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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^2) 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.

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.[1] 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.[2] 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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[1] 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.

[2] R.P. Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, Cambridge, 2001.

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forestry.[3] 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.[4]

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.[5]

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.[6] Computerized models of European deforestation since the Neolithic based on population estimates also reinforced these ideas.[7] 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.[8] 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*.[9] 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*.[10] 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.[11] The method itself was highly sustainable in the modern sense: areas to be cut yearly were planned so that the resource was not depleted.[12] 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.'[13] 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.[14]

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.[15] 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.[16] This holds true

[3] 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.

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

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

[6] 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.

[7] K. Klein Goldewijk, A. Beusen, G. van Drecht 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.

[8] G. Tack, P. van den Bremt 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.

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

[10] 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.

[11] 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.

[12] 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.

[13] Quoted in O. Rackham, *Hayley Wood: Its History and Ecology*, Cambridge, 1975, 26.

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

[15] For example Rackham, *Hayley Wood* (note 13); R.L. Keyser, The transformation of traditional woodland management: commercial sylviculture 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. Hédl, 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.

[16] 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.

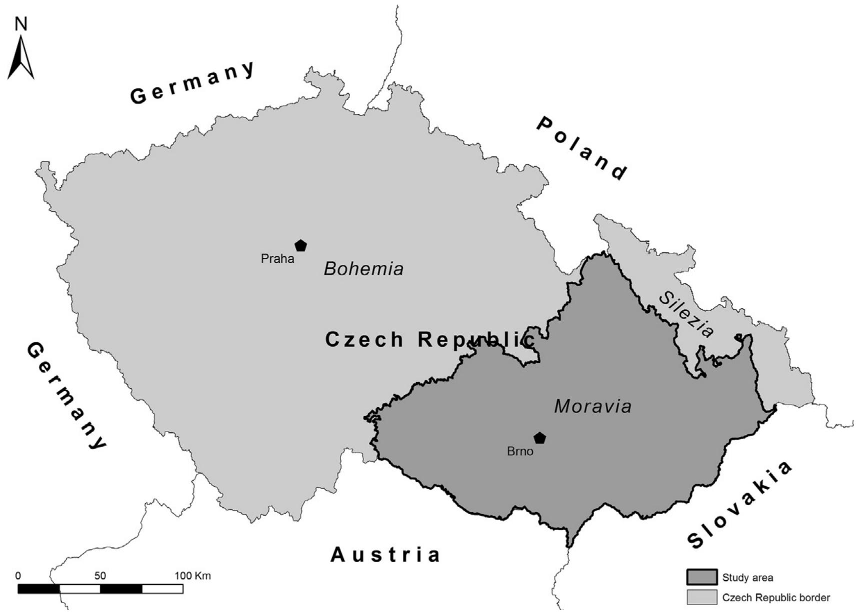

Fig. 1. Study area.

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.[17] 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^2 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 Silezia, 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.[18] 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.[19] In this period, two basic kinds of books were kept: those dealing with court cases and those

[17] Rackham, *Ancient Woodland* (note 8), 133–142; Keyser, The transformation of traditional woodland management (note 15).
[18] A. Boček, J. Chytil, V. Brandl and B. Bretholz (Eds), *Codex diplomaticus et epistolaris Moraviae*, 15 volumes, Olomouc and Brno, 1836–1903.
[19] K.J. Demuth, *Geschichte der Landtafel im Markgrafthume 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 Válkovi 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.[20] 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*.[21] 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.'[22] 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.[23] 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.[24] 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.[25] 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*).[26] 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 subcategory 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.[27] Another word worthy of attention is *virgultum*, which was often used as a

[20] 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. Matějek (Ed), *Moravské zemské desky. II. sv. řady olomoucké 1480–1566*, Brno, 1948 (hereafter ZDO II).

[21] G. Friedrich, Z. Kristen, J. Bistřický, 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).

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

[23] 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.

[24] P. Szabó, *Woodland and Forests in Medieval Hungary*, Oxford, 2005, 57–62.

[25] ZDB I (note 20), 369, no. 605.

[26] The survey has been edited: J. Truhlář (Ed), *Registrum bonorum Rosenbergicorum anno MCCCLXXIX 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.

[27] 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*.[28] 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.[29] The same is suggested by the contemporary Czech equivalents of *rubetum* and *virgultum*: *chrastina* and *křovina*.[30] Both of these words refer to shrubby vegetation.[31]

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.'[32] 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*).[33] 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.'[34]

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.[35] 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.[36] 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.[37] However, *Rubus* presently spreads under the influence of eutrophication and nitrogen deposition.[38] 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.[39] 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.[40] 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.[41] 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

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[28] 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.

[29] 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.

[30] 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.

[31] 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.

[32] CDB V/2 (note 21), 501: 'o lesiech a o křovinách, ješto ještě v rolí nejsú obráceny'.

[33] Truhlář, *Registrum bonorum Rosenbergicorum* (note 26), 28.

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

[35] P. Szabó, Ancient woodland boundaries in Europe, *Journal of Historical Geography* 36 (2010) 205–214.

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

[37] R. Hédl, 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.

[38] 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.

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

[40] 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.

[41] 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 Czech Geological Survey	Quaternary (soils, loess, sand and gravel; 26%) Palaeozoic rocks–folded, unmetamorphosed (schists, greywackes, quartzites, limestones; 15%) Tertiary rocks folded during the Alpine Orogeny (sandstones, schists; 12%)	Quaternary (soils, loess, sand and gravel; 31%) Tertiary rocks folded during the Alpine Orogeny (sandstones, schists; 13%) Tertiary rocks (sand, clays; 9%)	Quaternary (soils, loess, sand and gravel, 42%) Tertiary rocks folded during the Alpine Orogeny (sandstones, schists; 16%) Tertiary rocks (sand, clays; 12%) Tertiary deposits (27%)
Prevailing soil type	Pedological maps 1:50 000 Czech Geological Survey	Cambisol (48%) Luvisol (12%) Chernozem (11%)	Cambisol (35%) Luvisol (20%) Chernozem (18%)	Chernozem (28%) Luvisol (25%) Cambisol (20%)
Prevailing reconstructed vegetation type	Mykiška (1968)	Oak-hornbeam woodland (Carpinion, 40%) Herb-rich beech woodland (Eu-Fagenion, 17%) Acidophilous beech and silver fir woodland (Luzulo-Fagion, 16%) Alluvial woodland (Alnion incanae, 14%)	Oak-hornbeam woodland (Carpinion, 59%) Acidophilous beech and silver fir woodland (Luzulo-Fagion, 16%) Herb-rich beech woodland (Eu-Fagenion, 10%)	Oak-hornbeam woodland (Carpinion, 62%) Alluvial woodland (Alnion incanae, 18%)
Prevailing potential vegetation type	Neuhäusleová et al. (1998)	Oak-hornbeam woodland (Carpinion, 45%) Acidophilous beech and silver fir woodland (Luzulo-Fagion, 21%) Herb-rich beech woodland (Eu-Fagenion, 19%)	Oak-hornbeam woodland (Carpinion, 55%) Acidophilous beech and silver fir woodland (Luzulo-Fagion, 17%) Alluvial woodland (Alnion incanae, 10%)	Oak-hornbeam woodland (Carpinion, 70%) Alluvial woodland (Alnion incanae, 12%)
Current forest distribution	CORINE 2010 land cover mapping	8583 km^2		

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.[42] 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.[43] 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.[44] 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).[45] 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.[46] 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

[42] 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.
[43] G. Marsaglia, W.W. Tsang and J. Wang, Evaluating Kolmogorov's distribution, *Journal of Statistical Software* 8/18 (2003) 1–4.
[44] 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.
[45] 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).
[46] 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.

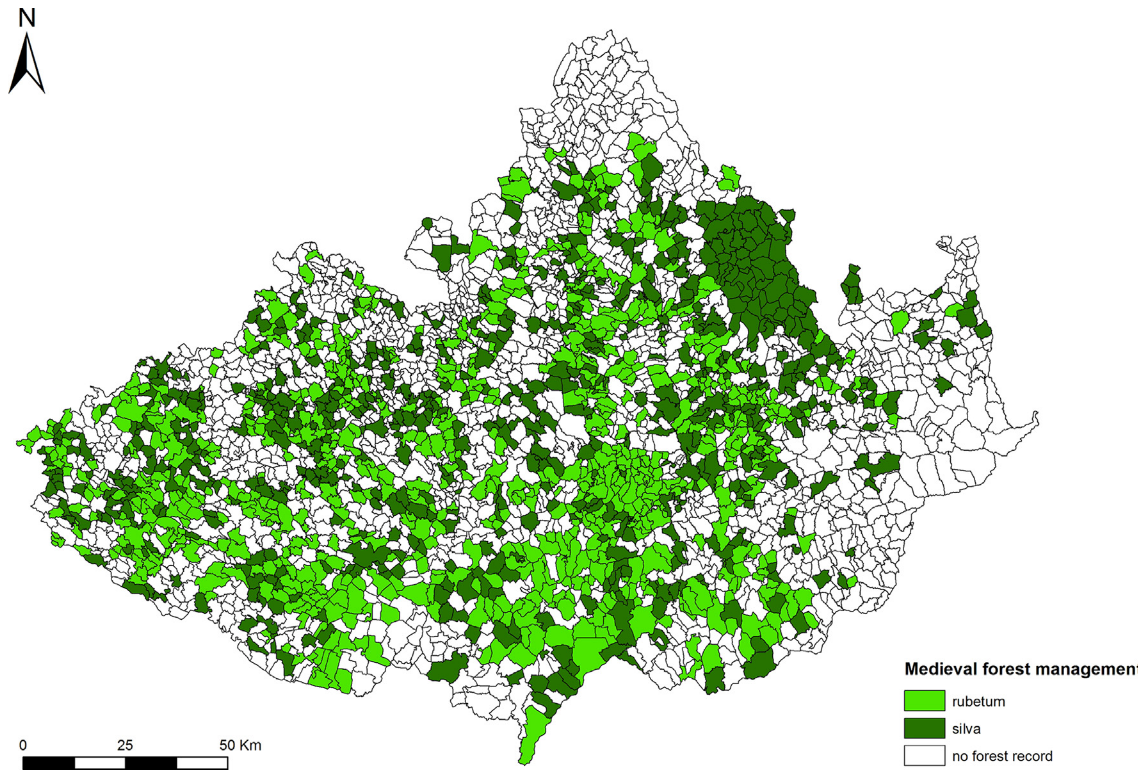

Fig. 2. Late medieval archival records in Moravia on coppicing (*rubetum*) and woodland in general (*silva*). Where both *rubetum* and *silva* were recorded for the same parish, the map shows *rubetum*.

single number, the area under the curve (AUC). Statistical analyses were performed in R (version 2.15.3).[47]

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).[48] 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.[49] 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

[47] R Core Team, *R: A Language and Environment for Statistical Computing*, Aukland, 2013.
[48] R. Mikyška, *Geobotanische Karte der Tschechoslowakei — Böhmen und Mähren, 1: 200 000*, Praha, 1968; Z. Neuhäuslová a kol, *Mapa potenciální přirozené vegetace České republiky*, Praha, 1998.
[49] 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. Hédl, P. Kuneš, P. Bobek and B. Pelánková, Continuity and change in the vegetation of a Central European oakwood, *Holocene* 23 (2013) 46–56.

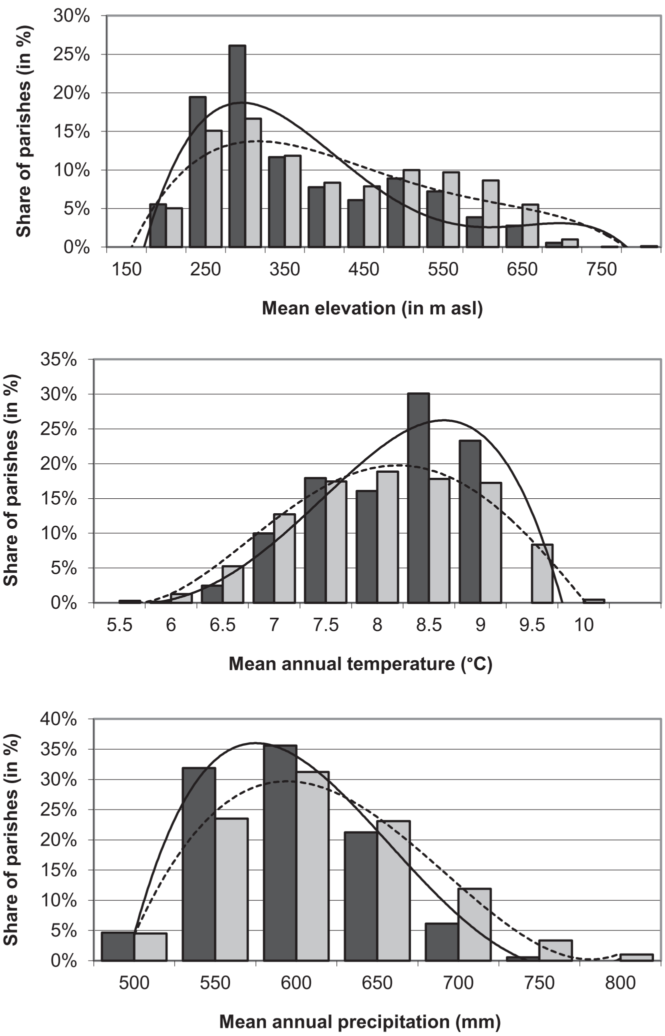

Fig. 3. Frequency distribution of *rubetum* (in black, polynomial trend shown by full line) and all forest records (in grey, polynomial trend shown by dashed line) along elevation, temperature and precipitation gradients.

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.[50] 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.[51] 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.[52] 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.[53] Taking 1.5 m^3 as the average means that 1,350,000 m^3 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^3 of wood per hectare, while in other regions (southwestern Europe) it is 3.3 m^3 per hectare.[54] However, these values are obtained in timber-oriented and dense high-forests, with considerable amounts of money and energy

[50] For example, Warde, Fear of wood shortage (note 5), 37–39.

[51] 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 obyvatelstva českých zemí*, Praha, 2004.

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

[53] 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.

[54] 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.

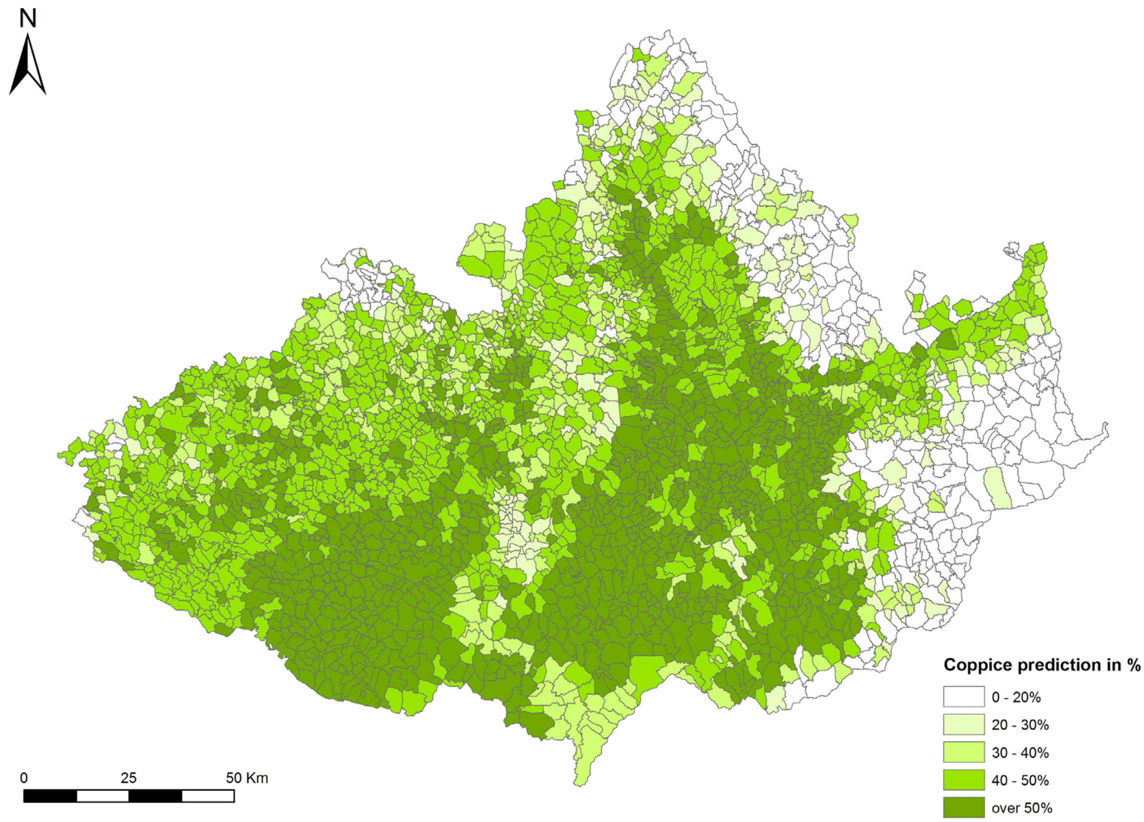

Fig. 4. Model of coppice distribution in the Late Middle Ages constructed using the MAXENT algorithm. Mean annual temperature, precipitation and elevation were used as predictors for coppice probability in individual parishes.

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.[55] 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^3 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^3 per hectare. General estimates for the Early Modern Period put productivity at ca. 3 m^3 per hectare.[56] 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.[57] Average firewood production was 1630 *Klafter*, that is 1.25 *Klafter*/ha. If we convert the local *Klafter* at 3.1 m^3, the result is 3.87 m^3/ha.[58] This needs to be multiplied by 0.66 to transform stacked wood into solid wood, which leaves overall yearly increment at 2.55 m^3 per hectare.[59] In sum, with firewood consumption at 1,350,000 m^3 and yearly increment at an optimistic 3 m^3/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^2. 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.[60] Such forests had much lower yields than 3 m^3/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.[61] 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.[62] It is therefore reasonable to assume that a large part of the 4500 km^2 of hypothetical woodland that could

[55] Rackham, *Ancient Woodland* (note 8), 140–142.
[56] For an overview, see Warde, Fear of wood shortage (note 5), 37.
[57] Müllerová, Szabó and Hédl, The rise and fall of traditional forest management (note 15).
[58] Nožička, *Přehled vývoje* (note 34), 21.
[59] M.A. Fonseca, *The Measurement of Roundwood: Methodologies and Conversion Ratios*, Wallingford, 2005.
[60] P. Szabó and R. Hédl, 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.
[61] 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.
[62] Galloway, Keene and Murphy, Fuelling the city (note 16).

have produced the 1,350,000 m^3 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^2 of woodland is a very high number. Currently there are 6671 km^2 of woodland in Moravia.[63] In the late 18th century, there were ca. 5140 km^2, in the mid-19th century ca. 5820 km^2, and in 1900 ca. 6104 km^2.[64] 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^2 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.[65] 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

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[63] According to CORINE land-use data, see Table 1.

[64] J. Radimský and M. Trantírek (Eds), *Tereziánský katastr moravský*, Praha, 1962, 29–30.

[65] 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.