaudum</i> agg.   | −0.38            | 0.3         | 0.572            |
| <i>Hieracium lachenalii</i>      | −0.53            | 0.4         | 0.516            |
| <i>Festuca ovina</i>             | −0.74            | 0.4         | 0.518            |
| <i>Melampyrum pratense</i>       | −0.87            | 0.4         | 0.527            |
| <i>Calamagrostis arundinacea</i> | −1.16            | 0.5         | 0.511            |
| <i>Homogyne alpina</i>           | −2.12            | 0.1         | 0.751            |

The statistic shows whether these species are more abundant in plots with historical litter raking (>0) or plots without litter raking (<0). Species are sorted according to the regression coefficient. Significant differences are marked in bold.

applied in various forest types may have differed because of human preference for the litter of some tree species over others (Gimmi & Bürgi, 2007; Pfeffer, 1948). Second, forest types may vary in their sensitivity to litter raking because of differing environmental (mainly soil) conditions. Differences in soil conditions in turn also determine dissimilar vegetation responses. Beer and Ewald (2005) attributed this inconsistency to greater depletion of N on N-rich soils compared to nutrient-poor soils. The change in soil pH can also depend on substrate acidity, because whereas the decomposition of leaf litter on basic substrates will result in pH decrease, the opposite will occur on acidic substrates. Third, forest types may differ in their ability to recover from disturbances, following the colonization credit hypothesis (Nave, Vance, Swanston, & Curtis, 2010). Finally, our data showed that the exploitation of upland vs lowland forests strongly differed (Figure 1; Table 1). To a large extent, such distribution coincides with the distribution of the main forest types. It is then a question of whether the forest types are independent from historical litter raking, i.e., to what extent were they formed by historical management. The legacy of raking on tree species composition was documented in the Swiss Rhone valley, where a significantly lower shift in species composition from pine to deciduous trees was found in stands which were formerly used for grazing and/or litter raking (Gimmi et al., 2010).

Gimmi et al. (2013) argued that no historical raking was practised in the lowland areas in the northwest part of Switzerland in the mid-19th century due to the availability of substitute products, such as straw. This may also explain the low occurrence of

historical litter raking in the lowland areas of Moravia, with the exception of the least forested (or completely deforested) areas and parts of river valleys (Figure 1). However, the Swiss authors did not come to their conclusions directly from archival data on litter raking but from proxy parameters. Specifically, they used the number of cattle per land unit as a proxy for litter demand, and grain production and the area of wet meadows as proxies for products.

The two forest types that responded significantly to litter raking by their species richness were oak forests (negatively) and eutrophic forests (positively). The species impoverishment in oak forests is relatively easy to explain, because this type of forest can be found mostly on nutrient-poor, acidic soils prone to further impoverishment due to litter removal. We argue that mainly species of acidophilous substrates, undemanding as regards soil nutrients, could survive the long-term effects of litter raking. The significant positive effect of historical litter raking in eutrophic forests is more difficult to explain. These forests are dominated by tree species such as lime and ash, producing litter rich in base cations, which results in fertile soils possessing a high buffering capacity (Lundström, Bain, Taylor, & van Hees, 2003). Therefore, high soil buffering capacity was assumed to ensure the resistance to acidification by litter removal. However, in the long run, the removal of noble hardwood litter may have intensified soil impoverishment. This could have suppressed the dominance of competitively strong species and created heterogeneous conditions suitable for plants with various demands on soil acidity and nutrients (Beer & Ewald, 2005). Quite paradoxically, the species enrichment in eutrophic forests historically subject to litter raking can be due to the arrival of species of mesotrophic and acidotrophic substrates normally not occurring there and co-existing with the original nutrient-demanding species.

### 4.3 | Biotic homogenization due to historical litter raking

Litter raking left a legacy of biotic homogenization in our study region. The mechanical disturbance by raking has most probably led to the local extinctions of sensitive species and the spread of less sensitive species, favouring decreased competition, which resulted in homogenized species assemblages (e.g., Wiegmann & Waller, 2006). The establishment of more similar species communities may have also resulted from consistent soil impoverishment across the environmental gradients.

A historical perspective of the role of traditional management sheds new light on biotic homogenization. Homogenization has been considered a modern threat to the Earth's biota in the context of biotic invasions and other global threats (e.g., McKinney & Lockwood, 1999). Biotic homogenization has been extended to forest vegetation due to game pressure or succession after the abandonment of coppicing (Kopecký, Hédli, & Szabó, 2013; Rooney, Wiegmann, Rogers, & Waller, 2004). Here we show that one specific form of historical management has left a long-lasting legacy in

regional forest  $\beta$ -diversity, rather than in species diversity on local scale ( $\alpha$ -diversity).

## 5 | CONCLUSIONS

In spite of a number of sources of uncertainty in our data, we provide the first quantitative evidence that historical litter raking left a weak but persistent and recognizable legacy in the present forest herbaceous layer. However, our results failed to confirm that litter raking led to the expected ecological changes, namely an increase in acidophilous oligotrophic species and a decrease in Ellenberg indicator values for nutrients and soil reaction. Finer-scale data on past litter raking practices will probably be needed to complement our results.

## ACKNOWLEDGEMENTS

The research leading to these results received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013)/ERC Grant agreement no 278065, and the Grant Agency of the Czech Republic project No. 17-09283S. Additional funding was provided by the Long-term Research Development Project RVO 67985939. We thank M. Chytrý and D. Michalčová for providing the forest vegetation samples from the Czech National Phytosociological Database. We also thank I. Bičík for population data from the LUCC Czechia Database.

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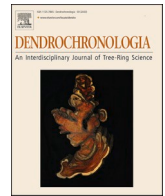
## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Appendix S1** Comparison of raked and non-raked plots according to particular forest types for selected variables assessed in the analyses.

**Appendix S2** Detrended Canonical Correspondence Analysis (DCCA) biplot of vegetation data, showing the first and second axes.

**How to cite this article:** Vild O, Šipoš J, Szabó P, et al. Legacy of historical litter raking in temperate forest plant communities. *J Veg Sci*. 2018;00:1–11. <https://doi.org/10.1111/jvs.12642>



## ORIGINAL ARTICLE

## Wood species utilization for timber constructions in the Czech lands over the period 1400–1900

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## ARTICLE INFO

## Keywords:

Central Europe  
Cultural heritage  
Dendrochronology  
Historical buildings  
Historical wood utilization  
Wood properties

## ABSTRACT

Longstanding demographic growth accompanied by rising settlement activities and development of industry led to an increasing demand on utilization of wood. Tree species were selected for their specific properties. As a consequence of regional differences of forest species composition, wood has become an extremely important trade commodity. Therefore, the utilization of individual species could substantially change in space and time. In this study, we use 8135 precisely dated timber constructions from a dendrochronological database to investigate spatio-temporal changes in wood utilization across the Czech lands from the 15th to the 19th century. Our results suggest that the utilization of individual species in historical timber constructions was primarily limited by their availability. Species selection was also based on wood properties and stem geometry. Most of historical constructions (99.7%), represented mainly by roofs and ceilings, are made of fir, spruce, pine, and oak. While fir constructions prevail in eastern Moravia and Silesia, spruce constructions are largely spread across the western and central part of the Czech Republic. Pine and oak constructions reflect natural occurrence of such forests in lower elevated central Bohemia and southern Moravia. Although fir prevailed in timber construction in the late-Medieval and post-Medieval times, planting of spruce monocultures resulted in its significantly increased utilization by the end of the 19th century. This study demonstrates the value of dendrochronological databases as an indicator of historical wood utilization.

## 1. Introduction

During the last millennia, gradual population and economic growth led to an expansion of settlement activities (Boháč, 1987; Fialová, 2007; Kaplan et al., 2009). Settlement expansion together with a boom in building activities mostly followed the periods of severe social, economic and political crises, such as the Great Famine (1315–1322 CE), Black Death (1346–1353 CE) or the Thirty Years' War (1618–1648 CE) (Ljungqvist et al., 2018; Kolář et al., in review 2021). Development of settlement and building activities required an increased consumption of wood (Nožička, 1957) as one of the most important natural materials, easily available, simple to handle and process (Klein and Grabner,

2015).

Thanks to its wide applicability, wood was represented in most buildings; either as part (usually roofs and ceilings) of houses made of bricks and/or stone or as a whole house (such as log houses). The selection of individual species for specific purposes in specific regions was likely based on their local availability and wood properties (Filková et al., 2015; Klein et al., 2016). Considering historical buildings, timber constructions were made of highly durable larch at high elevations of the Swiss Alps (Büntgen et al., 2006) and the Tatra region in Slovakia (Büntgen et al., 2013), spruce in foothill regions of the Austrian Alps (Klein and Grabner, 2015), or pine in the Netherlands (Sass-Klaassen et al., 2008) and Norway (Thun, 2005; Thun and Svarva, 2018), for

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<https://doi.org/10.1016/j.dendro.2021.125900>

Received 17 June 2021; Received in revised form 31 August 2021; Accepted 23 October 2021

Available online 28 October 2021

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instance. Representing broadleaved species, oak wood was frequently identified in specific historical constructions with increased requirements on strength, hardness and/or durability, such as roof and belfry constructions (Prokop et al., 2017; Roibu et al., 2021), half-timbered buildings (Vitas, 2020), supporting structures (McCarroll et al., 2019), and pile dwellings (Čufar et al., 2015; Akkemik et al., 2019). Additionally, many other species such as elm, ash, maple, beech, birch, alder, aspen, poplar, and lime occur in historical timber constructions (Havelka, 1928; Dejmál et al., 2014).

However, the availability of individual species changed in the past due to changing forest cover, forest species composition, and the development of timber trade. Starting in the Neolithic period, predominantly wooded Europe started to be converted to agricultural land (Fyfe et al., 2015; Roberts et al., 2018). Forest utilization even more intensified in Central Europe during the High Medieval Period due to colonization processes related to demographic and settlement growth, building activity, the establishment of fishponds, as well as the development of brewing, viticulture, mining, as well as the glass and metallurgical industries (Nožička, 1957; Průša, 1990). Since local forest supplies were not sufficient to cover the growing demand for forest products (high quality oak in particular), wood became an extremely important and strategic commodity and was transported on rivers over long distances to satisfy the dramatic shortage of timber in many regions (Bonde et al., 1997; Wazny, 2002; Kuniholm et al., 2007; Shindo and Claude, 2019; Roibu et al., 2021). To eliminate extensive and uncontrolled logging activities, forest laws were gradually and repeatedly introduced but they differed from region to region and usually did not present such a clear break from the existing management practice as was presented in older literature (Radkau, 1983; Woitsch, 2017). However, all tree species were used and no species was considered less valuable or undesirable until the end of the 18th century (Průša, 1990). In the 19th century, pine and spruce even-aged monocultures started to be planted to increase the volume of wood production (Nožička, 1957).

Wood properties and changes in forest species composition most likely influenced the utilization of individual species in space and time. Therefore, the aim of this study is to investigate wood utilization in timber constructions in the Czech lands between 1400 and 1900 by exploiting a dendrochronological database. We hypothesize that (1) utilization of conifers dominated in historical timber constructions because of their easy availability and relevant properties; (2) utilization of individual species was typical of specific regions; and (3) the spatial distribution of individual species and thus forest species composition have been increasingly affected by human activity, at the expense of natural tree species composition and distribution.

## 2. Material and methods

### 2.1. Input data from the dendrochronological database

The Czech dendrochronological database includes thousands of dated historical constructions, archaeological findings, subfossil trunks, art objects, and musical instruments ([www.dendrochronologie.cz](http://www.dendrochronologie.cz)). All of the wooden relicts, obtained by the persistent and enthusiastic work of Czech laboratories during the last decades, come from the current territory of the Czech Republic.

Thanks to the high precision of dendrochronological dating, we herein extract from the database the historical constructions from the 1400–1900 period where the last outermost tree ring (the so-called waney edge or waldkante) or sapwood (only in oak samples) were preserved. Only in such cases, we are able to exactly date each construction and thus classify the constructions into the relevant centuries. The outermost ring is the last tree ring, which was created before the tree was felled and can be identified by the round shape preserved on unworked timbers or by the presence of bark. The presence of the waney edge on timber allows us to determine the exact year, or even season, when the tree used for construction timber was felled. A waney edge

ending with earlywood suggests that the tree was cut down in the first half of vegetation period, whereas the presence of latewood indicates tree felling during the dormant season. If the waney edge is missing, an estimation of missing rings to the waney edge is only possible if oak sapwood rings are preserved. Oak is characterized by a limited number of sapwood rings, which are situated in the outer part of the stem. They are relatively easily distinguishable from dark heartwood. As the number of oak sapwood rings varies among trees from different regions, a range of 5–25 sapwood rings was determined for the territory of the Czech Republic (Rybníček et al., 2006; Prokop et al., 2017).

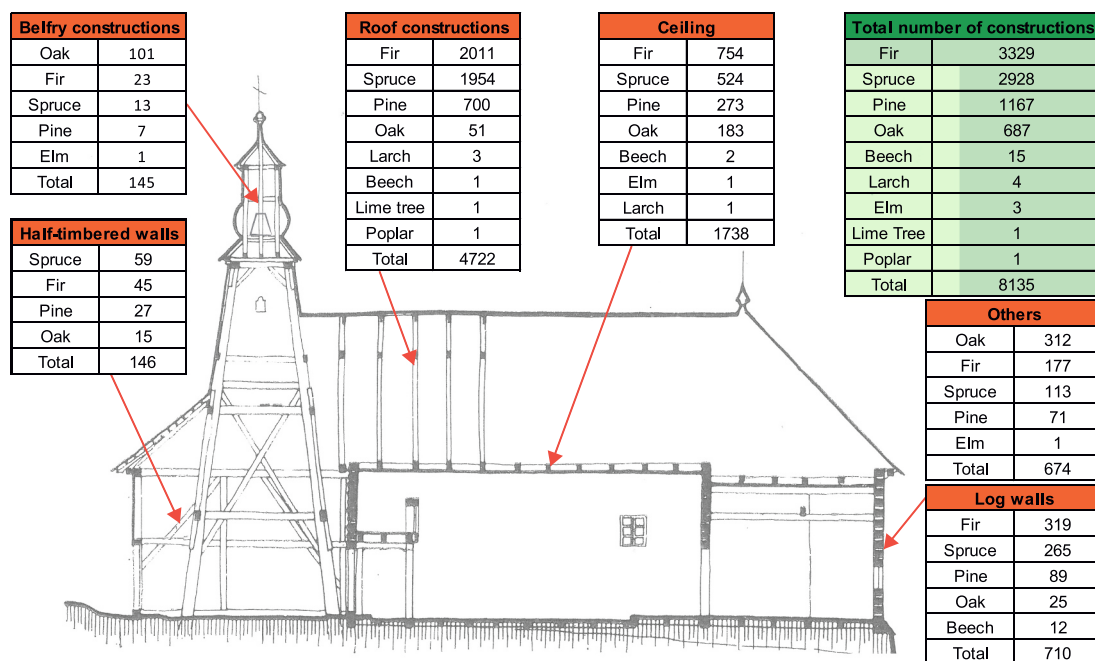
Our dendrochronological dataset consists of 8135 precisely dated historical timber constructions distributed across the Czech lands and covering the period from 1400 to 1900 CE (Figs. 1, 2a). The database of historical buildings includes mainly churches, castles, monasteries, residential and farm houses, log houses, and half-timbered constructions. Most historical buildings are represented by roof constructions, ceiling beams, and walls (both log and half-timbered) with 58%, 21%, and 11%, respectively (Fig. 1). Additional extracted parts of the buildings represent lintels, doors, stairs or belfry constructions in church steeples (Fig. 1). The vast majority of the timber constructions are made of conifers (91%), mostly fir (41% from the whole dataset), spruce (36%), and pine (14%). Broadleaved species are predominantly represented by oak (8% from the whole dataset) which was used mainly for belfry constructions as well as other specific constructions such as lintels, stairs, internal supporting structures (e.g. pillars), and arches. The utilization of other species, such as larch, beech, elm, and poplar, is very rare (<0.2%) in historical constructions.

Historical buildings were not always constructed using only a single tree species. For instance, the ceiling of a building could be made of fir while the roof, of spruce. In the roof construction of a church, tie beams could be of oak, while the rest of roof construction, of fir. If two or more species were identified in one construction, two different species-specific constructions were considered for the analysis. Only this method enabled us to detect whether specific species were preferably used for specific constructions or elements in a construction. Similarly, we considered reconstructions also as species-specific constructions. The time period between the original construction and the reconstruction of a building could be many decades or even centuries. Moreover, the reconstructed construction could make of different species than the original one. Due to this phenomenon, we are able to study possible changes in species selection/preferences or the regional availability of individual species.

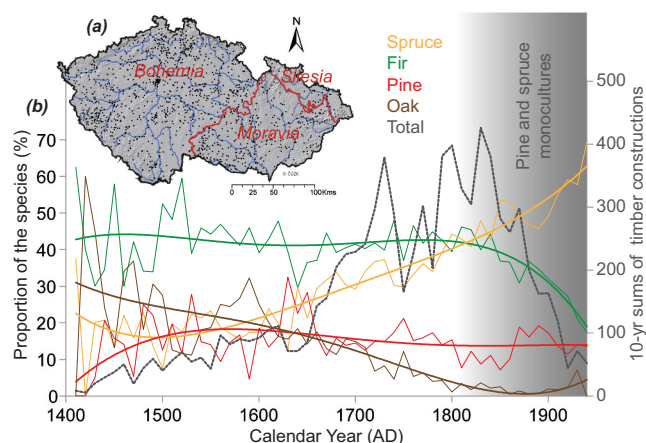
The number of individual dated tree-ring width (TRW) series coming from the same historical building has to be carefully considered to provide reliable information on historical wood utilization. The number of TRW series for a single historical construction ranges from one to dozens with respect to size and architecture, quality of preserved wood, wood species, etc. Using all dated TRW series from each construction could provide misleading results and interpretations because constructions with more TRW series would have more weight than constructions with a single TRW series. To avoid this bias and to capture more relevant information, we use only one date representing each species-specific construction in this study.

### 2.2. Map preparation

As a basis to create maps, we have assigned coordinates to each dated species-specific construction extracted from the dendrochronological database. Species-specific maps have been generated for the whole period as well as for individual centuries by converting coordinates to a point layer in software ArcGIS Pro 2.7. (ESRI Inc.). The 5th generation digital relief model of the Czech Republic (DMR 5G) from the Czech Office for Surveying, Mapping and Cadastre has been used as a background layer for altitude. Based on the background layer, we have calculated the altitude of each site.



**Fig. 1.** Proportion of individual species in different types of constructions and total number of dated species-specific constructions from the Czech lands for the 1400–1900 period.



**Fig. 2.** (a) All 8135 precisely dated historical timber constructions distributed across the Czech lands. The three historical regions of Bohemia, Moravia, and Silesia are also indicated (b) 10-yr moving sums of the total amount of the dated historical timber constructions (dotted line) and percentage proportions of fir, spruce, pine and oak smoothed by polynomial regression over the period 1400–1900 CE.

### 2.3. Temporal changes

The overall numbers of timber constructions as well as the numbers of the main species for individual years have been adjusted to 10-year totals with the intention to filter out their large inter-annual variability. This high-frequency signal may be related either to the completeness and the quality of the database, or to numerous diverse reasons of short duration and local character (political and economic situation, weather extremes, epidemics, etc.). All these factors may represent noise in this study. Overall trends were simulated with polynomial regression (loess filter).

### 2.4. Spatial analysis

As our intention was to compare the occurrence of wood species in timber constructions in space and time, we employed methods of point pattern analysis (Baddeley et al., 2015). In the first step we tested whether the spatial arrangement of the construction sites for individual species significantly differs from Complete Spatial Randomness (CSR). In the case of CSR, the construction sites would occur in a completely random fashion. Otherwise, one can expect that the spatial distribution approaches either a regular or a clustered pattern. For the CSR test, we calculated Ripley's K-function. This metric calculates the number of points that occur within a given distance of each individual point. Details on K-function calculation may be found in Dixon (2002). As we had no data outside the study region, we applied isotropic border correction (Ripley, 1988). In the second step, we compiled a density map presenting the number of construction sites per unit area as follows. A map (M1) was constructed for one of the four main wood species. Subsequently, a common density map (M2) was compiled for the three remaining wood species. Both density maps were standardized with zero mean and unit standard deviation for better comparison. Finally, the difference map (M2 – M1) was used to highlight the differences in the spatial distribution of the selected wood species with respect to the distribution of sites of the other major wood species.

The same comparison of density maps was done for individual centuries (15th–19th). Thus, we could better compare temporal changes in construction sites with respect to the main wood species. For point pattern analysis applied in this paper, the R package “spatstat” was used (Baddeley et al., 2015).

## 3. Results

Regardless of the species, most timber constructions are dated to the 18th (35%) and the 19th (35%) centuries (Fig. 2b; Fig. S5), whereas the fewest to the 15th century (4%). However, the distribution of the species-specific historical constructions considerably differs in space and time. The percentage proportion of individual species shows prevalent utilization of fir in historical constructions across Czech lands from the 15th to 18th century. Although spruce utilization was less frequent at



that time, its proportion in historical constructions gradually increased from the beginning of the 16th century and started to dominate in the second half of the 19th century, mainly at the expense of fir and oak. The abundance of pine constructions slightly increased until the 18th century, although its percentage proportion from the total amount remains relatively stable over time (Fig. S5). Among these dominant species, oak is the least common in historical constructions and its proportion considerably decreased in time.

Considering elevation, timber constructions are distributed from 136 to 1019 m asl with the median at 353 m asl (standard deviation=133 m). Interestingly, not only the highest located constructions (only 4 above 900 m asl) but also the lowest ones (7 lower than 150 m asl) were made of fir and spruce. The spatial distribution of the species-specific timber construction sites reveals a direct dependence on altitude (Fig. 3). As altitude also reflects other natural conditions, such as prevailing climate or soils, each tree species demonstrates a typical spatial pattern. This was partly proved statistically with the test against the random spatial distribution using the Ripley's K function (Fig. S6). Results of the test show a significant deviation from the randomness for the distribution of construction sites for all wood species analysed. Moreover, all four species demonstrate a significant tendency to clustering.

Differences in density maps show regions where individual species prevail compared to the other dominant species (Fig. 4, Fig. S1–S4). Only historical constructions made of fir are relatively equally distributed across the country albeit with the two regions of higher density in Central Bohemia (mainly Prague) and the Bohemian-Moravian Highlands (Fig. 4a). However, the spatial analysis of fir deviations shows that fir predominated in historical constructions particularly in the eastern

part of the Czech lands (Moravia/Silesia) while its proportion in buildings of western and central part of the country is less significant. This is related to the less frequent occurrence of spruce and pine constructions in Moravia/Silesia until the 17th century (Fig. S2 and S3). Spruce constructions are largely spread across the western and central part of the Czech Republic while they are rare in the eastern part (Fig. 4b). The average elevation of all spruce constructions is 394 m asl, which is the highest among the four dominant species, as demonstrated by clusters in highlands, sub-mountains and mountains regions, especially from the 17th century on (Fig. S2). Pine and oak constructions are located in lowlands with maximum elevations of 660 m and 760 m, respectively (Fig. 4cd). The spatial analysis of pine deviations shows that pine prevails in the historical timber constructions of western and southern Bohemia, while pine constructions were underrepresented in the Bohemian-Moravian Highlands over the centuries. From the 17th century, pine started to occur in southern Moravia (Fig. S3). The distribution of oak is concentrated especially to low elevated central Bohemia and southern Moravia. The proportion of the oak construction wood at higher elevations is negligible (Fig. S4).

#### 4. Discussion

A dendrochronological database, involving very detailed information about each construction, provides a unique opportunity to investigate spatio-temporal changes in wood utilization in historical buildings with respect to wood species and type of construction. Although only four species (fir, spruce, pine, and oak) dominate in historical constructions (~99%) in the Czech lands (Fig. 1), we observe substantial differences in their utilization, which can be caused by many reasons,

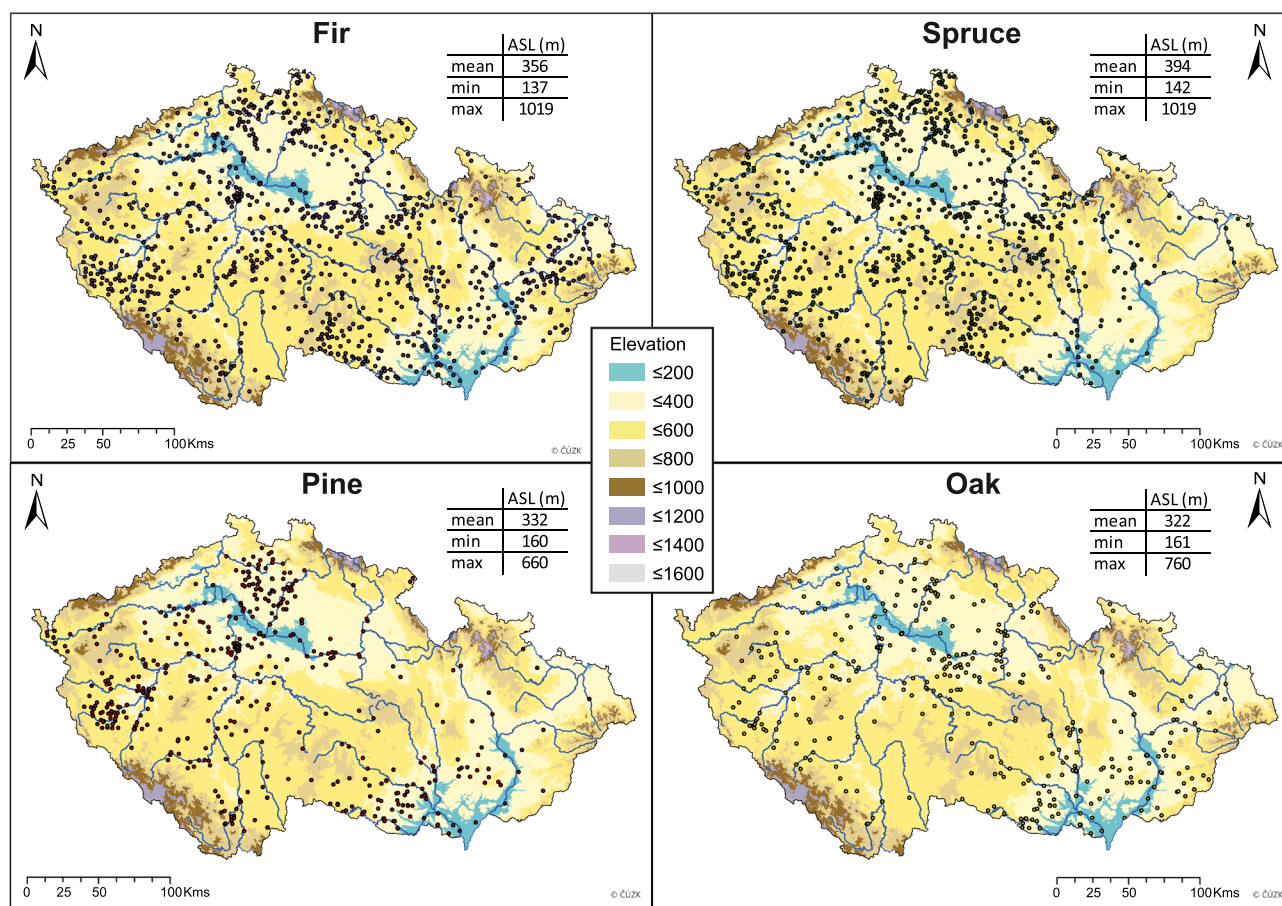
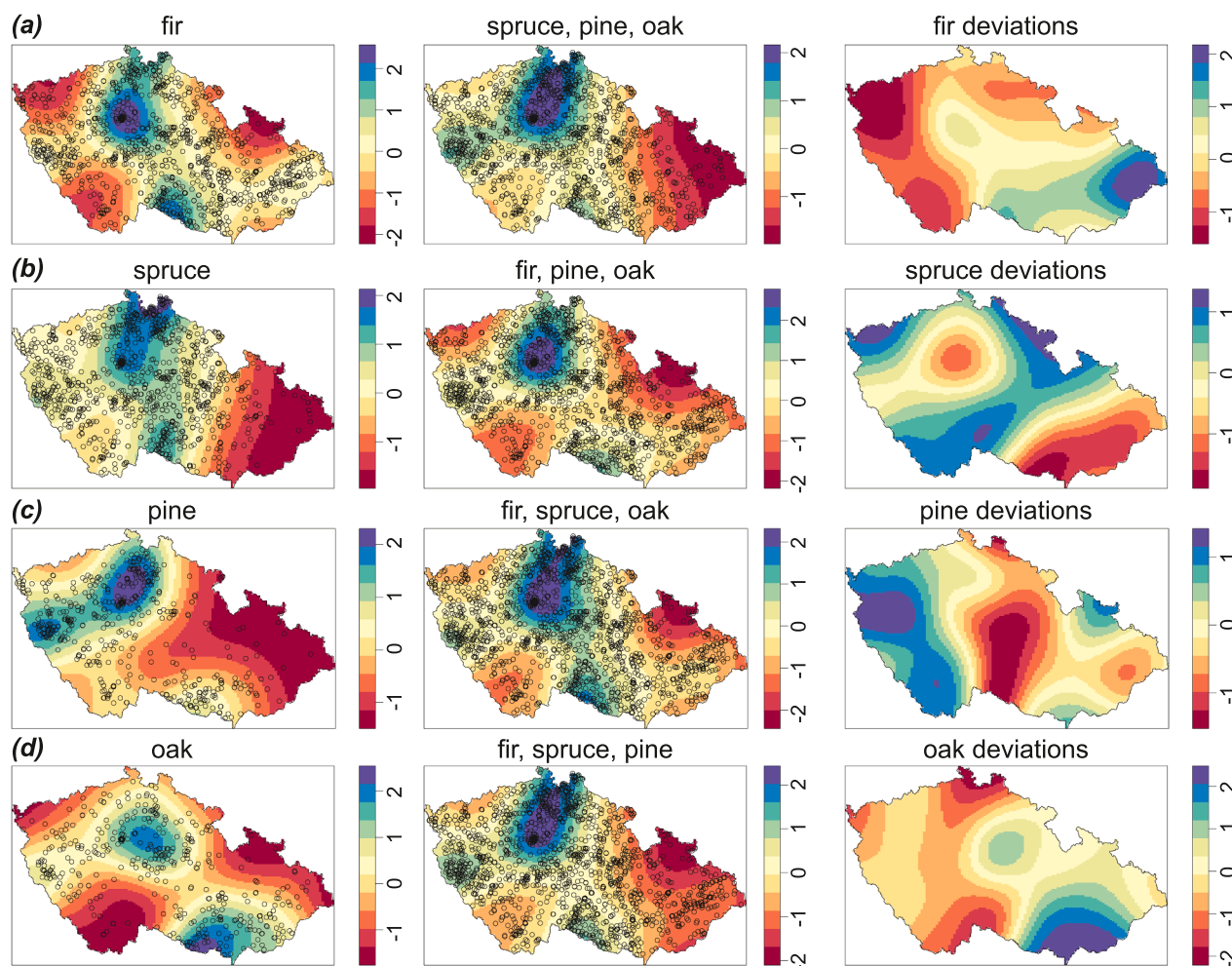


Fig. 3. Spatial distribution of fir, spruce, pine, and oak constructions in the Czech lands in the 1400–1900 period with inset tables showing minimum, mean and maximum elevations (ASL) of the sites.





**Fig. 4.** Spatial analysis of fir (a), spruce (b), pine (c), and oak (d) distribution over the entire study period. Points and standardized density fields indicate dated constructions for the particular species (left), for all the other tree species (middle) and the difference between the particular species and all the other tree species (right). The dark red (blue) colour indicates the areas where the density of the particular species is significantly lower (higher) compared to all the other wood species.

such as species-specific properties, type of construction, and regional availability reflecting forest species composition and/or timber trade.

#### 4.1. Wood utilization with respect to its properties and stem geometry

Wood properties and geometry of tree stem are pivotal for the intended use of wood in timber constructions. Out of all wood species, conifers prevail in almost all parts of historical constructions (Fig. 1), arguably due to their specific properties. Even though they differ slightly, all conifers are characterized by long and straight stems with minimum defects as well as by wood with an advantageous ratio between strength properties and density (especially spruce) and great durability in dry conditions (e.g. Jirout, 1928; Grabner, 2017; Tippner et al., 2020), as proven by very well preserved constructions that are hundreds of years old (Klein and Grabner, 2015). Thanks to these properties, coniferous wood is ideal for common structural parts of buildings made of timber, such as roofs and ceilings with a large span between supports, or walls where no gaps between horizontal logs are desirable. Generally speaking, dated wood samples are less abundant in walls of log houses than in roof constructions (Fig. 1) because houses entirely made of wood were often discouraged or prohibited (except for roof constructions) from the 18th century onwards due to fire protection regulations (Vařeka and Frolec, 2007) and started to be replaced by fired bricks and stone in the 19th century (Hájek, 2001). Interestingly, conifers were very common in half-timbered walls (Fig. 1) while oak was

frequently used in such constructions e.g. in Germany (Kyncl, 2017).

In addition, we reveal no significant pattern in preference of a particular conifer for particular constructions over the Czech territory. For instance, pine wood contains a much higher amount of resin than spruce and fir but the necessary straightness of the stem is not always provided (Klein and Grabner, 2015). Spruce is less prone to wood warping and cracking (Jirout, 1928). Fir is heavy when freshly felled (Jirout, 1928), which implies certain advantages and disadvantages in the use and processing of wood. In spite of these facts, differences in the proportions of individual conifers in historical constructions (Fig. 1) are not based on carpenters' preferences (Škabrada and Kyncl, 2003) but primarily on the local availability of the species.

Out of broadleaved species, oak is the most frequently identified (97%) not only in our dataset (Fig. 1) but also in archaeological excavations (Čufar et al., 2015; Muigg et al., 2018; Rybníček et al., 2018, 2020) as well as subfossil findings (Kolář and Rybníček, 2011; Kolář et al., 2013; Kern and Popa, 2016; Nechita et al., 2018; Rzepecki et al., 2019). Generally, oak is characterized by high strength and exceptional durability even under water (Kolář et al., 2014; Grabner, 2017; Baar et al., 2020). Therefore, oak wood was frequently used for elements under water (Čufar et al., 2015), in contact with ground (e.g. foundation beams of walls in log houses) or mechanically stressed elements such as internal supporting pillars in mills. Regardless of the region, 70% of belfry constructions and 67% of lintels were made of oak. Thanks to its excellent properties, frequent usage for various purposes and thus its

deficiency in some regions, oak was an extremely important trade commodity all over Europe (Eckstein and Wrobel, 2007; Wazny, 2011).

Although beech wood has been frequently identified in historical farm tools or even archaeological findings due to high durability under water (Cufar et al., 2014; Filková et al., 2015; Grabner, 2017; Muigg et al., 2018), its representation in historical buildings is very scarce (Fig. 1). Represented almost exclusively in farm buildings, crooked logs of beech were either deliberately used in walls (except for foundation beams) of barns and haylofts to make gaps and support air convection; alternatively, the gaps between logs were filled with clay or moss (e.g. timbered fruit dryers). In any case, most of the logs were damaged by wood-decaying insects and atmospheric corrosion as beech wood does not tolerate changes in humidity (Grabner, 2017). We can assume that more buildings were made of beech because beech wood was likely used as a replacement for more common species in the periods and/or areas of their deficiency, but these buildings have not been preserved.

#### 4.2. Spatio-temporal differences in wood utilization

The temporal distribution of the dataset is unstable over time (Fig. 2b) as 70% of the timber constructions fall into the 18th and 19th centuries. The number of timber constructions decreases back in time because very old wooden constructions are rarely preserved. It also decreases towards the present as a result of the smaller demand for dendrochronological dating of buildings from house owners after the late 19th century.

Over the 1400–1900 period, fir and spruce dominate in historical timber constructions across the Czech lands (Figs. 1 and 2b). Regardless of the type of construction, fir prevails in historical buildings until the end of the 18th century with about 40% in each century (Fig. 2b). Silver fir was one of the most widespread tree species across the Czech lands in the study period (Málek, 1981; Kozáková et al., 2011). Given that other conifers rarely grew in the easternmost area of the country, the spatial analysis of fir deviations shows that fir was almost exclusively used for timber constructions in that region (Fig. 4). From the beginning of the 19th century, the utilization of spruce wood increases at the expense of fir and oak, and dominates at the end of the century. This is in contradiction with results from the Austrian Alpine foothills where the use of spruce wood strongly declined at the same time, which could be explained by the increasing price of spruce wood or the increasing production of charcoal (Klein and Grabner, 2015). The gradual increase in spruce utilization resulting in its later dominance in the Czech lands could be explained by the interaction of three parallel processes. First, after a brief period of pine use, spruce was the preferred species in plantation forestry, starting approximately at the second quarter of the 19th century (Nožička, 1968). The ecological optimum for spruce growth falls into foothill and mountain regions with sufficient soil humidity (Kolář et al., 2017). Later on, spruce was planted out of this ecological optimum, at lower elevations. Second, as observed already by Málek (1970), spruce had probably started spreading centuries before it was promoted by foresters. Historical sources clearly show that it had a significant presence at the end of the 18th century (Szabó et al., 2017). Our database also shows that spruce utilization expanded eastwards as well as to lower elevations from the 17th centuries onwards (Fig. S2). The mean elevation of spruce constructions in the 15th century was 474 m asl, gradually decreasing to 386 m asl in the 19th century. The reasons behind this spread may include human influence as well as more favourable climatic conditions for spruce growth during relatively colder phases of the Little Ice Age. Another very important reason for the significant elevation decrease of spruce constructions can be the increased demand for timber due to increased building activity and associated timber trade and timber floating from more distant regions (Holec, 1971; Kolář et al., in review 2021). Timber floating, mostly of conifers, was documented in the Czech lands already during the Late Medieval Period (Scheufler, 1962; Holec, 1971; Lůžek, 1972). Trees harvested at higher elevations were transported down rivers for dozens

or even hundreds of kilometres to regions with wood shortage (Škabrada and Kyncl, 2003; Kyncl and Kyncl, 2006). Third, fir started declining in the 19th century. This decline is not easy to explain, and was probably caused by a combination of modern forestry methods, which do not favour fir regeneration, and a change in the disturbance regime (Volarík and Hédli, 2013).

Pine constructions are typical of particular Czech regions, mainly western, central and southern Bohemia from the 15th century and southern Moravia from the 17th century (Fig. S3). It suggests that the brief period of pine plantations in the 19th century (see above) was not significantly reflected in pine utilization in historical buildings. On the other hand, the distribution of pine constructions rather reflects natural occurrence of pine relict forests, which are particularly typical of these areas (Úradníček et al., 2009; Jamrichová et al., 2019). Although Jamrichová et al. (2019) concluded that pine forests with a significant admixture of oak continuously covered southern Moravia throughout the Holocene, pine started to appear in historical constructions more frequently as late as in the 17th century (Fig. S3). It suggests that despite the easy availability of pine, other species (mainly oak; Fig. S4) were preferred for timber constructions.

As the most important broadleaved species (Fig. 1), oak was frequently used especially in central Bohemia and southern Moravia (Fig. 4d, Fig. S4) even if its proportion gradually decreases. The high proportion of oak was likely caused by the lack of coniferous wood in the regions. For instance, in southern Moravia, the proportion of oak represents 60% of all timber constructions in the 16th century, whereas only 19% and 9% in the 18th and 19th centuries, respectively. Both regions are in the catchments of large Czech rivers (the Elbe River in Bohemia, and the Thaya and the Morava Rivers in Moravia) with very low elevations descending to about 150 m asl, with favourable natural conditions for oak growth, i.e., relatively warm environments with a broad spectrum of soil humidity (Dobrovolný et al., 2016). The easy and stable availability of oak during the centuries explains the abundance of oak constructions in these regions.

With a minimum representation, other species, such as beech, larch, and elm, were also dated despite the fact that tree-ring width chronologies for those species do not exist for the current territory of the Czech Republic (Kyncl, 2017). One can assume that the rare occurrence of these species in the dataset is caused by the lower probability of their successful dendrochronological dating. However, a closer look at our database, including also non-dated constructions, confirms that these species are very rarely identified in historical timber constructions. All constructions in the dataset made of these less common species were dated using the existing tree-ring width chronologies for oak, spruce, pine, and fir (Kyncl, 2017; Prokop et al., 2017) and are restricted to very specific regions. For instance, beech was identified in timber constructions from the 18th and 19th centuries mostly in the White Carpathians (very close to the borders with Slovakia). In this region and period of time, forests were abundantly represented by broadleaved species (mainly beech and oak), while conifers were less common. As another example, larch is detected almost exclusively in constructions located very close to the Jeseníky Mts. This is the only region of the CR where larch occurs naturally (Nožička, 1962; Wagner et al., 2015). The remaining species (elm, lime tree, and poplar) are identified usually only once in historical constructions and show no clear pattern.

#### 5. Conclusion

An ensemble of 8 135 precisely dated historical timber constructions from the Czech lands, represented mainly by roofs and ceilings, reveals the dominant utilization of conifers, mainly spruce and fir, regardless of the type of construction. The dominance of conifers reflects their wood properties and stem geometry. The widely distributed fir is gradually replaced by spruce expanding eastwards, likely as a combination of human influence and more favourable climatic conditions. The increasing planting of spruce monocultures was reflected in historical

constructions as late as the end of the 19th century. Regionally distributed pine and oak constructions reflect their natural occurrence at lower elevations. Highly durable oak is predominantly used in mechanically stressed constructions, such as belfries or lintels. Our results suggest that the availability of individual species was pivotal for their utilization in historical timber constructions, although wood properties and stem geometry played a very important role as well. The utilization of individual species in historical constructions very likely reflects regional differences in forest species composition, which may be verified only based on historical documentary evidence.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

This work was supported by the Ministry of Education, Youth and Sports of CR within the CzeCOS program, grant number LM2018123, the SustES – Adaptation strategies for sustainable ecosystem services and food security under adverse environmental conditions project, ref. CZ.02.1.01/0.0/0.0/16.019/0000797, and by long-term research development project no. RVO 67985939. The authors would like to thank Ondřej Brázda for his help with the completion of the database.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.dendro.2021.125900](https://doi.org/10.1016/j.dendro.2021.125900).

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# Local timber dominated pre-industrial construction: Insights from archival and dendrochronological data

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## ARTICLE INFO

### Keywords:

Building timber  
Forest history  
Central Europe  
Archival sources

## ABSTRACT

In pre-modern Europe, timber was notoriously difficult and costly to transport on land, therefore it is usually assumed that ordinary buildings – except for those close to navigable watercourses – were constructed using timber from local sources. We hypothesized that species of timber used in constructions prior to the late 19th century were commonly available in forests within a short distance from the location of the constructions. To test this hypothesis, we compared high-resolution archival information on the tree species composition of forests in Moravia (eastern Czech Republic, ca. 27,000 km<sup>2</sup>) in the 18th and 19th centuries to a database of 1231 dated timber constructions in the same region and period. Our analysis was based on the mutual distances between the locations of timber constructions and the occurrences of forests with the given tree species. We compared real distances with distances obtained through random simulations. Results showed that in more than half of the cases, the tree species from constructions occurred in the forests of the same township. In the rest of the cases, the modal distance values to the centroid of the nearest township where the same species was present in the forests were usually less than two kilometres and distances larger than five kilometres were generally rare. While our results testify to the availability of timber rather than to the direct source of particular pieces of timber, they strongly suggest that timber was usually sourced locally. We believe our interdisciplinary study demonstrated the usefulness of archival data in the research of timber sourcing. For future studies, we see the combination of our approach with dendroprovenancing and other natural scientific methods as the most promising way to gain deeper knowledge on the sourcing of timber.

## 1. Introduction

Before modern construction materials, such as concrete and steel, became generally available, most buildings in Europe were made of timber, stone and brick. Of these, timber was the most common in the sense that even stone and brick constructions contained timber in their roof and ceiling structure. Many thousands of houses, churches, barns, fortifications etc. were built each year in Europe using huge amounts of timber (Antoine et al., 2024). Timber itself was not necessarily expensive in all places and periods, but transporting it was notoriously difficult and therefore costly. Virtually the only profitable way to transport

timber over longer distances was floating on water (individually or bundled in rafts). Rivers were often modified to allow for timber floating, for example by straightening their beds or by constructing dams and loading platforms along their courses (e.g. Törnlund and Östlund, 2002; Johann, 2019). In later periods, even specialized timber floating canals were constructed in mountain areas. For example the almost 52 km-long Schwarzenberg canal, the construction of which started in 1789 and lasted for more than three decades, connected timber resources in the Bohemian forest to the Vienna markets (Lange, 2004). On larger navigable rivers and at sea, timber could also be transported on ships. Because of the excellent business opportunity long-distance timber trade

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<https://doi.org/10.1016/j.dendro.2025.126337>

Received 6 January 2025; Received in revised form 31 March 2025; Accepted 4 April 2025

Available online 6 April 2025

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provided in the Middle Ages and Early Modern Period, its economic history has been well-researched. Much is known for example about the timber trade from Poland, Germany, the Baltic states, Russia or Norway to the Low Countries or England (e.g. Kent, 1955; Hutchison, 2012; Banken, 2024).

Land transport of timber, however, was much more problematic. Pre-modern roads were usually in a poor state of repair and impassable during the rainy season. For example, a report from the end of the 18th century from Landshut in Bavaria noted that even though prices were high, wood was rotting away in just a few hours' distance because conditions were not suitable to transport it on land (Radkau, 2012). Steeper terrain also posed almost insurmountable problems (Johann, 2021). Furthermore, timber is very heavy for its bulk and therefore its transport requires considerable animal power. This meant financial as well as workforce constraints: wherever arable agriculture was practised, it had priority regarding the use of draught animals and the number of such animals in any case could not exceed the carrying capacity of particular regions. As a result, it is usually assumed that ordinary, low status buildings in pre-modern European settlements – except for those close to navigable watercourses – were preferably constructed using timber from local sources within a few dozen kilometres (Bridge, 2012). This situation changed only with the arrival of railway transport, which completely rearranged the former distribution network of many commodities. For the timber trade, this meant not only easier access to supra-regional resources but also the rapid expansion of the so-called “timber frontier” to previously inaccessible regions (Björklund, 2000).

There are several ways to test the validity of the hypothesis that timber in ordinary constructions came from local forests. Perhaps the best known is dendroprovenancing, which traces the geographic origin of individual pieces of timber by comparing their rings to local chronologies (Eckstein and Wrobel, 2007; Bridge, 2012; Gut, 2018). For example, D'Andrea et al. (2024) showed that low-status timber framed houses in Limoges, France in the 15th century were constructed mainly from trees from forests within a 50-kilometre radius around the city. Eissing and Dittmar (2011) demonstrated that timber in a 16th-century village house was cut either in local forests (oak) or transported from a distance of 20 km (fir) and also that the town of Nuremberg used mainly local timber and even introduced legislation to protect these resources. Seim et al. (2015) showed that medieval church roofs in southwestern Sweden were also constructed from local timber. However, as the original focus of dendroprovenancing was long-distance timber transport (Eckstein and Wrobel, 2007), so far most studies have focused on this aspect (cf. Domínguez-Delmás, 2020). Furthermore, as D'Andrea et al. (2024) noted, dendroprovenancing also has its limitations as regards the exact location of source timber especially if environmental conditions are uniform over larger regions. Therefore, novel methods and multivariate approaches for tracing the origins of wood have been tested, such as aDNA (Wagner et al., 2018), the  $^{87}\text{Sr}/^{86}\text{Sr}$  strontium isotope ratio (Rich et al., 2015), quantitative wood anatomy (D'Andrea et al., 2022), stable isotopes (Kagawa and Leavitt, 2010) or a combination of these (Akhmetzyanov et al., 2019; Domínguez-Delmás et al., 2020; D'Andrea et al., 2023).

While we acknowledge the usefulness and potential of dendroprovenancing and other studies, in this paper we follow a different, complementary and interdisciplinary approach. We focus on the connection between species of trees used in various constructions and the availability of these species in contemporary forests. We use spatially high-resolution archival information on the tree species composition of forests in a Central European region in the 18th and 19th centuries and compare this information to a large database of dated timbers from constructions in the same region and period. We hypothesize that the species of timber used in constructions prior to the late 19th century were commonly available in forests within a short distance from the location of the constructions.

## 2. Materials and methods

### 2.1. Study area

The study area covers Moravia and Czech Silesia (together c. 27,000 km<sup>2</sup>) in the eastern half of the Czech Republic in Central Europe (Fig. 1). Although these two territorial units had different origins, in the study period they often formed part of a common administrative framework and therefore for the purposes of this paper we refer to them together as Moravia. The area is made up of 3567 townships, i.e. villages and their surrounding lands including arable fields, forests, meadows and pastures. Townships are historically the lowest tier of local administration, whose territories were formalized in the 18th century resulting in an average size of ca. 7.5 km<sup>2</sup> (Szabó et al., 2017). Climate in Moravia is mild with mean annual temperatures of 1–10°C and precipitation of 500–1500 mm (Tolasz et al., 2007). The area includes agricultural lowlands in the southern and central parts, highlands in the west and mountains of max. 1491 m a.s.l in the north and east. Approximately one third of the area is covered by forests. The main types currently include thermophilous oak (*Quercus* spp.), oak-hornbeam (*Carpinus betulus*), beech (*Fagus sylvatica*) and spruce (*Picea abies*) forests. Especially spruce has increased through planting in the past two centuries. Another significant change in tree species composition in the recent past has been the almost complete disappearance of the previously very common silver fir (*Abies alba*).

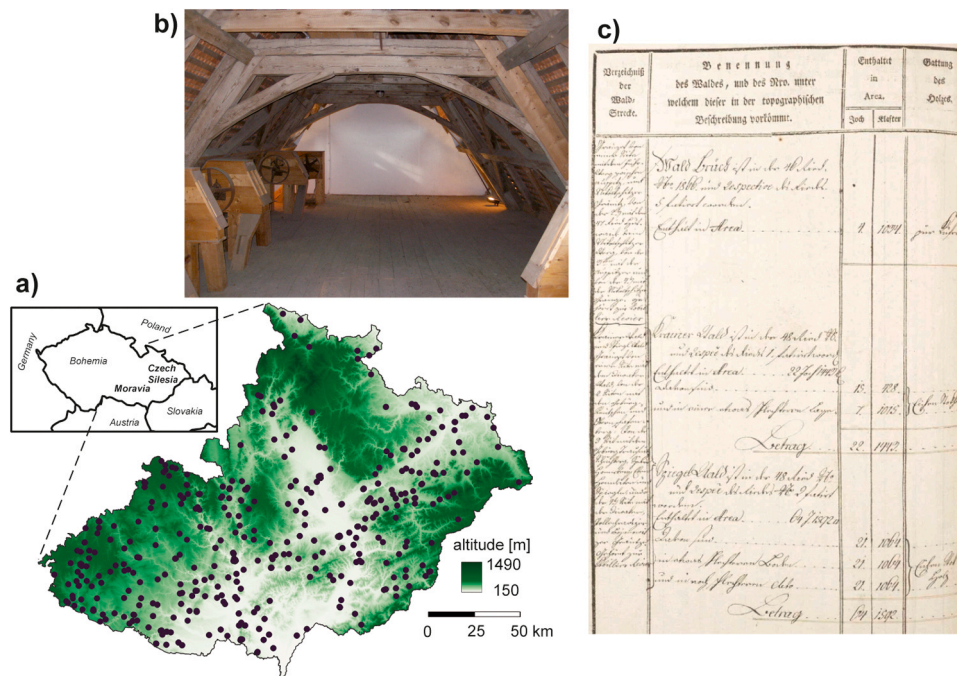
### 2.2. Data sources

#### 2.2.1. Archival data

Although much information is available on the tree species composition of Moravian forests from the Middle Ages and Early Modern Period, such data often have coarse spatial resolution and do not cover the entire study area (Szabó et al., 2018). The earliest conscriptions of tree species composition in Moravia that are available in high resolution for each township are the so-called Josephian and Stable cadastres, both compiled for taxation purposes by the Habsburg authorities.

The Josephian cadastre (named after Emperor Joseph II) was drawn up in 1787–1789 as the first cadastre to survey all land regardless of ownership with the same methodology. It included the so-called *Wald-Fassion*, describing the size and position of forests, their management and dominant tree species in each township. Trees were recorded using common names, which usually denote genera in the modern botanical sense (beech, oak, spruce, fir, pine, willow, ash). Nevertheless, several of these genera were represented by a single species (e.g. *Fagus sylvatica*, *Picea abies*, *Abies alba*) in Moravia until forestry plantations of non-native species became common in the late 19th century. Even though tree species composition was a compulsory element of the survey, in many cases the surveyors unfortunately distinguished only two categories: hardwood and softwood. From among the tree species that occur in the dendrochronological database (see below, chapter 2.2.2.), oak belonged to hardwoods, while fir, spruce and pine to softwoods.

The Stable cadastre (so called because it was supposed to last 'forever') consisted of three parts: geometric surveying, written surveying and evaluation (Bičák et al., 2015). In Moravia, geometric surveying was carried out between 1824 and 1836, concurrent with written surveying and followed by evaluation (i.e. establishing the monetary value of each parcel for taxation). The written survey and evaluation included surveys of forests as well, recording size, boundaries, dominant tree species and management. Most of the written forest surveys in Moravia are from the 1840s, while the Stable cadastre as such took legal effect only in 1851. As opposed to the Josephian cadastre, the Stable cadastre took decades to complete and therefore establishing any year as its exact date of origin is problematic. For the purposes of this paper, we took 1840 as the cut-off date, as we think this year represents a reasonable compromise between fieldwork and office work during the extremely complex and long-lasting work of preparing this cadastre.



**Fig. 1.** Map of the study area in Central Europe with dots indicating the locations of timber constructions (a) and examples of dendrochronological (b) and archival (c) data sources.

The availability of these two cadastral surveys offers an excellent opportunity to test our hypothesis on two datasets. As far as we know, the two surveys were independent of each other, therefore congruent results can reinforce our conclusions. For cadastral data, we used the methodology and database described in Szabó et al. (2018). Townships mentioned in the cadastres were identified with modern townships. This introduces certain ambiguities into the system but appears as the only workable solution on the level of 3567 townships, whose exact historical boundaries were only described as text (Josephian cadastre) or have not yet been digitized from the original maps (Stable cadastre) (Szabó et al., 2017). To reduce potential errors connected to changes in the boundaries of townships (cf. Frajer, 2019), we used the centroids rather than outer boundaries of townships in our calculations. Data on tree species composition was extracted for each township from both surveys. Whereas in the Stable cadastre data for tree species was reasonably complete without major gaps or ambiguities, in the Josephian cadastre we had to use for 425 and 811 townships data on hardwood and softwood, respectively, and aggregate these data with townships where data on tree species were available, i.e. oak + hardwood, pine + softwood, spruce + softwood, fir + softwood.

### 2.2.2. Dendrochronological data

All dendrochronological data were extracted from the Czech dendrochronological database ([www.dendrochronologie.cz](http://www.dendrochronologie.cz)), which includes almost nine thousand dated historical and archaeological wooden remains from the current territory of the Czech Republic from prehistory to the 20th century. We extracted all dated constructions 50 years before and after each cadastral survey. That is, constructions dated to the period 1740–1840 and 1790–1890 were used in the analyses of the Josephian cadastre and the Stable cadastre, respectively. On the one hand, we assume that forest surveys also reflect the period before the cadastres were published. On the other hand, conifers (mainly spruce and fir) reached the most suitable diameter and height for timber constructions between 70 and 100 years of tree age, as reflected by both contemporary literature (Jondl, 1840) and the mean length of the dated series (approx. 80 years) in our database. We therefore opted for this method of selection to ensure that the dendrochronological data are compatible with the realities of forests as described in the cadastres.

Thanks to the presence of the outermost tree ring (the so-called waney edge), we were able to determine the exact year (or even the season) when the tree used for construction timber was felled (Kolář et al., 2022).

In total, we used 1231 precisely dated historical timber constructions (623 for the Josephian cadastre and 608 for the Stable cadastre). These constructions were mainly residential and farm houses, churches, castles and monasteries. Most of the timber came from either roof constructions or ceiling beams with 65 % and 19 %, respectively. The vast majority (99 %) of the constructions in the study area were made of fir, spruce, pine, and oak (Kolář et al., 2021), therefore we selected for the following analyses only these four species. In our dataset, fir was the most common (682 constructions, 55 %), followed by spruce (329, 27 %), pine (124, 10 %) and oak (96, 8 %). Since historical buildings were not always constructed using only a single tree species, two different species-specific constructions were considered for the analysis if two or more species were identified in one construction.

### 2.3. Spatial analyses

To test our hypothesis for the individual tree species, we adopted a methodological approach based on the analysis of the mutual distance between constructions using the given tree species and townships where the species was present in local forests, as described below.

First, we tested whether the spatial distribution of the timber constructions in the study area differs from random distribution. A significant deviation from randomness may indicate that the real spatial arrangement of timber constructions is the result of certain processes or phenomena. We used a simple Clark-Evans test for randomness (Clark and Evans, 1954). This test computes  $R$  statistics as a ratio between the real (calculated from data) and expected (derived from a theoretical model) mean distance to the nearest neighbour. We tested the null hypothesis on randomness against the alternative hypothesis of a clustered distribution of constructions. Results based on the nearest neighbour distance may be biased due to the fact that timber constructions close to the borders may have the nearest neighbour hypothetically outside the study area. To correct for this 'edge effect', we applied a guard correction (Yamada and Rogerson, 2003). This approach first defines an inner

buffer zone. Constructions in this zone are allowed as neighbours, however, their nearest neighbour distances are not used in R statistics calculation.

In the second step, we used the concept of the nearest neighbour in order to investigate the spatial interaction of the constructions and the forested townships closest to them. For this purpose, we used the cross G-function (Baddeley et al., 2016). More formally,  $G_{ij}(r)$  quantifies the probability distribution of timber construction (i) nearest to the centroid of forested townships (j) within a given distance (r). Whereas theoretical  $G^{Pois}$  represents distribution of the nearest neighbour distances under complete spatial randomness (CSR),  $G^{bord}$  is a G-function from observed data and applying the same edge effect correction as explained above.

We then combined the two spatial databases in the form of maps, in which we distinguished two types of constructions based on whether the tree species in them occurred in the forests of the same township or not. For each construction whose tree species was not available in the forests in the same township, we calculated the distance to the nearest township with the given tree species. The distance was calculated from the position of the construction to the nearest centroid of a township with the given tree species.

We characterized the distribution of the closest distances of constructions to forested townships with their histograms. Considering the asymmetric right skewed shape of the histograms, we used the modal, i. e. the most frequent distance as the typical distance between constructions and forested townships. Subsequently, we randomly generated the position of the same number of constructions in the entire study area. For 999 simulations, we calculated the modal value of the closest distances of the constructions to forested townships and compiled a probability density function (pdf) from all simulated modal values. Using the pdf function, we calculated the probability of occurrence of the modal distance of constructions to forested townships calculated from observed data. The modal values represented only about 30 % of the closest observed distances of constructions from forested townships for all the tree species studied. Therefore, we repeated the same procedure for a stricter criterion, namely the distance of the third quartile, that is, the distance greater than 75 % of all observed distances. All computations were conducted in the spatstat R package (Baddeley and Turner, 2005).

### 3. Results

The Clark-Evans test demonstrated in all cases that the distribution of the locations of constructions differed significantly from random distribution and showed clustering (Table 1). The number of constructions located directly within townships with the occurrence of the given timber species and outside such townships was relatively similar in most of the eight studied cases (four tree species times two cadastral surveys). The highest and lowest proportions of constructions within townships with the given timber species were found for spruce and oak, respectively. The overall distribution of the distances of constructions from the nearest township with the occurrence of the given tree species was strongly asymmetric and positively skewed (see Table 1 and also the first columns of Figs. 6 and 7). This means a significant predominance of short distances. For instance, the most common distances (mode) varied from 606 to 1365 m and even the third quartile (Q75) distances mostly did not exceed 6000 m (highest value: 6059 m for fir in the Stable cadastre). However, in individual cases, the maximum distance of constructions from forest occurrence exceeded even 40 kilometres (such as for fir and spruce in the Stable cadastre). In effect, this means that the tree species in constructions in our dendrochronological database were usually available in a township within a few kilometres from the location of the construction. There were no major differences between the Josephian and Stable cadastres concerning these values.

The cross-G functions reinforced the notion that the locations of constructions and the centroids of townships where the given tree species occurred were typically close to each other (Figs. 2 and 3). Each plot contains two functions.  $G_{bord}$  above  $G_{Pois}$  represents positive

association (attraction), which means that many constructions and the nearest centroids of relevant townships were close to each other compared to CSR. Conversely,  $G_{bord}$  below  $G_{Pois}$  expresses negative association (repulsion), in which constructions very rarely occur close to the centroids of forested township compared to CSR. In most cases in both cadastral surveys, coniferous species in constructions and forests showed positive association until ca. 1500–2500 m and negative association above that value. In other words, at short distances their common distribution was more clustered than it would have been under a random pattern. Oak, however, showed positive association through almost the entire range of distance values in both surveys. In addition, the cut-off value between attraction and repulsion showed somewhat higher values for the Stable cadastre than for the Josephian cadastre. Overall, the analyses confirmed the hypothesis that the specific species of timber used in constructions in the study period were commonly available in forests within a short distance from the location of the constructions.

Figs. 4 and 5 summarise the spatial distribution of timber constructions and townships with the occurrence of the four tree species. Fir and spruce grew in higher-lying regions in the west, north and east, whereas oak was commonly found in the southern and central lowland areas. Pine was absent in the highest mountains but its area included some of the lowlands. The individual maps demonstrate that the constructions located furthest from relevant forested townships - at least for spruce, fir and pine - were mainly located in the southern part of Moravia, in the lowlands near the Austrian border.

Figs. 6 and 7 summarise the main results of two simulations whose aim was to quantify the extent to which the observed distances of constructions from the nearest relevant forested townships differed from the distances that would have been observed in the case of a purely random distribution of constructions. We compared two characteristics of the distance of real constructions from forests (mode and Q75) with the same characteristics obtained from 999 random simulations. The simulations demonstrated that the probability of the occurrence of the modal value of real data was very low in all cases. It was mostly less than 1 % and only slightly higher (4 %) for pine and oak in the Josephian cadastre. Similarly small probabilities were obtained in the case of the Q75 simulations for all studied tree species in the Stable cadastre and for spruce and oak in the Josephian cadastre. However, for pine and especially for fir in the Josephian cadastral survey, the probabilities of real distances in the distribution of simulated Q75 values were quite high. In other words, these two cases indicate that the occurrence of constructions further from forested townships was not exceptional. In sum, except for two cases out of sixteen, the simulations overwhelmingly demonstrated that timber species used in constructions were statistically significantly closer to forests where such species grew than they would have been under random distribution.

### 4. Discussion

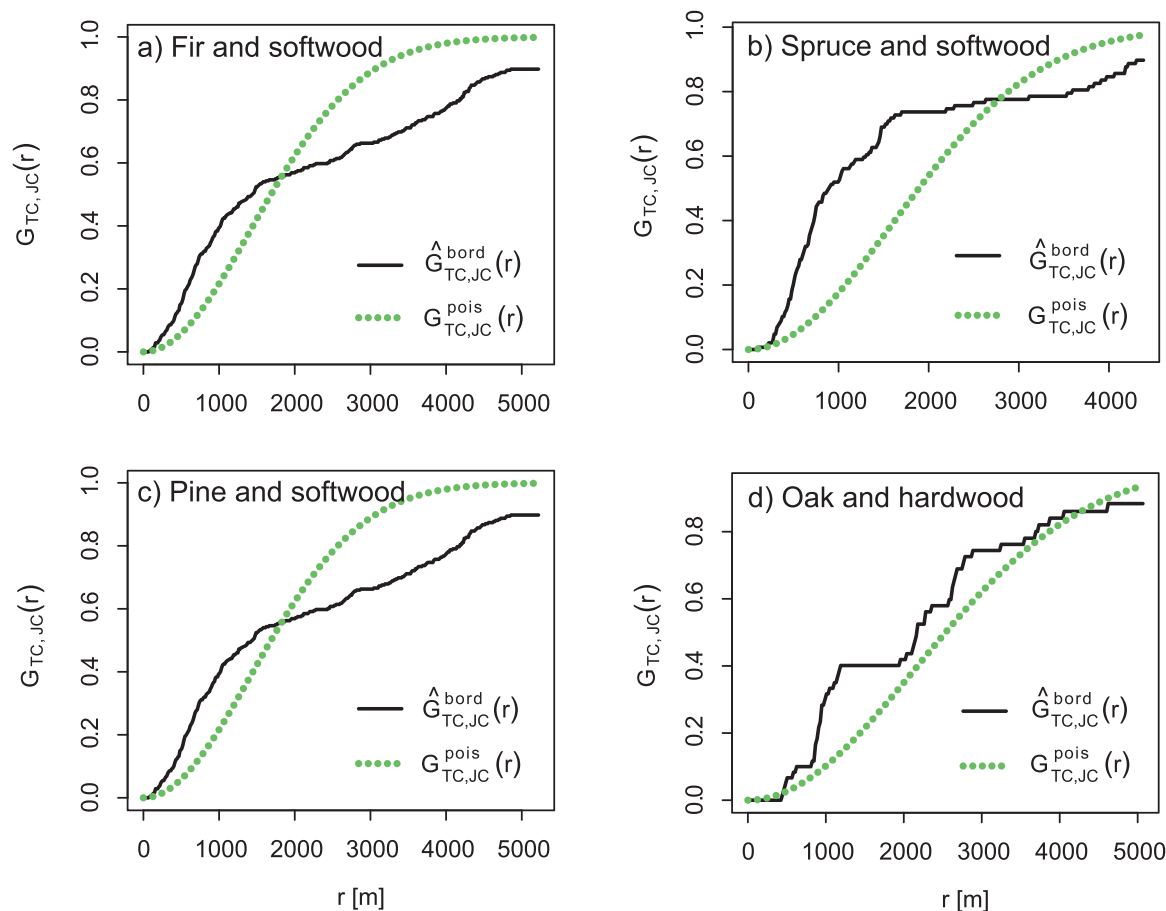
#### 4.1. Local sources of construction timber

Our analyses showed that the tree species used in constructions in the 18th and 19th centuries in Moravia were in the vast majority of cases available in local forests and that specific species of timber were rarely used far away from local sources. In more than half of the cases, the tree species from constructions occurred in the forests of the same township. In the rest of the cases, the modal distance values to the centroid of the nearest township where the same species was present in the forests were usually less than two kilometres and distances larger than five kilometres were generally rare. It is nonetheless important to keep in mind that our analyses concerned the availability of tree species rather than the precise geographical origin of particular pieces of construction timber. The question then arises whether or not socioeconomic conditions were favourable for the local procurement of timber for building purposes in the 18th and 19th centuries in Moravia. Generally speaking,

**Table 1**  
Number of timber constructions and their characteristic distances to the centroids of the nearest township with the occurrence of the given tree species for individual tree species according to the Josephian and Stable cadastres.

| tree species | source             | constructions in township with species |      | constructions in township without species |      | distance from centroid of nearest township with species (m) |             |        |      |      |            |       | Clark-Evans test, Guard correction |
|--------------|--------------------|----------------------------------------|------|-------------------------------------------|------|-------------------------------------------------------------|-------------|--------|------|------|------------|-------|------------------------------------|
|              |                    | n                                      | %    | n                                         | %    | min.                                                        | 1st quarter | median | mean | mode | 3d quarter | max.  |                                    |
| fir          | Josephian cadastre | 190                                    | 54 % | 161                                       | 46 % | 72                                                          | 666         | 1427   | 2320 | 763  | 3607       | 16567 | 0.61694*                           |
|              | Stable cadastre    | 118                                    | 36 % | 213                                       | 64 % | 72                                                          | 1023        | 2880   | 5488 | 1365 | 6059       | 44500 | 0.61209*                           |
| spruce       | Josephian cadastre | 108                                    | 73 % | 39                                        | 27 % | 120                                                         | 545         | 892    | 1686 | 606  | 1824       | 16567 | 0.60953*                           |
|              | Stable cadastre    | 113                                    | 62 % | 69                                        | 38 % | 19                                                          | 563         | 982    | 4041 | 661  | 2520       | 44500 | 0.56673*                           |
| pine         | Josephian cadastre | 28                                     | 43 % | 37                                        | 57 % | 222                                                         | 824         | 2098   | 2951 | 1073 | 4050       | 16567 | 0.60798*                           |
|              | Stable cadastre    | 34                                     | 58 % | 25                                        | 42 % | 126                                                         | 633         | 1600   | 3202 | 665  | 2814       | 20636 | 0.73171*                           |
| oak          | Josephian cadastre | 21                                     | 35 % | 39                                        | 65 % | 439                                                         | 936         | 2168   | 2447 | 1105 | 3312       | 8448  | 0.79275*                           |
|              | Stable cadastre    | 18                                     | 50 % | 18                                        | 50 % | 367                                                         | 846         | 2020   | 2321 | 930  | 3097       | 8069  | 0.74831*                           |

\* all R values are significant at < 0.001



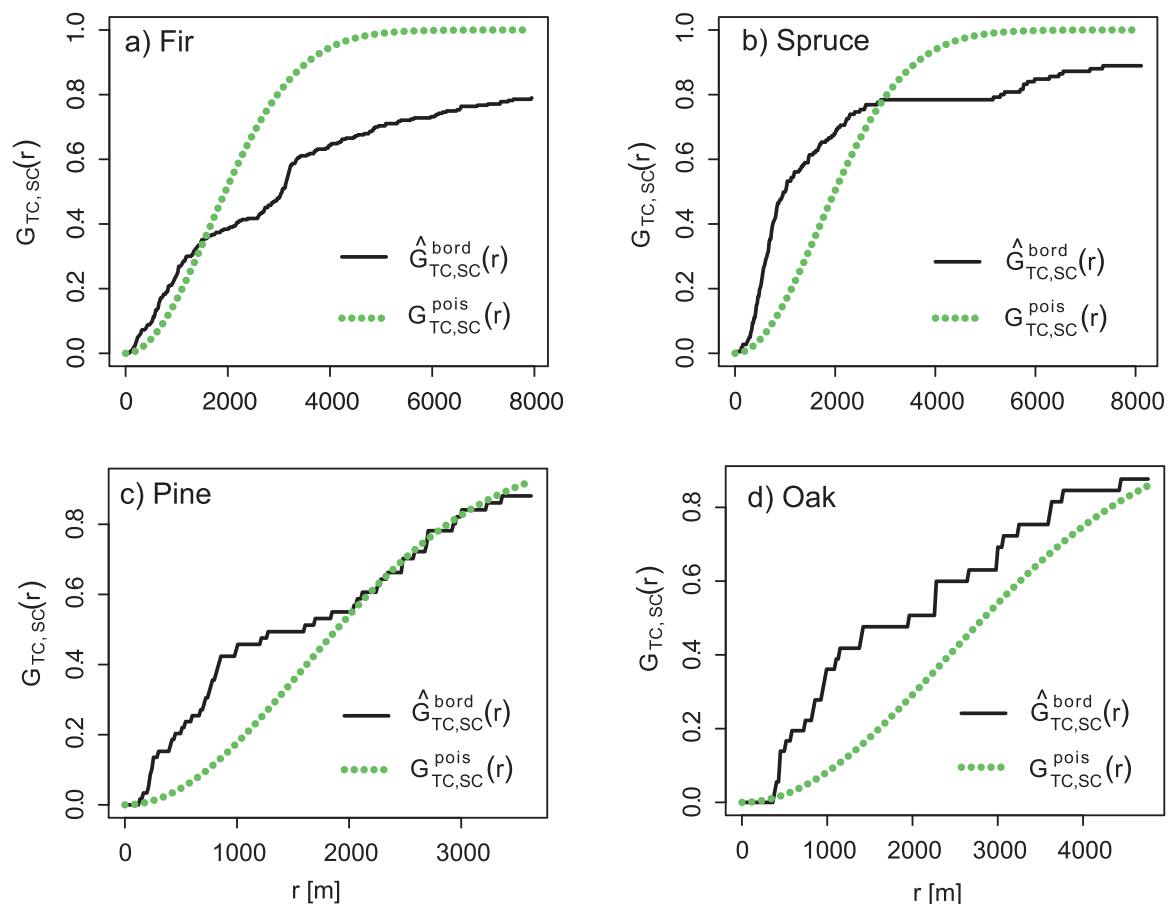
**Fig. 2.** The expected (Gpois) and observed (Gbord) cross-G functions representing the cumulative distribution of the nearest-neighbour distances between timber constructions and the centroids of the nearest townships where the given tree species occurred based on the Josephian cadaster. Gpois represents the distribution of the nearest neighbour distances under complete spatial randomness. Gbord assumes edge correction due to no information about the data outside the study area (see text for explanation).

there were two ways for non-noble subjects to acquire construction timber in this period. It was either taken from local forests to which members of the community had free access or, and this was much more common, it had to be bought from demesne forests, which represented the vast majority of all forests in Moravia (Szabó, 2021). In the first case,

the source of timber naturally had to be nearby. The same was probably true for the second case as well, because end users usually cut the timber themselves and had to pay for transportation.

The above considerations together with the combined evidence of 1231 timber constructions and detailed archival sources on coeval forest





**Fig. 3.** The expected ( $G_{pois}$ ) and observed ( $G_{bord}$ ) cross-G functions representing the cumulative distribution of the nearest-neighbour distances between timber constructions and the centroids of the nearest townships where the given tree species occurred based on the Stable cadastre.

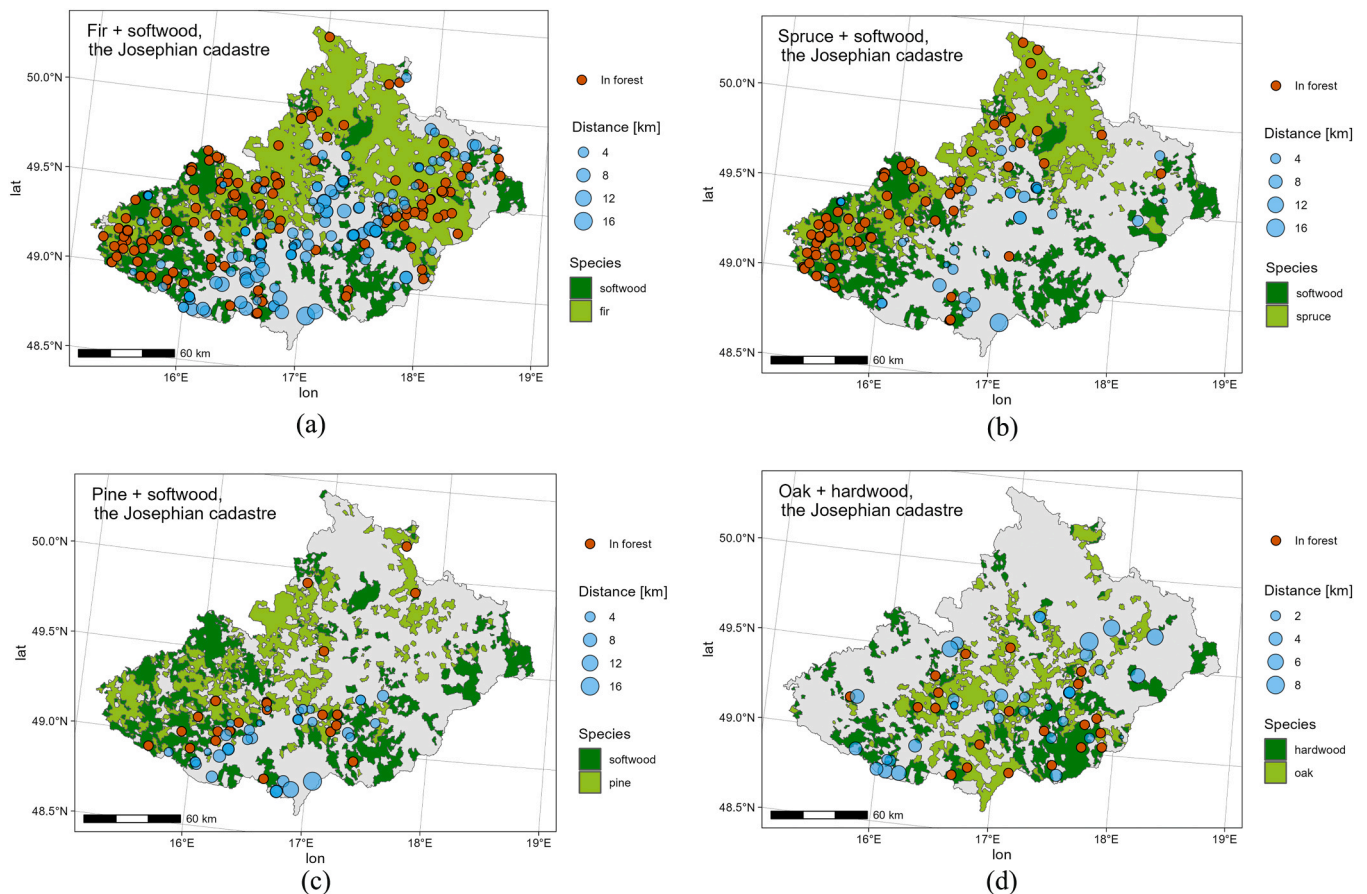
tree species composition suggest that people used local sources of construction timber and tried to avoid transporting timber over longer distances as much as possible. As succinctly put by the author of the forest management instructions attached to the 1754 Bohemian forest law: „one can easily perceive the advantages of tree cultivation, as many reasonable farmers have experienced, especially when one has timber close-by and does not have to procure it from far away for heavy costs and transport wages.”<sup>1</sup>

Land transport of timber to distant places was a notable exception even for the wealthy. In the early 1570 s, for example, Emperor Maximilian II ordered 600 larch (*Larix decidua*) timbers to be brought to Prague castle from Bruntál, ca. 220 km towards the east as the crow flies (Nožička, 1962b). Even if the trees could be transferred onto the Labe river around Pardubice, most of the journey had to be taken on land, which may explain why the Emperor had to repeatedly urge the local authorities and why it took more than a year for the timbers to eventually arrive in Prague. Such extraordinary measures were necessary because larch had some unique qualities but grew only in one small region of the Czech lands (Dudová and Szabó, 2022). Paying for transport, however, could be reduced or avoided in certain cases. For example, peasants in certain villages were obliged to transport timber for the overlord as part of their corvée labour (Chadt, 1913). These factors may have resulted in differences in the average distances between timber species and corresponding forests in the case of rural versus ecclesiastical/noble constructions (cf. Kolář et al., 2022). However, our post-hoc analyses revealed no such differences, and therefore we did not present these results in our investigations.

Forestry writers of the period were acutely aware of the difficulties involved in the land transport of timber. The second edition of Heinrich Cotta's seminal *Grundriß der Forstwissenschaft* (Fundamentals of forest science) contained a description of various ways of land and water transport, emphasizing that “transport by water is generally the more economical method and will therefore always be preferred where both methods are equally applicable” (Cotta, 1836). In a similar manner, the most authoritative book on timber transport, entitled *Handbuch für Holztransport- und Floßwesen* (Handbook of wood transport and rafting) devoted less than 200 pages to land transport as opposed to 600 pages describing water transport (Jägerschmid, 1827–1828). The greatest contemporary encyclopaedia of the German speaking world (initiated by Johann Georg Krünitz) discussed the financial aspects of the land transport of timber in more detail. According to this work, transporting timber to a distance of 2 miles (approximately 15 km, using the ‘German’ mile as defined in the encyclopaedia itself) cost 2–4 thaler, whereas the cost of timber per piece (depending on size and quality) was 6–12 thaler (Krünitz, 1781). To interpret these numbers, the concept of “theoretical supply radius” introduced by Galloway et al. (1996) can be used. This uses the formula  $R = (P - C) / T$ , where  $R$  is the radius in kilometres,  $P$  is the price,  $C$  is the production cost and  $T$  is the cost of transport per kilometre. In other words, the number of kilometres a piece of timber is worth transporting equals the number of times its price (minus production costs) was higher than transportation costs per kilometre. Computing with the average values of 3 thaler per 2 miles and 9 thaler per timber, we arrive at a radius of 6 miles, or ca. 45 km, which should be somewhat reduced because of the lack of information on production costs. The same encyclopaedia also added that timber could be transported at best 3–3.5 miles a day, which means that economically viable transport could last a maximum of 2 days. German forester

<sup>1</sup> Národní archiv Praha, PT, inventární číslo 1498–5.4.1754.





**Fig. 4.** Spatial distribution of fir, spruce, pine and oak trees in Moravian forests based on data in the Josephian cadastre (shaded areas). In 811 townships only 'softwood' and in 425 townships only 'hardwood' was distinguished, the pertinent category is therefore combined with the distribution of the given tree species. Dots indicate the locations of constructions distinguishing whether the given tree species was (red) or was not (blue) available in the forests of the same township. The size of the blue dot shows the distance to the centroid of the nearest township where the given tree species was available.

Hieronimus Hauck in 1866 provided much less optimistic numbers, when he claimed that timber could be profitably transported on land at most 10 hours (Schenk, 1996). Although these numbers do not directly apply to our study region, they provide contemporary context, which indicates that the typical distance between timber species in constructions and forests in Moravia was rather small. Unfortunately, there are no similar data available in the literature for Moravia. As an example of just how costly land transport could be, we quote the 1869–1871 account books of the Pozorice estate (southern Moravia), where the transport of a sack of charcoal on carts from the production places in the forests to the nearby ironworks represented almost the same amount as the wages paid to charcoal burners to produce the same one sack of charcoal and approximately ten times more than the hard work of preparing one charcoal burning platform in the local hilly terrain.<sup>2</sup> It should be added that the availability of construction timber, its price and the economics of transport could in some cases be also greatly influenced by the effects of windstorms (Brázdil et al., 2018) or bark beetle outbreaks (Brázdil et al., 2022). Overall, even if one allows for the possibility that timber was not always procured from the nearest available source, our results still fall well within the range that implies a lack of long-distance land transport of timber.

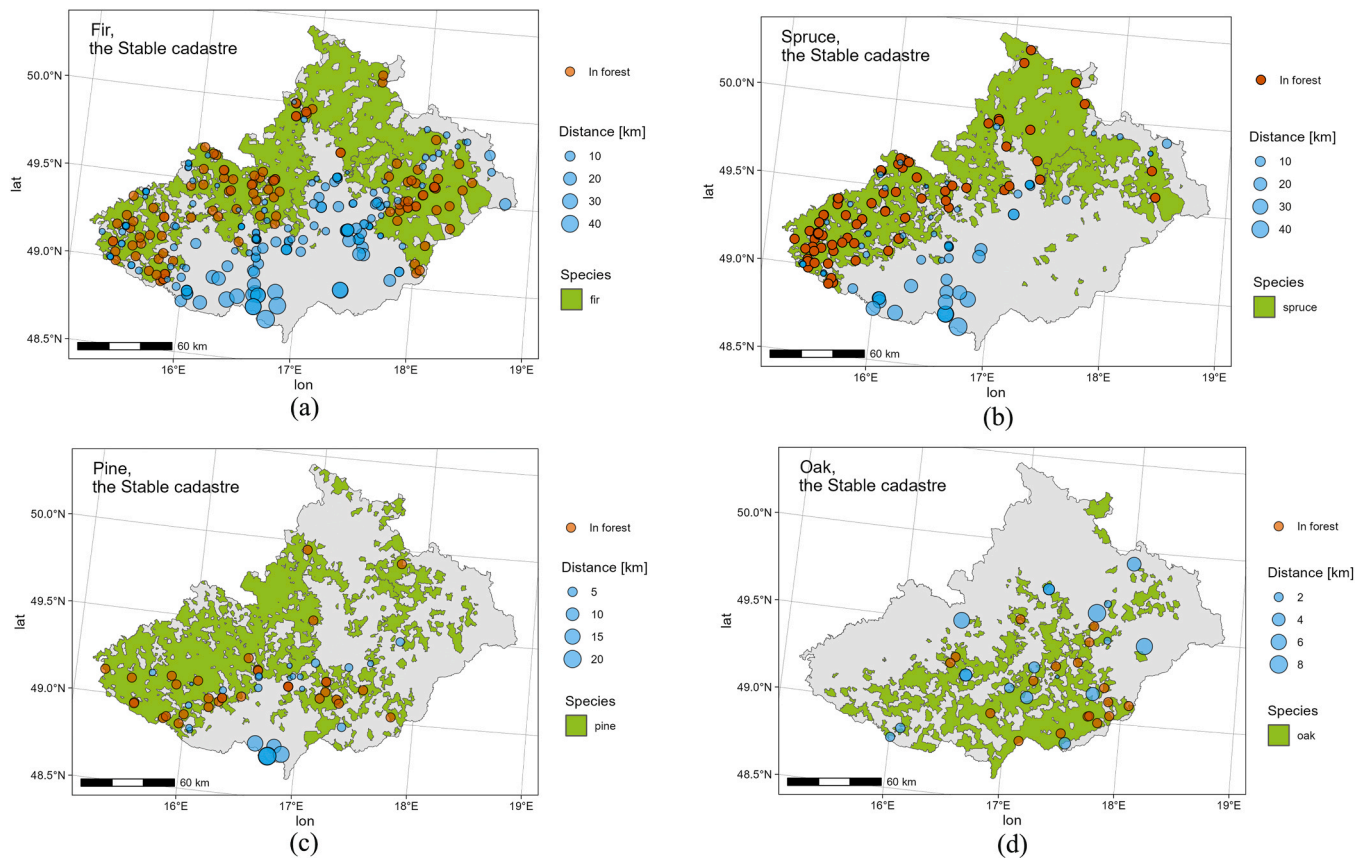
A further question is how far one can generalize our results in a European context. Bridge's (2012) thesis on local timber sources, quoted in the Introduction, is applicable only in regions, such as ours, which had a sufficiently high forest cover. However, in many areas of especially

North-Western Europe, there were few forests left by the end of the Middle Ages. Construction timber therefore often had to be brought from longer distances, or re-used, even modifying architectural styles to reflect the lack of resources (e.g. Dixon, 2001; Haneca et al., 2020). Timber shortages, while probably localized, were typical for many parts of Europe in the 18th and 19th centuries (Warde, 2006). In these regions, acquiring building timber formed part of a more complicated network of socioeconomic and natural factors than in our study area.

#### 4.2. Timber rafting

In the Czech Lands, like elsewhere in Europe (Hollister-Short, 1994), timber was transported over longer distances with the help of navigable waterways with documents going back to the Middle Ages for example in the case timber rafting to Prague (Holec, 1971; Svoboda, 2018). Large amounts of trees were floated especially from mountainous areas towards the central lowlands or, if gravity allowed, also towards foreign markets (Nožička, 1962a). In our case, the question arises whether timber found in constructions at larger distances from forests could be floated on rivers. It is, however, rather difficult to find an answer to this question at present. First, there has been little research on the topic in Moravia as opposed to Bohemia. Second, such research as exists has focused on larger rivers, and the suitability of smaller watercourses, which make up the vast majority of the water network of Moravia, for floating in the study period is not known. To evaluate possible patterns, we examined the position of timber constructions in our database in relation to the nearest watercourse including simulations similar to those described in chapter 2.3. Because of the dense network of small

<sup>2</sup> Moravský zemský archiv F 82 karton 1100.



**Fig. 5.** Spatial distribution of fir, spruce, pine and oak trees in Moravian forests based on data in the Stable cadastre (shaded areas). For the interpretation of red and blue dots, see legend to Fig. 4.

rivers, the results showed very low values. However, such numbers have probably little to do with coeval realities. A centrally commissioned overview of all Moravian rivers in 1826 claimed that the only rivers used for timber floating were the Morava and the Bečva (Jerábek, 1961). Even if this claim was probably exaggerated, it still indicates that rafting may not have been very common. Nonetheless, some patterns visible in our maps suggest that the distribution of fir and spruce in constructions in the 19th century might be connected to the courses of major rivers flowing through Brno (Fig. 5).

#### 4.3. Limitations of the sources and methods

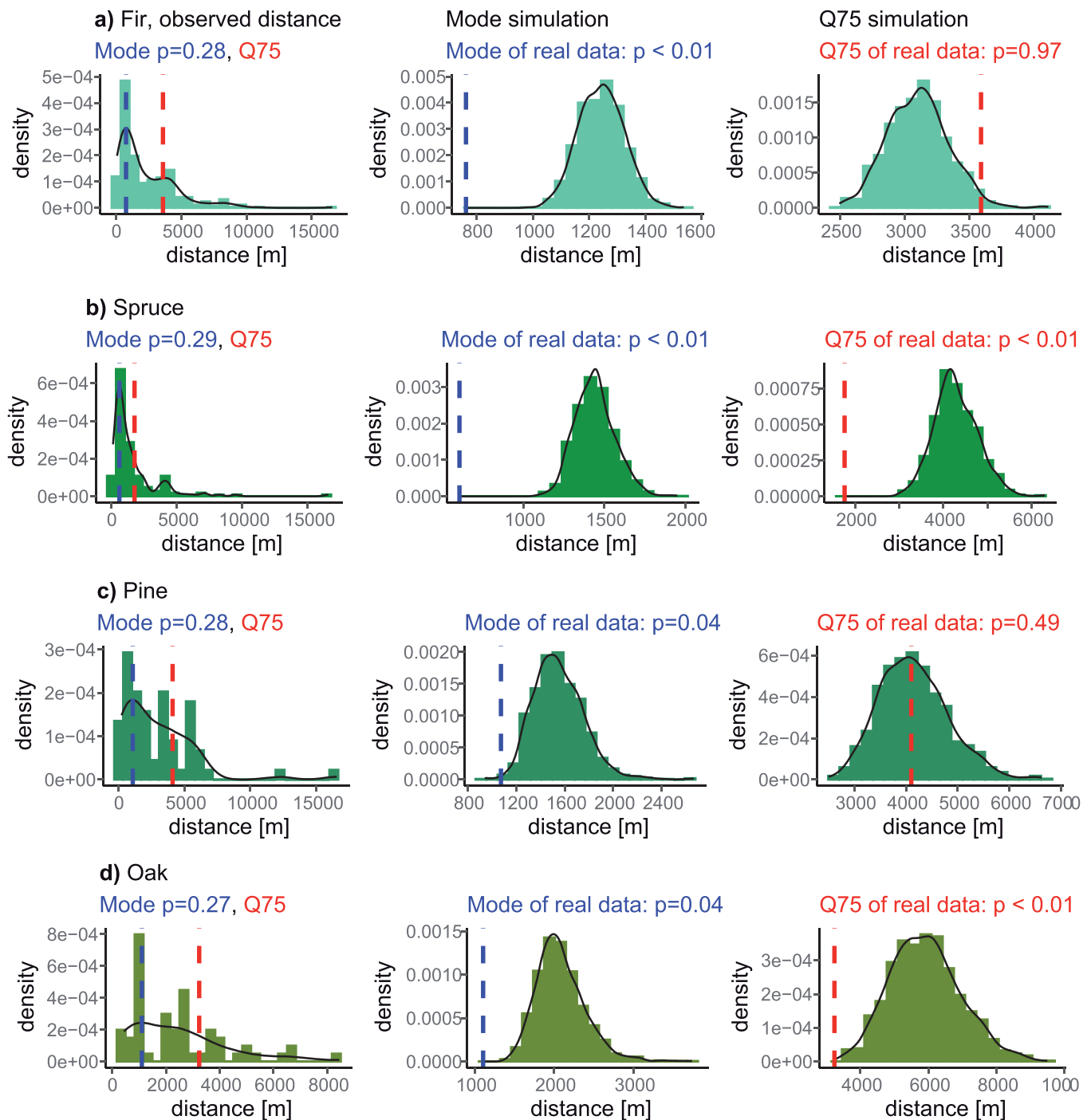
Although the results in most cases confirm our working hypothesis that the species of timber used in constructions were available in local forests, they may be affected by several uncertainties. First, cadastral surveys typically recorded only dominant tree species. The absence of locally rare species in the archival sources means that in some cases the distance between constructions and nearest relevant forested townships could be artificially enlarged. However, as more precise archival data would only have reduced these distances, this presents no significant problem as regards the interpretation of the results. A similar issue is that of the precision of archival data: the resolution of cadastral information is the township rather than individual forests. In other words, the centroids we used in our calculations do not exactly match the locations of forests where the pertinent tree species occurred. However, as mentioned above, the average size of townships is 7.5 km<sup>2</sup>, which translates to a radius of ca. 1.5 km. In other words, even if in the majority of cases the actual forests where the given tree species occurred had been in the most distant part of the township, our results would not be radically altered. A third problem is the possible ‘edge effect’ of constructions near the southern border of Moravia, where some of the

timber may have come from nearby forests in Austria, especially considering the transboundary possessions of significant noble families (Merki and Löffler, 2013). However, the two sides of the boundary are biogeographically rather similar, therefore the coniferous tree species recorded in our dendrochronological data are unlikely to have been more common in forests on the Austrian side.

It is also worth considering the differences between the Josephian and Stable cadastres. Information on tree species distribution in the former is much less precise, because, in lack of other information, we had to use the categories ‘hardwood’ and ‘softwood’ for many townships. This should blur the distinction between fir, spruce and pine, all of which are softwoods. Furthermore, many common broadleaved trees, for example, birch, poplar or lime, also belong among softwoods. This means that in particular cases the distance between the construction and the nearest township with the same tree species could be larger than our results suggest. Nonetheless, notable differences occurred only in Q75 values, where simulations for the Josephian cadastre showed non-significant values for fir and pine. In the case of fir, we believe this testifies to the almost universal presence of the species (including ‘softwood’ occurrences) combined with its widespread distribution in constructions, which showed the highest number of all tree species in all periods and surveys. As for pine, we probably witness a similar situation but with overall lower numbers. In this case, a further confounding factor could be the general tendency for pine constructions to occur at relatively lower elevations, where pine formed forests together with a number of broadleaved softwood tree species.

#### 5. Conclusions

Our results confirmed the hypothesis that tree species used in constructions in Moravia in the 18th and 19th centuries were generally



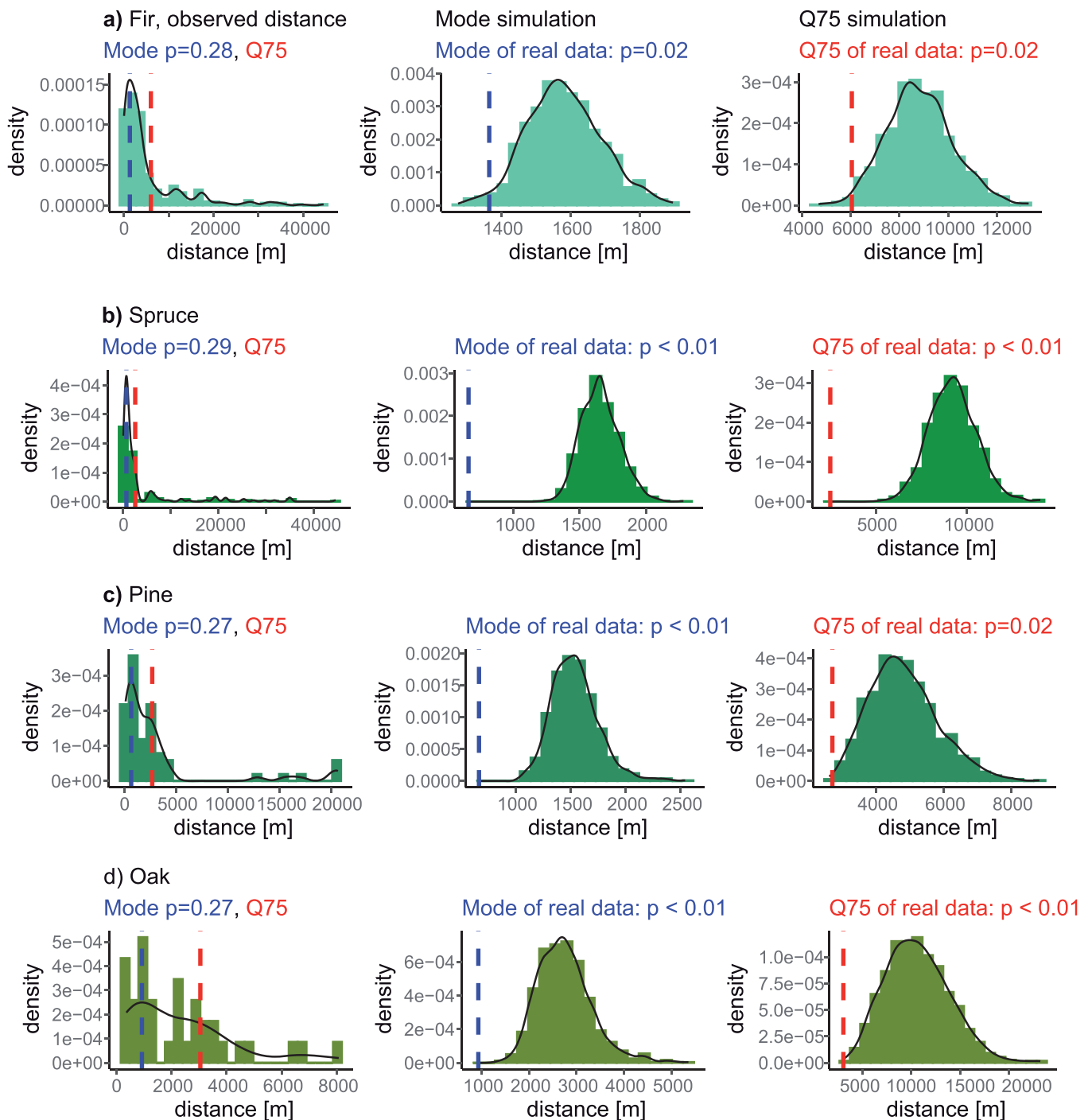
**Fig. 6.** Empirical (histogram) and theoretical (probability density function) distribution of the closest distances between real (left) and simulated (middle and right) locations of timber constructions and the occurrence of individual tree species based on the Josephian cadastre. Vertical lines indicate modal (blue) and Q75 (red) distances calculated from the real positions of the constructions. Note the different scales of the x and y axes.

available in local forests. While this demonstrates a pattern of probable supply areas, our data do not directly reveal that timber was in fact sourced locally. Nonetheless, in light of all other factors discussed above, this seems to have been the most likely scenario. This paper then adds to a growing body of literature discussing networks of timber supply in pre-modern Europe. As opposed to the more common dendroprovenancing studies, the novelty in our approach was the comparison of detailed and high-resolution archival data (i.e. contemporary information on forests) with a dendrochronological database. We believe our interdisciplinary study demonstrated the usefulness of archival data in the research of timber sourcing. For future studies, we see the combination of our

approach with dendroprovenancing and other natural scientific methods as the most promising way to gain deeper knowledge on the sourcing of timber in pre-modern Europe.

#### CRediT authorship contribution statement

**Szabó Péter:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Rybníček Michal:** Writing – review & editing, Data curation. **Kyncl Josef:** Writing – review & editing, Data curation. **Dobrovolný Petr:** Writing – review & editing,



**Fig. 7.** Empirical (histogram) and theoretical (probability density function) distribution of the closest distances between real (left) and simulated (middle and right) locations of timber constructions and the occurrence of individual tree species based on the Stable cadastre. Vertical lines indicate modal (blue) and Q75 (red) distances calculated from the real position of the constructions. Note the different scales of the x and y axes.

Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Kolár Tomáš:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Data curation, Conceptualization. **Kyncl Tomáš:** Writing – review & editing, Data curation.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Acknowledgements

This study was supported by long-term research development project no. RVO 67985939 and by the Johannes Amos Comenius Programme (P JAC), project No. CZ.02.01.01/00/22\_008/0004605, Natural and anthropogenic georisks.

#### Data availability

Data on the locations of timber constructions for the individual tree species are available at <https://doi.org/10.5281/zenodo.14801669>.



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# Effects of social and climatic factors on building activity in the Czech lands between 1450 and 1950: a dendrochronological analysis

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Received 21 May 2021; Revised 17 September 2021; Accepted 20 September 2021

**ABSTRACT:** The development of settlement and building activity is the result of socioeconomic, political and demographic changes in the past. However, accurate information on temporal variation in building activity is rather limited. Dendrochronological databases containing dated historical wooden constructions provide an important resource. We used 6514 tree-felling dates to reconstruct building activity in the Czech lands for the period 1450–1950. Comparing felling dates with historical events demonstrated that building activity was negatively associated with intense wars, particularly during the Thirty Years' War (1618–1648). After the Peace of Westphalia (1648), socioeconomic renewal and demographic growth were reflected in an upsurge of building activity, especially ecclesiastical buildings. While the construction of ecclesiastical and noble buildings culminated around the 1720s, rural buildings peaked in the 1780s and the 1820s. Although no direct effect of climate was demonstrated, adverse climatic conditions leading to harvest failures and subsequent famines (e.g. the 'Hunger Years' 1770–1772) significantly contributed to declines in building activity. In contrast, a higher number of felling dates were detected when strong and/or frequent windstorms occurred. This study provides a comprehensive understanding of building activity in Central Europe and advocates the use of dendrochronological databases for the investigation of human activities in history. © 2021 John Wiley & Sons, Ltd.

**KEYWORDS:** building activity; Central Europe; dendrochronology; early modern period; tree-felling dates

## Introduction

In Europe, sociopolitical changes have influenced long-term demographic processes for millennia. These in turn have been reflected in settlement development and building activity (Ljungqvist *et al.* 2018). Extensive military conflicts, such as the Thirty Years' War (1618–1648) or the Napoleonic wars (1803–1815), induced significant economic decline, the devastation of nature, and the destruction of human settlements (Tucker 2012). They also provided conditions favourable to the spread of various epidemics, e.g. plague outbreaks (e.g. Outram 2001; Stenseth *et al.* 2008).

Along with the sociopolitical effects, a higher frequency of climatic extremes, such as windstorms or drought spells, may also have affected building activity. Unfavourable climatic conditions could cause reduced food production (e.g. Brázdil *et al.*, 2019; Camenisch *et al.* 2016, 2020) or recurrent harvest failures (Pfister and Brázdil 2006). These factors could trigger famine episodes (Brázdil, *et al.* 2018a), such as the Great Famine (1315–1322) in northern and western Europe (Jordan 1996, Bauch *et al.* 2020) or the 'Hunger Years' (1770–1772)

in the Czech lands (Pfister and Brázdil 2006). Windstorms, on the other hand, could facilitate building activities by providing cheap building material in large quantities (Brázdil *et al.* 2017).

Periods of widespread social and/or political crisis were frequently followed by population growth, economic development and social prosperity (Fialová 2007; Van Ark and Crafts 1996), which sometimes led to intensified building activity. Although socioeconomic, political, demographic and climatic changes are often well described, their influence on the temporal dynamics of building activity in the past remains poorly understood. Building activity was usually mentioned in a general sense and rarely interpreted in its own right. This was done either in a negative context together with social crises and the devastation of human settlements (Tucker 2012) or in the positive context of prosperity accompanied by demographic growth (Fialová 2007) and the renovation or construction of houses, churches or castles (Pánek and Tůma 2018).

Because historical construction timber has been investigated by dendrochronologists for decades, dendrochronological databases provide a suitable source for analysing historical variation in building activity (Büntgen *et al.* 2006, 2013; Thun and Svarva 2018). Ljungqvist *et al.* (2018) studied long-term changes in building activity as influenced by warfare, plague outbreaks, grain prices and climate. However, large-scale

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studies may obscure regional differences. The timing of social crises are known to have varied from country to country and arguably so did the effects of such crises on building activity (Brázdil, *et al.* 2018a; Pfister and Brázdil 2006). Country-scale studies can therefore provide valuable insights into the regional diversification of past settlement and population development.

In this study, we analysed a set of 6514 intra-annually resolved tree-felling dates, as an indicator of changes in building activity. We extracted the felling dates from the database of dendrochronologically dated wood constructions from the Czech lands. We aimed to elucidate the effects of socioeconomic and political changes, epidemic outbreaks, and adverse weather and climate conditions on building activity over 500 years (1450–1950). We hypothesised that building activity was controlled mainly by intense wars while the effect of other factors was indirect and mediated by social and economic conditions.

## Material and methods

### *Felling dates*

The Czech dendrochronological database contains dated as well as undated historical wood constructions, archaeological findings, subfossil trunks, art objects and musical instruments from the territory of the current Czech Republic. All Czech dendrochronological laboratories that deal with the dating of wood relicts contributed their data to the database. Thousands of samples were dendrochronologically dated with intra-annual to multidecadal precision.

We extracted from the database only those historical constructions that had a clearly defined function, and were reliably dated through the preservation of the last outermost tree ring created before the tree was cut down (the so-called waney edge or Waldkante). This ring, which is in the dendrochronologist's centre of attention when dating any wooden relict, can be identified by the round shape preserved on unworked timber or by the presence of bark. The presence of the waney edge on a timber allows the researcher to determine the exact year when the tree was felled. Additionally, the waney edge can end either by earlywood or latewood. If only earlywood is preserved, the tree was cut down in the first half of the vegetation period. In contrast, the presence of latewood indicates tree-felling during the dormant season (autumn or winter of the given year or winter of the following year before the vegetation period).

Determining the year the tree was cut also approximates the date of construction (Klein and Grabner 2015), although the two do not necessarily coincide. Standing trees were often selected in the forest, cut, transported directly to the building site and built in without any storage time in-between (Eckstein 2007). Although Pacold (1887) reported that trees were cut and used for construction up to two years after cutting, a longer delay cannot be ruled out in some cases. Additionally, felling dates showing a range of several years from the same construction can suggest that the timbers were provided from the local timber market (Eckstein 2007) or that harvesting took several years because of the difficulties of wood transport in mountain regions, such as the Alps (Klein and Grabner 2015). Furthermore, the intended use of wood could play an important role. Although fresh wood could usually be used for roof constructions where it could dry out, Severin (1932) highlighted that wood used for ceiling timbers should be cut over the winter, dried out and seasoned for at least two years.

As we supposed that the main function of historical buildings was an important differentiating factor in building activity through time, two main subgroups of buildings were distinguished in this study. Ecclesiastical and noble buildings (churches, monasteries and castles) represented the first group. The second group contained rural buildings (residential and farmhouses, log houses and half-timbered constructions). The most frequently dated elements of these buildings were roofs, ceilings and walls, and, in the case of churches, also belfry constructions.

The number of individual dated tree-ring width (TRW) series coming from the same historical building had to be carefully considered to provide a reliable reconstruction of building activity. Depending on the size and architectural style of the individual buildings as well as on the quality and species of the preserved wood, this number could vary from one to several dozen. The exploitation of all dated TRW series from each construction could provide inaccurate and misleading results and interpretation because constructions with more TRW series would have more weight than constructions with only one TRW series. In order to avoid this bias and to capture trustworthy information on building activity, only one felling date representing each construction stage was used in this study. A construction stage was defined as the foundation, reconstruction or extension of a building.

### *Socioeconomic, epidemiological and climatic factors*

We assessed the socioeconomic, epidemiological and political effects on building activity indirectly using selected significant wars as well as epidemics and famines with a severe impact on the Czech lands between 1450 and 1950. We considered only conflicts that lasted several years and concerned a substantial part of the Czech lands. Such conflicts directly influenced people's daily lives and caused significant economic depression and social trauma as well as political and religious struggles. We included the Bohemian–Hungarian War (1468–1478), the Thirty Years' War (1618–1648), the War of the Austrian Succession (1740–1748), the Seven Years' War (1756–1763), the Napoleonic wars (1803–1815), World War I (1914–1918) and World War II (1939–1945). Concurrently, the number of felling dates for the war periods and for periods of the same length before and after the wars was calculated.

To evaluate the relationship between building activity and epidemic outbreaks, we collected evidence of plague, typhus and dysentery outbreaks from existing literature. Given that a large number of extensive as well as regional plague outbreaks recurred during pandemics between the 14th and 18th centuries (White 2014), in this study we selected only those plague outbreaks that spread across most of the Czech lands. First, we used the chronology of plague by Schulz (1901), who described outbreaks based on almost 300 individual historical documents. From these plague outbreaks, we selected the 16 most significant cases, which were then verified with the help of Fialová *et al.* (1998), Fialová (2007), Havlík (2006) and Maur (1995). Although the threat of plague diminished in the Czech lands in the first half of the 18th century, it was replaced by typhus and dysentery outbreaks. Two severe outbreaks, which occurred around the mid-18th century (Fialová 2007), were also taken into account.

Additionally, we considered famine as another potential phenomenon that influenced building activities. Complicated sociopolitical situations and/or the accumulation of adverse weather patterns that influenced agricultural production frequently led to famine (Brázdil, *et al.* 2018a). Considering the period of interest (1450–1950), the greatest famine in the

Czech lands – the so-called ‘Hunger Years’ – occurred in the early 1770s (Brázdil *et al.* 2001) when approximately 15% of the population died (Fialová 2007). This famine may serve as a typical example linking several triggering factors and causing (among other things) a decline in society which likely translated into a decrease in building activity.

Severe weather conditions might also have influenced building activity in the past. Such impact may be instant, as in the case of severe windstorms that directly influenced the accessibility of construction timber. On the other hand, short periods of deteriorating climate, such as a cluster of severe winters or hot and dry summers, may have contributed to disease outbreaks with a subsequent impact on economic conditions including building activities.

To assess the possible influence of climatic conditions on building activity, we used temperature (Dobrovolný *et al.* 2010) and precipitation (Dobrovolný *et al.* 2015) reconstructions compiled from documentary evidence and long instrumental measurements covering the last 500 years. We suppose that reconstructions derived from anthropogenic archives may preserve more signals of the adverse impacts of climate on society than proxy reconstructions, e.g. from tree rings. As document-based reconstructions are particularly suitable for preserving a short-term (inter-annual to decadal) signal (Brázdil *et al.* 2010), we analysed seasonal and annual values. We compared temperature/precipitation totals with felling-date indices for the original series and also for series smoothed with five- and ten-year moving averages.

The possible impact of windstorms on building activity was analysed from the database compiled by Brázdil *et al.* (2004). This database was also based on Czech documentary sources and covers the last millennium but with a distinctly lower density of records before 1500. We considered only windstorms of regional extent that caused forest disturbances and material damage in several places in the Czech lands. We found a total of eight such windstorms in 1610, 1801, 1813, 1817, 1821, 1833, 1868 and 1902.

### Data standardisation and methods of analysis

As outlined above, we analysed three chronologies of felling dates: i) the whole dataset, ii) ecclesiastical and noble buildings, and iii) rural buildings. As the chronologies of felling dates were compiled from varying numbers of samples through time, it was necessary to pre-process the raw data. First, we stabilised

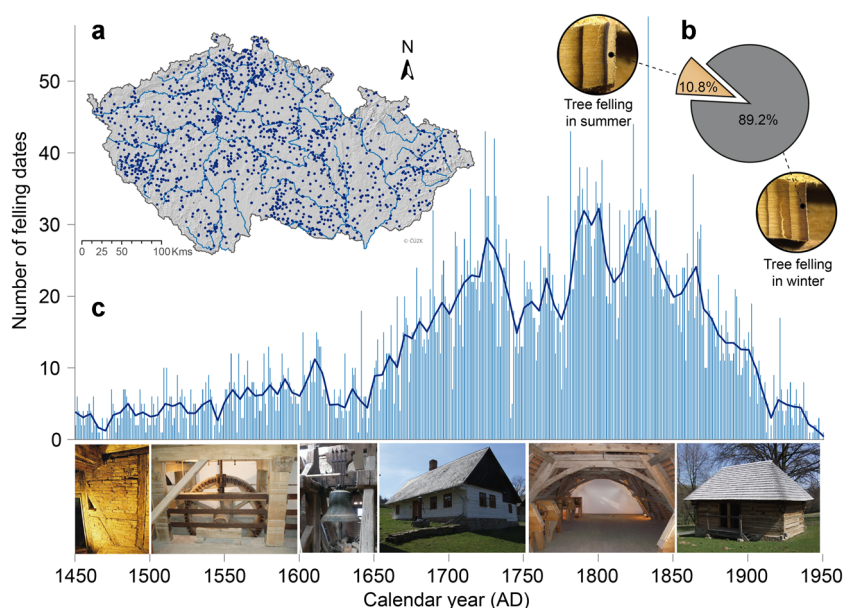
the variance by taking the square root of the raw data. This type of transformation is recommended for count data (such as felling-date numbers), which frequently follow the Poisson distribution. The square-root transformation brings the data to the normal distribution (Provencher St-Pierre *et al.*, 2018). Moreover, normality is required to satisfy the assumptions for the *t* test (e.g. Wilks, 2006). This parametric test is applied in the breakpoint detection algorithm used in this study (see below).

Long-term trends in the dataset of felling dates are most likely biased because the number of preserved building constructions usually decreases back in time (Ljungqvist *et al.* 2018). However, the number of dated constructions in our dataset also decreases in the most recent period (Fig. 1). This is due to several factors including a declining interest in dating buildings that are from a period for which there are reliable written records about buildings and their reconstructions. In addition, gradual changes in technology, materials and types of buildings may also have played a role. To minimise the effect of these unwanted aspects from the felling-date database, the long-term trend was modelled with a cubic smoothing spline with a 50% frequency cut-off at 300 years (Cook and Peters 1981).

The final chronologies of felling-date indices were expressed as the difference between the variance-adjusted raw data and the cubic smoothing spline. Thus the chronologies of felling-date indices used for the analyses were detrended and they have a zero mean and a standard deviation of one.

The standardised chronologies were analysed for possible occurrences of breakpoints indicating significant changes (decrease or increase) in the mean number of felling dates. The whole dataset was analysed for the full study period of 1450–1950, while the subgroups of ecclesiastical and noble buildings and rural buildings were analysed for the sufficiently replicated sub-periods of 1450–1913 and 1588–1941, respectively. For these sub-periods, sums of the felling dates did not drop below 20 values for at least 10 years.

We applied two different methods for breakpoint identification. The first one was based on a Sequential T-test Analysis of Regime Shifts (STARS) proposed by Rodionov (2004). The classification of breakpoints, which implies the start of a new regime, was based on calculating the so-called regime shift index (RSI). RSI represents a cumulative sum of normalised differences between the current mean level and the mean level of the (supposedly) new regime. Breakpoint position and the occurrence of the new regime were evaluated according to



**Figure 1.** (a) Spatial distribution of 6514 dendrochronologically dated historical construction timbers across the Czech lands in the period 1450–1950. (b) Proportion of trees felled in summer and winter. (c) Annually resolved values (vertical bars) smoothed by Lowess filter. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

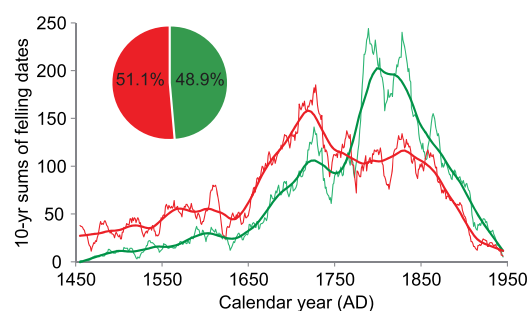
Student's *t* test for selected cut-off lengths and significance levels (Rodionov 2004). Testing different sets of parameters for regime shift detection, we finally settled for a segment length with a ten-year cut-off at  $p=0.1$  and Huber's weight parameter for outliers set to 2. Moreover, as we detected significant serial autocorrelation in felling-date indices with  $acf(1) = 0.34$ , we also applied pre-whitening prior to the application of the regime shift test. Here we used the 3.2 version of an Excel macro downloadable from <http://www.beringclimate.noaa.gov/regimes/>. The second method was Pettitt's test (Pettitt 1979) to detect years when significant change-points in the overall trend occurred. We performed this test in the R environment. For the test, we defined 50-year cut-off periods starting between 1450 and 1950. Given that abrupt changes are more easily detected when they occur towards the centre of the time series (Mallakpour and Villarini 2016), in the second round we calculated the test for 50-year periods lagged by 25 years beginning in 1475 and ending in 1925.

We used the superposed epoch analysis (SEA) to identify statistically significant departures in the number of felling dates caused by outbreaks of war, epidemics, famine, windstorm occurrence, and selected climatic extremes. The SEA was calculated in the *dplR* package (Bunn *et al.* 2020). A 95% confidence interval was estimated by 1000 randomisations. Serious plague, typhus and dysentery outbreaks as well as famine episodes were considered together (Brázdil, *et al.* 2018a). For wars as well as epidemic and famine outbreaks that spanned several years, we selected the first year of the event for the SEA. In the case of windstorms, event years were considered as those when at least 10 local windstorms and one widespread windstorm occurred. Finally, in the case of climatic extremes, event years were defined as those with temperature/precipitation above or below two standard deviations. Moreover, the overall coherence between the adjusted values of the felling dates and reconstructed temperature/precipitation was analysed using running correlations on seasonal and annual levels.

## Results

The long-term building history in the Czech lands was explored using 6514 tree-felling dates and the whole dataset consisted almost exclusively (99.7%) of four species: spruce, fir, pine and oak. Figure 1a shows a relatively uniform distribution of dendrochronologically dated buildings across the territory of the Czech Republic with higher densities in big cities (mainly Prague, Brno and Pilsen). Fewer felling dates came from northern Moravia and southern Bohemia. Waney edges, mostly terminated by latewood, demonstrated that almost 90% of the trees used for building purposes were cut down over the dormant season (Fig. 1b). The highest numbers of felling dates were reached in the 18th and 19th centuries; ca. 2800 felling dates were recorded in each of these centuries (Fig. 1c). The highest number of felling dates in a single year was recorded in 1833 (59 felling dates).

Altogether, 3183 felling dates were collected from constructions classified as rural and 3331 from ecclesiastical and noble buildings. However, the proportion of each type in the whole varied significantly through time (Fig. 2). Ecclesiastical (in total 1731) and noble (1600) buildings prevailed from the beginning of the chronology up to the 1770s, reaching their highest frequency around 1720. Within this group, ecclesiastical buildings dominated from 1650 to 1750 (Fig. S1). A substantial increase in felling dates from rural buildings



**Figure 2.** Proportion of felling dates of rural buildings (green) and ecclesiastical and noble buildings (red) expressed as 10-year running sums and smoothed by Lowess low-pass filter. [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

occurred in the 1770s and after that time this type dominated in the overall dataset. Two peaks in the number of felling dates from rural buildings were identified in the 1780s and in the 1820s.

## Temporal changes in building activity

Changes in building activity were expressed by the standardised felling-date chronologies with dominant inter-annual and decadal variability (Fig. 3c). In this variability, several phases of below-average and/or above-average values of different lengths could be recognised. Some of these were delimited by a sharp decline of values from the previous state. Such features may indicate regime shifts due to a single reason or a combination of reasons of natural and/or anthropogenic origin. We first tried to delimit such periods objectively using the regime shift approach and subsequently to search for possible causes.

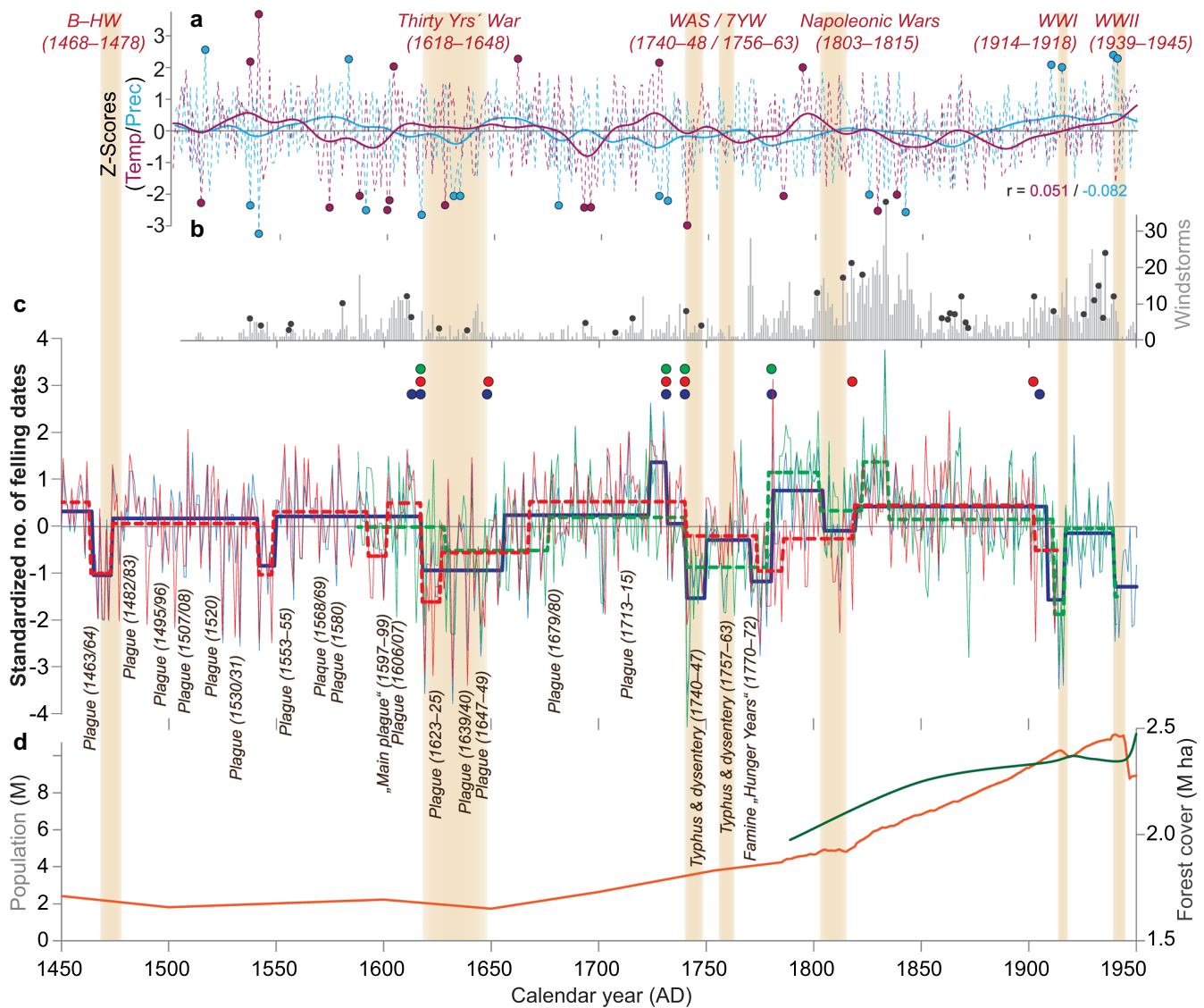
Our analysis revealed 18 phases in the whole felling-date chronology with breakpoints centred at 1465, 1474, 1542, 1550, 1618, 1656, 1724, 1732, 1741, 1750, 1771, 1781, 1805, 1820, 1909, 1917 and 1940 (Fig. 3c). Applying Pettitt's test, we basically confirmed three breakpoints detected using the STARS method (1618, 1741, 1781). In addition, another three downward (1614, 1731, 1905) and one upward (1648) significant ( $p < 0.05$ ) shifts emerged from the analysis (Fig. 3c).

As the subgroup chronologies did not cover the full study period, we revealed 14 phases in noble and ecclesiastical buildings, and 10 in rural buildings. Several phases corresponded to the phases of the whole felling-date chronology with a possible deviation of one or two years. Moreover, we detected further breakpoints centred at 1593, 1602, 1627, 1668, 1786 and 1903 for noble and ecclesiastical buildings, and 1629, 1677, 1779, 1803, 1823, 1835 and 1912 for rural buildings. All breakpoints and/or segments are discussed below with respect to possible explanatory variables.

## Influence of wars, epidemics and famines on building activity

Individual segments between two consecutive breakpoints mostly represented distinct periods of sharp decline in felling dates corresponding to the beginning of severe wars (Fig. 3c). There were only two segments of clearly higher values, centred in the 1720s and the 1790s. However, a closer look at the chronology showed that these two segments were rather the terminal stages of long periods of gradually increasing values from two relatively long periods of low values. The first one (between 1618 and 1656) approximately corresponded to the Thirty Years' War (1618–1648 AD) when the number of felling dates dropped by 34% compared with the period of the same





**Figure 3.** (a) Reconstruction of annual temperature (Dobrovolný *et al.*, 2010) and precipitation (Dobrovolný *et al.*, 2015) anomalies (w.r.t. 1961–1990) smoothed by Gaussian low-pass filter and Pearson's correlation coefficients between these climate parameters and standardised number of felling dates for the common period 1501–1950. (b) Number of recorded local windstorms with highlighted widespread windstorms (black dots) based on Brázdil *et al.* (2004). (c) Variability of standardised felling-date indices completed with the model of regime shifts indicating individual breakpoints using Sequential T-test Analysis of Regime Shifts (bold line) and Pettitt's test (coloured dots) for the whole dataset (blue) in the period 1450–1950 and separately for ecclesiastical and noble buildings (red; 1450–1913), and rural buildings (green; 1588–1941). The most severe wars, epidemics and famines are indicated. (d) Evolution of population and forest cover in the Czech lands (CSO). B–HW = Bohemian–Hungarian War, WAS = War of the Austrian Succession, 7YW = Seven Years' War. [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

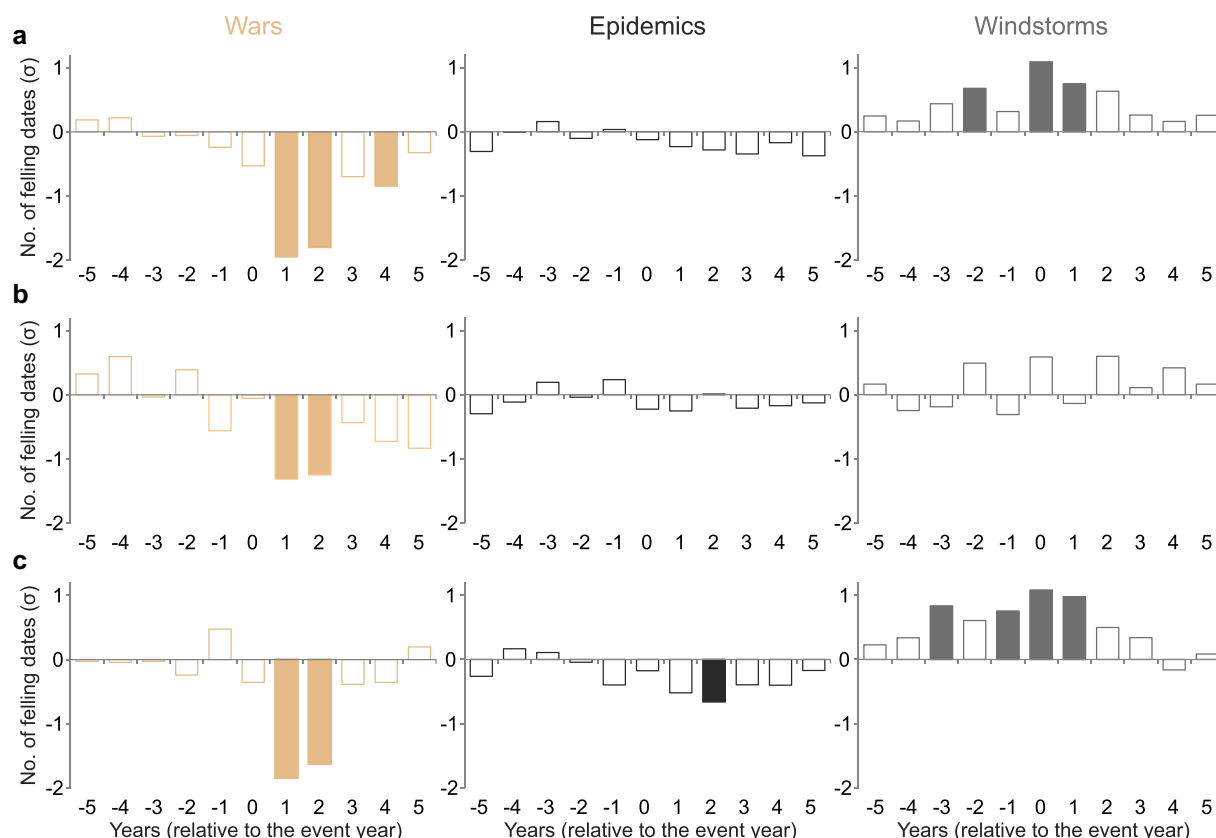
length before the war. Moreover, during this relatively long unfavourable period, three significant plague outbreaks and a substantial population decline occurred. During the three decades after the war, the number of felling dates more than doubled with a sharp increase, especially of ecclesiastical buildings (Fig. S1). The second period of low values covered the relatively long interval from the 1730s to the 1780s, characterised by two severe wars, significant typhus and dysentery outbreaks and the 'Hunger Years' famine. During the War of the Austrian Succession (1740–1748 AD), we detected one of the most significant declines in building activity (ca. 45% of the whole felling-date chronology when compared with the pre-war period). A relatively small drop was recorded during the Bohemian–Hungarian War, which is arguably the consequence of a generally lower number of felling dates in this period. However, the number of felling dates after the war almost doubled. A further drop recorded during the Napoleonic wars was reflected mainly in rural buildings. Another typical feature

of the chronology was a gradual decrease in felling-date indices after the mid-19th century. In spite of the detrending, this decline may still be an artefact of the lower number of dated samples. However, there were two distinct breakpoints approximately corresponding to the beginning of WWI and WWII when the number of felling dates decreased compared with the pre-war periods by 42% and 70%, respectively.

The SEA showed that building activity declined immediately in the first year of wars and was significantly low for the next two years (Fig. 4) in all three chronologies. Although a gradual recovery was apparent in the following years, building activity remained low even in the fifth year compared with pre-war levels, especially in the case of noble and ecclesiastical buildings.

As regards epidemics and famine, in total we identified 18 severe outbreaks of three diseases (typhus, plague, dysentery) and the most significant famine episode, the 'Hunger Years' (Fig. 3c). The most devastating plague outbreaks were distributed almost regularly in time from the beginning of the





**Figure 4.** Superposed epoch analysis (SEA) of departures from the mean of the standardised number of felling dates of the whole dataset (a), ecclesiastical and noble buildings (b) and rural buildings (c) for the first year of the most serious wars, epidemics, and the years with at least 10 local windstorms and one widespread windstorm presented in Fig. 3b. Full vertical bars indicate significant values ( $p < 0.05$ ). [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

study period to 1715 when the last widespread outbreak in the Czech lands was recorded. Typhus and dysentery outbreaks were connected with the wars of the mid-18th century. When applying the SEA, we did not detect any significant changes in the number of felling dates after the beginning of the outbreaks either in the whole chronology or in the noble and ecclesiastical chronology (Fig. 4) although a slight decrease was apparent. In contrast, rural buildings were significantly negatively impacted by epidemics.

### *Influence of climatic and hydro-meteorological extremes on building activity*

Comparing the number of felling dates with temperature and precipitation reconstructions, we did not observe any clear relationships using either annually resolved or low-pass filtered data (Fig. 3a). Running correlations were non-significant for seasonal and annual values over the whole study period (not shown here). Similarly, the SEA applied to the warmest, coldest, driest and wettest 'event' years did not reveal any signal in the felling-date chronologies.

In contrast, a positive relationship was observed between the number of felling dates and the number of strong windstorms in some cases. There is a clear consistency between the higher frequency of strong winds and periods of higher numbers of felling dates between approximately the 1820s and the 1840s with the maximum number of felling-date cases in 1833. Similarly, a short period in the 1860s with a higher number of felling dates corresponded to the period with seven large windstorms in the Czech lands (Fig. 3b). Considering local as well as widespread windstorms, SEA results indicated a significantly increased number of felling dates in the year of the event (windstorm) and one year after the event (Fig. 4).

## **Discussion**

Our results demonstrate that felling dates of historical wooden constructions reflect the dynamics of building activities and the related socioeconomic and political changes. In the following, we discuss the role of these factors, which were further complicated by epidemics and adverse climate.

The vast majority (approximately 90%) of trees were cut over the winter during the dormant season (Fig. 1), or, more specifically, between the end of the vegetation period in autumn and the beginning of the following vegetation period in very early spring of the following year. Winter harvest was preferred mainly because in this part of the year enough workforce was available with respect to agricultural schedules (Černý 1930). Additionally, winter harvest was often recommended in forestry literature because in this period trees contain no sap and they are easier to transport on snowy ground (Jondl 1840; Klein and Grabner 2015; Pacold 1887). Less frequent summer harvest (approximately 10%) can be determined more precisely based on the timing of tree cambial activity. In Central Europe, cambial activity mostly starts in April or early May when the first cells of earlywood are created. The transition between earlywood and latewood occurs around the end of June/beginning of July (Fajstavr *et al.* 2019).

Historical buildings include ecclesiastical and noble buildings as well as rural buildings. The latter are represented not only by residential but also farm buildings, such as barns and granaries. Ecclesiastical and noble buildings prevailed in the dataset from the 15th century to the mid-18th century. It is assumed that churches and castles were better maintained than rural buildings. Ecclesiastical buildings dominated from 1650 to 1750, which is likely a cultural-political phenomenon. This long period was characterised by domestic peace

(wars involving the Habsburgs took place outside the Czech lands), which led to economic and cultural development in which the Catholic church played a major role.

In contrast, rural buildings abandoned through migration or population loss slowly dilapidated. However, an unprecedented increase in rural buildings in the country started in the 1770s, which was accompanied by substantial demographic growth (Fig. 3d). This may be connected to the reforms of Maria Theresa and her son Joseph II as well as the end of the war period and the 'Hunger Years' famine (1770–1772) (Pfister and Brázdil 2006). Due to the abolition of serfdom by Joseph II, people acquired the right to move freely and get married without the consent of their overlord, as well as to leave to work and study outside the boundaries of their estate (Beales 1987). Many new houses and farm constructions were also built because larger allodial holdings started to be subdivided among tenants (Kazimour 1921). At the same time, the reforms of Joseph II also had a significant impact on ecclesiastical building. After 1782 many monasteries were dissolved and the operation of pilgrimage places was limited, which inevitably led to a decrease in the construction of ecclesiastical buildings (Fig. S1; Kadlec 1991). A more pronounced increase in ecclesiastical as well as rural building activity could be observed only after the Napoleonic wars. The last major wave of church construction happened after the abolition of servitude (monetary, in-kind or work dues of tenants towards the overlords) and the transformation of the patrimonial state organisation into public administration and mainly after the tax reform in the year 1848.

### *Temporal variability of felling dates*

The temporal distribution of felling dates allows two types of signal to be distinguished in the raw data chronology – long-term trends and high-frequency fluctuations (Fig. 1). Long-term tendencies were suppressed during the standardisation procedure as this type of signal does not relate directly to the development of building activity but rather reflects methodological issues or the drawbacks of available historical material. In addition, the number of felling dates decreased back in time. Very old wooden constructions were rarely preserved because of wars, wood decay or loss of durability. The decline in felling dates towards the present could have several causes. From the second half of the 18th century, the construction of wooden houses was often discouraged or even prohibited, and, except for roof constructions, houses were supposed to be made of stone or mudbricks due to fire protection regulations (Vařeka and Frolec 2007). Re-tolerance of wood from the 1830s, especially in isolated buildings in rural areas, was accompanied by industrial development and the use of other materials. Since the beginning of the 19th century, fired bricks and stone started to be frequently used in buildings instead of wood (Hájek 2001). Finally, the decreasing number of felling dates in the database could also be the result of a smaller demand from house owners for dendrochronological dating of buildings from the 19th and 20th centuries.

### *Relationship between building activity and socioeconomic changes*

Most significant regime shifts in the number of felling dates were associated with serious political conflicts accompanied by socioeconomic crises and demographic changes in the Czech lands (Fig. 3). In particular, the Thirty Years' War (1618–1648 AD), distinctly detected by all tests, was a drastic conflict in European history, which caused the devastation of many human settlements and was responsible for millions of deaths all over Europe (Parker 2013). In the Czech lands,

population decline was estimated to have been almost 30% (Fialová 2007). The impact of the war was reflected in all chronologies by an exceptional decline of building activity when the average number of felling dates per year was well below the previous period (Fig. 3) as also observed for Germany (Ljungqvist *et al.* 2018). The construction of rural buildings started to decline somewhat later than that of noble and ecclesiastical buildings. This was probably caused by the fact that after the battle of White Mountain (1620) the Catholic clergy gradually assumed control of Protestant churches (mainly because of the lack of Protestant priests). At the same time, among the upper classes, which were affected by the confession reform, large transfers of assets were realised. Rural areas were more severely affected mainly after 1631, when Swedish troops entered the Czech lands. During the war, large areas of the Czech lands were devastated and the sustained abandonment of settlements led to the disappearance of many villages (Fialová 2007). At the end of the war, socioeconomic development and demographic growth was a slow and long-lasting process (Fialová 2007) (Fig. 3d). Although the chronology of felling dates suggested that the recovery of society measured by building activity was not immediate, we revealed an unprecedented surge of ecclesiastical buildings soon after the war. Such buildings were arguably in a poor state of repair resulting from lack of upkeep and damage by passing armies (Spurný 1974, Parma 2019). Finances that had been previously taken up by war efforts were quickly redirected towards the renovation of ecclesiastical buildings, facilitated by the recatholicisation process. Noble residences were renovated a few generations later. This was followed shortly by building activities in cities and rural areas. Such enhanced building activity peaked as late as the 1730s. The subsequent sharp decline in the number of felling dates due to the War of the Austrian Succession was even stronger than the decrease attributed to the Thirty Years' War. This was arguably caused by the different geographical scale and intensity of the wars. Most of the Thirty Years' War took place in the German lands, whereas the Czech lands were not affected equally intensively throughout the entire 30-year period but mainly in 1618–1620, 1626, 1631–1632, 1639 and 1645. In contrast, the War of the Austrian Succession gradually spread throughout the whole territory of the Czech lands from Lower Silesia at the beginning of the war in 1740 to Moravia and Bohemia during the following two years. This most intensive period of this war led to a significant decrease in building activity and was slightly more pronounced for rural than for noble and ecclesiastical buildings (Fig. 3). This was likely caused by high taxes, and the social crisis deepened even more by typhus and dysentery epidemics. In the second half of the war period (1744–1748), we observed a slow recovery in the number of felling dates.

However, the War of the Austrian Succession was followed by the Seven Years' War and the 'Hunger Years', which entailed the second relatively long depression in building activity and confirmed the essential influence of wars. A similar pattern of variability expressed as clear shorter declines in building activity could be observed in the case of other wars during the 19th and 20th centuries (Fig. 2).

Our analysis also revealed two short declines in felling-date frequencies in the periods 1465–1474 and 1542–1550. Provided that the detected breakpoint years may vary slightly depending on the method used and parameter settings, we can speculate on the possible reasons for those two declines. The first one (1465–1474) may be partly related to the plague outbreak that occurred in 1463–1464, also in other European countries (Byrne 2004). Above all, this period roughly corresponds to the Bohemian–Hungarian War (1468–1478). During

the crusade announced by the Pope in 1466, Hungarian troops devastated the eastern part of the Czech lands especially, where numerous villages disappeared (Čornej and Bartlová 2007). However, there is no easy explanation for 1542–1550, as neither significant war events nor epidemics occurred in the Czech lands in this period. A possible explanation is the armed conflict between the Habsburgs and the Ottoman Empire (1540–1547), which led to the expansion of the Ottoman Empire to the immediate vicinity of Moravia. However, while the Czechs contributed financially to this war, no battles took place in Czech territory (Válka 1996).

Armed conflicts were frequently accompanied by various outbreaks of plague, typhus, dysentery or smallpox, which also substantially contributed to population declines (Fialová 2007). However, the SEA showed that epidemic outbreaks by themselves did not have a strong impact on building activity (Fig. 4). Although we selected only extensive epidemics which affected most of the country (Schulz 1901), the weakening of building activity was apparent but not statistically significant which is in contradiction to Ljungqvist *et al.* (2018), who found a significant negative correlation between building activity and the number of plague outbreaks. Considering one of the cruellest outbreaks in 1597–1599 (Fialová *et al.* 1998), which occurred outside of the selected war periods, the number of felling dates in these years clearly decreased with the decline culminating in 1600 (Fig. 3). In addition, the Habsburg monarchy led a cruel war with the Ottoman Empire between 1593 and 1606 in Hungary, which may have caused financial constraints, contributing to a decrease in building activity. In the following years, felling dates started to considerably increase with a single one-year drop in 1606, when another outbreak occurred. After this, the decrease was continuous until the social crises preceding the Thirty Years' War.

### *Influence of climate and hydro-meteorological extremes on building activity*

Climatic conditions affected agricultural (Trnka *et al.* 2014), viticultural (Brázdil *et al.* 2008; Holland and Smit 2010), silvicultural (Kolář *et al.* 2017) and livestock production (Espunyes *et al.* 2019) throughout history. However, their impacts were often indirect and periods of adverse climate often stood at the beginning of a chain of processes that led to economic crises or famines (Alfani and Gráda 2018; Collet and Schuh 2018; Pribyl 2017).

Although no causal link between the number of felling dates and climate variability was demonstrated in this study (Fig. 2), indirect effects cannot be excluded (Ljungqvist *et al.* 2018). For instance, the simultaneous occurrence of rainy autumns with cold springs and wet mid-summers in subsequent years could have a cumulative impact on agricultural production. Such weather caused three successive harvest failures in the Czech lands (Pfister and Brázdil 2006) and resulted in the Great Famine of 1770–1772 (Brázdil *et al.* 2001). In those years the number of felling dates decreased by 30% compared with the previous three-year period (Fig. 3). Therefore, even if there was no coherence between reconstructed temperature/precipitation and felling-date variability, some indirect and vicarious effects of unfavourable climate on building activity could be expected during the main phase of the Little Ice Age related to the Maunder minimum of solar activity in the 1645–1715 period (Eddy 1976). Colder climate with a higher frequency of hydro-meteorological extremes (Brázdil *et al.* 1994) could be at least partly responsible for the relatively long and gradual recovery of building activity after the Thirty Years' War (Fig. 3c).

We found a better expressed influence of climate on felling-date frequencies for large windstorms that caused considerable damage to forests. There was a positive correlation between windstorm occurrence and felling dates, especially for the latter part of the study period. This is related to the fact that the windstorm chronology may be partly biased due to the lower number of available documentary sources for the first part of the study period (Brázdil *et al.* 2004). The SEA captured a significantly higher number of felled trees, mainly for rural buildings, in years when nationwide as well as regional windstorms were recorded in documentary data (Brázdil *et al.* 2004, 2018b). This suggests that some windstorms may have provided enough easily available construction material for higher building activity in the following years. This may be the case for the large windstorm that hit the Czech lands on 18–19 December 1833. It caused extensive damage in woodlands in numerous places (Brázdil *et al.* 2004) and destroyed 3.7 million m<sup>3</sup> of timber (Vicena, *et al.* 1979).

Such a general concept obviously could not work in all cases of large windstorms. Other conditions, such as accessibility and the spatial distribution of uprooted timber, demand for construction wood as well as the general economic situation also had to be favourable. For instance, from the six well documented and most severe 'windstorms of the century' identified by Brázdil *et al.* (2004) since 1500 AD, only three windstorms (1612, 1833 and 1868) were followed by a distinctly higher frequency of felling dates than the previous years. On the other hand, windstorms in 1555/1556, 1740 and 1870 were not identifiable in the felling-date chronology. The 1740 windstorm was not visible probably because it coincided with the beginning of the War of the Austrian Succession. In the case of the 1870 windstorm, the market was probably already saturated after the 1868 windstorm. In some forest districts it was also noted that, in contrast to the 1868 windstorm, many trees were broken rather than uprooted in 1870, which made them useless as building timber (Brázdil *et al.* 2018b). Interestingly, Jondl (1840) mentioned that workers frequently cut trees during windy weather because it helped them with the felling although this practice was not recommended.

### **Conclusion**

In total, 6514 tree-felling dates from historical timber constructions revealed variations in building activity in the Czech lands over the period 1450–1950. Our results showed that building activity, as expressed by the number of felling dates, was influenced by socioeconomic and political changes in the country. The two most important and relatively long periods of decreased building activity corresponded to the Thirty Years' War (1618–1648) and the time interval from the 1730s to the 1780s. In contrast, increased building activity was visible around the 1720s and the 1790s. The highest number of felling dates was detected in 1833, the year of a large windstorm. Epidemic outbreaks proved to be less important for the number of felling dates. Although no direct relationship of tree-felling dates with temperature and precipitation was observed, adverse climate conditions leading to famine, e.g. in the 'Hunger Years' of 1770–1772, significantly contributed to a decline in building activity. Our study demonstrated that dendrochronological databases have great potential for the study of human activities in the past.

## Competing interests

The authors declare no competing interests.

**Acknowledgements.** This work was supported by the SustES – Adaptation strategies for sustainable ecosystem services and food security under adverse environmental conditions project, ref. CZ.02.1.01/0.0/0.0/16\_019/0000797, and the long-term research development project no. RVO 67985939. The authors would like to thank Jiří Bláha for providing us with the historical literature and Ondřej Brázda for his help with the completion of the database.

## Supporting information

Additional supporting information can be found in the online version of this article.

**Figure S1.** Proportion of felling dates of ecclesiastical (black) and noble buildings (grey) expressed as 10-year running sums.

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# Coppice abandonment and its implications for species diversity in forest vegetation



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## ARTICLE INFO

### Article history:

Received 17 December 2014

Received in revised form 3 February 2015

Accepted 4 February 2015

### Keywords:

Conservation

Forest management

History

Forest species composition

Resurvey of semi-permanent plots

Vegetation diversity

## ABSTRACT

Coppicing, once a common type of management in European broadleaved forests, was abandoned in many places after WWII. This form of management provided a variety of structural and microclimatic conditions for tree and understorey vegetation. After the abandonment of this intensive management, succession towards mature close forests ensued, and suitable habitats for species ecologically connected to coppicing were reduced. In our study, we chose a region in central Europe where coppicing was the dominant type of forest management until the first half of the 20th century but was abandoned after WWII. We investigated long-term changes in both woody and herbaceous species composition in the Lower Morava UNESCO Biosphere Reserve using historical sources and vegetation plot resurveys from the 17th to the 21st century. The impact of coppice abandonment on vegetation composition and on the conservation value of forests was evaluated. Dominant tree species appeared to be very stable throughout the past four centuries, but changes occurred in their proportions. A shift from species rich oak–hornbeam woodland towards species poorer communities with increasing proportions of lime, ash and maple was observed after the abandonment of coppicing. The observed tendencies partly differed according to site and data source. The conservation value of forests was measured as the occurrence of red-list species, which were considerably reduced after coppice abandonment. To stop the process of biodiversity loss and support the goals of nature conservation, the re-establishment of coppice management is proposed.

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## 1. Introduction

Although forest vegetation patterns generally depend on the demands and interactions of species along environmental gradients, in Europe they were co-shaped by human activities at various spatio-temporal scales (Buckley, 1992; Peterken, 1993; Sanderson et al., 2002; Rackham, 2003). Centuries of human management in European forests have modified species composition both by introducing certain species and genotypes, and by favouring certain species in selective cutting (e.g. Gil et al., 2004; Urbietta et al., 2008). Long-term anthropogenic impacts of various intensities are considered to be key factors in forest structure and species composition in regions with long human history in Europe (e.g. Decocq et al., 2004;

Dambrine et al., 2007; De Frenne et al., 2011) and elsewhere (e.g. Ross and Rangel, 2011).

In central Europe, broadleaved forests were coppiced for centuries. After fossil fuels became widely available, coppicing lost its importance. By the end of WWII, this form of management was almost completely abandoned. In a few decades, whole landscapes once covered with open woodlands were transformed into closed forest areas, which caused massive losses for biodiversity conservation (Miklín and Čížek, 2014). Most coppice woods have been transformed into high-forests either by replanting or by reducing the underwood to one or two large trunks ('singling out') (Peterken, 1996; Van Calster et al., 2008; Rackham, 2008). In coppice woods, a fine mosaic of differently-aged forest patches and the presence of scattered old trees provided favourable conditions for a variety of invertebrates (e.g. saproxylic beetles, Vodka and Čížek, 2013), macrofungi (Diamandis and Perlerou, 2001) or herbaceous plants (Bartha et al., 2008). While coppicing forms a dynamic mosaic supporting high species diversity, after the transformation to high-forest lighter phases and permanent open areas

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are reduced with significant consequences for forest flora and fauna. Species dependent on cyclic changes (adapted to early successional stages) become threatened and gradually disappear from the landscape (Beneš et al., 2006; Freese et al., 2006; van Swaay et al., 2006; Van Calster et al., 2008; Baeten et al., 2009; Hédli et al., 2010; Kopecký et al., 2013).

In recent decades, interest in the reintroduction of coppicing in order to protect endangered species (Fuller, 2013; Vild et al., 2013) and obtain a sustainable source of energy (European Parliament, 2009; McKenney et al., 2011) has been steadily increasing in many regions of Europe, including England, Germany, Switzerland and the Czech Republic (EEA, 2006). For the successful restoration and sustainable management of coppice forests, detailed knowledge on the influence of management on species composition and biodiversity is needed. The assessment of relationships between management changes and subsequent species replacement can bring insights into factors driving species distribution and abundance.

Our study concerns the Pálava Protected Landscape Area (PLA), part of the Lower Morava UNESCO Biosphere Reserve (BR) in the southeastern part of the Czech Republic. In this study, we investigated changes in tree species composition and changes in herbaceous layer composition and diversity. Trees were studied through the past four centuries, and species of the herbaceous layer (following Gilliam, 2007) through the past five decades by focusing specifically on changes following coppice abandonment. Two types of information were used – archival forestry data and resurveys of semi-permanent plots in the 1950s and 2000s. On the basis of information on historical changes in tree species composition, our main goal was to test the hypothesis that the abandonment of coppicing caused significant changes in both tree and understorey species composition and affected the conservation value of forests protected within national, EU and international legislatives.

## 2. Materials and methods

### 2.1. Study area

The study area (Fig. 1) is situated in southern Moravia, in the northwestern corner of the Pannonian Lowland. It is the warmest and driest part of the Czech Republic with an average annual temperature of 9.6 °C, average annual precipitation of 524 mm, and large seasonal variability. Valuable natural areas have been preserved in the midst of the intensively cultivated landscape. Apart from a few isolated segments, there are two larger forests: Děvín Wood (400 ha covering most of Děvín Hill) and Milovice Wood (2500 ha). The limestone slopes of Děvín Hill (with altitudes from 260 to 549 m a.s.l.) represent a sharp environmental gradient (Fig. 2). The northwestern (NW) slopes have deep and fertile luvisols and leptosols. They are almost fully covered by thermophilous to mesophilous oak–hornbeam and ravine lime forests. The top and the southeastern (SE) slopes are exposed to sun and wind, soils are poorly developed and vegetation is mostly dry grassland with relatively small extents of ravine forests and thermophilous oak forests (Horák, 1969; Hédli and Rejšek, 2007). The gently undulating loess plateau of Milovice Wood (altitudes of 180–324 m a.s.l.) is covered by luvisols and represents one of the largest compact complexes of subcontinental oak forests in the region (Hédli et al., 2010). Small-scale plantations of non-native black pine (*Pinus nigra*), and scattered black locust (*Robinia pseudoacacia*) are also present.

For centuries, forests in this area were managed as coppice or coppice-with-standards. The coppice cycle was gradually lengthened from 7 years in the Middle Ages to 30–40 years in 1938. In the middle of the 20th century coppicing was abandoned in the whole area, resulting in a forest age structure unseen for at least seven centuries (Müllerová et al., 2014). Forests in the study area

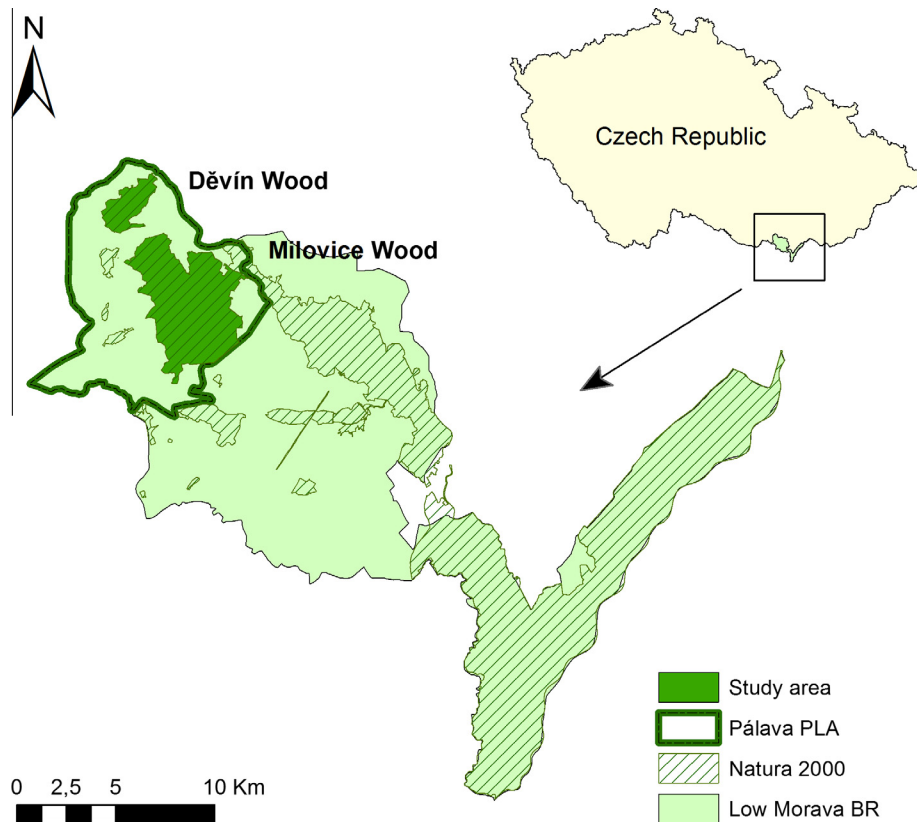
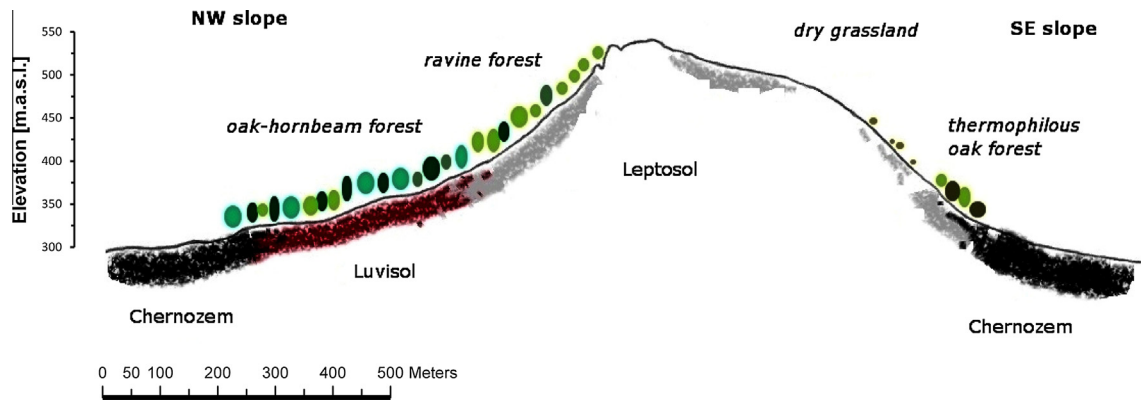


Fig. 1. Map of the study area with all type of protection marked (PLA = Protected Landscape Area, BR = Biosphere Reserve).



**Fig. 2.** Environmental gradient of the Děvín Hill. NW–SE section shows four main vegetation types including three ecologically and floristically distinct forest types, confined to specific environmental conditions defined by topography and soils.

were also intensively used for game keeping in certain periods. The first game preserve was established on the Děvín Hill in 1885 (300 ha, 80% of the hill). Because of its high ecological value, a strict nature reserve with non-intervention management (however subjected to high intensity game browsing) was established on the Děvín Hill (184.6 ha) in 1946. Milovice Wood has been managed as a high-forest since the abandonment of coppicing after WWII. In 1965/6, two additional game preserves were established in Milovice forest (1700 ha, 80% of the site; Szabó, 2010; Müllerová et al., 2014). In 1976, the Pálava Protected Landscape Area (8017 ha) Woods was set up, which included both study sites. In 1986, protection was increased by the creation of the Pálava UNESCO Biosphere Reserve. Due to the browsing damage from deer and mufon in the most valuable parts of the protected area the Děvín game preserve was closed in 1996, while the other two in Milovice forest are still active. In 2003, the Lower Morava Biosphere Reserve (354 km<sup>2</sup>) was created, which includes the Pálava PLA as well as the neighbouring Lednice-Valtice area and the floodplain forests at the confluence of Dyje and Morava rivers. To further protect this major European biodiversity hotspot, several large Sites of Community Importance under Natura 2000 were designated in 2005 in the Lower Morava UNESCO Biosphere Reserve (Fig. 1).

## 2.2. Data sources, processing and analyses

### 2.2.1. Archival forestry sources

For a qualitative assessment of changes in tree species composition during the past four centuries, forest surveys and forest management plans were analysed (Appendix S1, numbers in square brackets refer to individual sources in Appendix S1). The first two forest surveys were from the 17th century [1, 2]. These included general descriptions of species composition, especially as regards standard trees. More detail was provided by the Forest Management Plan (FMP) of 1807–1808 [3, 4], which recorded the age and species composition of underwood as well as the composition and number of standard trees in each compartment. FMPs from 1885 [6], 1901 [8] and 1933–1936 [9] dealt only with underwood, while FMPs from 1948 [11] and 1971 [13] contained data on both standards and coppice underwood. In the 2010 source [15] standards and underwood were once again treated together. Děvín Wood was covered by all sources, but, as far as more detailed sources are concerned, Milovice Wood was covered entirely only by the most recent sources (1971 and 2010 FMPs, [13, 15]).

For quantitative analyses of changes in species abundances after the abandonment of coppicing, large-scale forest maps (FM) containing precise information on forest extent and age, and the accompanying FMPs describing forest structure and management

were used. These were produced in 1947/8 [10 and 11], 1971 [12 and 13] and 2010 [14 and 15]. Historical forest maps were scanned, georeferenced, digitized and analysed in a GIS environment using ArcGIS 9.2 (ESRI, 2006). The first two sources provided details on the proportion of species of both standards and coppice underwood, whereas in the latest source (2010) standards and coppices were not differentiated and only overall species composition was given. Because of the dominance of underwood over standards in the study area, we considered the 2010 non-differentiated data to refer to underwood. The 1948 source referred only to tree genera and covered only Děvín Wood. The quantitative analyses of species abundance changes was therefore carried out in Děvín Wood in all three time periods, whereas in Milovice Wood only 1971 and 2010 data were taken into account. Species abundances were calculated from relative cover multiplied by the area of each plot.

### 2.2.2. Resurvey of semi-permanent plots

To assess the impact of 20th-century changes on the conservation value of forests, vegetation resurveys were undertaken. Pair-wise resampling of inexact localized species-plots was applied, an approach increasingly termed 'resurvey of semi-permanent plots' (Baeten et al., 2009; Hédl et al., 2010; Kopecký and Macek, 2015). Two sets of data from the 1950s were used, both by the same author (Horák, 1969; hereafter referred to as 'old' sample). Sampling plots were scattered over the whole area of both forests. Plots were originally located subjectively during fieldwork to cover the variability of forest types for management planning. As a result, the entire environmental and vegetation variability of forests in the 1950s was documented. The resampling of the original plots was performed in 2002–2003 for Děvín Wood (Hédl, 2005; Kopecký et al., 2013) and in 2006 for Milovice Wood (Komárek, 2008; Hédl et al., 2010; hereafter referred to as 'new' sample). Individual plots were localized following original maps scaled 1:10,000 and descriptions of terrain configuration from the original field notebooks. Information about tree species composition for plot re-location was used with precaution, giving priority to maps and terrain descriptions. In Děvín Wood, plot size most commonly varied between 200 and 400 m<sup>2</sup>, in Milovice Wood it was 500 m<sup>2</sup>. All vascular plant species in the tree, shrub, herb and woody juvenile (seedlings and saplings) layers were recorded in Děvín Wood. In Milovice Wood, tree and shrub seedlings (i.e. woody juveniles) were not distinguished from saplings and shrubs (cf. Chytrý and Danihelka, 1993), and they formed a broadly defined 'shrub' layer. Similarly to some archival forestry sources, the tree layer included both standards and coppice underwood at both sites. Species relative representation was estimated using cover scales that were transformed into the corresponding cover-abundance grades of Braun-Blanquet scale. In addition to the analysis of the herbaceous

layer, we used the data to analyse tree species composition at both sites and compared the results with data derived from archival forestry sources (cf. chapter 2.2.1). Sampling resulted in the independent analyses of 122 resurveyed plots in Děvín Wood and 46 plots in Milovice Wood. These datasets can be considered representative of the two woods regarding vascular plant species composition and relative coverage.

The analysis of changes in woody species composition used presence and estimated cover. To enable direct comparison with the results of tree species analysis from archival forestry resources, individual species belonging to the same genus were merged, and occurrences of these species in the 'tree' and 'shrub' layers were also merged. Thus, oak included *Quercus petraea* agg., *Q. robur*, *Q. pubescens* and *Q. cerris*, lime included *Tilia cordata* and *T. platyphyllos*, maple included *Acer campestre*, *A. platanoides* and *A. pseudoplatanus*, and elm included *Ulmus glabra*, *U. minor* and *U. laevis*. The category 'others' included *Aesculus hippocastaneum*, *Betula pendula*, *Cornus mas*, *Corylus avellana*, *Crataegus* spp., *Populus alba*, *Populus tremula*, *Prunus avium*, *Prunus mahaleb* and *Sorbus torminalis*. Two statistical parameters of the old vs. new samples were compared using bar graphs and chi-square tests. Frequency (percentage of plots with a species) and importance value (calculated as sum of percentage cover of a species divided by the total number of plots) were computed separately for Děvín and Milovice woods. The statistical significance of the null hypothesis – that number of plots or importance values for individual species do not differ between the old and new surveys – were calculated as chi-square statistics, where values from the new sample were taken as 'observed', and values in the old sample as 'expected'. Presences and absences for individual species were the categories entering the chi-square statistics computation.

The analysis of the herbaceous layer focused on (i) changes in the diversity of all herbaceous species with a height up to 1.3 m, and (ii) changes in the occurrence of rare and endangered herbaceous species (Grulich, 2012). Based on species lists in plots, we compared the total and average number of species in the old and new datasets, and the number of species present in both or in only one dataset. Changes in species richness at the plot level were tested by a Wilcoxon pair test (old vs. new sample per plot) and graphically presented using boxplots separately for the two sites. Rarefaction analysis (Colwell et al., 2004) was used to estimate species richness by randomly drawing a given count from the pool of plots. Average numbers of species and confidence intervals were then computed. Plot count was increased stepwise from 1 to  $N$  where  $N$  is the number of plots in the dataset. Following the categorization suggested in the Red List of vascular plant species of the Czech Republic (Grulich, 2012), we classified species into five categories: C1 – critically threatened, C2 – endangered, C3 – vulnerable, C4 – lower risk, and others. The relative occurrence of species in categories C1 to C4 was calculated as the sum of occurrences of the species in the respective Red List category divided by the sum of all species occurrences in the respective part of the dataset, i.e. old and new surveys separately for both sites. The statistical significance of the null hypothesis that no difference exists between the occurrences in old and new samples was tested for each of the four Red List categories using a chi-square test (see above). Statistical inference was computed in STATISTICA, version 12 (StatSoft, Inc., 2013).

### 3. Results

#### 3.1. Tree species composition

##### 3.1.1. Archival forestry data

Throughout history, tree species composition in the study area remained remarkably stable (Table 1). Dominant species were oak,

lime, ash and hornbeam. However, the two woods differed markedly. Whereas in Děvín Wood dominant species were oak, lime, ash and hornbeam, in Milovice Wood oak constituted a consistent majority for both standards and underwood. Other species formed only a minority (Table 1a and b). While coppicing was active (until WWII, 30–35-year rotation cycle), both woods showed remarkable stability in species composition with only minor changes, although in Děvín Wood the share of lime and ash standards grew at the expense of hornbeam during the period 1808–1948. Following the abandonment of coppicing, the abundance of dominant species changed, showing slightly different trends in the two. In Děvín Wood, oak showed increasing abundance, while hornbeam decreased and lime and ash remained stable (Fig. 3a). Other species, such as elm, maple, black pine, and black locust were relatively infrequent and stable. In Milovice Wood, the time span was shorter (only 40 years) and did not cover the period immediately after the last coppicing. Here we observed a marked decrease in the abundance of the dominant oak underwood, a considerable expansion of ash and maple, and an increase in horse chestnut (from less than 1–16 %). This tree was planted extensively in the game preserves of Milovice Wood in the 1980s to feed game on conkers. Other underwood species (hornbeam, lime) remained stable (Fig. 3b).

Although the detail of historical sources is limited (for example *Q. pubescens* and *Q. petraea* cannot be separated), the sharp environmental gradient on Děvín Hill from NW to SE (Fig. 2) is recognizable in historical tree species composition (Fig. 4). In the past half a century, the most abundant tree species differed along this environmental gradient. However, similar trends in lime dominance, as well as a remarkable decrease in hornbeam could be observed in all positions. The above-mentioned increase in oak and decrease in ash happened mainly on the NW slopes, and were less pronounced on the SE foothills.

Several non-native tree species were planted or occur spontaneously in the area. Black pine and black locust were both first mentioned in the 1885 FMP [6]. Around the turn of the 19th and 20th centuries, black pine plantations were established in the eastern part of Děvín Hill on previously unforested shallow rocky soils (10 ha), and some in Milovice Wood. Currently 5% of Děvín Wood and less than 1% of Milovice Wood is dominated by black pine. Black locust grows in low to very low densities on the NW foothills of Děvín Wood (1%), and in low to high densities on 2% of Milovice Wood. Larch, today present on a very small area in both woods, was also first mentioned in the 1885 FMP of Děvín Wood [6]. More recent alien tree species are Douglas fir (in Milovice Wood), two oak species (*Q. cerris* in low abundances in both woods; and *Q. rubra* in low abundances in Milovice Wood), tree of heaven (*Ailanthus altissima*, in low abundances in both woods), and ash-leaved maple (in low abundances in Milovice Wood).

##### 3.1.2. Vegetation resurvey data

In total 26 species were recorded in the tree layer in the two woods (Table 2a). The woody undergrowth, consisting of shrubs and woody juveniles, was even richer with at least 53 species recorded (Table 2b). Considerable differences between the woods can be observed in the dominant tree species. Děvín Wood was dominated with lime (mostly *T. platyphyllos*), ash, maples, hornbeam and mesophilous (mostly *Q. petraea*) as well as thermophilous (*Q. pubescens*) oaks. Milovice Wood, on the other hand, was an oak forest (almost exclusively *Q. petraea*) with moderate proportions of species that dominated in Děvín Wood. Total tree diversity in Milovice Wood is only half of that for Děvín Wood, which is reflected also in the diversity of understory woody species (Table 2b). Many thermophilous species are absent or nearly absent in Milovice Wood, e.g. *C. mas*, *P. mahaleb*, *Q. cerris* (planted),



**Table 1**  
Changes in tree species composition in Milovice Wood (a); and Děvín Wood (b). Species are ordered by abundance, divided into standards/coppice underwood with proportion of species is marked (if known). Numbers in brackets refer to individual sources in [Appendix S1](#).

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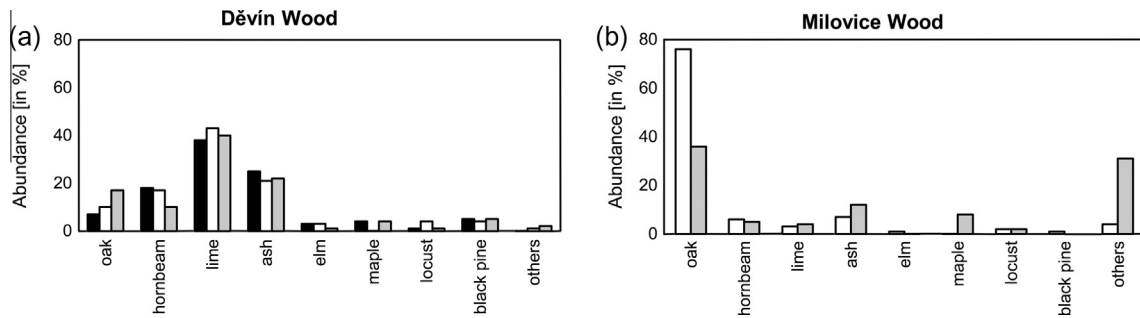
<sup>a</sup> Sources until 1971 covered only app. 2/3 of Milovice Wood (northern and southern part).

*P. nigra* (planted), *Rhamnus cathartica*, *Sorbus danubialis* or *Staphylea pinnata*.

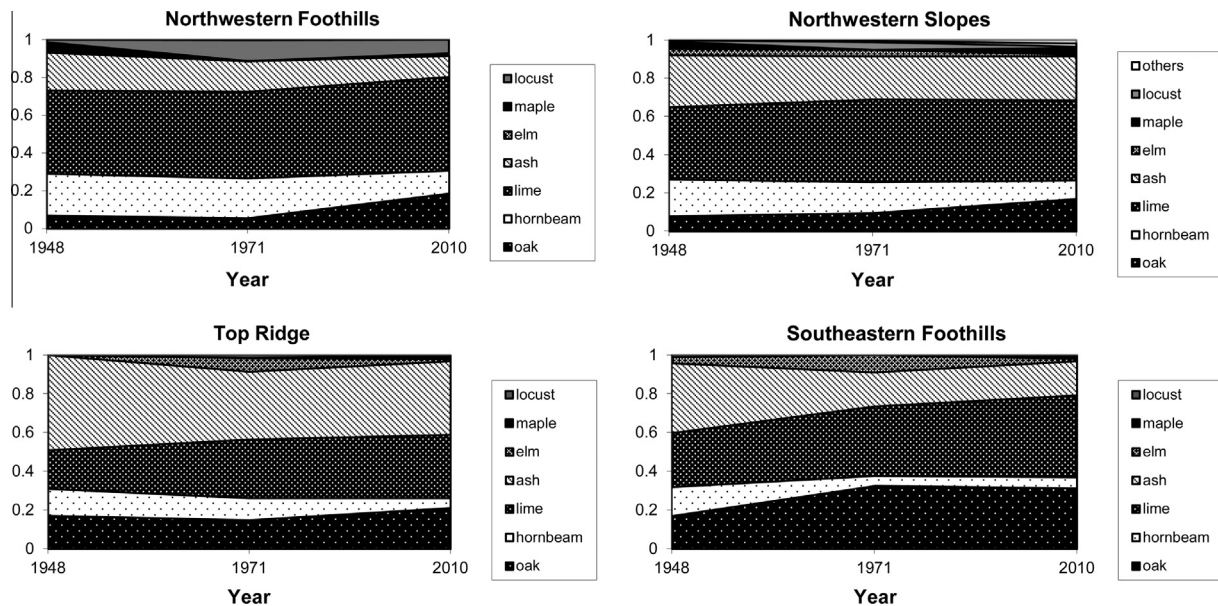
Changes in the occurrence of woody species (tree and shrub layers merged) showed similar trends in both woods (Fig. 5a and b). From the six major species (taxonomically mostly representing respective genera), the ones with decreasing frequency of presence in individual plots were hornbeam (chi-square test,  $p < 0.05$  in Děvín Wood,  $p < 0.01$  in Milovice Wood) and elm (significant only in Děvín Wood,  $p < 0.01$ ). Oak decreased in Děvín Wood ( $p < 0.01$ ), while it remained in all plots in Milovice Wood. Species with increasing frequency were lime (n.s. at either site), ash (significant

only in Děvín Wood,  $p < 0.01$ ), and maple (n.s. at either site). Other species were infrequent and changed relatively little (black pine, black locust) or gave ambiguous results ('others'; decrease in Milovice Wood,  $p < 0.01$ ). Regarding abundance weighted by coverage in plots (importance value of species, Fig. 6), the resulting picture in Děvín Wood was similar to the above described pattern in presence frequency, although with a somewhat different statistical significance of changes. Decreases in oak, hornbeam and elm were not significant, while increases in lime and maple were significant at  $p < 0.05$ . In Milovice Wood the results partly differed from Děvín Wood. The overwhelming dominance of oak (change n.s.) partly





**Fig. 3.** Changes in underwood tree abundances in Děvín (a) and Milovice (b) Woods based on archival forestry data. Black bars represent abundance in the 1950s, white ones in the 1970s and grey ones in 2010. For Milovice Wood, only 1970–2010 data were available.



**Fig. 4.** Environmental gradient of the Děvín Hill from NW to SE reflected in shifts in tree abundances during the last sixty years.

**Table 2**

Change in woody species composition from repeated sampling of vegetation plots in the 1950s and 2000s. Numbers are frequency (% of species occurrence in the datasets). Two oak and two lime species were merged because of high risk of misidentification.

| Species                                    | Děvín Wood (N = 122) |           | Milovice Wood (N = 46) |      |
|--------------------------------------------|----------------------|-----------|------------------------|------|
|                                            | 1953–1964            | 2002–2003 | 1953                   | 2006 |
| (a) Tree species                           |                      |           |                        |      |
| <i>Acer campestre</i>                      | 18                   | 20        | 17                     | 37   |
| <i>Acer platanoides</i>                    | 20                   | 16        | 2                      | 0    |
| <i>Acer pseudoplatanus</i>                 | 34                   | 34        | 0                      | 0    |
| <i>Aesculus hippocastanum</i>              | 0                    | 1         | 0                      | 0    |
| <i>Betula pendula</i>                      | 0                    | 6         | 7                      | 0    |
| <i>Carpinus betulus</i>                    | 57                   | 49        | 30                     | 26   |
| <i>Cornus mas</i>                          | 3                    | 1         | 0                      | 0    |
| <i>Corylus avellana</i>                    | 3                    | 3         | 0                      | 0    |
| <i>Crataegus species</i>                   | 1                    | 1         | 0                      | 0    |
| <i>Fraxinus excelsior</i>                  | 73                   | 87        | 33                     | 46   |
| <i>Pinus nigra</i>                         | 7                    | 6         | 0                      | 0    |
| <i>Populus alba</i>                        | 1                    | 0         | 0                      | 0    |
| <i>Populus tremula</i>                     | 2                    | 3         | 2                      | 0    |
| <i>Prunus avium</i>                        | 7                    | 3         | 7                      | 2    |
| <i>Prunus mahaleb</i>                      | 4                    | 0         | 0                      | 0    |
| <i>Quercus cerris</i>                      | 4                    | 1         | 0                      | 0    |
| <i>Quercus petraea</i> + <i>robur</i>      | 52                   | 40        | 98                     | 96   |
| <i>Quercus pubescens</i>                   | 25                   | 22        | 15                     | 9    |
| <i>Robinia pseudacacia</i>                 | 5                    | 5         | 2                      | 4    |
| <i>Sorbus torminalis</i>                   | 13                   | 10        | 7                      | 2    |
| <i>Tilia cordata</i> + <i>platyphyllos</i> | 79                   | 84        | 20                     | 28   |

(continued on next page)

Table 2 (continued)

| Species                                                             | Děvín Wood (N = 122) |           | Milovice Wood (N = 46) |      |
|---------------------------------------------------------------------|----------------------|-----------|------------------------|------|
|                                                                     | 1953–1964            | 2002–2003 | 1953                   | 2006 |
| <i>Ulmus glabra</i>                                                 | 44                   | 16        | 0                      | 0    |
| <i>Ulmus laevis</i>                                                 | 2                    | 0         | 0                      | 0    |
| <i>Ulmus minor</i>                                                  | 22                   | 2         | 4                      | 4    |
| Number of species                                                   | 22                   | 22        | 13                     | 10   |
| (b) Woody undergrowth species (includes shrubs and woody juveniles) |                      |           |                        |      |
| <i>Acer campestre</i>                                               | 60                   | 57        | 59                     | 54   |
| <i>Acer platanoides</i>                                             | 46                   | 69        | 20                     | 4    |
| <i>Acer pseudoplatanus</i>                                          | 38                   | 51        | 2                      | 0    |
| <i>Aesculus hippocastanum</i>                                       | 0                    | 1         | 0                      | 0    |
| <i>Berberis vulgaris</i>                                            | 1                    | 0         | 0                      | 0    |
| <i>Betula pendula</i>                                               | 0                    | 0         | 2                      | 0    |
| <i>Carpinus betulus</i>                                             | 56                   | 30        | 33                     | 24   |
| <i>Cornus mas</i>                                                   | 37                   | 29        | 11                     | 28   |
| <i>Cornus sanguinea</i>                                             | 27                   | 15        | 52                     | 17   |
| <i>Corylus avellana</i>                                             | 30                   | 13        | 35                     | 13   |
| <i>Cotoneaster integerrimus</i>                                     | 0                    | 1         | 0                      | 0    |
| <i>Crataegus species</i>                                            | 57                   | 41        | 39                     | 28   |
| <i>Euonymus europaea</i>                                            | 15                   | 4         | 2                      | 7    |
| <i>Euonymus verrucosa</i>                                           | 29                   | 11        | 13                     | 11   |
| <i>Frangula alnus</i>                                               | 0                    | 0         | 2                      | 0    |
| <i>Fraxinus excelsior</i>                                           | 92                   | 82        | 54                     | 46   |
| <i>Juglans regia</i>                                                | 4                    | 1         | 0                      | 0    |
| <i>Ligustrum vulgare</i>                                            | 17                   | 11        | 65                     | 35   |
| <i>Lonicera caprifolium</i>                                         | 1                    | 0         | 2                      | 0    |
| <i>Lonicera xylosteum</i>                                           | 15                   | 6         | 13                     | 4    |
| <i>Malus species</i>                                                | 4                    | 0         | 0                      | 0    |
| <i>Pinus nigra</i>                                                  | 2                    | 0         | 0                      | 0    |
| <i>Populus alba</i>                                                 | 1                    | 0         | 0                      | 0    |
| <i>Populus tremula</i>                                              | 6                    | 4         | 2                      | 0    |
| <i>Prunus avium</i>                                                 | 22                   | 13        | 7                      | 4    |
| <i>Prunus domestica + insititia</i>                                 | 0                    | 0         | 2                      | 0    |
| <i>Prunus fruticosa</i>                                             | 1                    | 0         | 0                      | 0    |
| <i>Prunus mahaleb</i>                                               | 16                   | 6         | 0                      | 2    |
| <i>Prunus spinosa</i>                                               | 1                    | 0         | 20                     | 0    |
| <i>Prunus tenella</i>                                               | 2                    | 0         | 0                      | 0    |
| <i>Pyrus communis agg.</i>                                          | 4                    | 7         | 2                      | 2    |
| <i>Quercus cerris</i>                                               | 4                    | 1         | 0                      | 0    |
| <i>Quercus petraea + robur</i>                                      | 52                   | 20        | 87                     | 35   |
| <i>Quercus pubescens</i>                                            | 23                   | 16        | 15                     | 2    |
| <i>Rhamnus cathartica</i>                                           | 11                   | 2         | 0                      | 0    |
| <i>Ribes uva-crispa</i>                                             | 1                    | 0         | 0                      | 0    |
| <i>Robinia pseudacacia</i>                                          | 6                    | 3         | 2                      | 2    |
| <i>Rosa canina agg.</i>                                             | 64                   | 37        | 33                     | 13   |
| <i>Salix caprea</i>                                                 | 1                    | 0         | 0                      | 0    |
| <i>Sambucus nigra</i>                                               | 7                    | 10        | 2                      | 4    |
| <i>Sorbus aucuparia</i>                                             | 2                    | 0         | 13                     | 0    |
| <i>Sorbus danubialis</i>                                            | 2                    | 0         | 0                      | 0    |
| <i>Sorbus domestica</i>                                             | 0                    | 1         | 46                     | 7    |
| <i>Sorbus torminalis</i>                                            | 18                   | 8         | 22                     | 13   |
| <i>Staphylea pinnata</i>                                            | 18                   | 24        | 0                      | 0    |
| <i>Tilia platyphyllos + cordata</i>                                 | 74                   | 86        | 2                      | 0    |
| <i>Ulmus glabra</i>                                                 | 37                   | 64        | 9                      | 2    |
| <i>Ulmus laevis</i>                                                 | 2                    | 0         | 0                      | 0    |
| <i>Ulmus minor</i>                                                  | 36                   | 13        | 20                     | 4    |
| <i>Viburnum lantana</i>                                             | 16                   | 9         | 7                      | 0    |
| Number of species                                                   | 44                   | 34        | 33                     | 24   |

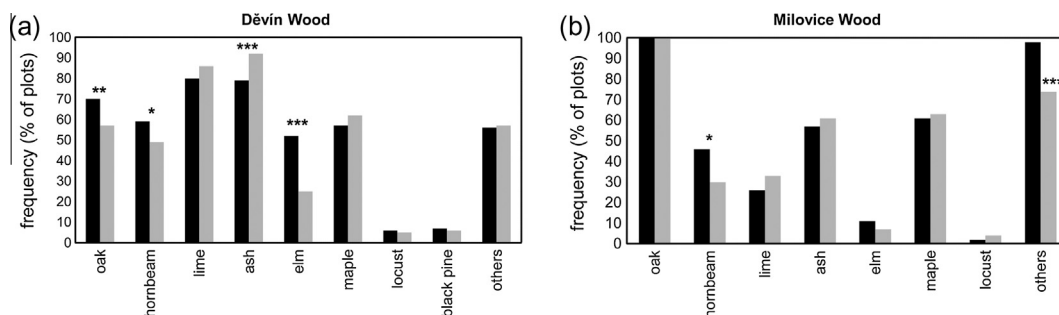
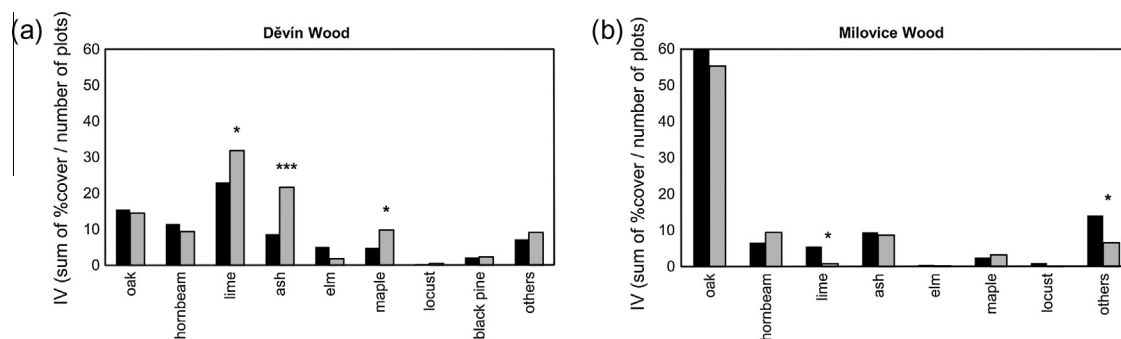


Fig. 5. Changes in the presence of tree species based on resurveyed vegetation plots in Dėvín (a) and Milovice (b) Woods. Tree and shrub layers were merged. Black bars represent frequency (% of plots with a species) in the 1950s and grey ones in the 2000s. Black pine is missing in the plots from Milovice Wood. Significance codes are 0.001 \*\*\*\*, 0.01 \*\*\*, 0.05 \*\*.



**Fig. 6.** Changes in average Importance Value of tree species based on resurveyed vegetation plots in Děvín (a) and Milovice (b) Woods. Graph design is same as in Fig. 4. Significance codes are 0.001 \*\*\*\*, 0.01 \*\*\*, 0.05 \*.

obscured the performance of other, less abundant species: lime (decreased at  $p < 0.05$ ), hornbeam, maple and especially elm (all three changes n.s.); Fig. 6b. The category 'others' decreased significantly at  $p < 0.05$ . By contrast, in Děvín Wood species composition was more even, at least relative to species frequency. A remarkable difference could be observed in species abundance (importance value): the main feature of the changes in tree species composition in Děvín Wood was the increase of lime, ash and maple (Fig. 6a).

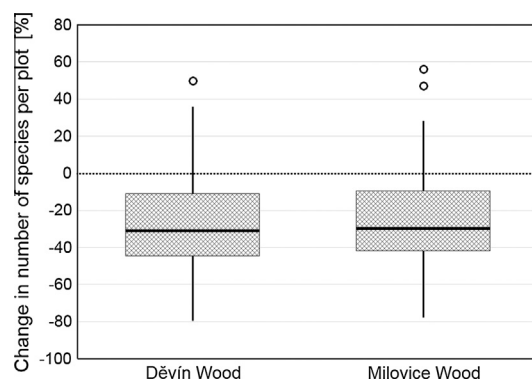
An additional insight into forest regeneration processes was provided by frequency change in understory woody species (Table 2b). In both woods, the total number of species decreased by approximately one quarter. The frequency of most species decreased while only several species became more frequent. The heaviest losses affected thermophilous shrubs and trees (*Euonymus verrucosa*, *Ligustrum vulgare*, *P. mahaleb*, *R. cathartica*, *Sorbus domestica*, *S. torminalis* and *Viburnum lantana*) or generally shrubby species of open habitats (*Cornus sanguinea*, *C. avellana*, *Crataegus* sp., *Prunus spinosa*, or *Rosa canina* agg.). Oaks (*Q. petraea*, *Q. pubescens*) failed to regenerate, decreasing by more than half at both sites. Elms either decreased (*U. minor*) or increased (*U. glabra* – in Děvín), probably reflecting the differing regeneration ecologies of the species. Similar differences can be observed for the regeneration of mesophilous maples (*A. platanoide*s, *A. pseudoplatanus*), for which an increase was recorded in the increasingly mesic forests of Děvín and a decrease in the dry, ungulate-browsed forests of Milovice Wood. Lime (*T. platyphyllos* and *T. cordata*), another species of dark and moist forests, showed increasing regeneration in Děvín Wood.

### 3.2. Herb species composition

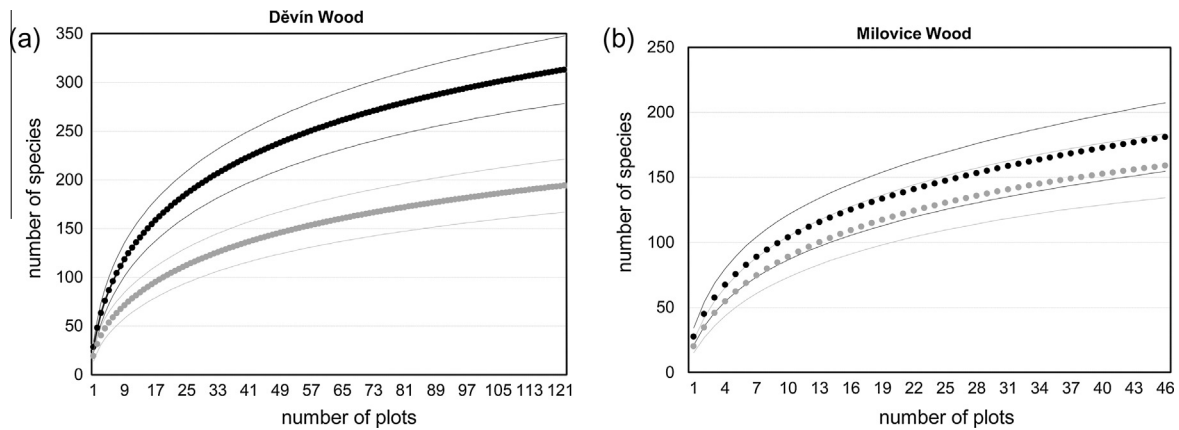
Changes in forest herb species over the second half of the 20th century were considerable. Out of 325 species recorded in Děvín Wood, 313 occurred in the old survey, while only 194 were present in the new one. 183 species (56%) were present in both surveys. A striking 130 species (40%) were observed only in the old survey, compared with only 12 species (4%) unique for the new survey. We recorded a similar situation for Milovice Wood with 234 species in total, out of which 104 (45%) were common in both datasets, 75 (32%) were exclusive to the old dataset and 54 (23%) were exclusive to the new dataset. Species exclusive to either dataset were mainly recorded only once. These rare species constituted 47% of species in the old and 75% of species in the new dataset in Děvín Wood, and 57% and 43%, respectively, in Milovice Wood. On the other hand, only a few species showed marked increase. No species could out-compete the performance of the alien *Impatiens parviflora* in Děvín Wood, which increased from 'absent' in 1953 to 56% of the plots fifty years later. In Milovice Wood, *Urtica dioica*, not present in the old survey, was recorded in 57% of plots in 2006.

Almost identical trends were observed in average species richness per plot. In Děvín Wood, average species richness per plot decreased from 28.4 to 19.3 (Wilcoxon pair test,  $p < 0.001$ ); in Milovice Wood, from 27.7 to 20.3 ( $p < 0.001$ ). This trend of species diversity decline was very similar at both sites (Fig. 7). Species richness estimated by rarefaction showed a striking difference in Děvín Wood between the old and new surveys; it was significantly lower in the new survey (Fig. 8a). However, in Milovice Wood, the estimated number of species was only slightly lower in the new survey and averages stayed within the confidence intervals of the other survey (Fig. 8b). Both estimates showed a continuously increasing trend in rarefaction curves, which indicates that there were probably still species in forest vegetation at both sites that were not present in the plots, particularly in Děvín Wood in the old sample. The rarefaction analysis illustrates the character of the studied vegetation with many rare species as indicated by the high proportion of singleton species mentioned above.

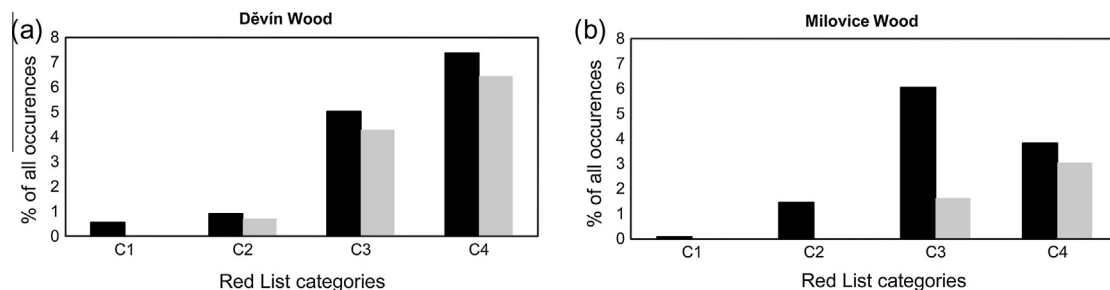
The occurrence of rare and endangered species decreased at both sites. This trend was more pronounced in Milovice Wood (Fig. 9b) than in Děvín Wood (Fig. 9a). However, change in neither of the Red List categories was statistically significant at  $p < 0.05$ . Critically endangered species (category C1) have completely disappeared from the resurveyed plots; strongly endangered (C2) and endangered species (C3) suffered higher losses in Milovice Wood, probably as an effect of the game preserves. Note the relative expression of the results; the absolute number of species is higher in Děvín Wood than in Milovice Wood, and so is the number of endangered species and their occurrences in plots.



**Fig. 7.** Change in species richness in herbaceous layer of two studied forests. Plot-wise difference between the number of species in new and old sample is calculated as % of the number of species in the old sample. Boxes show median and interquartile range, vertical bars are non-outlier range and circles outlier values. Three values exceeding the upper range of displayed change are not shown. Changes in both sites are statistically significant at  $p < 0.001$ .



**Fig. 8.** Estimation of species richness by rarefaction curves for Děvín (a) and Milovice (b) Woods. Black symbols and lines are for the 1950s vegetation surveys, grey colour is used for the 2000s surveys. Mean species richness is by rows of circles, 95% confidence intervals are by lines accompanying means.



**Fig. 9.** Changes in endangered herb layer species for Děvín (a) and Milovice (b) Woods. Relative occurrence (percentage) of the Red List species for the Czech Republic from the occurrence of all species in the datasets. Differences between the old and new samples were statistically insignificant (at  $p < 0.05$ ).

## 4. Discussion

### 4.1. Changes in woody species composition

Detailed historical information on tree species composition is relatively sparse. Generally speaking, quantitative data are more copious for species of standards, whereas only presence/absence was usually given for species of underwood, especially in older periods. This reflects partly the long-term interests of landowners in standards and partly business practices. From the Middle Ages onwards, standards were sold by the piece (different species had different prices) and therefore tended to be recorded as such, whereas underwood was marketed by the area and irrespective of species. In our case, archival forest sources contained detailed information on the proportions of underwood species only since 1948 (Děvín) or 1971 (Milovice). This roughly overlaps with the period covered by the vegetation surveys, which enabled us to examine the changes following coppice abandonment comparing the two kinds of sources.

Unlike vegetation resurveys, archival forestry records often referred to underwood and standard composition separately. Whereas underwood was harvested all at once, the composition of standards was subject to selective cutting and the promotion of desirable species. From the observed strong reduction of standard density in Děvín Wood in 1948–2011 (Altman et al., 2013) as well as from the rapid changes in standard composition in the period from 1948 to 1971, we can infer that standard felling happened mainly during the period of transformation to high-forests. Oak standards were often left while others (hornbeam, lime and ash) were mostly felled. In the 2010 FMP [15] underwood and standards were not separated, and because of the dominance of underwood we assumed species composition to be comparable with the

vegetation resurveys. This assumption could play a role in the inconsistency of the two information sources. Instead of oak increase, the shifts in species dominance recorded in archival records could refer to the reduction of standards of other tree species through selective felling, and could therefore not be explained by forest successional dynamics.

The differences observed between archival forestry data and vegetation resurvey results may also be due to sampling methodology. Forestry records typically refer to entire forest compartments of considerable sizes (Bürgi, 1999). By contrast, vegetation resurveys used sets of relatively small plots scattered on a small fraction of the studied forests and therefore provide higher spatial resolution but smaller spatial extent. No statistically random selection of vegetation resurveys was carried out. However, bias towards under or overestimation of common species was probably not high (Hédl, 2007; Michalcová et al., 2011), and the spatial layout of plots was balanced, albeit subjective. The methodology of forestry data acquisition certainly experienced slight changes in time and was not always applied properly (from areas not covered in this paper we know of examples when instead of re-measuring in the field, data were simply copied from the previous FMP changing only the age of the forest). For example today the composition of tree species in FMPs is derived from medium tree height and diameter using growth tables, and therefore if the trunks of the individuals of a species at a site are thicker than the average, the abundance of that species is overestimated. In our case, this may hold true especially for oaks on the NW foothills of Děvín Hill, which have large trunks and recorded the biggest increase in oak abundances.

Dominant tree species composition in the study area appeared to be very stable throughout the past four centuries, despite the lengthening of the coppice cycle (Szabó, 2010), the fluctuating

number of standards and the recent shift from coppice to high-forest management. These dominants were oak, lime, ash and hornbeam for both standards and underwood. However, their proportions changed and the observed tendencies differed partly according to the data source (forest records or vegetation resurvey) and between the sites. The observed shifts were connected mostly to changes in forest management.

From the changes of tree species composition we can infer the influence of shifts in management intensity from intensive coppicing to neglect although the archival and vegetation records did not always correspond. After the abandonment of coppicing, oak generally decreased, although in the case of Děvín Wood archival forestry records showed the opposite trend. This inconsistency could possibly be explained by the overestimation of oak abundance in forestry survey due to large trunks, discussed above. Ash and maple increased in both archival forestry records and vegetation resurveys. Congruent results were obtained for hornbeam, which generally decreased, and for lime and ash, which increased or fluctuated. A similar decline in light-demanding oak and increase in nutrient-demanding shady species (maple, hazel) were observed in resurvey data in Belgium (Vanhellemont et al., 2014), suggesting that such trends are common in European temperate lowland forests. The expansion of ash in Děvín Wood concurs with the expansion of this species in the ecologically similar Bohemian Karst (Hofmeister et al., 2004; Střeštík and Šamonil, 2006). Elsewhere in Europe, ash is in decline (e.g. Vanhellemont et al., 2014), largely due to the pathogen fungus *Chalara fraxinea* (Kowalski, 2006), now observed in most European regions including the Czech Republic (Jankovský and Holdenrieder, 2009). Our former conclusions for Milovice Wood that the forests have changed from oak and hornbeam dominated stands to forests dominated by mesophilic species (Hédl et al., 2010) can be extended to Děvín Wood where this change is even more pronounced, probably because of topography and soil conditions. This change may not be reversible due to poor oak regeneration observed in Děvín Wood both in our resurveys and in the reconstruction of oak recruitment by Altman et al. (2013).

#### 4.2. Changes in herb species diversity and composition

Decline in biodiversity and species richness in particular is recognized as a global process (Brooks et al., 2006; Butchart et al., 2010) threatening the functioning of ecosystems (Isbell et al., 2011) and human well-being (Díaz et al., 2006; Cardinale et al., 2012). Biodiversity decline at a global scale may not necessarily be paralleled at local scales because of species migrations; locally extinct species can be replaced by newly arrived ones resulting in zero net change. Reliable assessment of species richness change and its linking to environmental changes at a local scale can be achieved by using resurveys of semi-permanent plots (Chytrý et al., 2014; Kopecký and Macek, 2015). Increasing numbers of time series of diversity data allow for wider generalizations, such as the meta-analyses recently published by Vellend et al. (2013) or Dornelas et al. (2014). The former study used an extensive dataset of resurveyed vegetation plots from a range of the Earth's biomes and detected no overall decline in species richness; the departure from zero change was not significant. Slight increases in species richness appeared in forests and after canopy closure; post-disturbance succession (which was not confined to forests in this meta-analysis) resulted in marked species richness increase.

Following the classification in Vellend et al. (2013), our two sites are distinct examples of canopy-closure post-disturbance succession forests. However, the observed changes in species richness were in contrast to the findings of Vellend et al. (2013). Both forests underwent a marked plot-level decrease of species richness. Děvín and Milovice woods are formed by typical successional

forest communities where active coppicing with frequent disturbances was replaced by high-forests with less frequent disturbances. Both study sites (Děvín and Milovice woods) have been subject to ungulate pressure. Deer and mouflon impact is very complex. Unfortunately, currently there is not enough data for the assessment of the browsing effect. However, we can see a similar effect on vegetation in both forest complexes although in Děvín Wood the game preserve was established long before coppice abandonment whereas in Milovice Wood only in the 1960s. So it is obvious that the changes in game numbers did not have the same pattern at both sites and therefore we can infer the game browsing was not the driving element of vegetation change. In Děvín Wood, disturbances strongly decreased after the site was designated as a strict reserve shortly before the old vegetation records were made. In Milovice Wood, ground-disturbances by ungulates contributed to an increase of ruderal herbs, but at the same time they slowed down the process of biotic homogenization in the past decades. However, the succession from coppice to high-forest was probably the decisive element in the process of species richness decline (Chytrý and Danihelka, 1993; Hédl et al., 2010).

One of the reasons behind the differences between the results of the global meta-analysis and our study can be the time lag between the surveys. In our case the temporal distance between the old and new surveys is 53 years for Milovice Wood and ca. 50 years for Děvín Wood. By contrast, in Vellend et al. (2013) over half of the cases comprised plot resurveys after less than 25 years, and ca. 25% after 10 years or less. Climate change and pollution have affected vegetation composition and diversity well before the time span of such relatively short-term resurveys. In Europe and North America, the major impact of air pollution by acidic compounds happened between the 1960s and 1990s (Menz and Seip, 2004; Kopáček and Veselý, 2005) whereas the negative impact of nitrogen depositions on global biodiversity persists (Wamelink et al., 2009; Bobbink et al., 2010). The crucial distinction between the short and long-term comparisons can be due to the long-term cumulative impact of these factors.

Forest succession, as an ecological consequence of the conversion of coppices to high-forests or in general of coppice abandonment, was considered to be the cause of vegetation diversity decline by many studies (e.g. Bartha et al., 2008; Baeten et al., 2009; Van Calster et al., 2008). The impact of deer and other ungulates represents another long-term factor in temperate forests, although its consequences over longer time periods were rarely documented (Chytrý and Danihelka, 1993). Most studies inferred vegetation change under the influence of deer for no longer than two decades (Rooney, 2009; Nuttle et al., 2014). In the case of Milovice Wood, however, deer have interacted with forest succession after coppice abandonment for at least four decades, arguably preventing taxonomic homogenization via heterogeneous soil surface disturbances and by keeping the expansion of shrubs (mainly *A. campestre*) under control (Hédl et al., 2010).

The influence of deer is relatively unexpected but may be more common than previously thought. Resurveys from former coppices in the Czech Republic indicated that understory vegetation homogenization had not taken place at sites where deer was kept in high densities (our own unpublished results). However, deer clearly causes an increase of nitrogen-demanding, shade-tolerant species (ruderals), such as *U. dioica* in Milovice Wood. The prevention of homogenization is probably due to the expansion of ruderals, because many threatened species have locally disappeared. In both Děvín and Milovice woods, species richness decrease was not due to the strongly negative effect of invasive species reported for example by Vellend et al. (2013). Only a few species invaded the forests and only *I. parviflora* did it on a larger scale in Děvín Wood. Even this, however, had little effect on the native flora,



which was subdued rather by the succession towards shadier forest conditions (Kopecký et al., 2013).

All in all, generalizations about species richness change can provide different stories in different situations because (i) factors driving species richness change operate at various temporal scales, many of which are longer than a few decades, (ii) the impact of the long-term factors is typically cumulative, (iii) causality can be more complex than or even different from what simple categorizations would allow, (iv) last but not least, resurvey data contain inherent errors, in particular authorship bias, which can corrupt the results.

## 5. Implications for management

The ancient landscape of Pálava and adjacent river alluvia, now protected as the Lower Morava UNESCO Biosphere Reserve, has been co-formed by humans for millennia. We believe that its exceptional ecological value is partly due to long-term human influences and disturbances. The relative influence of ecological versus socio-economic driving forces can be very complex and can involve the long-lasting effects of management decision making, as shown for the area by Szabó and Hédli (2013). Traditional forest management, including coppicing, was abandoned due to socio-economic changes as well as a misunderstanding of the tasks and goals of nature protection. In the past, nature protection was understood either as the enlightened and centralized manipulation of ecosystems towards a predefined state (Chase, 1986) or as the protection of natural processes (the 'wilderness' or 'non-intervention' paradigm) (Cronon, 1995; Nelson and Callicott, 2008; for coppice forests, see Evans and Barkham, 1992). The Pálava example clearly shows the contradictions between non-intervention policies and the role of humans in maintaining ecosystem biodiversity. When foresters lost interest in managing the forests and nature protection took over the territory, non-intervention became the official rather than the default policy. Reinforcing the findings of earlier research (Chytrý and Danihelka, 1993; Beneš et al., 2006; Vodka et al., 2009; Hédli et al., 2010; Kopecký et al., 2013; Miklín and Čížek, 2014; Müllerová et al., 2014), our study demonstrated that non-intervention alone is ineffective in protecting biodiversity in the Lower Morava UNESCO Biosphere Reserve.

Despite the long neglect, forms and structures created by historical management are still preserved in the study area, and recently conservation efforts have been put in place to re-establish traditional management. Although it is often argued that the restoration of neglected coppices is technically problematic, Pyttel et al. (2013) and Matula et al. (2012) showed good resprouting ability for coppice stools after long periods of neglect. Furthermore, Leonardsson and Götmark (2015) found no effect of stool diameter on sprouting after conservation thinning in southern Sweden.

On the NE slopes of Děvín Hill 21.6 ha of overgrown coppices were harvested in 2009–2013 and further thinning is planned to reduce the density of shoots by 60%. Field observations from spring 2014 (Hédli, unpublished) showed two opposing development trajectories. On the one hand, new occurrences of thermophilous species such as *Polygonatum odoratum*, *Carex michelii* and *Vincetoxicum hirundinaria*, and regeneration of oak from seedlings indicate the positive impact of coppice restoration from the conservation perspective. Freshly created open-woodland habitats in Děvín Wood are also susceptible to expansion by nitrophilous species, such as *Alliaria petiolata*, *Campanula rapunculoides* or *I. parviflora*. The risk of release of soil-accumulated nitrogen after canopy opening seems to have concrete manifestations (Verheyen et al., 2012). In general, through the expansion of ruderal and invasive species to freshly cut areas, coppice restoration can pose a threat to the

conservation value of forests (Radtke et al., 2013; Vild et al., 2013; Ambrass et al., 2014).

Another challenge connected to attempts at coppice restoration is grazing pressure. Although the Děvín game preserve was abolished in 1996, mouflons and deer still live here in high densities (Riedl, personal communication), causing damage by overgrazing and preventing natural regeneration from coppice stools (cf. Chytrý and Danihelka, 1993). In Milovice Wood the two game preserves are still active and high numbers of ungulates would make coppice re-establishment practically impossible.

Both non-native tree species, black pine and black locust, although relatively rare in the study area, pose problems for nature conservation. Whereas black pine occurs only in plantations and does not spread spontaneously, black locust, an invasive species listed in the DAISIE database (<http://www.europe-aliens.org/>) as one of the 100 most aggressive invaders of the world, has the ability to spread fast both generatively and vegetatively, eventually altering the environmental characteristics of particular sites. Together with another alien, tree of heaven, which is already present in the area, it can soon become a real threat to nature conservation (Radtke et al., 2013).

## Acknowledgements

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013)/ERC Grant agreement no 278065, long-term research development project no. RVO 67985939, and CZ.1.07/2.3.00/20.0267 of the Ministry of Education of the Czech Republic. We thank our colleagues Z. Konopová for technical assistance and help with fieldwork, J. Horák for providing his vegetation records from the 1950s, J. Danihelka for tireless support during the resampling, J. Komárek for allowing us to use his 2006 resampling data and V. Riedl for useful comments.

## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.foreco.2015.02.003>.

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# Trends and events through seven centuries: the history of a wetland landscape in the Czech Republic

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Received: 22 September 2015 / Accepted: 25 July 2016 / Published online: 23 August 2016  
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**Abstract** Environmental change can be viewed as the combined result of long-term processes and singular events. While long-term trends appear to be readily available for observation (in the form of temporal comparisons or space-for-time substitution), it is more difficult to gain information on singular events in the past, although these can be equally significant in shaping ecosystems. We examined the past 700 years in the history of a lowland wetland landscape in the Czech Republic with the help of palaeoecological, ecological, landscape archaeological, and archival data. Macrofossil and pollen data were compared to known drainage works in the area and historical climatological data. Trends and events in habitat conditions were assessed using species indicator values. Results showed that ecological succession was the general process in the study area, detected as a trend towards eutrophication, desiccation, and vegetation closure. Short-term events

influenced development at the sites mainly from the second half of the nineteenth century. This is consistent with drainage history, although bias related to sample frequency cannot be excluded. On the whole, long-term trends and discrete events were complementary on different scales. We conclude that humans facilitated and accelerated background processes, which can be most likely associated with the succession of open wetlands towards terrestrial ecosystems.

**Keywords** Human impact · Macrofossils · Pollen · Species indicator values · Vegetation development · Drainage channels

## Introduction

The interactions between nature and human society are played out on many spatial and temporal levels from global to local and from millennial to short-term (Sayre 2005; Szabó and Hédli 2011). Environmental change can be described by long-term trends, probably the best-known

Editor: Wolfgang Cramer.

**Electronic supplementary material** The online version of this article (doi:10.1007/s10113-016-1033-0) contains supplementary material, which is available to authorized users.

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example of which is recent global warming (Parmesan and Yohe 2003). However, in many cases, short-term events can modify the effects of long-term processes. Such events can be highly localized (such as the drainage of a fishpond) but potentially global as well (such as the 1815 eruption of Mount Tambora) (Stothers 1984; Oppenheimer 2003). Both trends and single events can be periodically recurring (such as the coming of ice ages or the eruption of volcanoes), which makes them to a certain extent predictable, or more stochastic (such as the human agency behind global climate change) (McNeill 2000). Separating trends from discrete events is in itself a matter of temporal resolution. A useful method is to look at abruptness, which is “a function of magnitude over duration, best described relative to the life cycles of the organisms of interest or the successional speed of the ecosystems in which they occur” (Jentsch et al. 2007; White and Jentsch 2001).

Any long-term environmental change is arguably the combined result of underlying processes and singular events. It is to be noted that the effects of trends and events can markedly differ (Jentsch et al. 2007). However, whereas long-term trends appear to be readily available for observation (in the form of temporal comparisons or space-for-time substitution, Pickett 1989), many past singular events are simply not known (Rackham 2006). If the impacts of such unknown events reinforce long-term trends, they will be attributed to them by default, but if they counteract them, they may lead to false hypotheses. It is therefore of primary importance in the study of environmental change to have information both on long-term processes and on short-term, discrete events.

In this paper, we examine the long-term history of a lowland wetland landscape. Lowland wetlands are among those ecosystems that have been the most influenced by human activities. In this respect, they are one of the most sensitive indicators of environmental change. They have undergone a marked decline on a pan-European scale (Brander et al. 2012). The remaining wetlands are usually confined to forests or meadows. Sometimes, they occur in arable fields as well, where they provide important transitional refugia for wetland-associated organisms (Němec et al. 2014). Wetlands are threatened by changing water regimes and eutrophication, both of which can be considerably modified by intentional or indirect human activities, such as in site restoration or atmospheric nitrogen pollution (Bobbink et al. 1998). Nowadays, most Central European lowland wetlands represent shallow, eutrophic to hypertrophic systems that are highly dynamic in terms of basic factors, such as water depth, amount of nutrient and oxygen, and water temperature (Pott and Remy 2000; Khan and Ansari 2005; Čížková et al. 2013). Traditional uses, such as extensive grazing by livestock and domestic fowl, or mowing the reed beds and tall-sedge stands for use in

industry and agriculture, have only occasionally survived until the present. Eutrophication and management abandonment have resulted in the accumulation of large amounts of dead biomass, changes in nutrient cycling and water retention, and biodiversity loss related to the extinction of competitively poor, disturbance-dependent plant species (Middleton et al. 2006; Keddy 2010).

Due to the highly unstable conditions at such sites, the vegetation of shallow lowland wetlands is usually composed of vascular plant species of relatively broad ecological range and high eco-morphological plasticity (Balátová-Tuláčková 1976; Hejný and Hroudová 1987). However, even if these species are able to survive under a broad range of local environmental conditions, their ecological niche optima (i.e. the conditions in which the species occurs and reproduces most frequently) are usually narrow. At the level of vegetation composition, this means that smaller changes in environmental conditions are reflected by fast and pronounced changes in the quantitative representation of individual vascular plant taxa rather than by overall species composition change. By contrast, overall changes in species composition in wetlands are usually associated with considerable shifts in trophic status, and in the timing, duration and frequency of mechanical disturbances or climate-related events (Hejný et al. 1982; Rintanen 1996; Czerepko 2008; Strohbach et al. 2009).

We investigate the past 700 years in the history of a small forest wetland. We apply a historical ecological approach (Swetnam et al. 1999; Egan and Howell 2001; Szabó 2015), which combines research methods from the natural sciences and the humanities in multi-proxy research. Interdisciplinarity was a prerequisite in our work, because anthropogenic influence was one of the probable drivers of change. We used data and methods from four disciplines. *Quaternary palaeoecology* traditionally focused on ecosystem development in the Quaternary and especially in the Holocene (Birks and Birks 1980; Cappers and Neef 2012). Palaeoecologists usually put more emphasis on older periods, and research analysing the past few centuries is still relatively rare, although especially with the coming of  $^{210}\text{Pb}$  dating, there is no methodological reason for this to be so (Walker and Walker 2005). *Ecology* mostly focuses on recent patterns in species, populations and ecosystems. Knowledge of species niche, the ecological space potentially or actually occupied by individual species, can be used for an indirect assessment of environmental conditions (e.g. Chase and Leibold 2003; Wildi 2016). This can include the reconstruction of past environments wherever suitable fossil resources are available. *Landscape archaeology* deals with all periods of human history and prehistory, but, as opposed to traditional archaeology, more recent periods have always played a prominent role in it (Aston 1985). Last but not least,



*archival research* on landscape history in Europe can reach back to the eighth century (e.g. Sonnlechner 2004) although environmental historians have predominantly dealt with the nineteenth and twentieth centuries (Szabó and Hédl 2011). Combining the methodological opportunities offered by the individual disciplines, seven centuries appear to be a temporal scale for which relatively high resolution can be achieved to which each discipline can significantly contribute.

Through the combined interpretation of palaeoecological, ecological, landscape archaeological, and archival data, we ask the following interconnected questions: (1) How did the ecological conditions change at the study site in the past 700 years, and which factors induced such changes? (2) Do long-term trends significantly differ from site history reconstructed in higher temporal resolution?

## Materials and methods

### Study site

Dúbrava Wood (3600 ha) is located at the northwestern edge of the Pannonian Basin in the southeastern part of the Czech Republic (17°05'00"E, 48°52'40"N) next to the town of Hodonín on the fringes of the alluvium of the Morava river. Tree cover in the core area of the Wood has been stable for at least four centuries, although approximately one-third of the current forested area along the edges of the Wood was converted to pastureland for several decades in the early nineteenth century (Jamrichová et al. 2013; Szabó and Hédl 2013). The site is mostly flat, altitude varies between 164 and 242 m a.s.l. Climate is temperate subcontinental with ca. 9 °C of average annual temperature and 500–550 mm of annual precipitation (Tolasz et al. 2007). The Wood lies on eolic sands of Pleistocene origin of varying thickness. Soils are generally arenic dystric cambisols; in places with prolonged waterlogging gleyic soils occur (<http://mapy.geology.cz/pudy/>). The soils are mostly nutrient poor, slightly acidic and prone to desiccation in dry periods (Novák and Pelíšek 1943). Water conditions fluctuate during the year; in spring, many sites are waterlogged. Within the forest matrix, there are dozens of wet depressions of up to ca. 100 m in diameter.

### Field sampling and palaeoecological sample processing

We collected three profiles from three different wet depressions in Dúbrava Wood (Fig. 1). The sites named MS3, MS4, and MS15 were chosen out of 15 locations surveyed in 2008 through 2012. The sites are ca. 0.5 km from each other (Fig. 1) and reflect the same climatic,

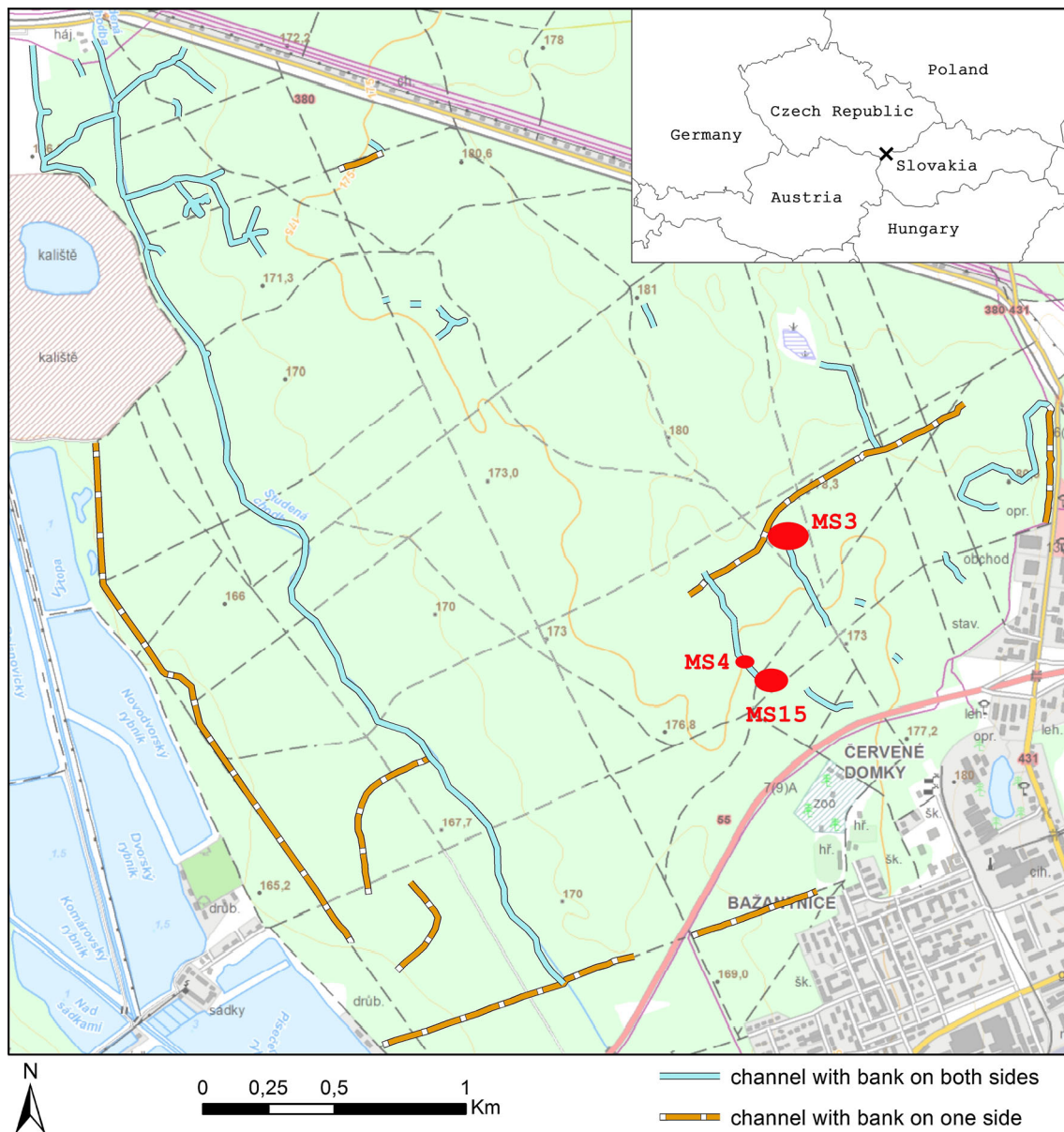
substrate, and topographic conditions. However, the shape of sites and their vegetation cover differs.

- MS3 was sampled from an oval-shaped treeless depression, which is ca. 100 m in diameter. This depression is covered with dense reed (*Phragmites australis*) vegetation, and a shallow pool can be found in the middle part, where organic sediment is wet and about 50–60 cm deep.
- MS4 was extracted from a treeless depression of ca. 30–40 m diameter. Organic sediment is only about 30 cm deep and relatively dry for most of the year. Vegetation is composed of shrubs and small trees (*Salix caprea*, *Alnus glutinosa*, *Betula pendula*); herbs include dominant *Phragmites*, then *Juncus*, *Agrostis*, and rare sedges, such as *Carex lasiocarpa* or *C. elata*, indicating formerly wetter conditions. *Sphagnum* is also present.
- MS15 differs from the other two sites by the depth and age of its organic sediment, which is 0.9 m and over 10 thousand years, respectively. The site is a treeless glade of about 25 m in diameter. The surrounding forest is composed of *Betula pendula*, *Alnus glutinosa*, *Quercus robur*, and *Salix* sp. The inner part of the site is dominated by grasses and forbs (e.g. *Polygonum hydropiper*), not reed as at the other two sites. Organic sediment is finely structured, moist but not waterlogged for most of the year.

Material for analysis was collected in August 2009 (MS3, MS4) and in September 2012 (MS15) from the walls of hand-dug pits using metal boxes of 10 × 10 × 50 cm. The profiles consisted of organic sediment with higher amounts of sand and/or clay. The amount of sand increases towards the bottom of each profile (for sediment descriptions, see Online Resources 1, 5 and 6). Organic sediments were sub-sampled at 1 cm (MS3, MS4) or 2 cm (MS15) intervals for pollen analysis, and at 2 cm intervals (MS3, MS4 and MS15) for macrofossil analysis. The upper parts of profiles MS3 and MS4 were sub-sampled at 4 cm intervals because of presence of rhizomes of *Phragmites australis*, which would have made finer resolution technically complicated.

### Chronology

The chronology of the profiles was obtained by AMS radiocarbon dating and by <sup>210</sup>Pb dating of the upper parts of the cores. Charcoals and seeds were isolated from the selected layers and sent for dating to the Centre for Applied Isotopes Studies, University of Georgia, Athens, GA, USA (UG). Radiocarbon ages were calibrated using the IntCal13 calibration curve (Reimer et al. 2013). <sup>210</sup>Pb dating was done at the Institute of Physics, Silesian University of Technology, Gliwice, Poland (MS3 and MS4), and at the Institute of Geochemistry, Mineralogy and Mineral



**Fig. 1** Map of the study area and its position in Central Europe. Palaeoecological sites (MS3, MS4 and MS15) and artificial channels are shown. Dashed lines represent current forest roads

Resources, Charles University in Prague, Czech Republic (MS15). Dates were obtained from the top 15 cm of MS15, the top 27 cm of MS3, and the top 28 cm of MS4 (Online Resource 2). Depth–age models were created with P\_Sequence (a Bayesian model of deposition) implemented in Oxcal 4.2.1 (Bronk Ramsey 2011) (Online Resource 3). The command boundary was incorporated into the model due to potential changes in sedimentation rate. The model reached the agreement value of 155 (MS3), 180 (MS4), and 115 (MS15). In the text below, we use mean values of modelled data within a 95.4 % confidence interval.

### Macrofossil analysis

The samples were wet-sieved using a set of sieves with mesh diameter of 1, 0.5, and 0.25 mm. No chemical treatment was necessary. Seeds and plant remains were determined according to Cappiers et al. (2006), Veličevich and Zastawniak (2006, 2008) and other available identification literature. They were also checked against the reference seed collection of the Institute of Botany, Czech Academy of Sciences. Values are presented as absolute numbers per sample for countable fossils (mostly seeds).

## Pollen analysis

The preparation of samples for pollen analysis followed standard techniques (Faegri and Iversen 1989). Samples containing mineral material were pretreated with cold concentrated HF for 24 h and then processed by KOH and acetolysis. At least 500 terrestrial pollen grains were identified using standard key and photo collections (Beug 2004; Reille 1995, 1998); for the determination of non-pollen palynomorphs we used van Geel et al. (1980). The nomenclature of pollen types follows Beug (2004). Pollen data are presented in percentage pollen diagrams constructed in the Tilia software version 1.7.16 (Grimm 2011). Total pollen sum (TS) was calculated based on terrestrial pollen sum taxa ((semi)aquatics, Pteridophyta, algae, fungi, and the other non-pollen palynomorphs (NPP) were excluded). The percentages of pollen taxa were based on pollen sums of arboreal (AP) and non-arboreal pollen (NAP) ( $TS = AP + NAP = 100\%$ ). The percentages of spores and NPP were related to the extended sum ( $AP + NAP + (\text{semi})\text{aquatics} + \text{spores} + \text{NPP} = 100\%$ ). The pollen diagrams were divided into developmental phases based on constrained cluster analysis by sum-of-squares (CONISS, implemented in the Tilia program; Grimm 2011).

Full pollen diagrams for profiles MS3 and MS4 were published previously (Jamrichová et al. 2013). For the evaluation of trends and events, we considered taxa related to the development of local mire vegetation [Cyperaceae, (semi)aquatics, spores, green algae, pteridophytes].

## Landscape archaeology of channels

Approximately 1000 ha in the southwestern part of Dúbrava Wood were surveyed by fieldwalking for visual remains of drainage and other channels, including woodbanks (based on the methodology of Szabó 2010). Channels were mapped by a hand-held GPS device; the results were visualized using the ArcGIS software. The physical remains of channels were also examined as regard basic structure in order to prepare a typology. Where channels crossed each other, we tried to work out a relative chronology of their ages. In addition, relevant historical written sources (for a list, see Jamrichová et al. 2013) were studied to obtain absolute dates for construction and/or desertion. Although some of the features we identified were not originally intended to serve as channels, all were used for that purpose for at least shorter periods of time; therefore, we will use the term “channel” throughout this paper to refer to all types of linear hand-dug features observed in the Wood.

## Environmental assessment

Trends and events in habitat conditions were assessed by using species indicator values. Indicator values, which

reflect the optima of a species' realized niche, have been widely used in vegetation ecology since the 1970s (for a review, see Diekmann 2003). Water level fluctuation during the growing season is one of the factors that are crucial for the survival and/or reproduction of many wetland plants (Hejný 1957, 1960; Moravcová et al. 2001). The tolerance of aboveground and underground organs to floods, summer drought, or frost also influences species composition. Because no indicator values sensitive enough to reconstruct water level fluctuations and related processes were available, we decided to create our own indicator values appropriate for use in wetland ecosystems—wetland species indicator values. These values were based on the long-term field experiences and results of germination/cultivation experiments of one of the authors (K.Š.) as well as on published papers (e.g. Hejný 1957, 1960; Balátová-Tuláčková 1968, 1976; Hejný and Husák 1978; Hroudová et al. 1992; Moravcová et al. 2001). We produced indicator values in relation to the following environmental factors: water depth (WD), water level fluctuations (WLF), insolation (IS), and trophic status (TS). We established values for vascular plant species identified in macrofossils using a numerical scale of 0, 1, 2, 3, 4, and sometimes also 5. Only non-woody wetland plant species were selected and used in the subsequent analyses. For species with broader ecological ranges, a range of values was set. Descriptions of scales for each indicator value can be found in Online Resource 4.

## Numerical analyses

Species used in the analyses are presented in Online Resource 4. These species represent a selection from the complete macrofossil assemblage (Online Resource 5). Only wetland vascular plant species were used. Trees, shrubs, and species of terrestrial habitats that do not tolerate waterlogging were excluded, because their seeds most probably originated from outside the wetland itself. Bryophyte macrofossils were not determined to the species level, and therefore, they were not evaluated.

For each sample, we calculated weighted averages for the indicator values of the species present as macrofossils (Ter Braak and Barendregt 1986). Species were weighted according to the width of their niche expressed as the range of indicator values, where species with wider ranges (see Online Resource 4) were given less weight. Although averages calculated from ordinal data received criticism in vegetation ecology (e.g. Podani 2006), a number of recent papers argued in favour of indicator value averages: “Despite their ordinal nature, it has been shown that average indicator values can characterize an area well, and can provide useful ecological interpretation” (Tölgyesi et al.

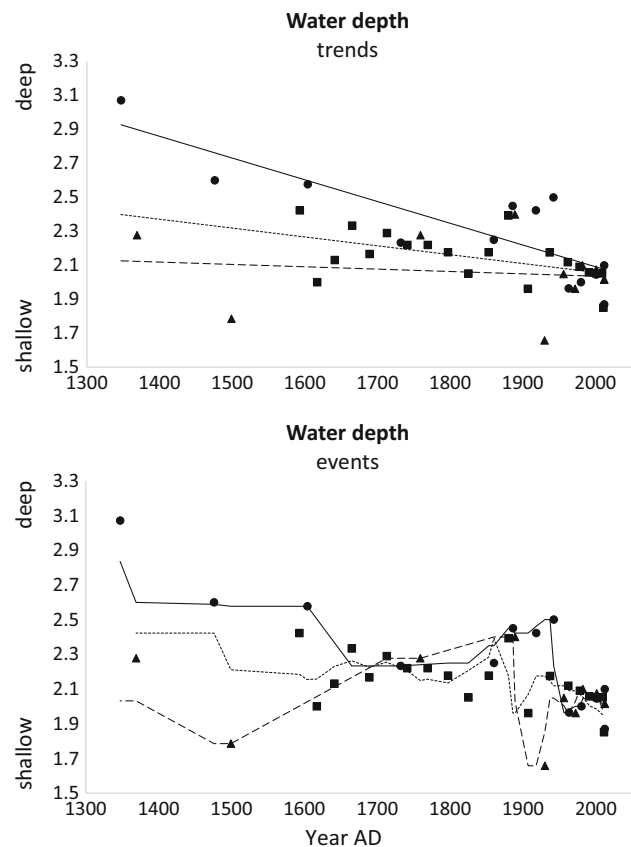
2014; see also Wildi 2016). Weighted averages of indicator values for samples were plotted on a timeline. Trends were visualized through linear regression. Short-term changes were plotted by a four-period moving average. Analyses were run separately for each of the three studied profiles to reveal variation among the sites.

Temporal patterns in variation in species composition with respect to indicator values were analysed with ordinations. Redundancy analyses (RDA) were calculated for the three sites separately, with time as an active factor and the four indicators as supplementary variables, which did not affect species composition patterns. The significance of the canonical axis was tested by a Monte-Carlo permutation test (5000 completely random permutations). Completely random permutation removes autocorrelation between the individual observations in time. Macrofossil species assemblages subject to ordination analyses were as in Online Resource 5 including species abundances, which were log-transformed to downweight over-abundant species. In total, 33, 27, and 43 species were included in the ordination analyses of MS3, MS4, and MS15, respectively. The results are presented in the form of ordination graphs; unidentified woody species, unidentified *Bryophyta*, all woody species, and less abundant herb species were excluded from the presented diagrams. Ordinations were calculated in CANOCO, version 5 (Ter Braak and Šmilauer 2012).

## Results

### Trends and events reflected in macrofossils

The detailed results of macrofossil analyses for individual profiles can be found in Online Resource 5. Linear regressions and moving averages through time for the four species indicator values are presented in Figs. 2, 3, 4, and 5. *Water depth* showed a general downward trend from permanent shallow water to only waterlogged soil. However, differences between sites were apparent. The downward trend was most pronounced for MS3, while at MS15, WD was only slightly decreasing, and the trend was almost neutral for MS4. The most visible discrete event (a sudden drop in WD) occurred in ca. 1900 at MS4 and MS15, and approximately half a century later at MS3. *Water level fluctuation* showed a rising trend from stable conditions to larger fluctuations at MS4 and MS15, while MS3 demonstrated the opposite trend. Sudden changes in WLF characterized the period since the end of the nineteenth century. *Trophic status* showed a rising trend from meso- to eutrophic conditions at each site. Stability in trophic status characterized each site until end of the nineteenth century, when fluctuation started to increase at MS3 and MS4, while

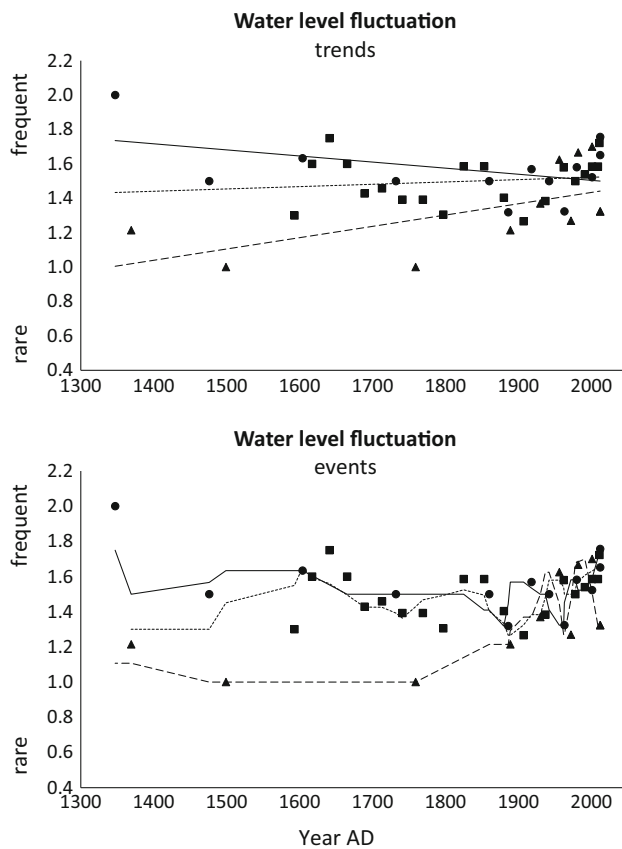


**Fig. 2** Trends and events in the past 700 years (x axis) in water depth detected by weighted averages of species indicator values in the samples. Gradient from shallow to deep water is marked on the y axis. The three sites are MS3 (circles and full lines), MS4 (triangles and hatched lines) and MS15 (squares and dotted lines)

MS15 remained more stable. *Insolation* demonstrated a decreasing trend, referring to the closing of the vegetation around the sites, except at MS4. Open vegetation was typical until the late nineteenth century, after which marked fluctuations commenced.

The results of RDA are presented in Fig. 6. According to the RDA model, macrofossil assemblages showed a significant trend in species composition through time (MS3:  $F = 5.4$ ,  $p = 0.015$ ; MS4:  $F = 3.9$ ,  $p = 0.023$ ; MS15:  $F = 24.5$ ,  $p < 0.001$ ; for each first canonical axis). The explained time-related variation in species composition is 33 % for MS3, 30 % for MS4, and 58 % for MS15. Common processes were the decrease in *Alisma* sp. (most probably *A. plantago-aquatica*), a species of open, shallow water habitats, which is rather sensitive to substrate desiccation, and the increase in a number of species, mostly graminoids tolerant to relatively dry conditions, such as *Phragmites australis*, *Calamagrostis canescens*, *Juncus effusus*, *Alopecurus aequalis*, and *Carex riparia*, but also of nitrophilous herbs, such as *Urtica dioica* and *Oenanthe aquatica*. This change in species composition indicates



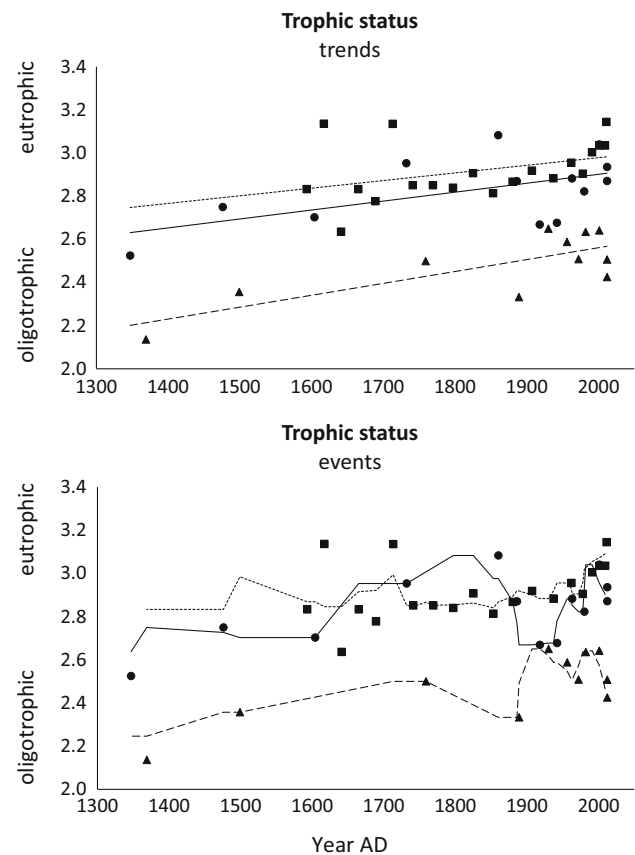


**Fig. 3** Trends and events in the past 700 years (x axis) in water level fluctuation detected by weighted averages of species indicator values in the samples. Gradient from rare to frequent fluctuation is marked on the y axis. The three sites are as in Fig. 2

succession towards increasingly eutrophic, less water-flooded habitats. In addition, the environmental trends revealed by indicator values showed that the deeper the water was, the less its level fluctuated. Trophic status seems to have increased in time and with water level fluctuations, while insolation decreased in time.

### Trends reflected in pollen

Percentage diagrams of selected pollen taxa and spores concentrating on local mire development are presented in Online Resource 6. The development of local mire vegetation in Dúbrava could be divided into four main phases (Fig. 7). Stable water conditions characterized the first phase of mire development (Phase 1; AD 1350/1600–1900). At the beginning of the eighteenth century (transition between Phases 1a and 1b), species indicating more eutrophic conditions started to occur in higher abundances. It should be noted that the internal dividing line between Phases 1a and 1b cannot be dated with much confidence because of the uncertainty in calibrated radiocarbon dates. By contrast, Phases 2–4 were



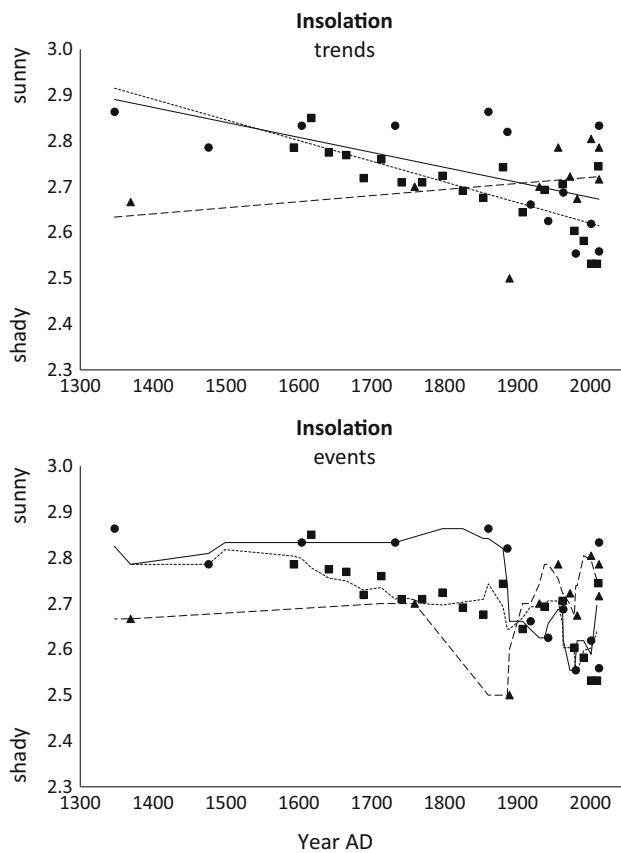
**Fig. 4** Trends and events in the past 700 years (x axis) in trophic status detected by weighted averages of species indicator values in the samples. Gradient from oligotrophic to eutrophic status is marked on the y axis. The three sites are as in Fig. 2

precisely dated with  $^{210}\text{Pb}$ . At the beginning of the twentieth century (Phase 2; ca. AD 1900–1950), several changes in (semi)aquatic macrophytes were recorded. Although these differed among profiles, they probably indicated higher WLF. Changes in mire vegetation composition implied decline in WD at MS4 and MS15, while at MS3 water depth seemed to have increased. From ca. 1950 (Phase 3; ca. AD 1950–1990), increase in trophic status was reflected in all profiles. There were also changes in water depth, which increased at MS4 and MS15. WD at MS3 declined and subsequently (after ca. 1970) increased. The last change in local wetland conditions occurred at the end of the twentieth century (Phase 4; ca. 1990–recent), when a significant increase in trophic status was recorded.

### Channels and drainage

Approximately 17 km of artificial channels were found in the study area. These represent an unknown fraction of the channels that once existed. Based on their physical structure, channels were grouped into two categories: (1)





**Fig. 5** Trends and events in the past 700 years (x axis) in site insolation detected by weighted averages of species indicator values in the samples. Gradient from shady to sunny conditions is marked on the y axis. The three sites are as in Fig. 2

a ditch with a bank on one side only, and (2) a central ditch with banks on either side. Results are visualized in Fig. 1.

1. In this category, we can distinguish between woodbanks and an unidentified structure. The woodbanks of Dúbrava Wood were made in the late 1780s (Moravský zemský archiv [MZA], F 5 kniha 232). They are massive structures, in the best preserved parts as much as 8 m across and 1.5 m high. An unusual bank-and-ditch structure cuts through the eastern half of the study area from the northeast towards the southwest. The bank is towards the east, where the town of Hodonín lies. This construction is smaller than the woodbanks, ca. 4 m across and 1 m deep. The purpose of this channel could not be identified, and we could not date it. Nonetheless, it is older than the drainage channels, which, as demonstrated below, were dug at the end of the nineteenth century and the beginning of the twentieth century. A drainage channel cuts across the unidentified channel and is therefore clearly of a later date.

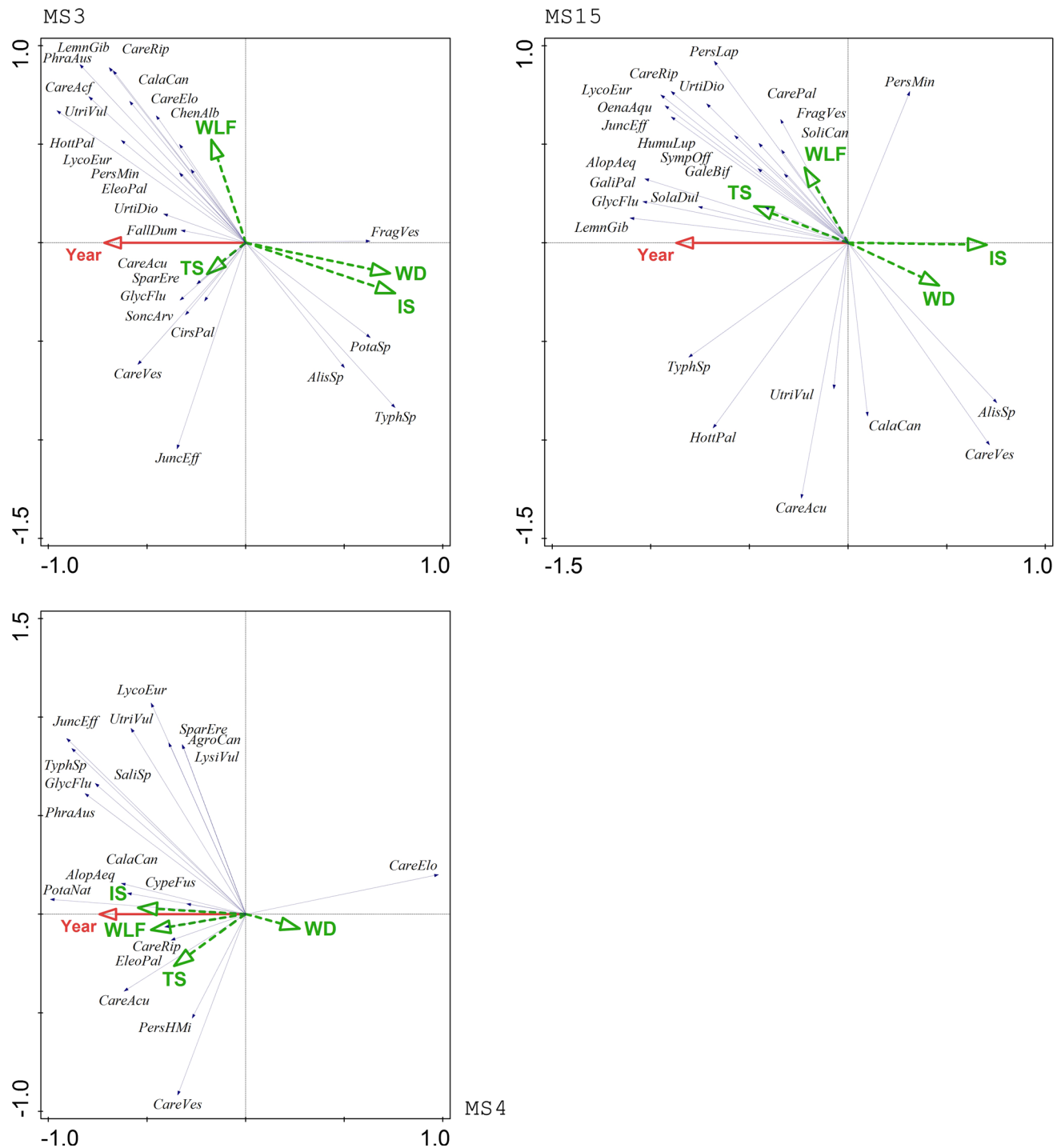
2. Two types of channels can be distinguished in this category: fishpond channels and drainage channels. The former include the large channel that runs along the fishponds in the western part of the study area. The earliest records of fishpond construction at the site are from the late fifteenth century to early sixteenth century (MZA F5 karton 2 inv.č. 24, karton 3 inv.č. 29, karton 11 inv.č. 744). The channel in the Wood was a special type of structure dug along fishponds to make the regulation of water levels more sophisticated. This channel was mentioned in the 1691 *urbarium* of the Hodonín estate (MZA F5 kniha 3). Drainage channels are much more frequent but much less robustly built in the study area. They served to drain the many small waterlogged areas in the Wood. Smaller channels led their water either into the fishpond channel or into the woodbanks, which were adapted to this new function. Drainage channels can be dated to the end of the nineteenth and beginning of the twentieth centuries. The 1925 Forest Management Plan (MZA F 263 kniha 1) contains detailed information on the construction and maintenance of drainage channels. In the period 1907–1924, in the whole of Dúbrava Wood, 1767 metres of new channels were constructed and 720 m of existing channels were renovated. This means that on average 104 m of new channels were dug every year; therefore, if all existing channels were renovated between 1907 and 1924 (which is unlikely), then drainage channel construction started in 1900 at the latest. Similar drainage works are known from written sources around the neighbouring villages of Dubňany in 1805–1855 (MZA F5 karton 28 inv.č. 909) and Lužice in 1901–1910 (MZA F5 karton 28 inv.č. 910). The end of channel construction and the abandonment of drainage operations can be roughly dated to the second half of the twentieth century. Post-WWII sources made no mention of channels, and conifer plantations always disregarded and ruined drainage channels. Currently no functional drainage channel exists in Dúbrava.

Each palaeoecological site (MS3, MS4 and MS15) was drained by drainage channels. MS4 and MS15 lay along the same channel, while MS3 had its own channel. In addition, the unidentified channel (category 1) ran in the close vicinity of site MS3. Other than these channels, the sites have no other water outlets.

## Discussion

### Trends, fluctuations and changes

Long-term development at the sites, as inferred from the species composition of plant remains, showed common



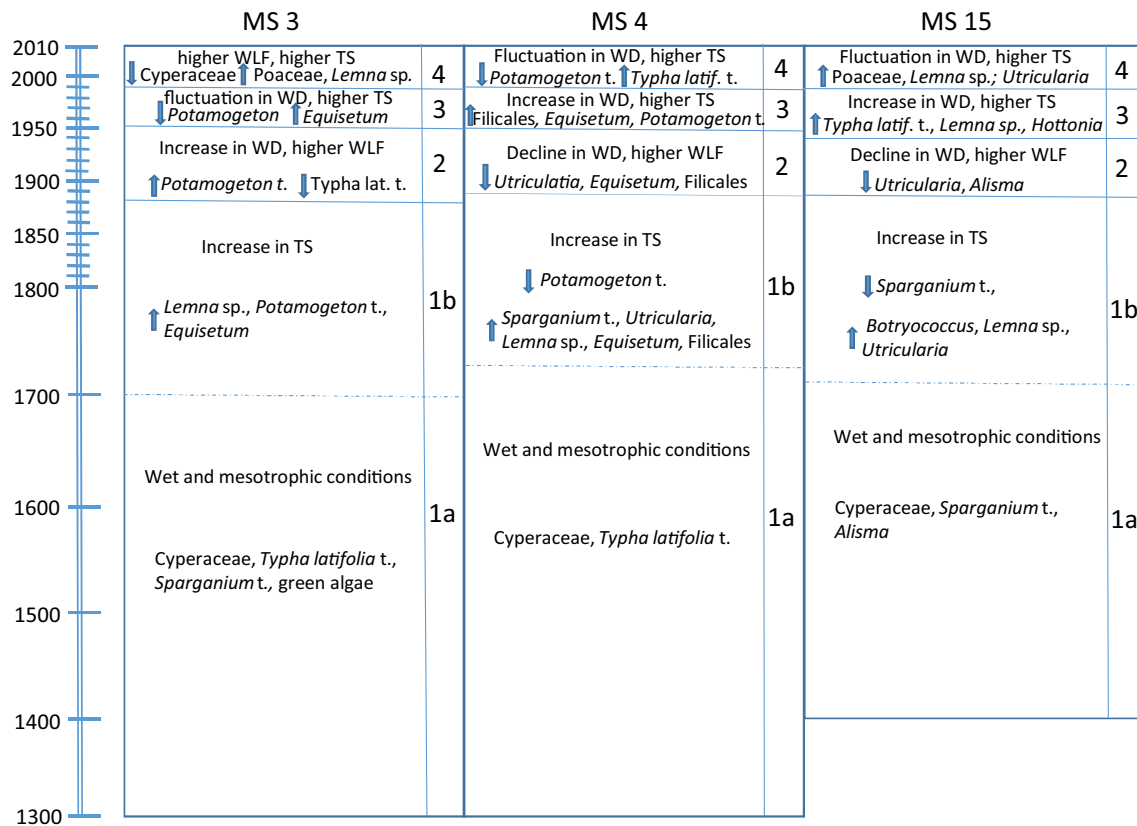
**Fig. 6** Redundancy analysis (RDA) diagrams showing variation in species composition over 700 years in macrofossils in the three analysed cores. Species indicator values are passively projected.

trends as well as local differences. The only universal trend, observed in each profile in both macrofossils and pollen, was eutrophication. In addition, the sites received progressively less light and water got shallower with increasing fluctuations. However, at some sites these trends were not very pronounced and exceptions existed: for

Temporal development was statistically significant at  $p = 0.05$  in all cases. For full species names, see Online Resource 5

example, water level fluctuation decreased with time at MS3 or water depth showed a neutral trend at MS4. Overall, MS4 had a different development from the other two sites, especially with regard to insolation.

Short-term events influenced the study sites mainly from the second half of the nineteenth century. Especially



**Fig. 7** Comparative table summarizing the development of local mire vegetation of all three profiles (MS3, MS4 and MS15) based on pollen analysis

remarkable are short-term changes in water depth. At MS4 and MS15, water depth suddenly decreased at the end of the nineteenth century, while the same happened at MS3 approximately half a century later. This is consistent with drainage history. Drainage channels around the sites were dug from the second half of the nineteenth century and we also reconstructed that MS4 and MS15 had lain along the same channel. This indicates that the channel draining MS4 and MS15 was constructed some time towards the end of the nineteenth century, while the channel at MS3 a few decades later. Drainage led to a drop in water level, to which plants were quick to react. When drainage channels were abandoned in the later part of the twentieth century, water depth bounced back towards previous values. It is also worth noting that the unidentified channel along MS3 cannot be connected to any single event.

A remarkably similar change in sedimentology occurred at all three sites in the 1960s–1970s. The transition from sandy (or somewhat clayey, MS15) sediments to a layer of organic material might have reflected environmental processes. Litter mineralization could be impeded during a period of increased soil wetness, or dead biomass accumulation could be connected to decreasing management activities. Neither explanation is very likely for the study

sites. Water depth decreased throughout the entire period (Fig. 2), and no significant changes in management are known from the 1960s and 1970s. More probably, the observed change in soil profiles can be interpreted as a result of pedogenesis (Brady and Weil 2008). The upper 10–12 cm represents the topsoil horizon of humus formation and fresh material from litter continues to contribute to further formation of this organic layer. At the same time, the bottom part of the organic layer gradually mineralizes, and the amount of sand increases.

### Ecological succession and human influence

The observed processes, mainly the trends inferred from the analysis of species indicator values, can be ecologically interpreted as succession from open water pools to closed vegetation dominated by tall grasses, shrubs, and eventually trees. Eutrophication is usually visible in the vegetation with some delay; hence, clear indicators of eutrophication such as *Lemna gibba* or *Carex riparia* appeared or strongly increased only in about the 1930s. Succession includes various mechanisms of species interactions, and unless some form of natural disturbance, such as floods or fire occurs, succession is usually understood as

a gradual process (Glenn-Lewin et al. 1992). Wetlands, despite their marked interannual variation, show relatively slow development, and their succession may last for millennia (Magyari et al. 2001; Lamentowicz et al. 2007). Several abrupt changes in species composition at our study site therefore suggest the existence of an external factor, likely a management impact, which can be supported by archival and landscape archaeological data. Drainage in the second half of the nineteenth century contributed to substrate desiccation and probably enhanced the succession process.

However, drainage was probably not the only human influence. The studied wetlands are embedded in a regularly managed forest in the vicinity of human settlements. Several types of biomass removal (e.g. wood cutting or haymaking) almost certainly occurred directly at the site. Species, such as *Carex* spp., *Typha* sp., *Juncus effusus* or *Phragmites australis* were cut as forage, animal bedding, or material for producing objects of domestic use. However, archival data provide solid evidence that forest clearing did not occur in the study period. Another potential disturbance, grazing by domestic animals, was practised in Dúbrava Wood, but not at the sampled sites (Szabó and Hédl 2013). We may assume that the complex development of the studied wetlands over the past 700 years combined both natural succession (detectable as trends in environmental conditions) and human impact. The latter included systematic factors like drainage and more or less random events connected to the usage of natural resources, mainly biomass.

### Potential sources of bias

The interpretation of observed results can be biased by the nature of fossil samples. The three major sources of possible error are taphonomy, sample frequency resulting from unequal sedimentation rate, and the sensitivity of indicator values to real environmental processes. Taphonomy influences the quality of the fossil record. Younger sediment layers are usually better preserved than older ones (Gifford 1981; Fernández-Jalvo et al. 2011), and many species may not be preserved in the fossil record at all. It is virtually impossible to separate this effect from the process of ecological succession, which involves gradual saturation by species (Clements 1916; Prach and Walker 2011). Therefore, the positive correlation of most species with time (see the results of ordination analyses) may be the result of better preservation of plant remains in younger layers. This taphonomic effect may be behind the apparent change in the macrofossil record with the change in sedimentation in the 1960s and 1970s.

This assumed taphonomic effect, however, may also have resulted from differential sampling frequency. This can be

demonstrated by the prevalence of short-term events in the past 150 years. Sampling at regular distances (see “Materials and methods”) resulted in relatively more frequent data from recent layers. Therefore, the moving average tended to show more fluctuation than for earlier periods. At MS15, for example, a larger number of samples for the past ca. 400 years resulted in the apparent signal of more short-term events especially for water depth and water level fluctuation. The number of samples we could use mostly depended on accumulation processes at the individual sites. At MS3 and MS4, sediments accumulated very slowly at the beginning (7–8 cm in half a millennium), followed by rapid accumulation (25 cm in 150 years). Because profiles were sampled evenly, fewer samples fell to the pre-nineteenth-century period. Sampling at higher resolution for earlier periods would have been difficult, because the sediment was sandy and not too compact. By contrast, at MS15 accumulation progressed at a more steady rate from the beginning the seventeenth century. It should also be noted that the sediments were relatively poor in macrofossils; therefore, increased sampling resolution is unlikely to have led to more detailed information. Rather small amounts of macrofossils in terms of plant species number as well as the number of seeds, oospores, etc. were indicated by other authors in various types of lakes throughout Europe (e.g. Bennike 2000; Pokorný and Jankovská 2000; Davidson et al. 2005; Wohlfarth et al. 2006). Some of the profiles presented in literature showed macrofossil assemblages similar to our profiles in Dúbrava Wood, especially with regard to the overall decrease in macrofossils with the increasing age of the layer (Bennike 2000; Pokorný and Jankovská 2000; Rasmussen and Anderson 2005; Davidson et al. 2005). However, other profiles exhibited opposite or mixed patterns, i.e. older layers were richer in macrofossils than younger ones (Wohlfarth et al. 2006; Stankevica et al. 2015) or layers without macrofossils alternated with the layers rich in macrofossils (Väliiranta 2006; Wohlfarth et al. 2006). The interpretations of the absence of macrofossils of aquatic and wetland plants have been highly varied, but they usually referred to abiotic and/or biotic factors at the site which could restrict macrophyte development, e.g. water depth (Davidson et al. 2005), lake drainage (Wohlfarth et al. 2006), low temperatures (Bennike 2000; Väliiranta 2006; Wohlfarth et al. 2006; Stankevica et al. 2015), high water turbidity related to algal bloom or sediment suspended in water (Rasmussen and Anderson 2005) and water chemistry (Bennike 2000; Väliiranta 2006; Stankevica et al. 2015). In some cases, the biological characteristics of individual species were also considered, e.g. limited production of seeds by some species or dispersal-based seed accumulations (Davidson et al. 2005). Somewhat surprisingly, few studies dealt with taphonomy-related issues (e.g. Thompson et al. 1993).

Finally, indication sensitivity may considerably differ among plant species (Lacoul and Freedman 2006). In

general, any species can give us environmental information in a certain context. Our estimates show that several of the analysed wetland species have relatively broad ecological optima (Online Resource 4). However, most species exhibit broad ecological optima related to some of the factors but narrow optima (i.e. higher indication sensitivity) in relation to other factors. Sediment samples containing few macrofossils the majority of which belong to species with lower indication sensitivity can be especially challenging. In such cases, several studies recommended a multi-proxy approach (Bennike 2000; Davidson et al. 2005; Wohlfarth et al. 2006; Lamentowicz et al. 2007; Stankevica et al. 2015). In this light, macrofossils and pollen in our study should be understood as complementary rather than mutually exclusive.

### Possible effects of climate

Variation in climate, especially precipitation, could also have played its role in site development. There are several hydrometeorological reconstructions available for the past 500 years for the entire Czech Republic as well as southern Moravia based on various proxies including archival documents and tree rings (Brázdil et al. 2002, 2012; Büntgen et al. 2011). Dobrovolný et al. (2015) concluded that these reconstructions demonstrated marked yearly and decadal variability in precipitation but did not indicate long-term trends. They could then be useful mostly in the interpretation of short-term changes visible in macrofossil analyses. In the following, we concentrate on possible connections between climate and discrete events at our sites in the nineteenth–twentieth centuries, when the most important changes in the fossil material were observed. As far as water depth is concerned, annual total precipitation data (Dobrovolný et al. 2015) and WD since ca. 1850 at our study sites showed a similar development. After a marked decline, precipitation totals steadily increased between ca. 1880 and 1950 [although this trend is not apparent either in seasonal total precipitation data or in southern Moravian draught series (Büntgen et al. 2011)]. At MS4 and MS15, water depth also increased in the first half of the twentieth century, which we interpreted to have resulted from the abandonment of drainage. While increased precipitation is unlikely to have raised the elevation of the water surface with drainage channels in place, more rain could complement the effects of channel abandonment. Hydrometeorological events could also influence water level fluctuations. Brázdil et al. (2012) noted a peak in extreme events (including floods and torrential rains) from 1821 to 1850 in a region immediately next to our study site. These seem not to have had an impact on water level fluctuation in Dúbrava. This may be due to the fact that Dúbrava lies (by local standards) considerably higher than the floodplain of

the Morava and not even large floods (such as the one in 1997: Hrádek (1999)) reach the forest itself.

### Conclusions

Drainage history can explain the sudden changes observed in water depth in Dúbrava Wood. Contrary to expectations, variability in precipitation seems not to have affected the sites much, where stability or slow, long-term and unidirectional changes were characteristic until the late nineteenth century. However, in the critical period of the late nineteenth century, there are some aspects of precipitation history that make it difficult to separate anthropogenic influences from climatic impacts. On the whole, long-term trends and discrete events were complementary on different scales. With some precaution, we may conclude that humans facilitated and accelerated assumed “background” processes, which can be most likely associated with the succession of open wetlands towards terrestrial ecosystems (forests).

**Acknowledgments** We would like to thank Petr Dobrovolný for his help with climatic data. The research leading to these results has received funding from the European Research Council under the European Union’s Seventh Framework Programme (FP7/2007-2013)/ERC Grant Agreement No 278065, from the Grant Agency of the Czech Academy of Sciences (Project No. IAA600050812), from the Czech Science Foundation (Centre of Excellence PLADIAS, 14-36079G), and from long-term research development Project No. RVO 67985939.

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## Traditional Woodland Management, Forest Legislation, and Modern Nature Conservation in East-Central Europe

Péter Szabó

[There is a wood called] Scheyben, which was at the time [of the survey] six years old. When it reaches seven years, it is estimated to be worth twenty marks.

—Extract from the rent-roll (*urbarium*) of the Mikulov estate from 1414

These woods, since there is in them a good growth of underwood and standards for building, can be utilized by wood-sales every year without causing damage for c. 20 florins.

—Extract from the rent-roll of Maršovice from 1651

The origins of the coppices that belong to Dobrau may be exclusively attributed to the faulty management of broadleaved forests.

—Extract from the forest management plan of Dúbrava Wood from 1864

Planned cutting in forest stands younger than eighty years is forbidden.

—Paragraph 33.4 of the Forest Law of the Czech Republic, 1995

[A] change of the current policy of growing high forest towards re-establishment of active coppicing . . . is a solution supported by both economic and conservation considerations.

—Comment by Beneš et al. in a 2006 paper on butterfly conservation in Milovice Wood

Although they concern different locations and therefore caution is needed when connecting them, the five quotations above express the main message of this chapter. They describe a full circle from medieval and early modern practices in woodland management through their rejection in the nineteenth and twentieth centuries to rediscovery and rehabilitation in recent times.<sup>1</sup> However, I do not simply argue that there is nothing new under the sun. The motivations behind the actions of those who produced these sentences were obviously not the same. Nor can we create a unified story for all places and all woodland management types. In this chapter, I will describe in some detail three management types (coppicing, wood-pasturing, and litter raking) and their contested and entangled histories in the past seven centuries in east-central Europe.

This chapter mainly concerns the territory of what is now the Czech Republic. This area contains three geographical–political units, together loosely referred to as the “Czech Lands.” Bohemia in the west and Moravia in the east formed, for most of their history, stable parts of the Czech kingdom and shared a ruler. The history of Silesia in the northeast was more checkered, and currently most of Silesia belongs to Poland. Most of my examples will come from Moravia.<sup>2</sup> Together with a handful of other areas in the region, in the sixteenth century, the Czech Lands became part of the Habsburg Monarchy and remained there until the formation of Czechoslovakia in the early twentieth century. The larger region where the Czech Lands are situated is sometimes referred to as east-central Europe. The term, which is political rather than spatial, refers to today’s Poland, western Ukraine, Slovakia, Czech Republic, Hungary, and western Romania. “East-central” implies certain transitional characteristics in the historical development of the region between the Orthodox East and the (often idealized and simplified) West.<sup>3</sup> Allowing for some broad generalizations that mask much variety in local developments, the region was transformed based on the western model in the thirteenth century and subsequently somewhat diverted from that model in the Early Modern Period (sixteenth to eighteenth centuries).<sup>4</sup> I will use some examples from Hungary as instructive parallels to developments in the Czech Lands, whereas I will rely much less on Polish material.

## Traditional Woodland Management

The general features of traditional woodland management have been described many times, including in this book.<sup>5</sup> The term itself was coined and is usually used to contrast with modern (“scientific”) forestry. There are three important features that distinguish traditional woodland management from modern forestry, which became the dominant force in European woodland management in the nineteenth century. First, as opposed to the heavy use of plantations in modern forestry, traditional management relied almost exclusively on the self-renewing capacity of trees. Although references to sowing seeds of trees in forests can be found in premodern documents, these were negligible oddities in a system that used the generative and vegetative abilities of trees to grow again after felling. Peasants in medieval and early modern east-central Europe were well-aware of what modern ecologists call “succession”: that in most circumstances in temperate Europe, a piece of land, if left alone, grows into a forest in time.<sup>6</sup> Perhaps the most succinct expression of this is the Hungarian word for “forest” (*erdő*), which, etymologically, can be loosely translated as “the thing that grows by itself.”<sup>7</sup>

Second, traditional management was driven by the “smallest tree that will do the job” principle.<sup>8</sup> Lacking power tools to move and chop up large trees, people strove to use the smallest piece of wood that was suitable for a given purpose. Anything larger was considered to lead to a waste of human energy, which people sought to avoid.<sup>9</sup> The 1414 rent-roll of the Mikulov estate, quoted at the beginning of this chapter, referred to woods older than the normal seven-year cutting cycle as overgrown and difficult to sell. Firewood was made of small underwood, and timber for the building of houses or fortresses was unusually small to the modern eye. Trees larger than around 30 cm in diameter tended to be used only in exceptional situations and in major constructions.

Third, traditional management relied on multiple uses of the same piece of woodland. The best-known example of this is wood-pasture, which combined animal grazing with wood production. Much less appreciated is the fact that even intensive coppice systems often included other types of uses. For example, late seventeenth and early eighteenth century woodland management instructions (*Waldordnungen*) for the Mikulov estate prescribed that grazing animals could be allowed into



coppices three years after cutting and that grass cutting was not allowed for four or five years.<sup>10</sup> With a coppice cycle of roughly thirteen years in this period,<sup>11</sup> any given part of the local coppice woods was under multiple-use for approximately two thirds of the time.

## **Practice**

The methods of traditional woodland management are many. Some have received more attention, especially those involving tree cutting. Broadleaved trees were usually coppiced (i.e., cut on a short rotation—seven to twenty-five years) to produce firewood. Building timber was grown in the form of standards: straight trees from seed that were allowed to grow through several coppice cycles. Archaeological evidence shows that coppice underwood was not selective as to species.<sup>12</sup> By contrast, in many parts of Europe, oak was promoted as a standard tree because of its superior qualities in building.<sup>13</sup> Coniferous trees do not grow from stumps and are therefore unsuitable for coppice management. Their traditional management is much less known, and is usually described within the framework of selective cutting.<sup>14</sup> In any case, in east-central Europe, woods were usually more copious at higher elevations, and therefore their management was arguably less intensive than that of sparse broadleaved forests in the lowlands.

The other prominent method of traditional woodland management is wood-pasture. This has created or maintained many iconic European landscapes from Windsor Great Park to Mediterranean savannas, and therefore it drew much research attention.<sup>15</sup> Local versions include, for example, the combination of hay meadows and trees in Scandinavia.<sup>16</sup> Much less attention was paid to other uses, especially to those that did not involve tree cutting. This partly stems from the fact that modern forestry (and therefore forestry historians) relegated these other methods of woodland management to “minor” uses. However, significance is a question of viewpoint. Recent research shows that such “minor” uses could be ubiquitous with considerable consequences.<sup>17</sup> Frequent litter raking (the removal of leaves from broadleaved and coniferous forests to be used as bedding for farm animals and subsequently as fertilizer) was argued to remove as much biomass from forests as tree cutting itself.<sup>18</sup> Bürgi and Gimmi rightly pointed out that the ecologically most significant management forms may not always be those best visible in historical sources.<sup>19</sup>

As in other parts of Europe, people in medieval and early modern east-central Europe realized that they needed to manage their natural resources so that they would be “maintained in good condition.” For example, woods around Ostřetín (eastern Bohemia) were described at the end of the fifteenth century as follows: “From these woods firewood can be sold each year for 600 groš without overcutting them. The pine stands that are here are banned so that they are not sold but preserved for [future] needs.”<sup>20</sup> This was a utilitarian view that treated woods similarly to other natural resources, such as meadows or fishponds. Nonetheless, it was based on remarkable foresight. By looking to “[future] needs,” the overlord of the Pardubice estate embraced a long-time perspective. It takes thirty to fifty years for a pine to reach timber-size—in other words, whoever created this woodland management regime was rather unlikely to see these pines cut down. That, however, was beside the point. Rather, plans were made so that the estate as a whole manages its woodland resources in a sustainable manner. It was easy to plan for a short coppice cycle, at least time-wise. Spatial organization was more of a challenge: the same document described the sequence in which individual woods that belonged to the castle of Pardubice were to be harvested on a nine-year rotation, showing that preference was given to larger areas to be cut at once rather than subdividing each wood into nine parts.<sup>21</sup> Parallel to this short-rotation and spatially sophisticated system, the estate (which included dozens of villages) needed to maintain a sufficient cohort of timber trees. Building activity was different from heating and cooking in the sense that it was intermittent and largely unpredictable. For example, after a village fire, many timber trees were needed at once. On the Mikulov estate, 616 standards were cut down in the winter of 1684–85 to help the inhabitants of Sedlec rebuild their settlement that had burnt down.<sup>22</sup> Because there were only a few thousand standards on the entire estate, this represented a significant proportion of the available resources. The aim of estate managers was to have the largest number of building timbers available at any given point without compromising coppice regrowth. Nonetheless, the “smallest tree” principle was applied to timber as well; therefore, standards that reached a certain age were harvested and sold. For example, some seven hundred standard trees were sold on the market on the Choustník estate (southern Bohemia) in 1447.<sup>23</sup>

Wood-pasture and other non-timber uses were organized along similarly sustainable lines. Care was taken not to overexploit forest resources, but this was understood not as a reference to some ideal

state but keeping the needs of the local community in mind. For example, in Dúbrava Wood, two detailed rent-rolls described wood-pasture management in the seventeenth century.<sup>24</sup> The system was rather sophisticated. It regulated the exact areas where each neighboring settlement had access rights. Smaller sections of these wooded areas were prescribed for specific animals (cows, cattle, goats, pigs, etc.) as well as for hay cutting. A clear distinction was made between all-year grazing and pannage (letting pigs in the wood to devour the occasional good crop of oak acorns).<sup>25</sup> At the same time, local woodland managers also had to make sure grazing animals did not get into freshly cut coppice areas. Lastly, the documents also contained information on whether or not payment was due for each use. The resulting landscape was a combination of coppices and wood-pastures with large and spreading trees in grassland.<sup>26</sup> A similar management regime was noted down in the oak woods around Litovel in central Moravia: wood cutting (coppice and standards), hay cutting (on woodland meadows and among trees), pannage, and pasture (of horses and cows) were all combined in a single forest.<sup>27</sup> In another example from the region, Samojlik and colleagues mapped traditional uses from the first to the eighteenth centuries in Białowieża forest (Poland), where the system was similar but apparently (partly because of the sheer size of the forest) less intensive.<sup>28</sup>

Normative sources described woodland management along similar lines. Apparently there was very little effort to enforce top-down regulation different from what was already happening on the ground. Normative sources differed in their spatial scale but were similar in that each one concerned the forests in the possession of a single overlord. The first efforts at centrally regulating all forests in the region originated in the eighteenth century.<sup>29</sup> Information on forests either was included in general instructions on the management of particular estates or formed separate “forest instructions.” The latter were compiled in larger numbers from the sixteenth century onward.<sup>30</sup> Royal regulations, among which the *Majestas Carolina* (ca. 1350) and sixteenth-century instructions to the “highest hunter of the Czech kingdom” (i.e., the highest forest official) are best known, did the same but pertained to woodland on royal estates.<sup>31</sup> The Habsburg rulers issued similar documents in this period in neighboring Hungary as well.<sup>32</sup> The contents of all these documents were rather similar, although attention to detail greatly varied. They almost always contained three elements. First, they emphasized the need for controlled cutting that had to be evidenced; the woodlot to be harvested had to be determined by local foresters and paid for in

advance; all other wood-cutting activities were banned; and foresters were obliged to record the transaction in an account book. There are plenty of examples for such detailed account books, especially from the seventeenth century onwards. While all this did not present any novelty as far as tree cutting was concerned, it represented an aim to introduce complete control over what was cut down. Second, the wood harvested had to be removed from forests within a limited amount of time, by the beginning of spring at the latest.<sup>33</sup> This was intended to facilitate regrowth. Third, and with a similar purpose, animal grazing was banned in freshly cut areas for a number of years.<sup>34</sup> Two more points were frequently, but not always, included in such instructions: the warning not to cause forests fires and the right of locals to gather dry and windthrown wood for their own use.

Some documents contain remarkable insights into management techniques. For example, the general instructions of the Duchy of Frýdlant (1628) include a passage ordering foresters to always cut at the edges of forests because cutting in the middle of a stand made it more susceptible to windthrow.<sup>35</sup> *Why* woods should be managed in this way was rarely deemed worthy of explanation. Similarly to economic documents, normative sources sometimes mention a wish to “avoid damage,” and occasional references of “favor to the people” can also be found.<sup>36</sup> A prominent document in which such a utilitarian perspective was not the only one is the above-mentioned *Majestas Carolina*, a failed attempt to codify Czech law by Emperor Charles IV (d. 1378). This included several sentences about the beauty of Czech forests, which was a source of admiration, and connected this to their preservation.<sup>37</sup>

## Rejection

The eighteenth and, especially, the nineteenth centuries brought significant changes not so much in immediate management as in attitudes. Mainly governed by central authorities representing the modern state (in east-central Europe enlightened absolutism), the traditional system of woodland management was no longer deemed adequate and was suppressed by various means. The story is well-known, and it is not my aim to retell it here.<sup>38</sup> However, I would like to point out that realities on the ground could and often did differ from textbook examples. Coppicing was accepted as a normal management practice throughout the eighteenth century. In contrast, nineteenth-century foresters

often snubbed it. However, where firewood was needed, and timber, especially coniferous timber, was unlikely to grow well, foresters were happy to continue with coppicing until the mid-twentieth century. The managers of the Mikulov estate woodlands noted in 1905: "the market for firewood is satisfactory, although it decreased in the past years with increasing coal consumption. However, it will still take a long while to bring all the necessary quantity [of coal]." <sup>39</sup> As a result, coppice management continued well into the twentieth century until it was abandoned in the 1920s–1940s. <sup>40</sup> This was typical for large parts of northwestern Europe. In Dúbrava Wood, the process was more peculiar. The system described above in connection with wood-pasture went through major changes in the late eighteenth century. <sup>41</sup> Woodland and pasture were separated, and coppicing, which had played only a lesser role in the previous regime, was enforced as the exclusive management of wooded areas. In effect, most former wood-pastures were transformed into coppices on thousands of hectares. Arguably because of site conditions, the attempt failed to bring the required results, or so those foresters that oversaw Dúbrava Wood in the mid-nineteenth century argued and whose dry remark on mismanagement I quoted at the beginning of this chapter. However, it took another century for the amount of high forests to overtake that of coppices. Notwithstanding the opinion of local forest managers, the area of coppices showed no decline until the 1930s. This was reflected in legislation as well: the 1928 Czechoslovak forest law still included twenty-year coppice cycles, and the 1960 forest law prescribed the transformation of coppices into high forests rather than banning coppice management as such.

Wood-pasture has had a worse press than coppicing in forestry history; but in fact, it was not more readily or generally rejected by most forest managers. As examples above showed, there was much awareness of the detrimental effects of grazing on young shoots in coppices already in early periods. Quite logically, when greater efforts were made to maintain only one use for each piece of land and also with greater emphasis on wood production, the presence of animals was seen as increasingly harmful. There was a seamless transition from the prohibition of grazing animals in freshly cut areas into encouraging their complete removal from forests: the argumentation did not have to change. For example, the forest code of 1754 for the Czech kingdom, issued by Empress Maria Theresa (d. 1780), acknowledged that a complete grazing ban in forests would be desirable but too onerous, especially for lesser woodland owners, and suggested letting animals



into one half of every forest while leaving the other half free of grazing in a spatially dynamic system.<sup>42</sup> The 1769 forest code for Hungary already aimed to introduce a blanket ban and suggested that woodland owners plant willows and poplars outside forests to be used as wood-pasture.<sup>43</sup> Nonetheless, the 1852 forest law of the Habsburg Monarchy took woodland grazing for granted and only aimed at keeping it within reasonable limits. In Czechoslovakia, it was only the 1960 forest law (the first comprehensive legislation since 1852) that completely banned grazing in all forests. Basically the same story can be told in Hungary, where a blanket ban came into effect with the 1961 forest law.<sup>44</sup>

Litter raking featured much less in twentieth-century forestry history than woodland grazing. This is in sharp contrast to the attention that foresters in the nineteenth century devoted to it. For example, in the 1850s and 1860s there was a lively debate in the journal of Bohemian foresters (*Vereinsschrift für Forst-, Jagd- und Naturkunde*) about what was called the “forest-litter question” (*Waldstreu-Frage*). The opening piece readily acknowledged that litter raking was a widespread practice and tried to point out its negative effects on the soil.<sup>45</sup> Some fifteen pieces by various authors followed. Their main focus was calculating the economic value of litter raking and juxtaposing this with economic loss through reduced tree growth. One Franz Kreß even conducted a twelve-year experiment in which he recorded the amount of litter raked and tree increment in a pinewood.<sup>46</sup> Other pieces dealt with the effects of raking on the chemical properties of the soil. Similar articles appeared in the journal of Moravian foresters as well.<sup>47</sup> The issue made it to the highest circles of forestry education. Sometime between 1864 and 1888, Anton Urbanek wrote his essay for the state forest examination (the examination necessary to be employed as a forester) on litter raking.<sup>48</sup> Basically all authors agreed that litter raking was bad for tree-growth and proposed to limit it. However, similarly to grazing, litter raking was still widely practiced in the first half of the twentieth century. A summary paper on grazing and litter raking in Czechoslovakia in 1948 basically repeated the claims and arguments that had been heard for a century adding only that both uses were now mainly practiced in smaller woodlands outside state ownership.<sup>49</sup> Once again it was the 1960 forest law that codified the complete ban of litter raking in forests.

The combination of pressure from official forestry, the substitution of forest products with alternative sources of energy, and restrictive legislation finally pushed traditional woodland management into sharp

decline in the mid-twentieth century. In 1930, there were still more than 130,000 hectares of coppices in the Czech parts of Czechoslovakia. This went down to around 103,000 hectares in the 1940s, 78,000 hectares in 1950, and 30,000 hectares in 1980.<sup>50</sup> Similar stories can be told for wood-pasture and litter raking in the Czech Lands as well as in neighboring countries. By the end of the twentieth century, traditional management practices all but disappeared from east-central European forests, lingering on only in more remote areas.<sup>51</sup>

## Rediscovery

In the 1960s, coppicing was rediscovered by a small group of British woodland ecologists. Their motivation was quite clearly rooted in nature conservation (in the modern sense). Coppice woods came to be valued because they harbored a large diversity of often rare plants. Because many of these plants are light-demanding, it quickly became clear that their continued presence was dependent on management. Since then, countless studies in inactive coppices all over Europe demonstrated that the closing in of the tree canopy through succession after the abandonment of management was detrimental to these plants. Logically, then, ecologists proposed the reintroduction of coppicing simply to save populations of rare plants. One of the first such sites was Hayley Wood in Essex, England.<sup>52</sup> In a reversal of the logical relationship between history and ecology, in many European regions, ecologists started to compile lists of “ancient woodland indicator” plants (i.e., those plants that tend to grow in woodlands with a habitat continuity on a centennial scale).<sup>53</sup> Together with Hooper’s hedge dating rule,<sup>54</sup> this was arguably the first time ever that purely ecological data (species distribution) became historical data (indicator of land-cover continuity). In the following decades, more types of organisms were added to the list. Some woodlands (such as Wolves Wood in Suffolk, England) are managed in the interest of bird protection. Several types of insects, notably butterflies, were shown to be strongly dependent on active coppicing.<sup>55</sup> Keeping in mind the initial strong resistance of foresters to coppice reintroduction, in a somewhat unexpected turn of events, foresters have recently embraced coppicing and have put considerable effort into mapping its economic potential. One of their motivations was the growing need for renewable energy sources. It now appears that coppicing can make economic as well as conservation sense.<sup>56</sup>

Wood-pasture had a somewhat different story. While grazing in woodlands was, as we have seen above, very much against the ideals of enlightened land managers, the resulting park-like landscapes were among the first to be appreciated for aesthetic values in aristocratic circles. Freestanding trees (usually but not exclusively of wood-pasture origin) were often incorporated into landscaped parks. A further aristocratic tradition that could create and maintain wood-pasture was hunting, in which semiwild rather than domestic animals kept the stands open.<sup>57</sup> That said, existing research suggests that the value of wood-pastures for modern nature conservation was realized later than that of coppice woods: in the 1990s in England and even later in the rest of Europe.<sup>58</sup> Early and much of later research centered on invertebrates: wood-pastures harbor the vast majority of very old trees in Europe, which are crucial for many of these creatures.<sup>59</sup> Perhaps because of this relatively late start, wood-pasture is perhaps the most prolific topic currently among traditional management types in the context of nature protection. As opposed to other types, the social aspects of wood-pasture are also intensively researched.<sup>60</sup> Because, especially in east-central Europe, wood-pasture is still a living practice, anthropological studies have tried to gather and analyze this knowledge for the purposes of nature conservation.<sup>61</sup> As far as legislation is concerned, wood-pasture is in a difficult position. Being a transitory category between grassland and forest, European legislative systems—which to a large extent take their land management concepts from the Enlightenment—find it difficult to deal with and therefore legally protect wood-pasture.

Litter raking has lagged behind coppicing and wood-pasture in being recognized as a possibly valuable contributor to nature conservation. The first review describing previous experiments with litter raking in forest stands came out in 2006, and a year later, Bürgi and Gimmi offered litter collecting as a “new tool for nature conservation” with a question mark at the end.<sup>62</sup> Ongoing experiments are not quite unanimous about the effects of litter raking. Clearly, there is mechanical disturbance and nutrient removal, but whether this is advantageous for rare plants that prefer poorer soils remains to be seen.<sup>63</sup> Further types of traditional nontimber forest uses (such as hay cutting or traditional bee keeping) are very little researched from the perspective of contemporary nature conservation. These examples show that the rediscovery of traditional forest uses is still in progress. One possible conclusion drawn from this process is to interpret traditional uses as interconnected parts of a coherent whole, which brings us back to the third distinguishing feature

of traditional woodland management I described at the beginning of this chapter.

Originally, as I argued above, the motivation of ecologists in proposing the reintroduction of traditional woodland management practices was mainly biological. They were little concerned with traditional ways of living or the cultural value of the accumulated ecological knowledge.<sup>64</sup> This has changed, especially since the 2000s and with research on wooded pastures. Among the aims of historical ecology, one of the disciplines dealing with the historical connections between people and nature is to map and preserve “traditional ecological knowledge,” which is seen as a value in itself.<sup>65</sup> Clearly the motivations of medieval and early modern woodland managers were different, even though similarities can be contextualized within a common framework, as the Introduction to the present volume exemplifies. It is, nonetheless, worth pointing out that choosing not to explain the rationale, as it were, of motivations was not specific to the pre-1700 period. In Latham’s 2015 excellent survey of the development of European forest conservation, “conservation” is contrasted with “protection” and “nature” with practical, aesthetic, cultural, and political reasons for protection. These latter are elaborated on in some detail, but what “nature” is and why it needs to be conserved seems too obvious to be explained.<sup>66</sup> Intriguingly and with direct relevance to the subject matter of the present chapter, Latham explicitly connected what he saw as the current “utilitarian” turn in nature conservation to medieval and early modern attitudes. Indeed, “ecosystem goods and services”—one of the buzz phrases of conservation ecology since the 2000s—have gained considerable momentum and are now central to much conservation research and legislation. The ecosystem goods and services concept is based on the idea that “healthy” ecosystems will provide the most services. Even though the definitions of this “health” would arguably differ between the Middle Ages and the twenty-first century, one can agree with Latham that a parallel can certainly be drawn. It kindles the imagination that the Millennium Ecosystem Assessment should talk about “damage” to ecosystems in a rather similar manner to the Czech rent-roll from 1651 I quoted at the beginning of this chapter.<sup>67</sup>

## Unintended Consequences

The last aspect of the connections between medieval/early modern “conservation” and modern nature conservation is what I call unintended

consequences. The degradationist narrative of the Enlightenment and scientific forestry may be gone, but one of its legacies is still very much with us: human societies are not seen as part of nature (the ecological jargon for human action is “anthropogenic disturbance”). The claim that this should not be so is nothing new. Löwenthal famously called nature and culture “Siamese twins, separated only at high risk of the demise of both.”<sup>68</sup> There is, however, more to this claim than the fact that *Homo sapiens* is just another species. There is growing evidence to show that humans and nature have coevolved with often surprising consequences. “Anthropogenic disturbance” is sometimes the *cause* of biological diversity rather than a nuisance in its way. In some types of ecosystems, this is understood: meadows, for example, have long been recognized as human-made and at the same time valued for their high biodiversity.<sup>69</sup> Woodland, however, perhaps because it is seen as the natural (i.e., human-free) vegetation of most of temperate Europe, was rarely interpreted in this framework. Coppices are obviously a good example of the coevolution, but the phenomenon goes deeper than the presence of light-demanding plants that disappear in lack of management. Entire ecosystems may be driven by human action and result in forest landscapes that are seen as “natural” in modern nature conservation. Perhaps the most sweeping example is the extinction of late Pleistocene megafauna. This obviously caused major changes in subsequent vegetation development in Europe (and elsewhere), and human hunting is one of the possible explanations.<sup>70</sup>

Less grandiose examples can be found in east-central Europe as well. With my colleagues, we conducted several studies in Dúbrava Wood to find out whether the protected oak woods have been, as is usually presumed, dominant at the site since the mid-Holocene. Medieval and early modern documents confirmed this view, but palynological results show a more complicated picture. While open vegetation with considerable amounts of oak has been present at the site for more than seven millennia, the current absolute dominance of oak has a much shorter history. In the fourteenth century, active management was introduced to protect and promote oak. This coincided with a significant increase in oak pollen. Gradually, even the name of the Wood changed. Earlier, it was called *Klečka* (“a place with shrubs”), but during the fourteenth through sixteenth centuries, this name gradually changed into Dúbrava (“oak wood”), arguably as a reflection of vegetation change.<sup>71</sup> Does this make Dúbrava Wood less valuable for nature conservation? The answer is no, but it does turn its interpretative framework around.



Oak seems to be particularly suspect when it comes to coevolution with humans.

My final example comes from Děvín—one of the woods on the Mikulov estate that has featured extensively in this chapter. Here, we found that the establishment of new oak standards simply stopped after management was abandoned in the late 1930s.<sup>72</sup> This probably has to do with light availability, but no straightforward explanation is available. If oaks in the wood are so much dependent on management, how did they get there in the first place, and how did they survive periods without humans? Or did they get into the wood together with people in prehistory, and were there no periods of neglect long enough to make them disappear? Or did they in fact periodically disappear only to reappear when people returned?

As these examples show, some of the consequences of historical human action in forests are very much intended. The medieval managers of Dúbrava Wood wanted to have more oaks in their forests and achieved this aim. However, they would not have dreamt of the vegetation association *Carici fritschii-Quercetum roboris* or Natura 2000 Sites of Community Interest. Through their activities, they still contributed to the emergence of these modern categories. In some senses, they actually created them. Areas of objectivized natural value at many sites did not survive in spite of anthropogenic disturbance; they were rather cocreated by past human societies. At least in long-settled lowland areas, much of what modern nature conservation values according to its own standards can be seen as partially the unintended consequences of past human action.

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## Notes

The writing of this chapter was supported by long-term research development project no. RVO 67985939 and by grant GA17–09283S from the Czech Science Foundation.

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# Coppice reintroduction in the Czech Republic: extent, motivation and obstacles

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Received: 7 September 2022 / Revised: 19 September 2023 / Accepted: 14 October 2023 / Published online: 9 November 2023  
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## Abstract

Coppicing is a form of forest management in European broadleaved forests. While it is still practised in south-eastern Europe, in central and western Europe it was almost completely replaced by high forest management. Currently, there are increasing efforts to reintroduce coppice management into former coppice woods. However, little comprehensive knowledge is available about the extent and management of coppice reintroduction and the processes governing it. In this paper, we present an overview of localities in the Czech Republic where coppice reintroduction was taking place in 2020. We identified 8 localities and conducted 10 semi-structured interviews with experts involved in their management in order to understand what motivated them to restart coppicing and what obstacles they have had to face. The main motivation of site managers is nature conservation, while the most important obstacles are operational issues, such as bureaucracy, complicated land ownership and legal responsibilities or lack of workforce. Other motivating factors identified in other European countries (production of a renewable energy source and potential for rural employment) have so far played a minor role in the Czech Republic. We conclude that a major challenge for future forest policies will be to utilise the economic experiences of regions with active coppicing to foster the spread of coppice woods in order to combine renewable energy production with biodiversity conservation.

**Keywords** Traditional forest management · Central Europe · Nature conservation · Management policy · Economic potential · Semi-structured interviews

## Introduction

Coppicing is a traditional forest management form, which used to be widespread in pre-industrial Europe, especially in the lowlands (Rackham 2003; McGrath et al. 2015; Szabó et al. 2015). It uses the ability of broadleaved trees to resprout after cutting from the stump or the root system.

The coppice stool (the stump on which young shoots grow) becomes permanent and can be cut many times, although some species lose some of their resprouting ability if uncut for longer periods (Matula et al. 2012). The origins of coppicing probably go back to prehistory, although direct evidence for this is rather difficult to produce (Waller et al. 2012; Out 2013). Coppicing was explicitly mentioned for the first time by classical Roman authors. Tree ring evidence suggests that it was common in the first millennium AD (Muigg et al. 2020). From the thirteenth century onwards, there is copious written evidence from many European countries about the technical details and the extent of coppicing. The coppice cycle in the Middle Ages was short (ca. 7 years) and was prolonged to ca. 30 years in the Early Modern Period (Szabó 2022).

Coppicing was gradually abandoned in western and central Europe from the second half of the nineteenth century onwards (Müllerová et al. 2014; Buckley 2020; Kamp 2022). The main reason behind coppice abandonment was the replacement of the main coppice product—fuelwood—by

Communicated by Andrés Bravo-Oviedo.

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cheap and widely available other sources of energy, mainly coal (Sieferle 2001). Many coppices were turned into high forest plantations. Others were 'singled-out', i.e. only the strongest shoot was left to grow on each coppice stool to produce a pseudo-high forest. Still others were abandoned and left with no management either by default or as part of non-intervention nature conservation. It is estimated that some 10–14% of European forests are managed as coppices today with the main strongholds for example in Turkey, Bosnia-Herzegovina, Serbia, Italy or Greece (Unrau et al. 2018; Buckley 2020). It needs to be noted, however, that many existing European coppice woods are not survivors of traditional management but plantations of fast-growing non-native tree species, for example of black locust (*Robinia pseudoacacia*, native in North America) in Hungary (Vítková et al. 2017).

In countries where traditional coppicing has become very rare, there have been attempts at its reintroduction since the second half of the twentieth century. Among the first known cases was the gradual recutting of Hayley Wood in England, which started in 1964 (Rackham 1975). Other examples are the area in the Salzgitter Höhenzug mountains in Germany, re-coppiced since 1986 (Strubelt et al. 2019), or a failed attempt after 1999 in Krumlov Wood, the first case of (experimental) coppicing reintroduction in the Czech Republic (Utinek 2004; Vild et al. 2013). Currently, coppicing is being restored at many locations in Europe, for example, in Belgium (Vandekerckhove et al. 2016), the Czech Republic (Štochlová and Hédli 2018), Germany (Ewald et al. 2018), Italy (Coppini and Hermanin 2007) or the Netherlands (Jansen and Kuiper 2004). Remarkably, similar processes of abandonment and revival of coppicing have been observed in Japan (Kuroda et al. 2012).

According to the majority of studies, coppice restoration has beneficial effects for many taxonomic groups constituting forest biodiversity, including ground herbs, butterflies, spiders and birds (Buckley and Mills 2015, Hédli et al. 2017, Fartmann et al. 2013, Fuller 1992, Hamřík et al. 2023; but see also Hambler and Speight 1995). The general idea behind conservation-based coppice restoration is that these forests have been influenced by humans for so long that their ecosystems have become dependent on coppicing. After coppicing had been abandoned, ecological succession resulted in darker, biotically homogenised forests (Van Calster et al. 2007; Hédli et al. 2010; Kopecký et al. 2013). Coupled especially with atmospheric nitrogen deposition (e.g. Dirnböck et al. 2014), this led to considerable biodiversity decline (Kirby et al. 2017), and consequently the future significance of coppice reintroduction for biodiversity maintenance is in little doubt. However, despite considerable efforts to map the current extent and state of European coppice woods (Unrau et al. 2018), detailed and comprehensive information on coppice reintroduction sites, key actors and processual patterns

is not available in any European country except for a low-resolution map for Germany by Kamp (2022). As a result, little is known about the motivation of those who initiate and manage the renewal of this traditional forest management form and about the challenges they face. Lack of information makes it difficult to develop effective policies to foster coppice reintroduction on local, regional, national and continental levels in Europe.

This paper aims to provide an overview of the current state of coppice reintroduction efforts in the Czech Republic. Our goals are (i) to create an overview of coppice reintroduction localities in the country, and (ii) with the help of qualitative data analysis, to understand what motivated site managers to start with coppicing and what obstacles they have had to face so far. Interpreting the results in a European context aims to foster future comparative research efforts, potentially leading to better-informed policies for coppice reintroduction within and outside the Czech Republic.

## Materials and methods

### Study region

The Czech Republic covers 78,870 km<sup>2</sup> with 10.9 million inhabitants in central Europe. The western part of the country (Bohemia) is surrounded by low mountains (highest peak at 1603 m a.s.l.), while the eastern part (Moravia and Czech Silesia) is more open to the north-east and south. Climate is temperate transitional between oceanic and continental (mostly Dfb according to the Köppen classification). Mean annual temperature varies from 5 to 10 °C, and mean annual precipitation from 500 to 700 mm, except in extremes. The main tree species on an altitudinal gradient from the lowlands to the mountains are oak (*Quercus* spp.), hornbeam (*Carpinus betulus*), beech (*Fagus sylvatica*), silver fir (*Abies alba*) and spruce (*Picea abies*). At present, forest cover is 34.1% (Chytrý 2017).

Approximately half of the forests are owned and managed by the state. The Czech forest law distinguishes three categories of forests: commercial forests (which aim at timber production), forests for special purposes (where for example nature protection, water protection or recreation takes precedence over timber production), and protective forests (whose aim is to protect the soil and where harvests are minimal). The history of coppicing in the Czech Republic goes back at least to the fourteenth century and coppice woods were probably omnipresent in the lowlands in the Late Middle Ages (Szabó 2010; Szabó et al. 2015). By the end of the eighteenth century, practically all non-mixed broadleaved forests in the lowlands were coppiced. Coppice abandonment started in the late nineteenth century and became near complete after World War II (Maděra et al. 2017).

## Identification of coppice reintroduction localities

We used our long-term experience to identify localities of coppice reintroduction in the Czech Republic. This was based on personal knowledge of the localities and their managers, as we have carried out systematic ecological and historical research at most of the localities for more than a decade (e.g. Szabó 2010; Kopecký et al. 2013; Hédli et al. 2017; Hamřík et al. 2023). A preliminary overview of coppicing reintroduction localities was published in Štochlová & Hédli (2018). For the present paper, we have identified one additional locality (Křivoklátsko PLA<sup>1</sup>). Since we conducted the research presented here (interviews in 2020), the situation has somewhat advanced. Even though, as far as we know, no new localities were added, existing ones have developed further.<sup>2</sup>

It should be noted that locality as a designation for the research unit in our study has a rather broad meaning in terms of physical and organisational form. In some cases, there are as many as five sub-sites spread over tens of km<sup>2</sup> and comprising multiple forest stands; in other cases, the whole locality is a single stand. The structure of coppicing reintroduction in the Czech Republic is complex and contains more than one hierarchical level. In order to maintain the consistency of the main message, we decided to follow the structure of sociological interviews when defining the localities as listed in this study.

## Research sample and analysis

Qualitative designs in forestry management research are rare, yet useful for understanding socially and culturally conditioned aspects of coppice reintroduction phenomena (see e.g. Górriz-Mifsud et al. 2015, Hoogstra-Klein and Burger 2013, Jay and Schraml 2013). In our exploratory study, we opted for a qualitative research strategy based partially on principles of grounded theory constructivist approach (Charmaz 2006). This approach enables an empirically grounded understanding of expert experiences, meanings and concepts, but also to grasp the processes behind the production of existing situations (Flick 2018). Qualitative inquiry typically uses relatively small research samples, and its strength lies in an in-depth and contextualized view of a complex study problem. To gain detailed knowledge about

the coppice localities and to understand the problems and obstacles of their management from the perspective of the local experts, we conducted ten semi-structured interviews with ten site managers in 2020. In sampling for the representatives of the coppice localities, purposive sampling was applied “looking for the core cases with the experience, knowledge, practice” (Flick 2018: 52). We aimed to find site managers who had the expertise and direct and recent experience with coppice management—either those responsible for proposing coppice reintroduction projects or those who worked as project leaders directly involved in coppice maintenance (Table 1). Semi-structured interviews are typically used to cover previously known key themes, however, the questions asked are open-ended, and the inquiry is dynamic as the order of the questions within the interview is not fixed. To obtain significant information, researchers also ask ad hoc questions that cover themes emerging from the particular interview, ask for further details, specifications or even use silence in order to enable the participant to reflect deeper on the theme (Brinkmann and Kvale 2015: 133). The interview guide for the semi-structured expert interviews (cf. Bryman 2008) contained themes such as historical and current site management practices, their extent or financing, motivations of site managers, perceived obstacles and problems of coppice reintroduction (for details, see Supplementary Material 1). These themes determined the main direction of the interviews and ensured that all aspects of coppice reintroduction were covered. However, each interview was unique and provided enough space for participants to formulate their perspectives and share their specific experiences (Charmaz 2006). The interviews took approximately one hour and were recorded and transcribed verbatim. The supplementary questionnaire focusing on the descriptive characteristics of the localities (size, information about the locality’s history or its current ownership and management, etc.) was completed by each research participant after the interview. Missing data were filled in later via short follow-up phone calls with the participants. Each participant signed an informed consent form. Participants were informed in advance that the complete anonymisation of the data would not be possible due to the uniqueness of the research localities, and all participants agreed to the overt use of the interview data before the interviews were conducted. The participants authorised the current text—they expressed their agreement with the interpretation of the data, and we incorporated their minor corrections into the manuscript. This collaborative verification in the final phase helped increase the validity of the descriptive data and the trustworthiness of the interpretations in the qualitative part of the research.

In addition to the descriptive mapping of the coppice reintroduction localities, the interview data were analysed inductively. Interview transcripts were firstly coded in open, line-by-line coding. To answer the research questions, the

<sup>1</sup> PLA=Protected Landscape Area (in Czech, Chráněná krajinná oblast) is a legal term in Czech nature protection that denotes a different overall focus than that in national parks, which are designed towards a non-intervention management regime. Otherwise, the two categories are basically the same in their physical, natural and historical conditions.

<sup>2</sup> Including for example a LIFE project with two experimental sites in Český kras PLA and one site in southern Moravia.

**Table 1** List of localities with coppice reintroduction in the Czech Republic and information on research participants

| Locality                                       | Research participant number | Position/profession                                                                                   | Education                                                                                                  |
|------------------------------------------------|-----------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Pálava PLA                                     | RP1                         | Pálava PLA—forestry expert                                                                            | Forest engineering (Mendel University)                                                                     |
| Utinkův háj                                    | RP2                         | Professional forest manager, forestry and environmental consultant                                    | Forest engineering and forest cultivation (Mendel University)                                              |
| Český kras PLA                                 | RP3                         | Český kras PLA—forestry expert, memorable trees, greenery outside the forest                          | Forestry secondary school Písek                                                                            |
| Školní lesní podnik Masarykův les Křtiny (ŠLP) | RP4                         | Školní lesní podnik Masarykův les Křtiny—director                                                     | Forest engineering (Mendel University)                                                                     |
|                                                | RP5                         | Školní lesní podnik Masarykův les Křtiny—Head of Development and Pedagogy Department                  | Faculty of Forestry and Wood Technology (Mendel University)                                                |
| Bílé Karpaty PLA I                             | RP6                         | Bílé Karpaty PLA—forestry expert                                                                      | Faculty of Forestry and Wood Technology (Mendel University)                                                |
| Bílé Karpaty PLA II                            | RP7                         | Bílé Karpaty PLA—agriculture, Project LIFE                                                            | Biology–Geology and Environmental Protection (Palacký University)                                          |
|                                                | RP8                         | Bílé Karpaty PLA—zoologist, Project LIFE                                                              | Systematic biology and ecology (University of Ostrava); PhD in zoology (University of South Bohemia)       |
| Křivoklátsko PLA                               | RP9                         | Department of Forest Management and Applied Geoinformatics, Mendel University—docent                  | Forest engineering (Mendel University); PhD at Faculty of Forestry and Wood Technology (Mendel University) |
| Podyjí National Park                           | RP10                        | National Park Podyjí—officer for natural management of forest and non-forest ecosystems, entomologist | Forest engineering (Mendel University); PhD in Landscape management (Mendel University)                    |

second step in coding focused specifically on motivation structures and on identifying obstacles and barriers from the perspective of local managers. We are aware that grounded theory approaches, including the constructionist one, primarily aim at theory building. However, for our exploratory study, we used the tools of grounded theory to identify patterns in the data and to formulate the main categories, which are further explored below.

## Results

### Overview of coppice reintroduction localities with basic characteristics

We identified eight localities in the Czech Republic where coppicing is currently being reintroduced (Fig. 1, Table 1). Information on research participants is included in Table 1. For detailed descriptions of each locality, see Supplementary Material 2.

When considering the past three decades of coppicing reintroduction in the Czech Republic, four localities appear to be the most developed (Table 1). In three (Pálava PLA, Český kras PLA and Podyjí National Park), the coppices form part of nature reserves of the highest level of protection. The fourth locality, Školní lesní podnik Masarykův les Křtiny, is under the special regime of a university forest

enterprise. In these localities, the reintroduction of coppice management has been actively promoted for at least ten years, and the total area of restored stands (implemented or planned) at each locality is in the order of tens of hectares. Furthermore, the site managers have a rather clear vision, which they are able to communicate and discuss. This promises a longer-term perspective and further expansion.

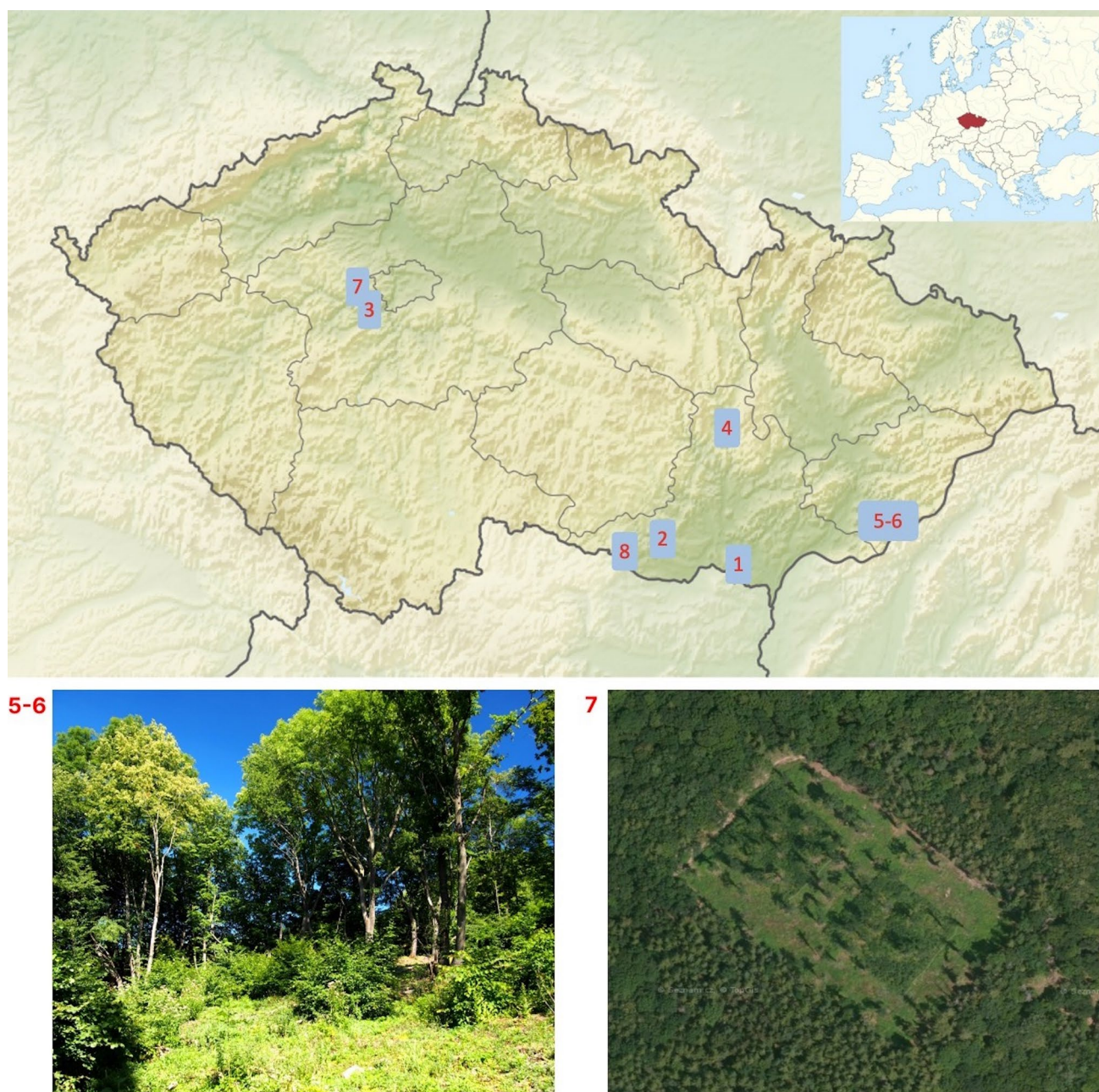
### Motivations

This chapter outlines the most important motivations identified in the managers' narratives about their experiences with the coppice reintroduction process: conserving biological and landscape diversity, raising awareness, climate change mitigation and economic benefits.

### Conserving biological and landscape diversity

Because coppice reintroduction typically happens in protected areas and the respondents were usually employed by nature conservation organisations, it is not surprising that coppice restoration in the Czech Republic is most often motivated by nature conservation purposes. This includes the protection of species or communities dependent on coppicing as well as the protection, restoration or fostering of two interrelated types of diversity: the biodiversity typical for open forests, and also more general landscape diversity.





**Fig. 1** The study region and the coppice reintroduction localities. 1: Pálava Protected Landscape Area (PLA). 2: Utinkův háj. 3: Český kras PLA. 4: Školní lesní podnik Masarykův les Křtiny. 5–6: Bílé Karpaty PLA I, II. 7: Křivoklátsko PLA. 8: Podyjí National

Park. Photographs: Demonstration of coppice management in Bílé Karpaty, source: Authors' own archive (left). Aerial image of restored area in Křivoklátsko, source: Mapy.cz (right)

Biodiversity was mentioned by almost all participants and given unequivocal importance. According to research participants, coppices represent a stand-type that is missing from current Czech landscapes, as a result of which some species are disappearing, as illustrated by the case of the Pálava PLA: “We knew that the species or the communities on Děvín were beginning to change. And for the worse, because some species were disappearing. So then

we started to look at what our predecessors were doing so that so many species were preserved and why these were now disappearing ... And it turns out that coppicing was abandoned sometime after the war and then nature conservation came in, and their first efforts were to leave everything to natural processes, to let it develop naturally. And from that time on the forests started to close in, they became thick and not hospitable for some of those species, and the



forests themselves changed” (RP1). RP1 also pointed out the ambivalence described in the literature as the protectionist versus conservationist approach to nature. In the case of Pálava, the conservationist approach led to a decrease in biodiversity. Many species need open habitats, and non-intervention management is not suitable for them: “*Coppice forests or coppices-with-standards hold a certain type of biodiversity that is dependent on human activities, but such forests are gradually disappearing from the landscape. And it is necessary to somehow maintain or support this biodiversity*” (RP4). Biodiversity rather than the “natural” state of the habitat was formulated as the major goal of coppicing, as also in the case of the Podyjí National Park, where the site manager focused on environmental diversity: “*That was in fact one of the goals – to introduce a mosaic-like spatial structure into the forests so that they are not all even-aged forests with the same density, height and age*” (RP10).

‘Mosaic’ appeared to be a keyword illustrating the biodiversity goal in coppicing. Coppicing was seen as a complex management system with important temporal dimensions and a high level of uncertainty: “*You need to realise that coppicing is not simply regenerating trees through shoots. Coppicing is a management system. So if I cut a part somewhere, I need to count with the fact that I will some time afterwards cut the part next to this first part. Because ... there is no certainty that high biodiversity is connected to freshly coppiced plots. But maybe biodiversity is dependent on stands with different conditions: fresh cuts, forests younger than ten years, closed forests with no light etc. So that all the organisms, which have various requirements, are able to find their own little corner, and when they stop feeling OK they move to the next spot*” (RP2). All managers seem to be aware of this prerequisite; therefore all those with sufficiently large areas plan to create a mosaic of various growth stages to support biodiversity via the environmental diversity of forest stands.

In addition to increasing the diversity of forest stands, respondents also mentioned their motivation to recreate the complex landscapes which used to be made up of a mosaic of various biotopes. Coppice forests were not only mosaics themselves but formed an important part of the more complex mosaic of the cultural landscape before the collectivisation of agriculture and the subsequent simplification of land use in rural areas during the communist era: “*At Zahrady pod Hájem there were coppices, that's how management worked. At the end of the village, there were gardens, small fields, meadows and a forest ... So the villagers went to get apples, potatoes, hay and wood ... All that was then abandoned because of collectivisation and the coppices became high forests. The point is to restore that landscape complexity, including the coppices*” (RP6). This historical image played an important part in the narrative of the motivation for the reintroduction of coppice management, which

was seen as a desired part of the wider process of landscape recovery.

### Raising public and professional awareness

The conservation motivation, built on the historical prevalence of coppicing in the Czech landscape, was also connected with the educational motivation. Because coppicing hardly exists in the Czech Republic nowadays, some managers see its reintroduction at their localities as a tool to inform and educate other foresters, students and the wider public. In some cases, this is based on their own research, such as in the privately owned forest Utinkův háj. According to its founder and proprietor, “*the original motivation [in Utinkův háj] has been research, because I wanted to somehow describe, publish and prove that [coppicing] is possible. ... I did my PhD on the topic, I'm interested in this management type, and I still read about it. ... I know that [in the Czech Republic] it's a marginal and suppressed topic also from the perspective of foresters, who, and I don't really know why, are convinced that coppicing is simply wrong. Even though it's not that wrong. I don't think it will redeem forestry as such, but in some stand types it's an option*” (RP2).

Managers of the Křivoklátsko forestry park, which is financed by the Forests of the Czech Republic (FCR),<sup>3</sup> expressed a similar motivation. In their case, the aim was not so much to convince than to demonstrate: “*The purpose of forestry parks is to show how classical forest management works. It's the opposite of national parks in some sense. Although forestry parks have no legal status, they are a sort of voluntary effort by foresters to demonstrate how they manage the forests*” (RP9). Because Křivoklátsko used to be a typical coppice area before the twentieth century, FCR chose to finance a project to reintroduce coppicing. Again, the historical legitimisation served as the basis for the reintroduction of this geographically and symbolically marginalised type of forest management. The area now also serves as a place to demonstrate traditional coppicing to forestry students and other interested parties.

### Preserving forest ecosystems in the context of climate change

For the past decade, there have been intense debates among scholars as well the lay public on the effects of global climate change on forests (Trumbore et al. 2015). Recent dry and hot periods appear to have influenced some of the coppice restoration sites discussed in this paper. While the

<sup>3</sup> Forests of the Czech Republic (in Czech, Lesy České republiky) is a state-owned company that manages 45.6% of the forests in the Czech Republic.

aforementioned inspiration by the mosaic of the pre-collectivisation landscape and educational purposes of coppicing reintroduction found their legitimisation in recovering the past, the climate change thread links coppicing management to the future: *"In those stands that are the most exposed to heat and drought ... oaks of generative origin tend to dry out. In such stands, coppiced oaks survive better because ... in coppice forests, for example, 40 individuals in the form of coppice stools share the water, but in high forests, you have, say, 150–160 mature individuals. And coppice stools are able to manage the water more effectively"* (RP4). According to RP4, the prevalence of coppices in the Mediterranean also attests to their resistance to heat and drought. This is why in ŠLP, restoring coppicing was thought to be the best solution to preserve forest ecosystems against the effects of climate change-related drought, especially in stands where natural generative growth does not occur and tree planting does not pay off.

In the hot and dry regions of southern Moravia and central Bohemia, climate change intensified droughts and aggravated already existing risks in even-aged forests. Coppicing is seen as a suitable management form outside extreme conditions as well: *"Oak tends not to regenerate after it falls down. So the stands break up and black locust appears. That was, in fact, one of the reasons why we started [coppice restoration]. Because we knew that if we don't start doing something now, stands will break up on a large scale and the biotope will decline"* (RP1).

### Economic aspects

None of the coppice restoration sites discussed in the paper was established for direct financial benefits. When managers mentioned economic aspects at all, they considered them secondary. In some cases, their aim was to simply prove that coppicing can be economically viable, rather emphasising an educational motivation aiming to increase awareness among professionals.

One of the economic benefits of coppicing is the production of firewood, which, however, is seen as limited in the current circumstances: *"Nowadays, customers prefer quality firewood, which means firewood of a certain length and diameter that fits easily into fireplaces. Customers want such wood delivered straight home. That puts limits on production – we cannot expect the market to want so much wood as can be grown on thousands of hectares of coppices"* (RP4). However, according to others, the demand for firewood has been growing recently. Furthermore, coppice firewood represents a distinctive quality: *"[it is] an exclusive product even now when we have so much wood from salvage fellings that we don't even know what to do with. But spruce wood from salvage fellings is simply not as good for heating as oak or hornbeam firewood"* (RP9).

According to most managers, coppices could be economically viable above all for small woodland owners who own a few hectares of woodland, live in the countryside and could provide their own firewood through this traditional management option. RP2 is convinced such people should be the target group of restoration efforts in the future: *"Now it's mostly nature protection, but I think that [coppicing] should be promoted mainly for production. Because I can dramatically lower management costs, and I can also establish a sustainable system relatively easily. ... From the perspective of forest management results, this should be more beneficial than high forests, which can generate enormous gains from small areas in certain periods and then nothing for decades"* (RP2). In contrast, in coppices, even small woodland owners can harvest a few acres every year and do not have to wait extended periods for economic profitability.

### Problems and obstacles

Besides their motivations for coppicing, managers also informed us about obstacles and problems they have encountered in the process of coppice reintroduction at the sites they manage in the Czech Republic. We identified five main types: legal framework, legitimacy of reintroduction, lack of workforce, biotic factors and abiotic factors.

#### Legal framework, administrative processes

Practically all localities (except for Křivoklátsko and Bílé Karpaty I) discussed in this study are categorised as "forests for special purposes", for which it was relatively easy to obtain an exception from the forest law, a necessary precondition to start coppicing. That is why none of the managers mentioned legislation as the main obstacle. In addition, the forest law has been recently amended to make coppicing easier, which was assessed positively by research participants: *"Now [the forest law] is prepared in a way that if the owner wants [coppicing], there aren't many legislative obstacles. It is more about negotiating with the state authorities, setting up some conditions and mutual respect. There is no ban. [Coppicing] is now very accessible, and it is up to the manager or the owner if they want it or not. If they think it makes sense or not"* (RP9). But this unproblematic view was not unequivocal, and according to others, it is still virtually impossible to start coppicing: *"Because it is a forest, you simply cannot start [coppicing]. There would really have to be a project for it, and the state authorities would need to authorise it. Which I think is very complicated"* (RP6). That is why in the Bílé Karpaty PLA, the managers chose to establish coppice forests in the area that is officially non-forest ground.

Related bureaucratic processes and often complicated structures of legal responsibilities at the localities were

among the problems most often mentioned by the research participants. In most of the problematic cases, the organisation responsible for coppice reintroduction either does not own the property or is not responsible for forest management, both of which lead to reduced capacities for action. This situation causes major problems, for example, in the Pálava PLA, where FCR is responsible for forest management. The complicated administrative framework is often linked to the conflicting agendas of various actors: “*We had to go through all the legal procedures. Nonetheless, the forest law says that the request for the exception [from the forest law] must be handed in by the manager of the forest appointed by the state, and that's again not us, or by the owner of the property*” (RP1). According to our research participant, forest workers employed by FCR often simply ignore instructions by the Pálava PLA. In some areas, the fear of complicated negotiations over ownership resulted in the substantial postponement of planned coppice reintroduction, such as in the Podyjí National Park. Managers at this locality decided to wait for more than a decade until the areas planned for re-coppicing were transferred from the city of Znojmo to state ownership. Ownership structures have complicated the reintroduction of coppicing also in the LIFE project in the Bílé Karpaty PLA, even though the managers tried to utilise privately owned land. Properties in the Bílé Karpaty PLA are typically small and discontinuous with many different owners, some of which are not easy to find. Even when available, small owners do not view coppicing as a preferable management type. In order to produce functioning coppices, the PLA wanted to find a larger contiguous area, which they have not managed so far, and coppicing is thus practised on small areas only.

### Legitimacy of coppice reintroduction

While many participants expressed their concerns about the complicated ownership structures, reintroducing coppicing on state-owned land did not result in a non-problematic process, either. The differing legitimizations of protected areas and competing views on the role and purpose of such areas came to the fore, highlighting the importance of establishing professional relationships and effective communication on the level of local actors. One of our participants commented on the beginning of the reintroduction process as follows: “*As a start, we had to convince [FCR] to carry out such management at all, which for them probably seems pointless. ... So we had to convince [FCR] to hand in the request. And because they don't really agree with the whole thing, it was quite demanding*” (RP1). The educational approach, mentioned above, accompanied by the long-term relationship with the major actors involved, also played an important role in the Český kras PLA. The PLA aimed at reintroducing coppices partly on state-owned land where FCR is

responsible for forest management. The planning phase was long, and the original standpoint of FCR was rather conservative, claiming that nature protection in a national nature reserve should aim at non-intervention: “*We have enlightened state forest management here. We've been cooperating with them for a long time, and we even do forest grazing. ... We couldn't do [coppicing] without them, and we're glad they were willing to go along*” (RP3). FCR appears to be the key actor: it is essential for the successful reintroduction of coppicing, but it also often represents a more conservative approach towards forest management.

In two cases, problems also emerged with the public viewing coppice cuts negatively. In Pálava, people from the general public often called the PLA, asking how it was possible that trees were harvested in a national nature reserve. At the ŠLP location in Lesná, mainly the inhabitants of Brno-Lesná were dissatisfied with the management, which contradicted the contemporary public image of a forest: “*Once the public is used to relatively uncluttered and pretty high forests, and we harvest those, and then it regenerates into a dark jungle, that makes a bad impression on the public*” (RP5). This conflict caused enormous problems for the entire institution as well as for Mendel University. The managers tried to explain their agenda on information plates, and there were even public presentations at ŠLP Křtiny about coppice management. Both conflicts settled down after a while when the public got somewhat used to coppice woods.

### Lack of workforce

Lack of workforce to carry out coppicing was mentioned as a side issue. In the Podyjí National Park, this led to missing some of the deadlines for harvest, clearing out the wood or setting up the fences. “*The first year, it happened that we fenced off the fresh cuts awfully late, when the shoots were already growing, and they were very much eaten by the animals. In the end, things worked out, but it showed us that we need to organise all steps of the coppicing process systematically*” (RP10). In the Bílé Karpaty PLA, the general depopulation of the region causes problems for coppice management as well. In the past years, many contractors that normally work in the area have taken up more lucrative jobs in the Vysočina region, where large forest areas destroyed by a bark-beetle outbreak needed to be harvested on short notice. In general, according to our participants, there are simply too few people working in agriculture.

### Biotic factors

In addition to legal, administrative and symbolic obstacles to coppice reintroduction, invasive and expansive plants pose varying levels of threats at the localities. In the Pálava PLA, they are seen as a potential problem after stands are cut,

but at the Podyjí National Park and, to a lesser degree, in the Bílé Karpaty PLA, they are already a significant issue. At Zahrady pod Hájem, where there are fewer coppice stools, wood small-reed (*Calamagrostis epigejos*) and thistle (mostly *Carduus* spp., *Cirsium* spp.) invade from neighbouring forests. “*Those invasives are starting to suppress the herb layer, which came up amazingly strong in the first and second years ... We're trying to eliminate them mainly by pulling them out, at least the thistles. For wood small-reed, we should use chemicals, which we don't want. But we're expecting the herb layer to evolve and eventually to suppress the small-reed*” (RP6).

At the Podyjí National Park, invasive trees cause major problems. “*Black locust and tree of heaven [Ailanthus altissima] appeared basically on all the plots where we had started to reintroduce coppicing. These invasive species thrive through the disturbances caused by harvests and the subsequent removal of wood. That's a risk of this management that you support not only the beneficial species but also the invasive ones, and you have to account for these in the management*” (RP10). Based on previous experiences, managers apply herbicides straight to the trunks of these trees in order to eliminate them. In addition to invasive trees, many species of ruderal herbs also appeared at the coppice sites. However, the hope is that these will disappear through natural succession.

A significant problem is also represented by game numbers, in particular the number of mouflons in the Český kras PLA and roe deer at the other localities. Young shoots are regularly eaten by these animals; therefore, the managers try to fence off newly cut areas. The situation is similar at Křivoklátsko. However, the problem with game is not specific to coppices. In fact, forests of generative origin are even more at risk: “*The advantage of coppice shoots is that there's a great many of them and they have the roots of the shoots, so they're very vital. When animals eat them, they grow back again, sometimes even stronger than seedlings*” (RP5). This, however, appears to work better for larger plots, whereas for smaller plots, fencing is necessary.

### Abiotic factors

From among abiotic factors, drought has caused the most significant problems in coppice reintroduction. In Utinkův háj, the dry years of 2018 and 2019 eventually led to the abandonment of the original plan to create a coppice-with-standards, instead of which the locality will probably be managed as a simple coppice. The oaks chosen as standards were slowly drying out and therefore had to be cut down in order to preserve their ability to coppice. In contrast, in the Český kras PLA, there occurred problems with stools rather than standards. During the drought of 2015–2016, many coppice shoots dried out. However, the area affected

was relatively small, and the managers believe this will not influence the overall results of coppice reintroduction at the locality.

## Discussion

Coppice reintroduction in the Czech Republic is a bottom-up process, although often within an institutional framework. It is advanced by the efforts of dedicated forestry or biology experts, who often become site managers. Exploring the motivations and experiences of these managers and mapping the obstacles they have encountered is therefore a key research task, which can be best approached by the qualitative design we chose. However, we are aware that qualitative research design with purposive sampling and inductive data analysis have limitations. We presented only a part of the complex issue of coppice reintroduction and emphasize that other stakeholders, such as land owners, experts from state forest institutions, or other conservationists might have a different perception of the process. Our research focused on the perspective of those experts actively involved in coppicing reintroduction and must be read as such.

Pan-European research identified three main reasons behind the recent increased interest in coppice forests: (1) their role as a renewable energy source, (2) their usefulness in biodiversity protection and resilience to biotic and abiotic disturbance factors, and (3) their potential as a source of rural employment (Unrau et al. 2018, see also Wolfslehner et al. 2009).

Our results were similar to these as regards biodiversity. The reason behind this is probably the fact that most of our research participants were involved in nature protection. However, while there is a general consensus that coppicing is beneficial for biodiversity (Müllerová et al. 2015; Kirby et al. 2017; Buckley 2020; Kamp 2022), our research participants had differing opinions about the resilience of coppices to climate change. Some argued that coppice stools, with their well-developed root systems, can withstand higher temperatures and drought better than tall trees of generative origin in high forests (cf. Stojanović et al. 2017), others observed the drying out of standards or even coppice stools at their sites. This apparent contradiction probably stems from a combination of extreme site conditions (shallow, desiccation-prone soils), unexpected extreme climatic events (summer droughts) and management decisions (opening up the canopy and leaving standard trees unadapted to the conditions) at both Utinkův háj and Český kras. In other localities with deeper soils, such as Pálava or Bílé Karpaty, no major drought damage to trees is evident. Oak species, often used by foresters both as coppice resprouts and standards, are highly plastic in terms of water household and especially in relation to drought. It appears that regeneration

through coppicing may indeed be an appropriate strategy to counteract the increasingly drier conditions of the Czech Republic (Matoušková et al. 2022; Řehořková et al. 2022). However, the assumption that coppicing will compensate for the effects of climate change may eventually fail, as tree species face their physiological limits (e.g. Tognetti et al. 1998). Furthermore, vegetative regeneration does not allow for natural evolution towards more resilient tree genotypes, therefore genetic lineages adapted to milder climates may not be able to survive future climate extremes.

Our research participants were well-aware of the dangers posed by invasive plant species in recoppiced forests. This is a general problem at all of our research localities. In particular, black locust (*Robinia pseudoacacia*) has become invasive in Europe (Vítková et al. 2017), although evidence for it being promoted by coppicing is relatively scarce (e.g. Radtke et al. 2013). The spread of black locust and also of tree of heaven (*Ailanthus altissima*) is being actively prevented in the restored coppices in Podyjí National Park, and it may soon be necessary elsewhere, e.g. in Pálava PLA. On the other hand, the eradication of native weeds, for example mowing thistles (*Carduus*, *Cirsium* and other related taxa) by the managers in Bílé Karpaty, seems quite unnecessary and even harmful to biodiversity (e.g. Swanson et al. 2011). These plants form an early stage of succession in clearings before forest plant communities spontaneously recover. During the first two to three years after clearing, endangered annual species that have already lost their suitable habitats in the surrounding agricultural landscape also appear (Vild et al. 2013; Hédli et al. 2017).

As for the other two factors identified by Unrau et al. (2018), coppicing has so far not been considered as a source of rural employment in the Czech Republic. Quite the contrary, workforce (or, to be more precise, lack thereof) was mentioned as an obstacle for coppice reintroduction by our research participants. This may be connected to local population decline (as argued for Bílé Karpaty) or perhaps to a lack of interest among locals in manual forestry work. In the twentieth century, the diversification of rural regions in the process of rural transition (Pospěch 2014) manifested itself in varying degrees of depopulation impact, levels of industrialisation and job opportunities as well as diversified transportation and connectivity enabling people to commute for work. In general, after 1989 there was a tremendous outflow of workforce from agriculture and forestry and a rapid shrinkage of agricultural production. As the unemployment level in the country is low (between 2 and 3% in 2021 through 2023: Český statistický úřad 2021) and work in forestry is among those with the lowest wages, the field is currently not attractive for local workers. Depopulation is especially significant in peripheral regions (Vaishar et al. 2020), which, at the same time, often include protected areas with potential coppice reintroduction sites.

Coppicing as a source of renewable energy has so far played a minor role in the reintroduction of this management type in the Czech Republic. This is in stark contrast with international scientific literature, which devoted considerable attention to this topic. The circumstances in some of these studies clearly differed from ours in that they examined functioning coppice systems rather than reintroduction efforts (Spinelli et al. 2014, 2016; Schweier et al. 2015). However, other papers addressed the potential of coppice products (Suchomel et al. 2012; Jansen & Kuiper 2004) in situations not unlike that in the Czech Republic. A recently published paper by Mejstřík et al. (2022) investigated biomass production at one of our coppice reintroduction localities, pointing out that the yield from resprouts depends on the density of standards. The type of response differs among the tree species: oak and hornbeam respond negatively, while lime and field maple remain unaffected. Regarding the biomass from resprouts, the economic function of coppices probably cannot include anything else than fuelwood. If woody resprouts are left to grow for longer than 20–30 years, the resulting logs require significant labour to cut and split. Producing construction timber using conventional methods is more profitable. Nevertheless, economic issues may play a stronger role in coppice reintroduction in the future than they do at present.

Only a few studies addressed the opinions of those directly involved in coppicing (continuously active or reintroduced). Bartlett (2016) completed questionnaires with 204 coppice workers active in south-east England. In this region, coppicing remained alive all through the twentieth century, therefore the research participants were not reintroducing it but depended on it for their livelihoods. The SWOT analysis resulting from the questionnaires in Bartlett (2016) showed that the main threats to coppicing here were insurance and housing costs, personal health and injury, competition from other workers and imports, lack of workforce, and legislation and bureaucracy. Because these research participants were manual workers, their answers reflect particular concerns that only partly overlap with our results. Notably, workforce and legislation were deemed problematic in both samples. On the other hand, biodiversity, the leading motivation for our participants, apparently played no role for English managers, even though it was part of the governmental agenda to promote coppicing (Bartlett 2016). At the same time, English coppice workers mentioned educational goals even though more in the context of bringing awareness to local products than promoting cultural heritage as at our localities. On the level of individuals, those identified as the 'new tradition' (educated middle-class individuals taking up coppicing-related crafts) in Collins (2004) are closer to our participants. These workers entered coppicing from partly romantic reasons connected to living and working in the countryside.



In another paper, Bartlett et al. (2018) studied barriers to the development of small-scale coppice management in Europe. Their participants included academics as well as practitioners; the main obstacles observed tended to focus on economic issues. The related issue of energy wood production was investigated through surveys among 232 owners of small private forests (mainly coppices) in Croatia and Serbia. Participants showed a positive motivation vis-à-vis the creation of new jobs and commercial opportunities. Again, this is in contrast with our results, which showed that research participants did not consider economic issues as overly important.

## Conclusions

Coppicing in the Czech Republic is being reintroduced at a handful of localities. The key role in the bottom-up process is played by local site managers that are mainly motivated by nature conservation. The perceived obstacles are of a practical nature (administrative barriers, complicated ownership and responsibility structures, lack of workforce). This signifies a situation in which coppicing may remain a small-scale activity in protected areas dependent on the initiative of site managers and irrespective of larger socioeconomic considerations. However, general European trends indicate that coppicing can gain more ground if it is accepted as a viable economic alternative to high forests, mainly for small woodland owners. Our research participants were also aware of this issue, but, with few exceptions, they did not consider it too relevant for themselves. In any case, economic motivation appears to be important in countries or regions where coppicing is still an active management form. In western and north-western Europe, in this sense including the Czech Republic, a major challenge for future policies will be to utilise the economic experiences of regions with active coppicing to foster the spread of coppice woods in order to combine renewable energy production with biodiversity conservation.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s10342-023-01626-0>.

**Acknowledgements** This study was supported by project no. TL02000314 from the Technology Agency of the Czech Republic and by long-term research development project no. RVO 67985939 of the Czech Academy of Sciences.

**Author contributions** A.K. P.S. and R.H. conceived the concept of the paper. L.G.B. designed the analysis method. A.K. collected the data with the help of R.H.. A.K. and P.S. performed the analysis. A.K., P.S. and L.G.B. wrote the main manuscript text with contributions from R.H.. P.S. prepared Fig. 1. All authors reviewed the manuscript.

**Funding** This study was supported by project no. TL02000314 from the Technology Agency of the Czech Republic and as a long-term

research development project no. RVO 67985939 of the Czech Academy of Sciences.

**Availability of data and material** Not applicable.

**Code availability** Not applicable.

## Declarations

**Competing interests** The authors declare no competing interests.

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